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Moving Up The Learning Curve: The Digital Electronic Revolution in Canada, 1945 - 70

By

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ABSTRACT

In the decades immediately following World War II, a new constellation of technologies and industries emerged as powerful engines of global economic development. A nation's capacity to innovate on the frontiers of digital electronic technology became a crucial measure of its techno-economic development. During the formative years 1945 - 1970 the major industrialized nations of the world scrambled to assert a domestic design and manufacturing competence within the digital electronic paradigm. The scramblers included Canada.

Through a series of six case studies, this thesis presents the first fine-grained view of Canada's efforts to jump on the nascent, global, digital electronic wave. At the heart of the narrative is the historical process that created Canada's first "community" of digital technologists. The salient features of Canada's ascent of the learning curve associated with digital technologies are the unprecedented role of military enterprise in the creation of a peacetime pool of scientific and technical skills in industry and in government defence laboratories; the smaller, sometimes erratic, but nevertheless important role of civilian public enterprise in nurturing industrial learning after the military's retreat; the surprising contribution of branch plants to fostering indigenous technical knowledge accumulation and skill acquisition at the very frontiers of technical change; and the ability of this newly created pool of expertise, in its design decisions, to refract the global, digital innovation wave through the Canadian context.

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To my supervisor, Professor Donald Davis, I want to express my deepest felt gratitude. Over the past years he has played an immeasurably important role in my apprenticeship to become an historian. He moved my mind beyond the physical artifact and helped me learn to examine technological change in its broader socio-economic and political context. In guiding me through my thesis, Prof. Davis has given so generously of himself. At times when emotional disaster threatened my studies, his genuine concern for my well-being was reassuring. Prof. Davis exemplifies the best in what an educator and mentor should be and it has been a privilege to be his student.

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An Historiographic Context

In December of 1945, the world had just produced its first and only fully functional digital electronic computer called ENIAC. Known to a very small circle of people, and understood by even fewer, ENIAC made scarcely a fold in the socio-economic and industrial fabric of the day. However, in the ensuing half century, the digital electronic paradigm it pioneered has touched almost every aspect of modem existence. Whether or not one wants to go so far as to argue that "being digital" has become a measure of modernity itself, one fact remains incontestable: a nation's capacity to innovate products on the frontiers of digital electronic technology has become the crucial measure of its techno-economic development. Not only has it driven postwar growth, but this "transformative" technology has profoundly redefined the economic production function across every sector of the economy.

The foundation of each nation's present capacity to exploit the commercial opportunities of the digital paradigm world was laid in the quarter century following World War II. The years from 1945 to 1970 marked the critical period when a new generation of Schumpeterian entrepreneurs first created the new industries to exploit digital electronic techniques. It was also during this period that each nation first created the core of academic, governmental and industrial expertise from which present day technical competence in the digital universe is rooted. It was during the formative years of 1945 to 1970 that the major industrialized nations of the world, challenged by the rise of the United States of America's technological and industrial hegemony, first scrambled to assert a domestic design and manufacturing competence within the digital electronic paradigm.

The scramblers included Canada. During those formative years, the digital electronic revolution played itself out within the Canadian political economy. Through a series of case studies, this thesis weaves a narrative of Canada's quest from 1945 to 1970 to create a self-reliant capacity to use, adapt, invent, and commercialize digital electronic technology. In so doing, it illuminates the important role that Canadian peacetime military enterprise played in shaping radical technological change during the postwar economic boom. Canada's experience during World War II and the geopolitics of the ensuing Cold War fostered the emergence of an unprecedentedly assertive Canadian peacetime military. In defence of its sovereignty and in quest of a more commanding voice in postwar international affairs than it had before the war, Canada flirted with military self-reliance.[1] A cornerstone of this self-reliance was the determination to be an active participant within the North Atlantic Triangle in the research, development, and testing of advanced weapons systems.[2]

In addition to the military dimension, this narrative extends its investigation of the process of technological change into the civilian sector and adds much needed balance to the current Canadian nationalist historiography of technological change in which foreign subsidiaries are depicted as passive agents, stripped of any desire or capacity to pursue leading-edge innovation. The problem with this debate is its remarkably ahistorical nature. There have been macro-level generalizations about the role that foreign capital, branch plants, local elites, conservative finance, and so forth have played in stifling Canadian innovation, but there are few detailed historical narratives that lay bare this process for a specific technology of some consequence. By the term "of some consequence," this thesis refers to the Schumpeterian argument that the history of economic development since the Industrial Revolution has been characterized by a series of "waves" of radically new innovations. Each wave has been associated with the emergence of new industries that collectively became the new engine of sustained economic growth. The most consequential feature of the post-World War II innovation wave was the digital electronic revolution. A goal in writing this narrative is to provide a richer and more nuanced account of how national economic, political, and corporate forces shaped the specific contents, extent, direction, and rhythm with which digital innovation propagated through Canada.

This thesis also examines how two foreign-owned subsidiaries, the British-owned Ferranti-Packard Ltd. and the American-owned Sperry Gyroscope Company of Canada Ltd., jumped on the fourth innovation wave at an early stage and tried to exploit domestic and international opportunities in the new and rapidly expanding market for digital electronic-based

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[1] The argument that Canada flirted with military self-reliance in the years between 1945 to 1959 was suggested in Keith Krause, *Arms and the state: patterns of military production and trade* (Cambridge: Cambridge University Press, 1992). See also Robert Van Steenburg, "An Analysis of Canadian-American Defence Economic Co-operation: the History and Current Issues," in *Canada's Industrial Base: The Political Economy of Preparedness and Procurement*, ed. David Haglund (Kingston: Ronald Frye, 1988), 189-219.

[2] The North Atlantic Triangle refers to Great Britain, Canada, and the United States of America.

products.[3] Far from being passive puppets of some foreign multinational, these two branch plants showed themselves to be remarkably innovative firms with an aggressive program to develop an all-Canadian, in-house research and development (R&D) and manufacturing capacity of international stature--in computer design, digital communications, real-time distributed data processing equipment, and real-time digital electronic automation of batch manufacturing.

An important subtext in this thesis is the importance for a small open economy to keep itself technologically busy during the onset of a new innovation wave. The legacy of Canada's first twenty-five years experience with the digital electronic innovation wave does not lie in any specific commercial success story. Rather it resides in the early creation of a national pool of technical know-how that served to keep the nation always within reach of the leading edge of technical change and that was always looking for market niches to exploit. The case studies in this narrative reveal the crucial role that the military, and later, civilian public enterprise, played in creating and nurturing Canada's first generation of core competence in the global digital electronic revolution that occurred after World War II.

Schumpeter, Neo-Schumpeterians, and Innovation Waves

An important metaphor underlying this historical narrative is Schumpeter's notion of global innovation waves. In the depth of the Great Depression, this Harvard economist argued that economic development of the world's major industrialized nations had proceeded since the end of the eighteenth century as a series of bursts, or "waves," marked by periods of high growth

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[3] See Norman R. Ball and John N. Vardalas, *Ferranti-Packard: Pioneers in Canadian Electrical Manufacturing* (Montreal & Kingston: McGill Queen's University Press, 1994). Their narrative, however, stresses the history of the company's dominant business activity: the manufacture of capital goods for the electrical power sector, in which utilities were the dominant customers. As a result, their discussion of Ferranti-Packard's digital electronics innovations, though it touches on all the key artifacts, fails to situate the process of technological change within the broader political economic context of post-World War II Canada. Reconstructed almost entirely from the personal recollections of former company engineers, the work of Ball and Vardalas does not examine the extent to which public enterprise profoundly shaped the rhythm and direction of digital innovation at Ferranti-Canada, a theme which is a cornerstone of this thesis. The Ferranti-Canada story, as told in the Ball and Vardalas book, is reconceptualized here thanks to new and extensive research into the records of the Defence Research Board, the former Department of Defence Production, Royal Canadian Navy, Canada Post, Air Canada, Federal Reserve Bank of New York, Industry Canada, and the Science Council of Canada.

rates and a concentrated appearance of radically new innovations and products.[4] These bursts originated from the leadership of those entrepreneurs who saw opportunities for monopoly profits arising from radical innovation. If successful, the entrepreneur could enjoy a period of uncontested high profits. But these have always encouraged imitation; a bandwagon effect would occur as new competitors swarmed in to share in the profits. It is this "swarming" around a cluster of radical innovations that corresponds to the emergence of what Schumpeter called the new "leading sector" of economic growth. For Schumpeter, the rapid expansion of these new industries was not simply a consequence of economic growth but the cause of it.[5] With time, however, the advantage of technological exclusivity would disappear, competition would intensify, profits and the rate of new fixed capital investment would decline, and the leading sector would cease to be the engine of economic expansion. Graphed, this evolution would reflect the basic S-shape governing the life-cycles of new products: slow acceptance, accelerated market demand, finally relative decline in market interest. As the once radical innovations saturated the market, refinements to them in subsequent years would bring diminishing returns. The more basic the innovation underlying the new products, the longer the life-cycle would be.

Considerable debate swirls around the Schumpeterian interpretation of long-term economic growth and the role of innovation in this growth. One problem lies with economic long waves themselves. Doubters argue that there is insufficient evidence so far to demonstrate a temporal synchronization over a wide range of economic variables.[6] Or they dispute whether

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[4] Joseph Schumpeter, *Business Cycles*, 2 vols. (New York: McGraw-Hill, 1939).

[5] Within this context, economic development is a process of reallocation of resources between industries. This process automatically leads to structural changes and disequilibria as labour, capital, and credit flood into the emerging leading sector.

[6] The problems revolve around the statistical interpretation one gives to disparate sets of economic time series. The debate is far from resolved. For the most recent comprehensive overview of the long-run time series used and the relative merits of the various quantitative data analyses used see Joshua Goldstein, *Long Waves* (New Haven: Yale University Press, 1988), Chaps. 8-12 and apps. A and B. Even if one assumes the existence of long economic waves, there is considerable debate over Schumpeter's supply-side view that innovation leads economic growth. Another problem with Schumpeter's model is its apparent determinism. Arnold Pacey argues that this interpretation leads to a deterministic view of history, because "it implies that processes are at work which no human intervention can decisively alter." See Pacey's *The Culture of Technology* (Cambridge: MIT Press, 1983), 31. Recent interpretations of Schumpeter's work, particularly in Europe, have moved away from Schumpeter's model of periodic economic behaviour. They suggest the idea of a wave with no predetermined amplitude or periodicity. When and how an economy makes the transition from a downturn to an upturn is historically contingent. Hence, each of the four past waves have been outcomes of its own unique historical context. See Andrew Tylecote, *The Long Wave in the World Economy* (London, New York: Routledge, 1991); and Christopher Freeman et al., *Unemployment and Technical Innovation: A Study of Economic Long Waves and Economic Development* (Westport, Connecticut: Greenwood Press, 1982). Contrary to Pacey, individual human action is decisive in the Schumpeter model. Carlo Cippola also

(continued...)

radical innovations do indeed come in waves, or clusters.[7] Yet, Christopher Freeman, John Clark, and Luc Soete, economists from the University of Sussex's Science Research Policy Unit, have put together a convincing empirical study to support the argument that radical innovations have indeed clustered since the Industrial Revolution.[8] Based on a disaggregated analysis of a large and up-to-date list of innovations, Freeman, Clark, and Soete divide innovations into those of "product" and "process." "Product" innovations are radical innovations that introduce fundamentally new products or services. Product innovations, which are supply-driven, engender a fundamental shift in economic development and create a new leading sector, or sectors, which will form the basis of the expansionary upswing. These innovations correspond to the activities

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underscores "the creative response of history" that imbues the Schumpeterian model." Carlo Cippola, *Between Two Cultures* (New York: W.W. Norton, 1991), 71

[7] In his 1940 review of Schumpeter's "Business Cycle," Simon Kuznets took exception to the idea that innovations could appear clustered over time. In 1978, Kuznets reiterated his disagreement with Schumpeter when he again argued that major innovations were randomly distributed through time. See Simon Kuznets, "Technological Innovations and Economic Growth," in *Technological Innovation: A Critical Review of Current Knowledge*, ed. P. Kelly and M. Kranzberg (San Francisco: San Francisco Press, 1978), 335-356. Gerhard Mensch produced an empirical study of innovation clustering along with mechanisms to explain this phenomenon. Gerhard Mensch, *Stalemate in Technology: Innovations Overcome the Depression* (Cambridge, Mass.: Ballinger, 1979). Mensch asserted that major innovations had clustered around depressions because they offered the only solution out of what he describes as a "technological stalemate." Though Mensch adhered to the idea of innovation bunching, he was critical of Schumpeter's "Heroic Innovator" paradigm as the cause of discontinuities. Mensch proposed that one examine "the discontinuity in the preconditions for innovation which change the market opportunities and propensities of entrepreneurs to innovate." Gerhard Mensch et al., "Changing Capital's Values and the Propensity to Innovate," *Futures*, 13:4 (1981): 284. Edwin Mansfield challenged the empirical basis of Mensch's work: "[Mensch's] evidence does not persuade me," wrote Mansfield, "that the number of major technological innovations conforms to long waves of the sort indicated by his data ... The hypothesis that severe depressions trigger and accelerate innovations is also questionable." Edwin Mansfield, "Long Waves and Technological Innovation," *American Economic Review* 73:2 (1983): 144. Nathan Rosenberg and Claudio Frischtak also found Mensch's economic argument for innovation bunching "far from convincing." They do not see why the depression should provide a push into new product lines that were rejected under earlier, more favourable economic circumstances. If anything, they assert, "depressions tend to make entrepreneurs and managers (as well as sources of financial capital) overly cautious, committing resources which are just adequate for marginal improvements upon the existing technology." However, he adds: "this does not exclude committing resources to the basic design of new products....Research and development expenditures during phases of retardation (or depression) provide, at most, the technological basis for sustained growth during expansion. Research and development expenditures should be viewed as the necessary but not sufficient condition to bring about the commercialization of new products and the actual application of new techniques of production. Other conditions must be present, in the form of acceptable perceptions of future risk and returns, before firms will commit large amounts of resources to the construction of new plant capacity." Nathan Rosenberg and Claudio Frischtack, "Technological Innovation and Long Waves," in *Design, Innovation and long Cycles in Economic Development*, ed. Christopher Freeman (New York: St. Martins Press, 1986), 19-20.

[8] Freeman et al., *Unemployment and Technical Change*. Rejecting Mensch's methodology, Freeman et al. found no evidence to support Mensch's conclusion that major innovations were most concentrated in the deepest part of a depression. Mensch's use of invention data (rather than innovation data), the somewhat arbitrary manner in which inventions were classified as either "basic" or "improvement," and the dependence on a list of inventions that focussed on pre-World War II data, seriously compromised his methodology and results.

of Schumpeter's entrepreneurs. "Process" innovations, on the other hand, are aimed at producing the existing set of products and services in a more efficient way. Process innovations, argue Freeman, Clark, and Soete, tend to dominate during the intense competition that follows "swarming." Process innovations are demand-driven and arise from the competitive pressure to rationalize production, lower costs, improve the product, or create further product differentiation.[9] By means of this classification of innovations, Freeman, Clark, and Soete have provided a bridge between Schumpeter's supply-side view of autonomous innovation and Jacob Schmookler's demand-side perspective that innovation "is as much an economic activity as is the production of bread."[10]

The Schumpeterian model presents four innovation waves since the beginning of the industrial revolution: first, steam mechanization of production starting at the turn of the nineteenth century; second, the constellation of innovations beginning in the mid-nineteenth century that revolved around railways; third, the electrical, chemical, and automobile industries at the close of the nineteenth century; and fourth, the cluster of innovations in computer, solid state electronics, telecommunications, and synthetic materials that occurred during the postwar economic boom from 1945 to about 1970.[11] The onset of each of these innovation waves has not been a spatially homogeneous process. Each innovation wave first appeared in one or two countries and then over time spread to others. Because substantial monopoly-like economic advantages accrued to the first nations to implement the new cluster of radical innovations, these

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[9] Rod Coombes and Alfred Kleinecht have further disaggregated the innovation classification. While some innovations can be classified easily as pure "product" or "process," other innovations can fit both depending on the perspective one takes. For example, a computer numerical control system may be a product innovation for a capital goods producer, while the final user who adopts this technology sees it as a labour-saving improvement. Their work, however, still corroborates Freeman et al.'s basic assertion that product innovations dominate the upswing while process innovations dominate the downswing. See Rod Coombs and Alfred Kleinecht, "New Evidence on the Shift Toward Process Innovation During the Long-Wave Upswing," in *Design, Innovation and Long Cycle in Economic Development*, 78-103.

[10] Jacob Schmookler, *Invention and Economic Growth* (Cambridge, Mass.: Harvard University Press, 1966), 208. The categorization of innovation also sheds light on the debate over the relationship between technological change and employment. The first burst of innovations and the swarming that follows develops a growth momentum through economies of scale. These effects, according to Freeman et al. are employment-generating because skills are in short supply in the leading sector. It is during this period that new educational programs are put in place to ensure a rapid growth of the skilled labour force that the leading sector requires. The labour intensive nature of growth on the upswing is accompanied by rapid increases in wages. However, during the downswing, the economies of scale quickly lead to excess capacity. Innovation, mostly process, is then driven by the imperative to rationalize. While innovation generates employment on the upswing, it displaces labour on the downswing.

[11] Freeman et al., *Unemployment and Technical Innovation*. See also Tylecote, *The Long Wave in the World Economy*.

nations wanted to retain their initial monopoly over the various technological modes that comprise the innovation wave. Other nations, however, naturally wanted to break this monopoly.[12] This tension manifests itself internationally as the process of innovation diffusion. The rate of the diffusion depends on the complexity of the technologies, the ability of the recipient nation's economic, corporate, social, cultural, political, and educational institutions to appropriate these technologies, and the ability of the nation within which the original innovations took place to block the diffusion.[13]

This thesis seeks to understand how the diffusion of the fourth innovation wave unfolded within Canada's political economy; more specifically, the extent to which Canada gained the capacity to design and manufacture the "product innovations" of the newly emerging digital electronic paradigm. Not only will such an investigation shed light on how the process of innovation in Canada proceeded during this period of dramatic global technological change, but it will also contribute to an ongoing historical debate over the strengths and weaknesses of Canada's manufacturing sector. Freeman, Clark, and Soete have argued that "there are substantial advantages in being the first to implement the new cluster of radical innovations."[14] The speed and extent with which Canada's small, open, and somewhat peripheral economy has been able to design and manufacture "product" innovations offers a measure of this nation's industrial prowess. The following, detailed recounting of the process of Canadian innovation in digital electronics introduces more empirical clarity into the historical debate surrounding the nature of

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[12] Freeman et al., *Unemployment and Technical Change*. Luc Soete's article "Long Cycles and the International Diffusion of Technology," in *Design, Innovation and Long Cycles in Economic Development*, 214-230, offers an interesting discussion of the interplay between a nation's attempt to monopolize its technological advantages and the dynamics of international innovation diffusion.

[13] The upswing of the first long wave, 1790 to 1814, was based on the cluster of innovations that surrounded the application of steam power to mechanization. Britain's attempts to protect its technological advantage by blocking the export of machinery could not stop migration of British technician/entrepreneurs to Europe. They used their knowledge to set up profitable steam-based factories in Europe. From 1814 to 1842, the international diffusion of steam technology was rapid. The simplicity of steam technology accelerated this diffusion. However, by 1845 a new leading sector of economic growth appeared: locomotive and railways. Britain still dominated this technology, but it was being overtaken by the U.S. and Germany after 1865 through import substitution and tariff protection of infant industries. The new economic boom at the turn of the twentieth century was centred on electricity, the automobile and chemicals. Here the U.S. and Germany emerged as the leading economic powers. Britain's inability to keep up in the third wave was a result of its failure to initiate closer links between science and industrial technology. This failure was rooted in British social and educational institutions. Germany and the U.S. were better able to retain control of these innovations because of their complexity. That is, far more scientific knowledge was needed to appropriate these innovations. The upswing of the fourth long wave, after World War II, saw the U.S. emerge as the unchallenged economic power. See Soete, *Long Cycles and the International Diffusion of Technology*; and Tylecote, *The Long Wave in the World Economy*.

[14] Freeman et al., *Unemployment and Technical Innovation*, 167.

Canada's industrial and economic development in the postwar years.

Innovation in the Canadian Political Economy: A Discourse of Passivity

Until the 1960s, Canadian economic historians and political economists portrayed Canada's march to modernity in terms of the rise and fall of one staple export after another. From cod fisheries, fur, timber, gold, wheat, base-metal, pulp and paper, and then to oil and gas, Canada's economic development involved an incessant search for new global opportunities in natural resource exports. Underlying this "staples" model of development was the assumption, first promulgated in the late 1920s by the eminent Canadian political economist W. A. Mackintosh, that Canada would be able to use its natural resource exports as the springboard to a more technologically sophisticated and diversified manufacturing-based economy, as the U.S. had done.

At the start of the 1970s, as the rapid economic expansion that characterized the post-World War II era ended, an important intellectual shift occurred in the interpretation of Canada's historical development. A new generation of Canadian nationalist historians and political economists started to argue that Canada had failed to break away from its excessive dependence on raw material exports as the engine of growth. Within an anti-American, anti-imperialist, and socialist ethos, the new historical discourse on Canada's economic development looked to Third World models of dependency to explain Canada's "truncated," or "arrested" pattern of economic development.[15] Armed with macro-economic indicators drawn from foreign investment, export and import trade, and manufacturing data, the new political economists created a profile of Canada which resembled that of semi-industrialized nations. Inspired by the Third World oriented discourse of underdevelopment, the new political economy described Canada's postwar history as a process of "de-industrialization." As a result of "de-industrialization," Daniel Drache concluded in the early 1970s that Canada had moved from a semi-centre economy to a semi-peripheral one. Over a decade later Melissa Clark-Jones similarly framed the "de-

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[15] Ironically, Harold Innis, who was a contemporary of Mackintosh, became an intellectual cornerstone of the new political economy. Glen Williams points out that Innis was recast in the Leftist ideological discourse of the 1970s and 1980s, as a Canadian nationalist, anti-continentalist, anti-imperialist, and a forerunner of dependency school. See Glen Williams, "On Determining Canada's Location Within the International Political Economy," *Studies in Political Economy* 25 (Spring 1988): 107-140.

industrialization" thesis within a model of "continental resource capitalism."[16]

The nationalist discourse pointed to the dominance of foreign-owned branch plants as the chief culprit for Canada's "de-industrialization."[17] Borrowing from the Latin American underdevelopment literature, political economists argued that dependency arising from the branch plant had blocked the creation of an indigenous Schumpeterian class.[18] Instead, the branch plant had created a comprador capitalist class.[19] Thus Mel Watkins asserted the view that the dominance of foreign-owned branch plants had "arrested" the emergence of a Canadian industrialist class;[20] R. T. Naylor asserted that the old mercantile elite, beneficiaries of Canada's early staple economy, subsequently had blocked the emergence of a Schumpeterian class through their control of Canada's financial and political institutions.[21] Kari Levitt asserted that the dominance of the subsidiaries of foreign multinationals had blocked the emergence of a class of Schumpeterian entrepreneurs, that is, innovators and risk-takers who could create new leading sectors.[22] Wallace Clement's sociological study of the Canadian corporate elite similarly sought to prove that an unequal alliance had created a comprador group of Canadian capitalists linked to American multinationals, a link which guaranteed the Canadian commercial elite control of the distribution and finance aspects of the economy while abdicating control over industrial

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[16] The Clark-Jones's argument is that the American military's search for assured access to strategic natural resources during the Cold War increased Canada's dependence on staple exports. Melissa Clark-Jones, *A Staple State: Canadian Industrial Resources in Cold War* (Toronto: University of Toronto Press, 1987). This view was also argued by Paul Phillips and Stephen Watson, "From Mobilization to Continentalism: The Canadian Economy in the Post Depression Period", in *Modern Canada, 1930 -1980s*, ed. Michael Cross and Gregory Kealy (Toronto: McClelland and Stewart, 1984), 20-45.

[17] Jim Laxer, "Canadian Manufacturing and U.S. Trade Policy", in *Canada Ltd.: The Political Economy of Dependency*, ed. Robert Laxer (Toronto: McClelland and Stewart, 1973), 127-151. In the foreword to "Canada Ltd.", Robert Laxer emphasized the centrality of the "de-industrialization" thesis both as a framework within which to understand Canada's historical development in the 20th century and as "a rallying cry for Canadians to join the movement for independence though socialism and socialism through independence" (p. 9).

[18] Kari Levitt pushed the dependency model to argued that "Canada provided a dramatic illustration of the stultification of an indigenous entrepreneurial class" by the dominance of the foreign-owned branch plant. Kari Levitt, *Silent Surrender: The Multinational Corporation in Canada* (Toronto: Macmillan, 1970), 58.

[19] Wallace Clement argued that in exchange for control over the distribution and financial aspects of the Canadian economy, the nation's capitalist elite had ceded control of industrial development to American multinationals. See Wallace Clement, *The Canadian Corporate Elite* (Toronto: McClelland and Stewart, 1975).

[20] Mel Watkins, "Economic Development In Canada," in *World Inequality: Origins and Perspectives on the World System*, ed. I. Wallerstein (Montreal, 1975), 97-112.

[21] R.T. Naylor, *The History of Canadian Business*, 2 vols. (Toronto: Lorimer, 1975).

[22] Levitt, *Silent Surrender*.

development to the multinationals.[23]

Having raised the question, "What went wrong with Canadian industrialization?," nationalist political economists and historians never examined the relationship of industrialization to the process of invention, research, and development.[24] Though the process of innovation is an essential ingredient to any nation's industrial development, the nationalist historians rarely examined in an explicit and detailed manner how structural factors shaped the contents and direction of industrial research and development in Canada during periods of dramatic global shifts in the technology. In particular, there has never been any study of how Canada created and sustained a capacity to innovate in one of the most important cluster of technologies driving the 1945 to 1970 postwar economic boom: digital electronics and computers.

When the nationalist political economic discourse first emerged in the late 1960s, J. J. Brown had just published his grim assessment of the history of Canadian technology.[25] "The paradox that enlivens the history of Canadian invention," wrote Brown in 1967, "is that Canada is a great producer of ideas, yet it has virtually no native technical industries."[26] Brown's resolution of the paradox was a scathing condemnation of Canadian industrial culture, if not society itself: "We tend to be terrified little men, clutching frantically at what we have and afraid to take any risk whatsoever even for large rewards."[27] Brown suggested that fear of losing the comfortable life had led Canadians to forfeit their ability to risk and create, and to accept integration into the American economic empire.

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[23] Clement, *The Canadian Corporate Elite.* See also Glen Williams, *Not for Export: Toward a Political Economy of Canada's Arrested Development* (Toronto: McClelland and Stewart, 1983). For a more recent vintage of the debate over Canada's inability to break the staples trap, see Wallace Clement and Glen Williams, eds., *The New Canadian Political Economy* (Montreal & Kingston: McGill-Queen's University Press, 1989); and Gordon Laxer, ed., *Perspectives on Canadian Economic Development* (Toronto: Oxford University Press, 1991).

[24] After reviewing ten new books on the "New Political Economy," Jack McLeod was struck by the conspicuous absence of any concrete discussion of how the process of technological change fits into political economy. Jack McLeod, "Paradigms and Political Economy," *Journal of Canadian Studies* 26 (Spring 1991): 172-181. For McCleod, this state of affairs merely corroborated observations made by Richard Simeon who, as research coordinator for the MacDonald Commission, observed that for economists, technology was simply not an issue. During the Commission's hearings economists denied that there was any evidence of a technological revolution, or any speed up of technical change, and they did not present any models of economic change that encompassed technology as an explicit model. See Richard Simeon, "Inside the MacDonald Commission," *Studies in Political Economy* 22 (Spring 1987):167-179.

[25] J.J. Brown, *Ideas in Exile* (Toronto: McClelland and Stewart, 1967), 339.

[26] *Ibid.*

[27] *Ibid.*, 340.

Nearly fifteen years after Brown's condemnation of Canada's technological record, Christian DeBresson[28] rebutted Brown's idea that innovation had died in Canada. Labelling Brown's work as methodologically flawed, DeBresson accused Brown of having falsely shaped public opinion and of fostering the myth that Canadians lacked the nerve to be innovators/entrepreneurs. The thrust of DeBresson's argument was that Canada's use of foreign technology has not been a process of imitation. Rather, the import of technology has entailed a creative adaptation to the existing economic and social context.[29] In a detailed inter-industry study of how innovation flowed between suppliers and users, DeBresson concluded that, except for a few industries, innovative activity was alive and well, and driven by Canada's staple industries.[30] Reinforcing Schmookler's model of demand-driven, incremental innovation, DeBresson's data underscored the vitality of "process" innovations within Canada's staple economy. However, without any access to detailed primary case studies of the Schumpeterian firms that created the fourth innovation wave, DeBresson was unable to explore the vitality of "product innovations" in Canada, particularly during the critical onset of the wave. As a result, DeBresson missed the important distinction between innovations which lead to the birth and growth of a new leading sector, and those innovations which occur in the declining phase of the leading sector's life-cycle.[31] The automotive industry, for example, whose emergence as a leading sector during the early twentieth century was nourished by product innovations, had by the 1940s become a sector whose growth was dominated by process innovations.

Brown, by contrast, did make one reference to abortive innovation in digital electronics as further evidence of Canada's inability to risk and create native technical industries. Yet, there were other case studies in Canadian computer technology, of which he was surely aware, given his pioneering work in automation, that he did not bring to light. These examples, to be examined in detail in this thesis, underscore the simplistic nature of Brown's interpretation of the history of Canadian technology and the incompleteness of DeBresson's rebuttal. At the start of

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[28] Cristian DeBresson, "Have Canadians Failed to Innovate? The Brown Thesis Revisited," *History of Science and Technology in Canada Bulletin* 6 (January 1982): 10-23.

[29] The idea that adaptation has been central to Canadian technological development was the central theme in a collection of articles in Bruce Sinclair et al., *Let Us Be Honest and Modest* (Toronto: Oxford University Press, 1974). "Nothing more strongly characterizes the Canadian situation," wrote Sinclair, Ball and Patterson, "than the continual selection of techniques from other societies....The ability to adapt is just as critical as the ability to originate"(p. 2).

[30] Chris DeBresson and Brent Murray, *The Supply and Use of Technological Innovation in Canada: Strengths and Weaknesses* (New Westminster, British Columbia: Cooperative Research Unit on Science & Technology, 1983), 203.

[31] This would also include innovations in former leading sectors which may co-exist with the current leading sector.

the 1970s, the newly created Science Council of Canada refurbished Brown's assertions within a more encompassing political economic model of Canada that saw foreign ownership as the principal obstacle to Schumpeterian product innovation.

Throughout the 1970s and 1980s, the Science Council of Canada expanded the nationalist debate on Canada's "truncated" development to include the nation's capacity to carry out scientific research and advanced experimental engineering.[32] The Council drew sustenance from the "new political economy" while at the same time bolstering its intellectual arguments by explicitly linking "de-industrialization" to the nation's industrial capacity to do R&D. "Technological underdevelopment," argued the Council, was the cause of Canada's de-industrialization.[33] Echoing Kari Levitt, one Science Council advisor argued that Canada's industrial structure fostered only dependent and imitative firms that were incapable of Schumpeterian product innovations.[34] The preponderance of foreign ownership in Canadian economic life, contended the Council, had seriously impeded Canada's ability to develop and control the technological capability necessary to ensure its economic, and hence its political self-determination. For the Council, the absence of "technological sovereignty"[35] undermined Canada's ability to ensure its future prosperity.[36] As the 1945 to 1970 "product" innovation wave came to an end, the Council, recognizing the strategic importance of digital electronics and computers, voiced concern over the absence of a national plan to create a Canadian capacity for design and manufacture within this cluster of technologies.[37] Since it did not refer to Canada's prior twenty-five year experience in trying to appropriate the digital electronic revolution, the

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[32] Science Council of Canada, *Forging the Links: A Technology Policy for Canada*, Report 29 (Ottawa: Supply and Services Canada, 1979). For the in-depth analysis underlying this report see, John Britton and James Gilmour, *The Weakest Link: A Technological Perspective on Canadian Industrial Underdevelopment* (Ottawa: Supply and Services Canada, 1978).

[33] Science Council of Canada, *Forging the Links*.

[34] James Gilmour, "Industrialization and Technological Backwardness: The Canadian Industrial Dilemma," revised text of a paper delivered at Seminar on Technological Sovereignty, 18 May 1977, organized by Science Council of Canada and held at Le Cercle Universitaire d'Ottawa.

[35] The Science Council of Canada first employed the term "technological sovereignty" in 1977. Science Council of Canada, *Technological Sovereignty: A Strategy for Canada - Eleventh Annual Report, 1976-77* (Ottawa: Supply and Services Canada, 1977).

[36] For a critique of the Science Council of Canada's position on "technological sovereignty," see Kristian Palda, *The Science Council's Weakest Link* (Vancouver, B.C.: The Fraser Institute, 1979).

[37] Science Council of Canada, *A Trans-Canada Computer Communications Network: Phase 1 of a Major Program on Computers*, Report No. 13 (Ottawa: Ministry of Supply and Services, August 1971); and *Strategies of Development for the Canadian Computer Industry*, Report No. 21 (Ottawa: Information Canada, August 1973).

Council's studies presented a snap-shot of Canada's predicament that was stripped of any historical context. In its critique of corporate R&D, the Council did not offer any in-depth studies of how the innovation process had actually unfolded within Canadian companies identified with the fourth global innovation wave.

By contrast, this thesis provides the first detailed look at how foreign-owned Canadian subsidiaries endeavoured to design and market digital electronic technology. It shows that the nationality of ownership did not, in itself, prove to be an obstacle to the pursuit of product innovation in Canada. In his study of the "Competitive Advantage of Nations," Michael Porter stressed the importance of the geographical location of R&D over the nationality of corporate power.[38] Porter's analysis only hinted at the role of a nation's military in encouraging foreign firms to let their subsidiaries do R&D. Long before the Science Council of Canada advocated its nationalist R&D agenda, Canada's Departments of National Defence and Defence Production had been fostering domestic R&D and industrial capacity in all things digital electronic. Had the Science Council been aware of this military-funded research by foreign subsidiaries in Canada, its advice might have been more pertinent to decision-makers.

Canadian Military Enterprise and Jumping on the Fourth Innovation Wave

By linking national defence with national welfare, argues historian Merrit Roe Smith, the military establishments of the industrialized nations have played an important historical role in shaping technological and economic change. In developing this argument, Smith underscores the importance of the "complementarity of military and economic forces" in the development of the American industrial system.[39] His own social history of armoury practice at Harper's Ferry, West Virginia, during the first half of the nineteenth century illustrates how military enterprise impressed its psyche on design, manufacturing technology, and the labour process of an entire

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[38] Michael Porter, *The Competitiveness of Nations* (New York: Basic Books, 1984).

[39] See Merritt Roe Smith, "Introduction," in *Military Enterprise and Technological Change*, ed. Smith (Cambridge, Mass.: MIT Press, 1987), 1-37. This introduction offers a valuable overview of the main themes that have emerged, in American historiography, in the study of military enterprise in its relation to economic technological, and social change. The entire collection of essays looks at various institutional aspects of military enterprise and technical change.

industrial sector.[40] As Smith and David Hounshell have demonstrated, interchangeable parts and specialized machine tools, which later became the technical basis of mass production, had deep roots in the American army's preoccupation with standardized performance and construction down to the smallest subassembly.[41] Furthermore, Smith's narrative reveals that the introduction of interchangeable parts was not simply a neutral add-on to existing shop floor production techniques. Rather, interchangeable parts entailed a redefinition of the nature of work and of who controlled the labour process.[42] The international rate of diffusion of the "American System of Manufactures" thereafter was relatively slow until it became an urgent matter for the military of Europe's major powers. It took World War I, argues William McNeill,[43] to provide the crisis whereby military imperatives pushed Europe away from its older socio-economic patterns and closer to the mass-production society.

Surprisingly, given his intellectual debts to the 1970s radical political economists, sociologist Gordon Laxer suggested in 1986 that the absence of a dynamic military was a significant contributing factor to Canada's arrested political economy and truncated technological capabilities. "Instead of developing a domestically owned and innovative engineering industry under the protective care of an independent military policy," wrote Laxer, "it relied almost exclusively on foreign technology, which was a major factor in the emergence of the branch-plant structure."[44] Other scholars have described Canadian military as ineffective in promoting economic growth or industrialization. But they, like Laxer, did not move beyond generalities to study the details in any industry as important as digital electronics.

While historians have written about how the life-and-death struggle of World War II served to expand Canada's technological and industrial capacity, few have examined this subject

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[40] Merritt Roe Smith, *Harper's Ferry Armory and the new Technology: The Challenge of Change* (Ithaca, N.Y.: Cornell University Press, 1977).

[41] For an extensive historical analysis of interchangeable parts and specialized machine tools, and the rise of mass-production economy, see David Hounshell, *From American System to Mass Production, 1800-1932* (Baltimore: Johns Hopkins University Press, 1984).

[42] Lewis Mumford argued that standardization, uniformity, mass consumption, the necessity for regulated order, and large-scale co-ordination, which are all characteristics assigned to mass-production culture, have been inherent dimensions of military organization since ancient times. Lewis Mumford, *Technics and Civilization* (New York: Harcourt Brace and World, 1934); and *The Myth of the Machine: Technics and Human Development* (New York: Harcourt Brace and World, 1966).

[43] William McNeill, *The Pursuit of Power* (Chicago: University of Chicago Press, 1982).

[44] Gordon Laxer, "Class, Nationality, and the Roots of the Branch Plant Economy," in *Perspectives on Canadian Economic Development*, 256-7.

for the postwar era.[45] David Zimmerman, for example, in a fascinating study of the Royal Canadian Navy (RCN), describes how, at the outbreak of World War II, this institution was totally unprepared to manage the scientific and technological demands of modern warfare. By the end of the war, however, the RCN had learned to integrate the scientific/technical mind with the military mind. This discovery begs the question: what happened to this technological capacity after demobilization? In an epilogue to his narrative, Zimmerman suggested that "much of [RCN's] accumulated wartime scientific and technical expertise was lost as a result" of Mackenzie King's "ill-conceived" policy of slashing military budgets. Though Zimmerman's wartime examination of the RCN draws on considerable primary source evidence, his postwar speculations rest on no more than the first few months after the war.[46] His assessment echoes that of political scientist James Eayrs, and certainly captures King's intentions in late 1945.[47] But then intruded the Cold War. The consequent shift in geopolitics undermined the Prime Minister's anti-military agenda and allowed the RCN, along with the other Services, to pursue a technologically mediated vision of self-reliance.

The nationalist political economic discourse of the 1970s and 1980s that came to dominate postwar historiography no doubt was a disincentive to any scholarly study of the role of Canada's military in shaping the nation's technological and industrial capacity. The pivotal thesis of this discourse was that Canada had been de-industrialized by continentalization and the dominance of foreign-owned branch plants. Continental defence was cast as an agent of de-industrialization. Canada's postwar military alliance with the United States, suggested the nationalist discourse, not only intensified the "Staple State" but also accelerated the

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[45] For example, the military historiography listed below all in some way deal with the 1945 to 1958 period, but none devote much space to the question of how the military shaped Canada's capacity to design, adapt, build and use technology: B. J. C. McKercher and Lawrence Aronsen, eds., *The North Atlantic Triangle in a Changing World: Anglo-American-Canadian Relations, 1902-1956* (Toronto: University of Toronto Press, 1996); Marc Milner, ed., *Canadian Military History* (Toronto: Copp Clark Pitman, 1993); Desmond Morton, *A Military History of Canada* (Toronto: McClelland & Stewart, 1992). See also four articles by Lawrence Aronsen: "Planning Canada's Economic Mobilization for War: The Origins and Operation of the Industrial Defence Board, 1945-1951," *The American Review of Canadian Studies*, 15 (Spring 1985): 38-58; "From World War to Limited War: Canadian-American Industrial Mobilization For Defence," *Revue Internationale d'Histoire Militaire*, no. 51 (1982): 208-245; "Canada's Postwar Re-armament: Another Look at American Theories of the Military-Industrial Complex," Historical Papers, Canadian Historical Association (1981): 175-196. James Eayrs, *In Defence of Canada* (Toronto: University of Toronto Press, 1972).

[46] David Zimmerman, *The Great Naval Battle of Ottawa* (Toronto: University of Toronto Press, 1989).

[47] Eayrs, *In Defence of Canada*.

dismantlement of Canada's capacity to industrialize and to diversify the economy.[48] For those who saw only dependence and deindustrialization in Canada's post-World War II defence planning, it was natural to assume that military enterprise did little to promote indigenous research and development on the frontiers of technology. They argued that the American military-industrial machine's need to secure access to natural resources reinforced the historical dominance of staple exports in the Canadian economy. This may be true, but it was not the totality of the military's impact on Canada. The search for petroleum, nickel, and uranium did not preclude a quest for semiconductors.

Lawrence Aronsen is the first and the only historian to examine in some detail the extent to which a Canadian military-industrial complex emerged during the immediate post-World War II years. In some respects, his work offers a counterbalance to the nationalist model. While recognizing that the continental military alliance accelerated Canada's economic integration with the United States, Aronsen has also underscored the benefits of this connection to Canadian manufacturing.[49] Through the vehicle of the branch plant, he argues, Canada was able "to maintain state-of-the-art production through technology transfer." Aronsen goes on to explain: "American integration of Canada's resources and industrial defence production...was particularly beneficial to the host country....The American-controlled high-technology industries, such as automobiles, electronics and oil refining, recorded the highest rates of productivity in North America as measured by output per man-hour."[50] While Aronsen thus understands that the framework of continental defence allowed Canada to become good at copying sophisticated American designed products and techniques, his work does not reveal if Canadian military enterprise fostered indigenous design capacity.

On the question most pertinent to this thesis, whether Canada's military was able after World War II to generate and sustain its own advanced weapons research and development program, Aronsen slips into a nationalist discourse: "Canadian defence industries had a closer liaison with American military officials on questions concerning equipment design and

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[48] For example see Clark-Jones, *A Staple State: Canadian Industrial Resources in Cold War*, Phillips and Watson, "From Mobilization to Continentalism: The Canadian Economy in the Post Depression Period."

[49] Lawrence Aronsen, "From World War to Cold War: Cooperation and Competition in the North Atlantic Triangle, 1945 - 1949," in *The North Atlantic Triangle in Changing World: Anglo-American-Canadian Relations, 1902-56*, 184-219.

[50] Aronsen, *From the World War to Cold War.*

production than they did with the Canadian military."[51] Aronsen, however, does not present any evidence to substantiate his contention that Canadian military enterprise played a minor role in shaping a national industrial R&D agenda. Furthermore, his analysis does not reveal if the creation of a domestic design capacity accompanied the growth of Canada's high-tech defence-oriented industries. In other words, were these Canadian manufacturers of high-tech military equipment to which Aronsen refers merely passive copiers of American designs or did they also promote an indigenous capacity to do R&D in leading-edge technologies, such as those of the fourth innovation wave?

J. L. Granatstein's argument in 1993 that a widespread "envy" of American military equipment drove Canadian postwar defence planning reinforced Aronsen's speculations.[52] Granatstein has of course brought up the demise of the AVRO Arrow (unviable because it was unsellable in the United States) to illustrate the insurmountable problems that Canadian technology faced within the context of a continental defence driven by the large and powerful American military-industrial complex.[53] The Arrow is frequently the illustrative example when historians discuss Canada's postwar relationship with the United States government and military.[54] Yet there has been little or no attempt to determine whether the technological ambitions that drove the AVRO Arrow were an isolated exception to the general rule of buying defence materials off the American shelf, or whether they reflected a broader and more systematic defence initiative to nurture an indigenous R&D capacity. If the latter, then it is important to look past the Arrow to Canada's military-industrial complex, whose nature has

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[51] Aronsen, "Canada's Postwar Re-armament: Another Look at American Theories if the Military Industrial Complex," 195.

[52] J. L. Granatstein, "The American Influence on the Canadian Military, 1939-1963," *Canadian Military History* 2 (Spring 1993): 63-73.

[53] J. L. Granatstein, *Canada 1957-1967: The Years of Uncertainty and Innovation* (Toronto: McClelland & Stewart, 1986). In particular see Chap. 5, "The Defence Débâcle." Though Granatstein uses the term "Innovation" in the title of his book, the issue of technological change is rarely brought up.

[54] For a discussion of the Arrow see James Dow, *The Arrow* (Toronto: James Lorimer and Co., 1979) and Palmiro Campagna, *Storms of Controversy: The Secret of the AVRO Arrow Files Revealed* (Toronto: Stoddart Publishing, 1992). The only other frequently discussed examples used to illustrate the impact of U.S. Cold War imperatives on Canadian technological development are the "Early Warning Lines". For the single most extensive coverage of the construction of the Mid-Canada and DEW Lines see Joseph Jockel, *No Boundaries Upstairs: Canada, the United States and the Origins of the North American Air Defence, 1945-58* (Vancouver: University of British Columbia Press, 1987).

been obscured by the aircraft's political notoriety.[55]

The end of World War II did not bring a complete dismantling of Canada's military as had been the case after World War I.[56] New postwar geopolitical realities infused Canada's military with an unprecedented peacetime purpose. Rising political tensions between the former Soviet Union (U.S.S.R.) and the United States raised the frightening possibility of another world war. With the misfortune of being on the flight path of a possible nuclear attack by Soviet bombers and missiles, peacetime defence took on a new meaning for Canadians. In addition to defending Canada, the military also participated in the defence of Europe. For the Canadian government, participation in a multilateral military alliance, such as the North Atlantic Treaty Organization (NATO), was a way to counterbalance American hegemony in the postwar era. This unprecedented, self-reliant, peacetime defence role had a profound impact on Canada's postwar technological and industrial development that Canadian historiography has yet to explore fully.

This thesis shows that the Canadian defence establishment's efforts to shape technological development in Canada after the World War II constituted part of what historian Keith Krause has called Canada's first and only "flirtation with an independent [arms] production policy."[57] The new postwar complementarity between military enterprise and industrial development encouraged Canada to attempt to leapfrog up the international hierarchy of arms production. In 1939, Canada had been stuck on the "fourth tier" of arms-producing states. This terminology, indeed the idea of "tiers" in general, comes from Keith Krause who describes the historical structure of arms production and trade in the world in terms of five levels.

Tier one suppliers innovate at the technological frontier. Tier two suppliers produce weapons at the technological frontier and adapt them to specific market needs. Tier three suppliers copy and reproduce existing technologies, but do not capture the underlying process of

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[55] Other than a small number of publications on the AVRO Arrow and the DEW Line works, one finds little interest in the Canadian historical literature on the relationship between Canada's peacetime military and the process of technological change. A review of *Scientia Canadensis*, the official journal of the Canadian Science & Technology Historical Association, reveals the complete absence of any published work on this subject. Even in the scholarly journal *Canadian Military History*, one does not find any attempt to study military enterprise as a force shaping Canada's peacetime technological development.

[56] Morton, *A Military History of Canada*.

[57] Krause, *Arms and the State*, 131. See also Van Steenburg, "An Analysis of Canadian-American Defence Economic Co-operation."

innovation or adaptation.[58] Tier four consists of "strong customers" who can buy and use sophisticated weapons. In the tier five level are "weak customers," who either do not know how to use the weapons they purchase or do not purchase advanced weaponry. An important feature of this hierarchy, according to Krause, has been its relative stability. Great mobility up and down the hierarchy is very difficult.

Prior to World War I, Canada was essentially at tier five, a weak customer. During World War I, however, it moved up to tier four to become a "strong customer."[59] In his book, The Great Naval Battle of Ottawa, Zimmerman recounts the difficulties Canada had moving from strong customer to a tier three supplier during World War II. At the end of World War II, Canada sought to jump to tier two, and on occasion to tier one. Arctic research, DATAR, the Mid-Canada Line, Velvet Glove missile, the AVRO Arrow, George Bull's super-cannon research, transistor circuit design research in the mid-1950s at the DRTE, and research into communications in the high arctic are examples of upward jumps. These efforts, however, contained fundamental contradictions. Krause points out that tier one and two suppliers find their strength in a domestic market. The fundamental dilemma faced by the Canadian military was how to get local industry to invest in R&D and production technology even though the volume of Canadian procurement was not sufficient to support this investment. "The real problem," noted one Department of National Defence memo in 1958, "is not establishing a development group in industry but of keeping it in business."[60]

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[58] Krause, *Arms and the State*, 31-33. The relationship between the three tiers of suppliers lies in the generation and international diffusion of innovations. Krause has used Melvin Kranzberg's typology of technology transfer to characterize these levels. Melvin Kranzberg, "The Technical Elements in International Technology Transfer: Historical Perspectives," in *The Political Economy of International Technology Transfer*, ed. John McIntyre and Daniel Papp (New York: Quorum Books, 1986), 31-45.

[59] Desmond Morton's account of Canadian military build-up during World War I illustrates the jump to tier four. Morton, *The Military History of Canada*

[60] W. A. Thomson (Defence Research Board), Memorandum to Dr. Meek (Defence Research Board), 16 May 1958, Records of Canada's Department of National Defence, RG 24, Accession 83-84/167, box 7369, file DRBS-170-80/E5, pt. 2, National Archives of Canada, p. 4. Thomson goes on to write, "we should look beyond the first contract and be honest with the contractor as to what subsequent defence development or production contracts he might expect, if any. In every case, while it is safe to tell him that ECDC would attempt to make the fullest use of his facilities if future projects needed such facilities, he must clearly understand that he would be foolish indeed to depend on military contracts in order to maintain the facilities".

Overview of the Narrative's Flow: The Seven Case Studies

While American historiography on the subject is rich, the role of peace-time military enterprise in shaping post-World War II Canadian technological and industrial development remains inadequately explored. Most work in this area has revolved around Canada's efforts to design and manufacture one of the most advanced all-weather fighter interceptors of the 1950s, the CF-105, or AVRO Arrow. Joseph Jockel's political and institutional analysis of the Mid-Canada Line and the DEW Line alludes to Canada's efforts to establish a high-tech electronics industry, but does not explore its articulation.[61] Through three case studies, the first half of this thesis examines how, within the emerging digital electronic revolution of the late 1940s and 1950s, Canadian military enterprise shaped the direction and rhythm of domestic research and development.

Chapter 2 looks at how the quest for military self-reliance called for a domestic capacity to do large-scale, automated, high-speed computations. In 1949, the need for a national computational facility resulted in the military's support of a *university* effort to design and build Canada's first electronic digital computer. Chapter 3 examines how the Royal Canadian Navy, in its attempts to define for itself a unique postwar role within the North Atlantic Triangle alliance, became from 1948 to 1956 the single most important institutional force within Canada pushing to create an indigenous *industrial* capacity to design and manufacture digital electronic technology.

Chapter 4's theme is the centrality of the transistor in resolving the complexity/reliability impasse facing the design of large-scale military digital electronic systems. The focus in Chapter 4 is the role of a *government* defence laboratory in advancing and diffusing transistor circuit design know-how in Canada.

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[61] Jockel, *No Boundaries Upstairs*. Jockel relates how Canadians had already crystallized a technology when the American's started thinking about the idea of a Distant Early Warning (DEW) Line. This technology was developed at McGill University and the Defence Research Board by 1947. Popularly known as the "McGill Fence," it was used in the construction of the Mid-Canada Line seven years later. Though the construction the Mid-Canada Line was initiated by the United States, Jockel suggests that it would be a mistake to think that Canada was coerced into building it. For Jockel, the Mid-Canada line served Canadian interests as much, if not more than, American ones. The pressure that C.D. Howe, the Minister of Defence Production, brought to bear on Brooke Claxton, the Minister of Defence, to approve an all-Canadian air defence warning system underscores the military's technological and industrial role. "If the Canadian electronics industry is to play an effective part in the joint defence of North America," Howe wrote to Claxton in 1953, "it must be given an opportunity to participate in the actual production of electronic equipment."

An important theme that emerges from the narrative in Chapters 2, 3, and 4 is how Canada's relationship within the North Atlantic Triangle served as both impetus and deterrent to the Canadian military's program of technological self-reliance.[62] Brebner's triangle metaphor aptly places Canadian history at the crossroads of two powerful geopolitical and economic currents: the east-west transatlantic interaction with Great Britain and a north-south continental interaction with the United States. The Canadian military enterprise's entire policy of technological and industrial self-reliance had to be defined within the shifting tensions that bound the Canadian vertex to the two vertices of the North Atlantic Triangle during World War II and the immediate postwar years. Linked to two industrial and military powers, the Canadian military became a leading advocate of trans-national standardization as a way to ensure that Canada's small and open economy could play an active role within the alliance. Through chapters 2, 3, and 4, the reader will learn how Canadian military enterprise, in its pursuit of technologically mediated self-reliance, created and sustained the nation's first pool of expertise in digital electronics and computers.

Chapter 5 discusses how two public institutions, faced with mounting public and political pressure to improve service, turned to radical innovation and the digital electronic paradigm. The Post Office Department set out to be the first in the world to sort mail automatically by means of an "electronic brain." Trans-Canada Air Lines (Air Canada) decided to merge computation and communications and pioneer in the development of a national automated seat reservations system. An important theme in this chapter is how two public enterprises, with very different technological cultures, managed innovation. Chapter 5 underscores the crucial role civilian public enterprise played, when Canada's flirtation with military self-reliance wavered, in sustaining the core of digital electronic know-how that had been built up.

Chapter 6 examines how the subsidiary of an British company tried to use the R&D for the Post Office and Trans-Canada Air Line projects to advance its ambitions of becoming Canada's first domestic computer designer and manufacturer. Ferranti-Canada had been one of the Royal Canadian Navy's key industrial partners in the exploitation of digital technology for naval warfare. Chapter 6 reveals how this Canadian subsidiary tried to design a technological

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[62] John Bartlet Brebner, *The North Atlantic Triangle* (New York: Columbia University Press, 1945). Despite emergence of the United States from World War II as the dominant economic power as well as Canada's largest trading power, Brebner's pre-war idea of the North Atlantic Triangle did continue to have some relevance in the early postwar years. After all, Canada still retained strong political and military ties with Britain. See Edgar McInnis, *The Atlantic Triangle and the Cold War* (Toronto: University of Toronto Press, 1959).

niche for itself in a market dominated by IBM, yet was stymied by international and internal corporate forces .

While Chapters 5 and 6 deal with a British-owned Canadian subsidiary, Chapter 7 concerns the role of an American-owned subsidiary in creating an indigenous capacity to design and commercialize the "product" innovations of digital electronics. Here the story revolves around the efforts of Sperry Gyroscope of Canada Ltd., a subsidiary of Sperry Rand, to break its dependence on the uncertain defence market of the post-Korean War era to develop civilian-oriented products. In a classic Schumpeterian initiative, Sperry Canada tried to move itself through radical innovation into an exclusive market niche based on digital electronic technology: the numerically-based control of machine tools. As it saw this market being eroded by the swarm of imitators, the company again tried to move into an even more exclusive digital niche: this time, the Sperry Gyroscope of Canada became the first company in the world to market computer numerical control(CNC) to use computers on the shop floor to reprogram machine-tools. Chapter 7 examines the role of Canadian public enterprise and parent-firm relationships in Sperry Gyroscope of Canada's effort to define a world product mandate. An important theme here, as in all the other chapters, is how the process of innovation was filtered through Canada's political economy.

The six case studies that follow offer the first fine-grained view of Canada's participation in the fourth innovation wave and of the process that created the nation's first community of digital technologists. The salient features of Canada's ascent of the digital electronic learning curve were the unprecedented role of the military enterprise in the creation of a peacetime pool of scientific and technical skills in industry and government defence laboratories; the smaller, sometimes erratic, but nevertheless important role of civilian public enterprise in nurturing industrial learning after the military's retreat; the surprising contribution of branch plants in fostering the accumulation of indigenous technical knowledge and the acquisition of skills at the very frontiers of technical change. In sum, in "learning by doing," the nation's first generation digital electronic practitioners in their design and management decisions refracted the global innovation wave through a Canadian context.

Chapter 2

Canadian Military Enterprise: The Early Development of Computers in the University

In 1936, Canada did not possess a single anti-aircraft gun. The armaments guarding the Pacific and Atlantic entrances to Canada, at Esquimalt, British Columbia and Halifax, Nova Scotia, were defective. Furthermore there were no bombs for the twenty-five outdated aircraft comprising Canada's Air Force.[1] Canada's military unpreparedness extended beyond equipment inadequacies and into the ranks of its meagre leadership. "By disbanding the hard-won expertise of the Canadian Corps so thoroughly after 1919, by starving the tiny Permanent Force and the larger but weaker Non Permanent Active Militia during the 1920s and 1930s," writes historian Jack Granatstein, "Canada's governments ensured that when war came in September 1939 there was nothing in place to meet its demands but good wishes."[2] The Chiefs of Staff concluded in 1945 that "Canada had not had to pay the awful price of defeat, but still had to pay dearly for lack of preparedness."[3]

As the nation planned for postwar reconstruction, the memory of Canada's unpreparedness on the eve of World War II haunted the minds of Canada's military leaders. In 1945, in the midst of a massive demobilization program, the leaders of the three Services wanted to retain a sizable peacetime defence force to serve as a nucleus around which the nation could mobilize in a future war.[4] Peacetime military preparedness, however, demanded far more than

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[1] Morton, *A Military History of Canada*, 176.

[2] J.L. Granatstein, *The Generals: The Canadian Army's Senior Commanders in the Second World War* (Toronto: Stoddart, 1993), 258.

[3] Air Marshal Robert Leackie, Vice Admiral Jones and Lieutenant-General Foulkes, "Postwar Policy for Scientific Research for Defence", brief to the Cabinet Committee on Research For Defence, 31 October 1945, Records of the Canada's Department of National Defence, RG 24, vol 11,997, file DRBS-1-0-181 pt. 1. Henceforth records of the Department of National Defence, RG 24, will be called DND.

[4] The full-time manpower requirement for this defence force was set at 105,788 men: 55,788 for the Army, 20,000 for the Navy, and 30, 000 for the Air Force. In addition, the Army, Navy and Air Force proposed an additional 177,396, 20,000, and 50,000 men respectively to serve in the Reserves. The Royal Canadian Navy, which wanted to expand beyond its wartime escort role, called for the construction of a modern naval force of 2 aircraft carriers, 4 cruisers, 18 destroyers, and an assortment of other patrol and training vessels. The Air Force asked for new fighters, bombers, transport carriers, photo-reconnaissance aircraft and other auxiliary aircraft -- 18 squadrons in total. J. M. (continued...)

retaining high levels of recruitment and conventional equipment procurement. The pivotal role that scientific research and technological development had played in the latter years of World War II had made a profound impression on the Canadian Chiefs of Staff. Rockets, automatic fire control, guidance systems, radar, atomic energy, synthetic materials, operations research, and the electronic digital computer were the more dramatic developments arising from wartime imperatives. To ensure Canada's capacity to design, adapt where necessary, test, manufacture, and use the most advanced weapons, the nation's military leaders set out to define a national scientific, technological, and industrial policy. O. M. Solandt, the Director General of Defence Research, summed up the new attitude: "The defence of Canada," he asserted to Cabinet, "requires that she be continually prepared to make and use the most up-to-date weapons of war."[5]

The military's determination to expand the nation's research and development (R&D) capacity reflected Canada's efforts to assure a voice for itself within the inner circle of postwar Western military powers. Canada, to be sure, realized that it could not carry out the same scale and scope of defence development as the United States or the United Kingdom. Hence, Canada pursued a policy of specialization and co-operation. Canada set its contribution to the alliance after 1945 as a small set of research, development, and testing programs of interest to itself and the entire alliance. Though the Canadian military understood the financial necessity to limit diversity in its R&D program, it still had very high ambitions: the military wanted Canada to situate itself at the leading edge of some facets of military technology in order to have something to horse-trade with its allies.

Whether the military chose guided missiles, automated fire control, digital radio communications transmission, or supersonic fighter aircraft, the fact remained that access to fast, large-scale, computational facilities was essential to any weapons development program. Until the early 1950's, electronic digital computers were not standardized products that could be ordered from commercial concerns. Instead, they were one-of-a-kind prototypes developed by defence agencies or in military-funded, university projects. Thus when the University of Toronto's proposed to establish a national computational centre, the Canadian military saw one

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[4](...continued)
Hitsman, "Canada's Postwar Defence Policy, 1945-50", Report No. 90, Historical Section, Army Headquarters, March 1, 1961, DND, vol. 6928, file 90.

[5] O. M. Solandt, "Policy and Plans for Defence Research in Canada", May 1946, Cabinet Document D-61. Records of the Office of the Privy Council of Canada, RG2, vol. 2750, file Cabinet Defence Committee Documents, vol. II. Henceforth Records of the Office of the Privy Council of Canada, RG2, will designated as OPC.

possible way to assure itself access to computational power.

While Canada had lost many of its men in battle, it was one of the few nations that emerged from the war with its industrial infrastructure and economy intact. In fact, the war had dramatically expanded Canada's technological and industrial capacity. Filled with an unprecedented sense of possibilities, the Canadian military purposively led the nation into its first peacetime weapons development program. This chapter investigates how these ambitions fostered Canada's first ever experiments in digital electronic computers at the University of Toronto. Computers were central to plans for Canadian autonomy: without these "engines of the mind," any program to exploit the intensive use of science to develop modern weapons system would quickly grind to a halt. Before we can discuss the computer research program at the University of Toronto, we need to explore how the military's pursuit of self-reliance created the favourable conditions that would allow the University of Toronto to finance its computer project.[6]

Peacetime Military Enterprise Offers New Outlet For Canadian Academic Research

In a brief to the Cabinet Committee on Research for Defence in 1945, the Canadian General Staff underscored "the modern need for progressive research and development in the interests of national defence."[7] "The new weapons of tomorrow," warned the brief, "may decide the outcome of a war in a matter of days by destroying the industrial capacity of a country, its system of communication, and the will of the people to resist."[8] The accelerated rate at which science and technology had been applied during the war demonstrated, in the view of the

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[6] The only published discussion of the early computer work at the University of Toronto is Michael Williams, "UTEC and FERUT: The University of Toronto's Computation Centre", *IEEE Annals of the History of Computing* 16 (Summer 1994): 4-12. Williams, a computer science professor at the University of Calgary, has had a long interest in the history of computer technology. Over the years, we shared sources and exchanged ideas on the early history of computers in Canada. Prof. Williams started working on this article the same time I was preparing this chapter. The intended focus of Williams's well written account is internalist. Consequently, Williams did not attempt to place UTEC in the broader political and economic context of post-World War II Canada. On the internalist aspects of the UTEC computer there is considerable overlap between this chapter and William's account. But because he set out to write an overview, Williams had less opportunity to explore the broader technical issues that shaped some of the key design issues that this chapter has explored.

[7] Leackie et al., "Postwar Policy for Scientific Research for Defence", 31 October 1945, DND, vol 11,997, file DRBS-1-0-181 pt. 1.

[8] *Ibid.*

Canadian Chiefs of Staff, that a well-orchestrated, national military research and development program was vital in peacetime. An essential element in this program was the creation of a new partnership between academic, industrial and military research.[9] For the Chiefs of Staff, it was imperative that science and technology become an integral part of the military mind.[10]

In their 31 October 1945 memorandum to Cabinet, the Chiefs of Staff underscored the fact that Canada had neither the financial resources, industrial infrastructure, nor the size of Armed Forces to support a research, development, and production program across the entire spectrum of modem defence needs. To ensure access to the latest weapons technology, Canada would have to nurture the interchange of scientific and technical know-how and equipment within the North Atlantic Triangle.[11] But any tripartite technology-sharing arrangement would collapse if Canada could not pull its own weight. To have access to the military technology of its allies, Canada would also have to make its own valuable scientific and technological contributions.[12] This insight left open the question: in which facets of defence research and production should Canada seek to develop a comparative advantage?

In 1946, in a policy brief to Cabinet, Dr. O. M. Solandt, the first Director General of

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[9] These principles were not original to the Canadian peacetime military mind. In fact they were taken directly from Vannevar Bush's 26 January 1945 presentation to a Select Committee on Postwar Military Policy of the U.S. Congress.

[10] To drive home the unassailable logic of their message to Cabinet, the Canadian Chiefs of Staff even cited the views of the vanquished. "These principles wholly, or in part," the General Staff wrote, "have also been stated as prerequisite by Albert Speer, Reich Minister of Armaments and War Production and Col.-Gen. Alfred Jodl, Chief of the German Supreme General Staff, in recent interrogation carried out in Germany." Leackie et al., "Postwar Policy for Scientific Research for Defence", 31 October 1945, DND, vol 11,997, file DRBS-1-0-181 pt. 1.

[11] In the midst of World War II, John Brebner coined the metaphor of the North Atlantic Triangle which cast Canadian history in the context of its interplay with the United States and Great Britain. Brebner, *The North Atlantic Triangle.* Edgar McInnis, historian and President of the Canadian Institute of International Affairs, took up the North Atlantic Triangle metaphor to explain the forces shaping Canadian foreign and military policy in the Cold War. The prime considerations for Canada," wrote McInnis, "are based on her direct relations with the United States and the United Kingdom, and these are wider implications and importance for Canada than are the direct relations of those two countries for either of them....There is virtually no aspect of Canadian policy that is not conditioned by these relations; and by virtue of this salient fact, Canada's interest in the triple grouping is more concentrated, more continuous, and relatively more unqualified than that of either of the other two members." McInnis, *The Atlantic Triangle and the Cold War*, 12. At another point he adds, "[Canada's] interests impel her to play the role of friendly intermediary to the utmost of her capacity, and to use whatever means are within her power to reconcile any divergences of views or policies between her two major associates." *Ibid.*, 9. Thus while the British vertex declined in economic and political meaning throughout the first half of the twentieth century, as a result of the North American continentalization, this metaphor still resonated in Canadian military thinking in the years immediately following the World War II.

[12] "It is neither essential nor economical," wrote the Chiefs of Staff, "that [Canada] should maintain applied military research on the entire field of service requirements, but we must contribute our part if we are to share in the experience of these other countries." Leackie et al., "Postwar Policy for Scientific Research for Defence", 31 October 1945, DND, vol 11,997, file DRBS-1-0-181 pt. 1 (p. 4).

Defence Research, reiterated the strategic importance of mounting an independent defence research initiative. He argued that only through judicious specialization of arms research, development, and production could Canada be an equal partner in the alliance.[13] While Solandt emphasized the importance of exploiting new Canadian ideas, he was also keenly aware of the pitfalls of pursuing uniquely Canadian designs. Ultimately, the product of Canadian weapons research had to be in harmony with the military practices of its allies and their equipment standards. But Canada was faced with the dilemma of having to reconcile two different standards: the first arose from Canada's historic transatlantic military ties with Britain. The second was a consequence of the growing American pressure for a unified continental defence system.

The pursuit of interchangeability and standardization within the North Atlantic Triangle became "the cardinal principle" of Canada's postwar defence research, development, and production policy. During World War II, most of Canada's production of military equipment was destined for British and Commonwealth use. Tuned to American design and manufacturing standards and practices, Canadian industry ran into serious problems when it tried to gear its production to British-designed military equipment. "That these difficulties were overcome," observed the Chiefs of Staff, "was not due to planning but to the achievement of our industry and the fortuity of time for the task."[14] In any future war, reasoned the Chiefs of Staff, Canada would once again be called upon to become Britain's arsenal, but without the "fortuity of time" to make the conversion to British production standards.

By 1946, however, the American military had concluded that the next war would be decided in North America, and not Europe. Because advances in military technology were making the United States increasingly vulnerable to heavy attack from its northern flank, the American military wanted to establish an integrated defence system that included Canadian territory. Fearful for its sovereignty, Canada could not agree to this unless it had an active partnership in the defence of North America. Collaboration with the United States in defending

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[13] "Canadian research facilities will be most effectively used," argued Solandt, "if they are concentrated on a relatively small number of projects. If this is done," wrote Solandt, "the quality of [Canada's] research will be so high that the results will be acceptable to our larger partners in exchange for the results of their research. " Solandt, Policy and Plans for Defence Research in Canada, May 1946, 6. Solandt, "Policy and Plans for Defence Research in Canada", May 1946, OPC, vol. 2750, file: Cabinet Defence Committee Documents, vol. II, (p. 6).

[14] Leackie et al., "Postwar Policy for Scientific Research for Defence", 31 October 1945, DND, vol 11,997, file DRBS-1-0-181 pt. 1 (p. 4).

North America further intensified the harmonization of Canadian and American technological and industrial standards. Faced with these conflicting objectives, it was in Canada's interest to promote greater standardization across future British and American weapons development. To be a credible broker between the two systems, however, Canada would have to "share more actively in research, development and design with both the United Kingdom and the United States."[15]

The military's efforts to be a voice in peacetime technological, industrial, and economic planning was not well received by others in government. Prime Minister Mackenzie King, along with most of his senior civilian policy planners, wanted to return the military to its pre-war obscurity. King had a deep-seated and life-long mistrust of the military, argues political scientist James Eayrs.[16] Very early on in World War II, he had become convinced that the "unless [the military] was carefully watched the ambition of [its] officers was likely to lead Cabinet into difficulties."[17]

King was not alone in his suspicion of the military. Canada's civil service elites, argues Eayrs, saw the military as intellectually unprepared to tackle the complexities and subtleties of postwar policy issues. Unlike the United States where the military was actively brought into the federal government planning after World War II, the Canadian political and civil service elite were anxious to remove the military from any role in postwar policy formulation. The lack of any formal university education within the ranks of Canada's most senior officers was seen, according to Eayrs, as proof of the military's inability to appreciate the complex nuances of postwar national policy. Yet the exigencies of war had catapulted the military into prominent policy roles. With the end of the war, Canada's civilian policy community sought to end this intrusion on its power and to return the military to the periphery.[18]

On 12 December 1946, King gave Brooke Claxton the task of pulling the reins in hard on the postwar ambitions of the Armed Services. King and his Cabinet had already forced two

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[15] *Ibid.*

[16] Eayrs, *In Defence of Canada.*

[17] King's belief that senior officers in the Armed Services had conspired against his Government's approach to the conscription crisis hardened his resolve to keep the military as far away as possible from the process of postwar national policy formulation. MacGregor Dawson, *The Conscription Crisis of 1944* (Toronto: University of Toronto Press, 1961), 27.

[18] Eayrs argues that the civil service elites aversion to military influence and advice stemmed from its belief that Canada's "senior officers lacked the type of training that was needed to deal with national security in a nuclear age. What is its collective experience — at sea, on land, or in the air - equipped its members to comprehend their new environment much less to shape it. The answer was thought to be not very much." Eayrs, *In Defence of Canada*, 55-56.

successive reductions in the manpower and armament requests of the Chiefs of Staff for Canada's postwar defence forces when Claxton took over as Minister of Defence.[19] In offering Claxton the defence portfolio, King emphasized the need to bring the independence and extravagance of the Armed Services back under control. The Services "were continuing to go too far" warned King.[20] Referring to Claxton's former post as Minister of National Health, King presented the need to cut back defence as a guns-or-butter issue. The Government could not target social needs, King argued, if its Armed Services continued to spend at current levels.

On choosing Claxton to be the "hatchet man," Mackenzie had not reckoned with Claxton's conviction that the shifting postwar geopolitical realities called for strong defence policies. Although Claxton did proceed to make considerable savings in the 1946-47 defence budget, and twice force down the Chiefs of Staff's 1947-48 budget estimate of $339.8 million, Claxton balked at Cabinet's request for an additional 10 percent across-the-board cut.[21] As Eayrs points out, Claxton's experience with Soviet negotiating techniques at the 1946 Paris Peace Conference "led him to believe that the time had come for Canada, in the company of friends and neighbours, to turn for protection to the military."[22]

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[19] By August 1945, the Army had slashed its staffing requirements for full-time soldiers to 30,000. The Air Force lowered its expectations to 10 squadrons and 20,000 full time airmen. Minutes of Cabinet Defence Committee, August 14, 1945, OPC, vol. 2748, File: Cabinet Defence Committee Conclusions, vol. 1. At the 24 September 1945 meeting of the Cabinet Defence Committee, Armed Forces allocations received their final cut before being presented to Parliament by the Government. Full-time staffing for the Army, Navy and Air Force were set at 25,000, 10,000 and 15,000 respectively. The Navy saw its demand for cruisers and destroyers cut back to two and 12 respectively. Minutes of Cabinet Defence Committee, 24 September 1945, OPC, vol 2748, file Cabinet Defence Committee Conclusions, vol. 1.

[20] J.W. Pickersgill and D.F. Foster, *The Mackenzie King Record, III, 1945-1946* (Toronto: University of Toronto Press, 1970), 394.

[21] Though Government had approved a defence budget of $500.5 million (this amount also includes the costs of demobilization and special projects like the Northwest Staging Route) for 1946-47 fiscal year, Claxton managed to lower that estimate by $102 million under budget. Brooke Claxton, Memorandum for the Cabinet: Defence Estimates, 4 February 1947, OPC, box 70, file D-19 (1947), Cabinet Document #389. Claxton saw these 10 percent across-the-board cuts as "unreal and misleading." He warned Cabinet that the cuts would not only "disastrously affect the organization of the Department on a sound administrative basis," but they would also "demoralize the active forces and reserves." Claxton went on to argue that these additional cuts, which in his mind completely overlooked Canada's strategic needs, would "not be in accord with the public's desire respecting defence." Claxton felt that "the experiences during the war, the postwar attitude of the Soviet Union, increasing recognition of the strategic importance of the north, as well as the dangers involved in the new weapons, have combined to make Canada, like other countries, more defence conscious than ever before, and our people recognize that if another war comes it will come without warning and without giving us time to prepare after war begins."

[22] In an unpublished autobiographical sketch, Claxton wrote, "Unless the free countries built up their defences together we would go down the drain one by one. About this I had no doubt and my experience at the Paris Conference...had confirmed my conviction." Eayrs, *In Defence of Canada*, 22.

Canada's Peacetime Defence Research Program and National Computational Capacity

The Allied pursuit of victory in World War II and the American pursuit of power in the immediate postwar years drove the early development of high-speed, large-scale computational technologies. The first fully functional, electronic, digital computer ENIAC arose out of the necessity to automate complex ballistic computations in order to accelerate the production of vital bombing tables. The construction of the first atomic bomb entailed even more complex mathematical computations. ENIAC was developed too late to be used in the Manhattan project. Only through considerable manpower and ingenuity did the scientists at Los Alamos succeed in using the existing manual desktop tabulators and semi-automatic, electro-mechanical punch-card machines to carry out the complex scientific calculations needed. Such herculean efforts, however, would not have produceed timely design answers for the construction of Edward Teller's hydrogen bomb. But ENIAC proved very useful for the design of Teller's new, frightening, and more destructive engine of war.

The computational demands arising from intensive and systematic application of science to weapons development went beyond atomic and thermonuclear bombs to include development of guided missiles and supersonic aircraft. The equations of hydrodynamics and aerodynamics that these technologies required had long proven impenetrable to traditional abstract mathematical analysis. Indeed, John von Neumann, the eminent American mathematician and scientist who had the ear of the American military, proclaimed that only the electronic computer could open up the laws of hydrodynamics to the requisite analysis. From the moment ENIAC was completed, von Neumann declared the machine inadequate. He called for the construction of a new generation of performance-driven computers. Since there were no commercial incentives sufficient in the 1940s to justify industrial R&D in large-scale electronic computers, it took the escalating political tensions between the United States and the Soviet Union to provide the deep pockets to underwrite this costly development.

By 1948, ever increasing tensions between the Soviet Union and the North Atlantic Triangle alliance, the accelerated exploitation of science in the development of military systems, and soon, the ascendency of Louis St. Laurent to Prime Minister created the circumstances and politics to support the Canadian military's push for technological self-reliance and the accelerated entry of digital technology into Canada. In April 1947, the Canadian government created the

Defence Research Board (DRB).[23] Established as a fourth independent Service, DRB's mandate was to run a research program that would respond to the common needs of the other three Services.[24] The Chairman of DRB sat as an equal member on the Chiefs of Staff, an arrangement which distinguished Canada from most other nations.[25] By the second year, 1948-49, DRB's budget had grown from 1.6 to 7.2 percent of total military expenditures.[26]

Created to rationalize and consolidate the research for the three Services, DRB set about defining Canada's participation in the creation and diffusion of defence technology within the North Atlantic Triangle alliance.[27] In his 1946 brief to Cabinet, Solandt, in consultation with the Chiefs of Staff, identified atomic warfare, bacteriological warfare, chemical warfare, guided missiles, rockets, supersonic aerodynamics, gas turbines and jet propulsion, electronics (radar and communications) and the Arctic as the high priority items of Canada's defence research and development program. Though computers were omitted from DRB's original list, it became apparent very quickly that the success of the military's weapons development programs depended

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[23] D. J. Goodspeed's work remains the best single work on the early history of the Defence Research Board. *A History of the Defence Research Board of Canada* (Ottawa: Queen's Printer, 1958).

[24] Military leaders adamantly opposed earlier suggestions that the National Research Council could, as it had done during World War II, meet the research needs of Canada's armed forces. In a meeting with the Minister of Defence, the Chiefs of Staff and Solandt, the Chairman of DRB, argued that there was an "urgent need" for a separate research organization "to ensure that Canada [would be] in a position to ask for, and receive, a share in the research and development work which is being undertaken in the United States and the United Kingdom." Furthermore, they argued that the NRC was not set up to bridge the gap between research and the military user. "The application of scientific knowledge to defence problems," the military explained to Claxton, "must be the function of the Defence Services." Minutes of the Second Meeting of the Interim Defence Research Board, 20 January 1947, DND, vol. 11,996, file DRBS-1-0-43-2, pt. 1.

[25] "Instead of leaving defence research to be conducted by a separate government department or by a number of government departments, as is the case in Britain, France and Russia, or instead of having of having it conducted by the Armed Forces themselves, as is broadly the case in the United States, Canada decided that defence research should be the responsibility of a separate organization, serving the Navy, the Army, and the Air Force and closely integrated with them but concerned with the scientific aspects of war." Goodspeed, *A History of the Defence Research Board of Canada*, 2.

[26] In absolute terms, DRB appropriations rose from $3.9 million to $19.8 million. The first figure is based on DRB budget data presented in Goodspeed, *A History of the Defence Research Board*, 110, and the second is deduced from app. C, "Table of DND Appropriations by Major Category", in D. J. Godspeed, *The Canadian Army, 1950-55: Part 1*, Canadian Defence Policy, Report No. 93, Historical Section, Army Headquarters, June 1961, DND, vol. 6928, file 93.

[27] See Solandt, Policy and Plans for Defence Research in Canada, May 1946, OPC, vol. 2750, File: Cabinet Defence Committee Documents, vol. II. In the fall of 1947, the Scientific Adviser to the Chiefs of the General Staff presented an extensive analysis of Canada's R&D requirements in atomic warfare, biological warfare, and chemical warfare. See O. Mass, General Staff Requirements for Research in the Field of Special Weapons, 4 September 1947, DND, vol. 4124, file 3-900-43-2. For a detailed list of electronics research and development areas of interest to the military see Memorandum to the Secretary, Joint Communications Committee: Canadian Armed Services Electronic Research Requirements, 19 June 1947. DND, vol. 4233, file DRBS-640-43.

on a capacity to do large-scale computational problems at high speeds.[28]

Without computational self-reliance there would be no military self-reliance. The power to reduce the design time of new military technology now made the nascent electronic computer a vital part of the arms race. "The electronic computer," noted B. G. Ballard, the Director of NRC's Electrical and Radio Engineering Division, "provides a tool which increases tremendously the capacity of a given staff...and enables the design to be completed in a sufficiently short period of time so that the data employed does not become obsolete before the design is completed."[29] On 8 July 1947, DRB's Electronic Advisory Committee discussed "the need for an electronic computer in Canada."[30] Though the Committee had no direct experience with large-scale digital computers, it nevertheless felt that these machines were of strategic importance to Canada's military research programs, particularly at the Canadian Armaments Research and Development Establishment (CARDE),[31] where the need was "urgent." Before bringing up the matter with the Chiefs of Staff, the Committee wanted to have a more accurate picture of the military's future requirements for such a machine. An informal survey of the three Services on this matter revealed the belief that "Canada should have an electronic computer to enable her to pursue her own research program independent of foreign countries....Until Canada is equipped with a suitable computer centre, she will be obliged to rely upon foreign aid for many of the designs which require large-scale calculations. If it is agreed that Canada should be independent in this respect, then the time has arrived to initiate a computer centre in Canada."[32]

In the context of the Canadian military's concern over the absence of computer technology based on digital electronics, a group of University of Toronto mathematicians,

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[28] For example, much of the forty-person years required to design a new aircraft resulted from having to do extensive calculations by manual means. B. G. Ballard, Letter to P. W. Nasmyth, 2 January 1948, DND, vol. 4233, file DRBS-3-640-43.

[29] *Ibid.*

[30] Minutes of the Second Meeting of the Electronics Advisory Committee, 8 July 1947, DND, vol. 4233, file DRBS-3-640-43.

[31] CARDE (Canadian Armaments Research and Development Establishment), in Valcartier, Quebec, was the military agency charged with carrying out the research and development associated with many of Canada's advanced weapons projects such as guided missiles, bomb ballistics, super high velocity field guns, and rockets.

[32] B. G. Ballard, Letter to P. W. Nasmyth, 2 January 1948, DND, vol. 4233, file DRBS-3-640-43. Of the three Services, the Navy was the most vocal proponent of the electronic computer. As examined in the next chapter, the Navy saw the electronic digital computer as an integral part of modern weapons systems, and not simply as a computational tool for scientific research. As early as 1947, the Navy's electronics research laboratory was articulating a technological scenario where real-time digital electronic information processing would be used directly in battle, or in preparation for battle through battle simulators.

scientists, and engineers found the opportunity to advance their own interests and ambitions which they had harboured since 1946. Word of American research on large-scale automatic digital computation began to filter into Canada in 1946. Curious to learn more about this remarkable, but as yet unseen, technology, a group of University of Toronto professors set up an interdepartmental Committee on Computing Machines.[33] In the Summer of 1946, the Committee organized a fact finding mission to the United States, its goal to learn first hand what had been achieved in "the construction of large-scale high-speed computing machines and to enquire into the nature of the computations undertaken by existing machines."[34] In its subsequent report to the university, the Committee concluded that the purchase, or even replication, of any of the existing American computers would be premature. "Both those using [these] machines and those designing them, without exception," observed the Committee, "agreed that all existing machines are obsolescent in the sense that no copies of the large machines will be made in the future."[35] The rapid flux and unpredictable metamorphosis in computer technology called for a wait-and-see approach reasoned the Committee; a clearer paradigm of computer design was needed before the university should build or acquire its own machine.[36] Though the construction of a computer

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[33] Dean S. Beatty, a professor of mathematics at the University of Toronto, first raised the idea in late 1945. *Summary of Activities of Committee on Computing Machines*, 10 October 1947. An attachment to a letter to O.M. Solandt from B.A. Griffith, dated 14 October 1947. Calvin Carl Gotlieb Papers, B88-0069, box 001, file UTEC, University of Toronto Archives. Henceforth this collection will be called Gotlieb. The Committee was comprised of Professor W J. Webber (Chairman), Department of Mathematics; Professors B. A. Griffith (Secretary) and A. F. Stevenson, Department of Applied Mathematics; and Professor C. Barnes, Department of Physics; Professor V. G. Smith, Department of Electrical Engineering.

[34] The university's Advisory Committee on Scientific Research sponsored this mission with a $1,000 travel grant. J. W. Hopkins, Memo to File: Report on Visits in Boston and New York Areas in Collaboration with University of Toronto Committee on Computing Machines, 5 July 1946. Record of the National Research Council of Canada, RG 77, vol. 134, file 17-15-1-20, National Archives of Canada. Henceforth this collection will be called NRC. Funding came specifically through the Advisory Committee on Scientific Research. At the Committee's invitation, the National Research Council sent two representatives to participate in this mission: Dr. J. W. Hopkins, a member of the Interdepartmental Meteorological Committee and N. L. Kusters, from the Radio and Electrical Engineering Division. From 10 June to 31 June 1946, the combined University of Toronto and National Research Council delegation visited all the key research facilities in high-speed, large-scale computation: the Massachusetts Institute of Technology, I.B.M., Harvard University, Bell Laboratories, R.C.A. Laboratories, the University of Pennsylvania, and the Institute of Advanced Studies, at Princeton.

[35] *Preliminary Report on Modern Computing Machines*, August 1946, Records of the National Research Council of Canada, RG 77, vol. 134, file 17-15-1-20, National Archives of Canada. Henceforth Records of the National Research Council of Canada, RG 77, will be called NRC.

[36] The Committee thought it wise to wait for the outcome of John von Neumann's ambitious computer project at the Institute of Advanced Studies in Princeton. If successful, von Neumann's ideas promised dramatic improvements in this very embryonic technology. J. W. Hopkins, the National Research Council representative who accompanied the University of Toronto delegation, had come to the same conclusion. "Any actual construction [of a computer] to be undertaken in Canada," concluded Hopkins, "should be suspended until the results of at least the pilot version of

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in the near future was ruled out, the Committee did call for the creation of a small computational laboratory in the University of Toronto as an initial training ground in scientific computational techniques.

Nearly one year after its initial report to the university, the Committee's ambitions expanded dramatically as it called for the creation of a Canadian computation centre to handle all of the nation's scientific computational needs.[37] In an effort to enlist financial backing, the Committee draped its ambitions in the language of national imperatives. The absence of a large-scale high-speed computation facility, asserted the Committee, seriously impeded scientific and technological progress in Canada. Extracting further knowledge about the physical world from abstract mathematical models was becoming increasingly elusive.[38] Important mathematical problems essential to scientific and technological advance, argued the Committee, were either "treated as insoluble, solved imperfectly, prepared for solution at a computing centre in the United States, or solved at a cost of very tedious calculations carried out with existing facilities and involving months or even years of effort."[39] Taking a clue from von Neumann's argumentation in the United States, the Committee saw a purely electronic machine as the only effective way for Canada to break through the computation impasse. The Committee then turned to the only two agencies with money available to help create a national computation centre at the university itself: the National Research Council (NRC) and the Department of National Defence

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[36](...continued)
Professor von Neumann's machine are to hand." J.W. Hopkins, Memo to File: Report on Visits in Boston and New York Areas in Collaboration with University of Toronto Committee on Computing Machines, 5 July 1946, 7. NRC, vol. 134, file 17-15-1-20.

[37] The Committee suggested that a staff might be needed "to work in two or even three shifts per day, so as to maintain almost continuous operation of the computational facilities for research purposes." Preliminary Plans for a Proposed Computing Centre at the University of Toronto, Appendix 2 in a letter from B. A. Griffith to O. M. Solandt, 14 October 1947, Gotlieb, box 001, file UTECS.

[38] The Committee's views reflected the views of noted American scientists who argued that the advancement of the physical sciences had become contingent on high-speed computation. Herman Goldstine and John von Neumann argued that the "advance of analysis is, at this moment, stagnant along the entire front of non-linear problems. That this phenomenon is not of a transient nature but that we are up against an important conceptual difficulty is clear from the fact that, although the main mathematical difficulties in fluid dynamics have been known since the time of Riemann and of Reynolds, and although as brilliant a mathematical physicist as Raleigh has spent the major part of his life's efforts in combating them, yet no decisive progress has been made against them -- indeed hardly any progress which could be rated as important by the criteria that are applied in other, more successful (linear!) parts of mathematical physics." Cited in William Aspray, *John von Neumann and the Origins of Modern Computing* (Cambridge, Mass.: The MIT Press, 1992), 59.

[39] Preliminary Plans for a Proposed Computing Centre at the University of Toronto, Appendix 2 in a letter from B. A. Griffith to O. M. Solandt, 14 October 1947. Gotlieb, box 001, file UTECS.

(DND).[40] Both these institutions had an urgent need for computational power: the military for its weapons development program and the NRC for its atomic energy research program at Chalk River, Ontario.

E. G. Cullwick, Director of Electrical Research at DRB, informed the University of Toronto's Committee on Computing Machines that its proposal would undoubtedly be of value to the Defence Research Board.[41] At a separate meeting with university representatives on 8 January 1948, in Ottawa, NRC and DRB agreed that Canada needed computational capabilities, such as proposed by the university, and expressed a willingness to fund a five-year program to establish a "first-rate," full computing centre.[42] The general objective, agreed upon by all at this meeting, was to have a full scale electronic digital computer in operation by 1953 and a highly skilled professional staff capable of exploiting the computational potential of such a machine.[43]

The strategy adopted was an incremental one: from 1948 to 1953, the Computation Centre's capabilities were to be expanded in three distinct phases. The first and most immediate step was to lease IBM punched-card machines and start training a professional staff. Not only was this staff to be competent in one or more areas of applied mathematics, but it also had to understand how to translate science and engineering problems to machine-based numerical methods. The next phase in the plan called for the construction of an interim, large-scale, electro-mechanical computer based on the relay, switching technology used in telephone exchanges. Though much slower than a purely electronic computer, the relay computer offered fast, risk-free entry into large-scale computational technology. The university recommended copying Bell Laboratories's latest design at a cost of $45,000. This estimate was based on the Committee's expectation, which appears to have arisen from assurances from George Stibbitz at Bell Laboratories, that there would be no licensing fees. While the first two phases were being carried

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[40] Until the construction of a computer, the Committee asked the National Research Council for a $10,500 grant to purchase conventional desk tabulators and $4,000 per annum to lease IBM punch-card, processing machines. The Council replied with $6,500. This amount supported the rental of IBM punch card equipment and the salaries of two junior assistants to operate the equipment, from April 1947 to March 1948.

[41] E. G. Cullwick, Letter to B.A. Griffith, 27 November 1947, Gotlieb, box 001, file UTECS.

[42] Originally, DRB and NRC both agreed to give $15,000 each, and that DRB would puts aside $100,000 for the actual construction of the computer centre. Because of administrative constraints, DRB could not set aside funds for some possible future use. Instead, NRC and DRB, each agreed to provide $20,000 per annum.

[43] Progress Report on the Proposed Computing Centre at the University of Toronto, 22 March 1948 prepared by B.A. Griffith, Secretary of the Committee on Computing Machines, for Sidney Smith, President of the University of Toronto, Gotlieb, box 001, file UTECS. In this report, Griffith recapitulates the 9 January discussions with DRB and NRC.

out, the plan called for the gradual development of an electronics research team to construct an electronic computer after a period of experimentation.[44]

The decision of DRB and NRC to support the creation of a computational centre at the University of Toronto was no doubt influenced by the absence of any other site contenders. The university had the intellectual resources to develop an effective, multi-disciplinary team in scientific, computational techniques. But was the university the best place to design and build a full-scale, electronic digital computer? If any single Canadian group had the theoretical and production engineering experience to build a computer in 1948, it was the NRC. Indeed, the NRC had already concluded the previous summer that it was "the organization best qualified to build an instrument of this nature."[45] The Electronics Advisory Committee, agreeing, recommended that if the Chiefs of Staff [were] in agreement, "a proposal should be forwarded to the D. Mackenzie, [the president of NRC], with an offer of financial support from the Services and DRB."[46] However, nearly a year later, the head of NRC's Radio and Electrical Engineering Division, B. Ballard, wrote to D. Hartree, a noted British physicist and computer pioneer, that while "it would be profitable for us to undertake the development of an electronic computer at the National Research Council.....We feel that we could not justify a computing machine in the laboratory for work in this district."[47] The existing historical record is silent on whether the DRB ever made an offer to NRC. Neither is there any information on how Mackenzie felt about the idea of NRC embarking on such an undertaking. For whatever reasons, NRC did not venture into computer technology.[48]

Just days before Christmas in 1948, the university computer group received the unexpected news that they had been misinformed by Stibbitz and that the licensing fees for the

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[44] *Ibid.*

[45] Minutes of the Second Meeting of the Electronics Advisory Committee, 8 July 1947, DND, vol. 4233, file DRBS-3-640-43, 5.

[46] *Ibid.*

[47] B. G. Ballard, Letter to D. R. Hartree, 30 April 1948, NRC, vol. 52. file 17-28B-1, pt. 1.

[48] Ironically, over a decade later, NRC's Electrical and Radio Engineering Division started to explore computer circuit design as part of a top secret project to develop a radar-based, counter-mortar system. NRC's efforts to build on this experience and find a niche for itself as an innovator in computer hardware were a failure. The group then tried to pioneer educational software to be run on main-frame, or mini-computer, based time-sharing environments.

Bell relay computer would be $25,000.[49] The cost estimates for copying Bell's "X75320 Network Computer" thus jumped from $45,000 to $70,000. At a meeting held in Ottawa on 16 March 1949, attended by Davies (from DRB), C. J. Mackenzie, W. B. Lewis, E. C. Bullard and C. C. Gotlieb, the decision was made to drop the relay computer and to accelerate the program to build an electronic computer.[50] DRB agreed to increase its annual funding of electronics research and development at the university from $20,000 to $30,000. NRC's contribution remained at the original stated level of $20,000 per annum. In addition, DRB promised to pay "an undetermined larger amount when the time [came] to commence construction of the computer".[51]

The rationale for dropping the relay computer remains unclear. In retrospect the decision to bypass this electro-mechanical technology and to go directly to a purely electronic computer may seem obvious. But in the context of 1948-49, the relay computer had distinct advantages. It was easier to design, build, and maintain. Unlike ENIAC, and other electronic computers of the day, the relay machine neither consumed vast quantities of electrical power nor required elaborate climate control systems to keep it from overheating. Relay computers were no more cumbersome in size than their purely electronic counterparts. Furthermore, they were far more reliable and required less servicing. The relay computer's principal limitation arose from the slower switching times of the telephone relays used because the mechanical motion of the armature in the relay limited the overall speed of the computer. Purely electronic switching, offered the prospect of enormously greater speeds.

If quick access to a useful large-scale computational facilities had been the military's prime reason for funding the University of Toronto project, then, in the context of 1949, the relay computer offered a prudent approach. Despite speed limitations, relay computers still offered a cheaper and quicker technological solution for a wide range of large-scale scientific computations than did purely electronic approaches. In the 1945-51 period, a whole range of relay computers, from small to very large, found extensive use in military and academic settings. The United

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[49] L. Stiles, Letter to E. C. Bullard, 23 December 1948, Gotlieb, box 1, File-UTECS. Northern Electric acted as Bell Telephone Laboratories' Canadian representative in this matter.

[50] Mackenzie notified Lewis of the proposed meeting and asked him to attend. The goal of this meeting, Mackenzie wrote Lewis, was "to go over the [University of Toronto] proposals in detail and get them in such a form as we think may appeal to the Council and the Board." C. J. Mackenzie, Letter to W. B. Lewis, 23 February 1949, NRC, vol. 52, file 17-28B-1 pt. 1. Lewis was included in this meeting because he was the Director of Research of NRC's atomic energy research project at Chalk River which was to be one of the university's main customers for computations.

[51] W. H. Barton, (Secretary, Standing Committee on Extra-Mural Research, Defence Research Board), Letter to E.C. Bullard, University of Toronto, 22 April 1949, Gotlieb, box 001, file UTECS.

States Army's Ordnance Department had three relay computers running at the Aberdeen Proving Ground, Maryland and another at Army Ground Forces in Texas. In 1949, the American National Advisory Committee on Aeronautics had just completed construction of a relay computer to be used in laboratories at Langley Air Force Base. The United States Navy had three relay computers in operation for its Bureau of Ordnance and another at its Office of Naval Research.[52] Installed in 1948 at the U.S. Naval Proving Ground, the Mark II relay computer was running twenty-four hours a day, six days a week, on ballistic research problems.[53] In 1951, the Naval Proving Grounds built the Mark III, another relay computer.[54] At the Aberdeen Proving Ground, where both the electronic ENIAC and a Bell Telephone Laboratories' relay computer were used for scientific computations, Dr. L. Alt, observed that the "Bell Laboratories' machine and ENIAC represent two extremes....The ENIAC is adapted to very long problems, provided they are not too complicated and do not need too much storage capacity. The Bell Laboratories' will handle the most complicated problems, requiring considerable number storage, provided they are not too long. The ENIAC prefers continuous runs, the Bell Laboratories machine does not mind 'on-and-off' problems.'[65]

Though its slow switching speed would limit the long-term utility of the relay computer, it nevertheless offered Canada a valuable two-to-three year interim solution to its computational research needs, thereby affording the university's Computation Centre an earlier, and hence faster, opportunity to develop its computational expertise. In addition, a relay computer would have also provided the Computation Centre's hardware engineering team with more time to grow in size and experience before tackling the construction of an electronic computer. But the

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[52] This information was taken from a list entitled "Existing and Practically completed Digital Computing Machines developed by or presently on loan or contract to the Government", in the journal *Mathematical Tables and other Aids to Computation*, 2, (1946-47): 237. In Japan, relay computers played an important role into the early 1950s. See Ryota Suekane, "Early History of Computing in Japan", in *A History of Computing in the Twentieth Century*, ed. N. Metropolis et al., (New York: Academic Press, 1980), 575-578. At the same time Canada cancelled plans to build a relay computer, Sweden decided that its first large-scale computer should be based on relay technology. Called BARK (Binar Automatisk Rela Kalkylator) this computer was designed, built and tested in little over one year. Goran Kjellberg and Gosta Neovius, "The BARK, A Swedish General Purpose Relay Computer", *Mathematical Tables and other Aids to Computation* 5 (1951): 29-34.

[53] *Digital Computer Newsletter*, Office of Naval Research, Mathematical Sciences Division, vol. 3, No. 3 (October 1951): 2

[54] *Ibid.* The Mark III's first set of computations concerned the development of fire-control systems.

[55] L. Alt, "A Bell Telephone Laboratories' Computing Machine: Part I", *Mathematical Tables and other Aids to Computation* (1948-49): 1-84, 84. The Bell relay computer installed at the Aberdeen Proving Ground, however, was bigger than the one proposed for the University of Toronto. The former used 9,000 relays while the latter called for 3,000.

decision was not made to go with the surer, but lower-performance, relay computer.

Since DRB was to carry the entire costs of building both the Bell Relay computer and the electronic computer, one can reasonably assume that DRB was the prime mover behind the change of plans. The added licensing fees may have caused DRB to stop and ask if the relay computer, an interim solution, was worth the expense. And yet, it is doubtful that the relay computer would have been dropped had the university insisted on using it. Though it meant postponing the introduction of large-scale computational techniques, the promise of accelerating the development of an electronic computer seduced the university. The Computation Centre Committee's thinking on this matter was quite different when it met on 6 January 1949 to reassess the role of the relay computer in light of the new costs.[56] Anxious to get immediately on to the learning curve of large-scale computation technology quickly, the Committee reaffirmed the short-term to mid-term importance of the relay computer. Because it was impracticable to design and test its own relay computer in a short time, the Committee felt it was important to convince DRB of the merits of following the original plan and to buy the Bell relay computer.[57]

DRB's willingness to reallocate funds to an accelerated hardware-development program underscores an additional facet that electronic computer R&D presented to Canada's military. Digital electronics were just starting to appear at the very frontier of weapons systems research. Designing and building computers was thus a useful vehicle for fostering a national capacity in digital circuit design.

The cancellation of the relay computer, at the 16 March meeting, raised the stakes in the Computation Centre project dramatically. Those who needed computational power clung to the expectation that an electronic computer would be constructed quickly as the university Committee had so confidently promised.[58] Yet, Canada's entire computational program now rested on the shoulders of a small, inexperienced team of engineers. N. L. Kusters, a senior engineer in NRC's Electrical and Radio Engineering Division, expressed serious reservations

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[56] Present at this meeting were Dean S. Beatty, Professors Bullard, Smith, Stevenson, Barnes, and Webber, as well as Dr. Gotlieb.

[57] The revised costs were included in a formal grant proposal made to NRC on 27 January 1949. The corresponding proposal to DRB no longer exists. The amount requested from NRC was $21,000. This proposal, however, reveals that DRB was asked to underwrite the entire cost of the relay computer: $70,000 to build it and $21,000 for operating expenses. E. C. Bullard, Application for as Grant for Research, 27 January 1949, NRC, vol. 52, file 17-28B-1 pt. 1.

[58] The university's confidence in its own abilities may have reinforced DRB's arguments. Two months earlier, the Committee on Computing Machines stated that only a year of experimentation in component design would be needed before its team's could start construction of a full scale computer "without serious risk of major error in policy". *Ibid.*

about dropping the relay computer and accelerating the electronic computer program.[59] In a memo to his director, Kusters wrote:

> *While the University of Toronto might be an ideal place for the location and operational responsibilities of Canada's computing center, there is considerable doubt in my mind whether it is the appropriate place for the development of a large scale electronic digital computing machine....Most of the people [engaged in the development program] have a limited amount of practical experience which seems to be out of proportion with the magnitude of the project. A project of this size requires a large amount of experimental background, a relatively large staff which is permanently assigned to the project, and sufficient [sic] close contact with production methods to make sure that none of the advantages achieved by tedious design are lost between the bread-board model and the final machine.*[60]

The cancellation of the relay computer heightened the necessity to develop an electronic computer as quickly as possible. Yet this sense of urgency did not translate into a practical design approach. No real effort was made to reproduce a design proven elsewhere. Neither was the team content to use less advanced, but nevertheless, workable technological solutions. Copying a design that had proven itself elsewhere was one way to make the task a easier. By 1949 the IAS computer was serving as the genetic code for a whole generation of computers in the United States. Some were identical clones while others were close adaptations.[61] Though members of the University of Toronto's Committee on Computing Machines had contact with the Institute of Advanced Studies computer group, no attempt was made to copy the Institute's machine.[62] Instead, the lure of ever higher performance and the desire for originality drove the designers to a project called the UTEC Mark I (University of Toronto Electronic Computer).

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[59] N. L. Kusters, as the reader will recall, was one of the two representatives NRC selected to participate in the mission to the U.S. organized, in the summer of 1946 by the University of Toronto Committee on Computing Machines, to learn about the state of computer developments.

[60] N. L. Kusters, Memorandum to B.G. Ballard, 13 June 1949. NRC, vol. 134, file 17-15-1-20.

[61] In 1948, Los Alamos decided to build its copy of the IAS machine. This involved a close working relationship between the Los Alamos and Princeton groups. Just before the decision was made in Canada to accelerate the construction of an electronic computer, the Aberdeen Proving Grounds had already agreed to build two copies of the IAS computer. ORDVAC (Ordnance Discrete Variable Automatic Computer) and ILLIAC (Illinois Automatic Computer) followed the IAS logic design very closely. In 1949, the Argonne National Laboratory decided to build an exact copy of the IAS machine.

[62] There is no evidence in either the University of Toronto, National Research Council of Canada, Defence Research Board, Institute of Advanced Studies, or in the John von Neumann archives that the University of Toronto team ever entered into any serious discussions with von Neumann over the question of copying the IAS computer.

From the moment Josef Kates was brought in on the University of Toronto's electronic computer project in 1948, his ideas, ambition, and assertive drive became the dominant elements shaping it.[63] After the Nazi rise to power, Kates, a secondary level student, fled from Vienna and made his way to Canada. While working at the Imperial Optical Co. in Toronto on wartime ordnance work, Kates managed to earn a high school degree as well as to complete a correspondence course in radio electronics. In 1948, after four years of study, Kates completed a Bachelor of Science degree in physics at the University of Toronto. Prior to enrolling in university, Kates's efforts to pursue an invention had brought him to the attention of Rogers Majestic, and during his entire undergraduate studies, Kates worked for Rogers Majestic: first on high power tubes and then, after the war, on receiving radio tubes.

Kates was a graduate student in electrical engineering when the Committee on Computing Machines asked him to join the project in 1948. At about the same time, another graduate student in electrical engineering, Alfred Ratz, was also enlisted. By 1949, the development of Canada's computer hardware was resting completely on the shoulders of these two graduate students.[64] Before DRB would release any money for the construction of a full-scale electronic computer, a small successful prototype had to be built. In the summer of 1949, Kates and Ratz, along with one technician and five summer students, set out to design and build the UTEC Mark I.[65]

C. C. Gotlieb, who had recently completed his doctorate in physics, was given the job of overseeing the development of a large-scale, high-speed computational research program at the university. Gotlieb's interest and experience lay in the broader questions of devising and applying computational techniques to solving large scientific calculations. He spent most of his time leading a team of mathematicians and scientists in the development of numerical methods for IBM punched card machines and desk tabulators until UTEC was ready. Lacking an electrical engineering background, he left the details of hardware design to Kates and Ratz. Despite their junior status, Kates and Ratz became the *de facto* hardware experts of the computer project. The

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[63] Sometime in the 1950s Josef Katz had his name legally changed to Kates. This work will refer to him by his later name, even in the period before he changed his name. Only in the footnotes will the distinction be maintained when appropriate.

[64] In time, students Casciato, Richardson, and Stein were added to the team.

[65] The plan was to have UTEC Mark I "handle numbers of approximately 4 decimal digit accuracy...be able to add, subtract and choose among different order sequences...This model will contain about 600 vacuum tubes and will occupy a space of approximately 4 feet x 4 feet x 6 feet." Progress Report as of October 1, 1949, NRC, vol. 52, file 17-28B-1, vol. 1.

details of how Kates and Ratz worked out the design between themselves is not known. But it was Kates's forcefulness and persuasiveness that continually convinced the Committee on Computing Machines, DRB, and NRC that he and Ratz had the right approach.

The military's ambiguity over the primary objective of the UTEC project fueled Kates's and Ratz's pursuit of novelty. The inexperienced team's pursuit of new and faster circuits, a radically new arithmetic tube, and parallel electrostatic memory continually pushed back the completion date of UTEC Mark I. After two and half years, UTEC Mark I still did not completely satisfy the design goals specified in 1949. This delay set the stage for conflict between those engineers absorbed by the challenge, excitement, and glory of building a computer, and the scientists and mathematicians impatient for a computational tool. In the end, this conflict of interests sowed the seeds for the project's demise.

Efforts to design and manufacture a new class of vacuum tubes for digital electronic circuits illustrate how Kates's ambitions and pursuit of performance delayed the construction of UTEC Mark I. Though the "electron" was revolutionizing computation, the vacuum tube itself was quickly becoming a "reverse salient" in the development of large scale digital systems.[66] The pursuit of greater computational power demanded a continual increase in the overall number and complexity of computer circuits. In the late 1940s and early 1950s, the drive toward higher circuit complexity ran up against the vacuum tube's economic and technological limitations. Circuits composed of thousands of vacuum tubes consumed great amounts of power and occupied considerable physical space. The IBM702, which was comprised of 5,562 tubes, consumed 87 kilowatts of power and occupied 250 square feet. The "UNIVAC," with 5,600 tubes, consumed 120 kilowatts and occupied a phenomenal 1,250 square feet.[67]

Kates wanted to design and build the university computer around a new special vacuum tube of his own design. He argued that his invention would not only cut down dramatically the number of tubes needed to achieve a given computational capacity, but it could also produce

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[66] The notion of "reverse salients" plays a central role in Thomas Hughes's historical analysis of technological change. See Thomas P. Hughes, "The Evolution of Large Technological Systems", in *The Social Construction of Technological Systems*, ed. Wiebe Bijker et al., (Cambridge, Mass.: The MIT Press, 1990), 51-82; and Thomas Hughes, *Networks of Power: Electrification in Western Society, 1880-1930* (Baltimore: Johns Hopkins University Press, 1983).

[67] These figures for the IBM702 and the "UNIVAC" were taken from a detailed 1955 survey of commercially available computers. See John Carroll, "Electronic Computers for the Businessman", *Electronics* 28 (June 1955): 122-131.

substantial increases in speed.[68] Kates's invention implemented the entire input-output functional table of binary addition in one tube through the internal manipulation of electric potential gradients. He argued that this manipulation was attainable through the proper placement and shaping of electrodes within the tube. Kates's ongoing doctoral work in the physics of vacuum tubes convinced him of the theoretical correctness of his idea. His experience with vacuum tube technology at Rogers Majestic convinced him that such a tube could be mass-produced.

In February 1949, V. G. Smith, a member of the university's Committee on Computing Machines and a professor of electrical engineering, wrote to the Director of NRC's Radio and Electrical Engineering Division asking if NRC would undertake the construction of a prototype of Kates's binary adder tube concept.[69] But in April 1949, after a tour of American computer centres, Smith had second thoughts about Kates's idea. "We sense," Smith wrote to Ballard, " a general theorem that the same results may be obtained by clever circuit design and ordinary tubes and that the computing centres have chosen this path. While we have not abandoned the idea it does not have a high priority with us just now."[70]

Smith's sense of the word "we" may have referred to other members of the Committee, but it did not include Josef Kates. In May of 1949, Kates wrote a report in which he argued that, in comparison to conventional electronic, digital, design practices, his binary adder tube promised "greater reliability, greater simplicity, greater speed, a smaller fraction of components required, and a more compact and sturdier tube than conventional grid-controlled tubes."[71] While the senior members of the Committee on Computing Machines vacillated over the merits of the binary adder tube concept, Kates promoted the idea to the military and industry. Despite numerous difficulties, P. A. Redhead, from the Microwave Section of NRC's Radio and Electrical Division, succeeded in building the first working model of the binary adder tube in

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[68] The conventional approach of the day called for about six triodes for each 1-bit adder circuit. Hence in a parallel machine, 240 triodes were needed just to add two 40-bit numbers. Kates argued that his proposed smaller tube could replace the six larger triodes. This argument was used by Kates in Josef Kates, UTECs Report No. 27: Special Tubes, 7 September 1949, Records of Canadian Patents and Development Limited, RG 121, vol. 40, file L14-1220-1, pt. 1, National Archives of Canada. Henceforth the Records of Canadian Patents and Development Limited, RG 121, will be designated as CPDL. In some instances eight triodes could be found in a single digit binary adder circuit. This would then raise the number of tubes needed to do add two 40-bit numbers to 320. An example of a conventional adders circuit can be found in photograph 5b of Josef Kates, UTECS Report No. 20: Binary Adder Tube, 17 June 1949, CPDL, vol. 40, file L14-1220-1, pt. 1.

[69] V. G. Smith, Letter to B. G. Ballard, 24 February 24, 1949, NRC, vol. 52, file 17-28B-1, pt. 1.

[70] V. G. Smith, Letter to B. G. Ballard, 13 April 1949, NRC, vol. 52, file 17-28B-1, pt. 1.

[71] Josef Katz, A Binary Adder Tube, 21 May 1949, CPDL, vol. 40, file L14-1220-1, pt. 1.

early June 1949.[72] Within days of receiving the tube, Kates had constructed a demonstration of a single digit binary adder. He immediately declared the crude prototype a success. With better prototypes coming from Redhead's laboratory, Kates set out to convince the industry of the commercial potential of his invention.

Kates did not confine the scope of his idea to only the arithmetical operation of addition. He also designed a tube that could do subtraction.[73] In a letter to Redhead, Kates confided that the principles of the prototype adder tube could also be used to reduce the speed of multiplication considerably. Because the operation of multiplication in computers was implemented as a succession of many additions, Kates saw this operation as a serious bottleneck in computational speed. The fastest computer of the day multiplied two numbers in about 250 microseconds. Kates suggested that he could design a tube that could perform multiplication in one step and in only a few microseconds.[74]

Was Kates wasting his time? History's 20/20 hindsight reveals that transistor technology overcame the vacuum tube reverse salient. However, in the context of the late 1940s and early 1950s, the ascendency of the transistor was not at all evident. The technical and institutional "inertia" of the vacuum tube was considerable and the superiority of transistors very much in doubt.[75] Any vacuum tube innovation that could alleviate the size and complexity bottleneck in electronic digital circuit design still had the glitter of great technical achievement and commercial success. In July of 1949, discussions started between Kates and Canadian Patents and Development Limited over the issues of patent rights and commercialization. A crown corporation and a wholly owned subsidiary of the NRC, Canadian Patents and Development Limited (CPDL) was created in 1947 to patent and promote the commercialization of promising

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[72] Redhead apologized that because of "very unskilled labour" and the absence of jigs, "the concentricity of the digital plates leaves much to be desired." He also mentioned the great difficulty in "sealing the bulb to the stem...It cracked all over the place; but we were able to save the tube." P. A. Redhead, Letter to Josef Katz, 10 June 1949, CPDL, vol. 40, file L14-1220-1, pt. 1.

[73] In addition to sharing the same advantages of the binary adder tube, the binary subtractor tube allowed for direct subtraction without the additional time and circuitry needed for complementation. Josef Kates, UTECs Report No. 27: Special Tubes, 7 September 1949, CPDL, vol. 40, file L14-1220-1, pt. 1.

[74] Josef Kates, Letter to P. A. Redhead, 15 June 1949, NRC, vol. 52, file 17-28B-1, pt. 1. One month after his letter to Redhead, Kates produced a design for multiplier tube. Josef Kates, UTECS Report No. 23: Special Switch Tubes, 14 July 1949, CPDL, vol. 40, file L14-1220-1, pt. 1.

[75] The interplay of vacuum tube and transistor interests in the early days of computer technology is examined in Chapter 4, where the role of the military in the promotion of solid state technology is discussed in the context of the Defence Research Telecommunications Establishment Computer.

inventions from NRC and other government financed research. CPDL agreed to pursue patents rights for Kates's invention; it also accepted to facilitate the necessary industrial development of the tube and to handle the licensing of the patent.

CPDL asked six Canadian companies if they were willing to develop the binary adder tube beyond the prototype stage.[76] After examining the prototype, Rogers Majestic, Canadian Westinghouse, and Canadian Marconi expressed a definite interest. To get a better idea of what the development of the tube would entail, each of these three manufacturers produced some samples based on Kates's specifications. Of the three companies, Kates found the Canadian Marconi samples "wholly unsuitable."[77] By the end of the summer of 1949, Rogers Majestic and Canadian Westinghouse each agreed to undertake the development of the tube at its own expense on the condition of being given exclusive worldwide rights. However, with a patent application still not filed, CPDL was in no position to offer any party an exclusive license.

Efforts to move Kates's patent application through the American, French, British, Dutch, German and Canadian systems proved extremely frustrating. The difficulty lay in the characterization of Kates's tube. What were the unique elements of the tube that could withstand prior patent claims? Answering this question turned out to be far harder than anyone expected and delayed considerably the actual filing of the patent. Kates was certainly not the first to propose vacuum tube switching devices. High speed switching in telegraphy,[78] telephony,[79] and even radio[80] had been the focus of several patents. RCA's wartime work on automated digitally-based anti-aircraft fire control had produced several important patents in vacuum tube electronic switching.[81] The art of ascribing claims to a patent is to cast as wide a net as possible without

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[76] The companies were Northern Electric, Canadian Marconi, Radio Valve, Canadian General Electric, Rodgers Majestic, and Canadian Westinghouse. B. G. Ballard, Letter to P.A. Redhead, 22 June 1949, NRC, vol. 52, file 17-28B-1, pt. 1.

[77] J.W. MacDonald (General Secretary of CPDL), Letter to E.C. Bullard (Chairman, Committee on Computing Machines, University of Toronto), 15 October 1949, CPDL, vol. 40, file L14-1220-1, pt. 1.

[78] Ruben Hadekel, *Improvements in or relating to Telegraph Apparatus*, British Patent no. 549,358, filed 1 April 1941, issued 18 November 1942.

[79] Montford Morrison, *High Frequency Circuit Selector*, U.S. Patent no. 1,977,398, filed 31 May 1930, issued 16 October 1934. Albert Skellett (assigned to Bell Telephone Laboratories), *Electronic Discharge Apparatus*, U.S. Patent no. 2,217,774, filed 27 May 1939, issued 15 October 1940.

[80] Alfred Stuart (assigned to Bendix Aviation Corporation), *System of Frequency Conversion*, U.S. Patent #2,293,368, filed 20 June 1940, issued 18 August 1942.

[81] George Morton and Leslie Flory (assigned to Radio Corporation of America), *Electronic Computing Device*, U.S. Patent no.2,446,945, filed 25 August 1942, issued August 10, 1948. Richard Snyder and Jan Rajchman (assigned to
(continued...)

pulling in any prior patent claims. Unable to circumscribe all the subtleties of this new technology, Smart & Biggar, the Ottawa law firm handling CPDL patent claims, repeatedly kept snagging their net on one objection after another.

In a letter to J. W. MacDonald, the General Secretary of CPDL, E. G. Bullard, the Chairman of the University of Toronto's Committee on Computing Machines expressed his concern "about the long time [CPDL] people were taking in getting the protection of a provisional patent for Kates's adder tube. I hear rumours of a similar development in Holland and whether this is true or not, I am quite certain that someone else will come upon the idea in the very near future."[82] MacDonald replied that CPDL was pursuing the "matter vigorously, but that, in all matters electronics, it is necessary to make very detailed searches in order that the patent application, when drawn may meet in advance any objections which could be raised in respect of prior patents in the same or similar fields."[83] MacDonald failed to keep his promise that a patent would be filed by the end of 1949. Not until January 17, 1951, twenty months after CPDL first agreed to promote Kates's invention, was a patent finally filed in the United States.[84]

Delays in filing a patent application threatened to stop further industrial development of the binary adder tube, until the Royal Canadian Navy's (RCN) DATAR project entered the scene.[85] DATAR, which called for the marriage of computer, radar, sonar, and communications into one digital medium, called for circuit complexity, scale, and reliability that could not be easily supported by the existing vacuum tube technology. Kates's claim that his invention was applicable to a wide range of digital switching problems in computers and computers caught the RCN's attention, because of the considerable miniaturization that would follow if Kates was right.[86]

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[81](...continued)
Radio Corporation of America), *Calculating Device*, U.S. Patent no. 2,424,289, filed 30 July 1943, issued 22 July 1947. Jan Rajchman (assigned to Radio Corporation of America), *Electronic Discharge Device*, U.S. Patent no. 2,494,670, filed 26 April 1946, granted 17 January 1950.

[82] E.C. Bullard, Letter to J.W. MacDonald, 7 November 1949, CPDL, vol. 40, file L14-1229-1, pt. 1.

[83] J.W. MacDonald, Letter to E.C. Bullard, 18 November 1949, CPDL, vol 40, file L14-1220-1, pt. 1.

[84] In documents sent to Smart & Biggar, from the U.S. patent examiner, 17 January 1951 is given as the filing date of Kates patent "Electronic Vacuum Tube". See CPDL, vol. 40, file L14-1220-1, pt. 2.

[85] DATAR is discussed the subject of the next chapter.

[86] "The Binary Adder Tube now under development is a physical embodiment of a particular type of function table (matrix, switch). Function tables are major elements not only of Electronic Computers, but also of many kinds of communication and regulating systems: (e.g. pulse code communication, telephone networks, radio controlled

(continued...)

In September 1949, the RCN agreed to fund further research and development of the Binary Adder Tube at Rogers Majestic, with Kates retained by the company as a consultant. Three types of promising switching tubes emerged from the RCN's R&D contract.[87] As RCN funding to Rogers Majestic started to run low, the former proposed that DRB also contribute to the tube's further development. W. B. Lewis's favourable evaluation of Kates's invention added considerable weight to the RCN's suggestion. Lewis corroborated Kates's contention that the application of the switching tube went beyond computers. Kates's invention, suggested Lewis, could "prove of great importance to the major communication concerns that policy should be carefully considered." He went on to warn that "if the Canadian effort is too small the large firms will probably discover certain vital features for which they would secure patents. This would be least harmful to Canadian interests if either the basic features are patented and sold to such company before any large expenditure is made in Canada, or detailed publication is made so as to make future patent action difficult."[88]

To accelerate the testing and practical application of the tubes, DRB and Rogers Majestic decided to focus on the binary adder tube and freeze its design. According to M. L. Card, the Royal Canadian Air Force representative on the military's Electronics Standards Sub-Committee (ESSC), the prior RCN contract had "produced several improvements in the original design, involving an analysis of the tube theory, multiple-beam construction, rod elements and double-ended and subminiature packaging, to the extent that an early production model of a satisfactory adder tube could be made available during May 1950."[89] The goal of the DRB X-17 contract was to develop reliable, rugged, and standardized subminiature models of Kates's tube suitable for military applications.

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[86](...continued)
mechanisms, telephone circuits, etc. Electronic computers consist essentially only of function tables and registers. Every gate in an Electronic Computer may be considered a rather simple function table. This report restates the principles regulating electron flow in the Binary Adder Tube and hence shows that this method is applicable to every switching problem. Limitations are of a practical rather than theoretical nature." Kates, UTECS Report No. 23, 14 July 1949.

[87] The three types of Switching Tubes were: a Double Beam Binary Adder Tube, with a rod construction T61/2 miniature envelop and 9 pin miniature base; a Double Beam Multipurpose Switch Tube, with a T61/2 envelop; and A Double Beam Binary Adder Tube with a T3 subminiature envelope and bottom base circular lead arrangement. See M. L. Card, ESSC Memorandum: Information to DRB Liaison Officers concerning addition of Katz's Switch Tube to DRB Contract X-17, 30 March 1950, Gotlieb, box 001, file UTECS.

[88] W.B. Lewis, Memorandum to the Director of Electrical Research, Defence Research Board, 3 January 1950, NRC, vol. 52, file 17-28B-1, pt. 1.

[89] Card, ESSC Memorandum: concerning addition of Katz's Switch Tub, 30 March 1950.

When it comes to the development and commercialization of inventions, timing is critical. If there ever was a door of opportunity for Kates's switching tubes, the inability to file a patent quickly and to accelerate its industrial development closed the door. Following Kates's paper to the International Radio Engineering Convention, Jan Rajchman, from RCA's computer research group, raised "the possibility of obtaining a non-exclusive license with the right to grant sub-licenses under [Kates's] U.S. applications and patents."[90] In exchange for a total of twenty switch tubes, RCA offered Kates a prototype of the Selectron memory tube that it was pioneering. As for Kates's ideas for other kinds of switching tubes, no working laboratory prototypes were ever built.[91]

Interminable delays and endless skirmishes characterized the pursuit of patent rights as Kates and CPDL lawyers responded to a never ending litany of objections from patent examiners. Lewis had warned earlier that "if patent action is taken and an attempt is made to obtain a monetary gain[,] the forces called into play might be too great for any peace of mind of the inventor."[92] As the quest for patent rights dragged on into 1955, Lewis's words were prophetic. Finally, by 1955, approvals for Kates's Binary Adder Tube were won in the United Kingdom, France, Holland, and Germany. But in the United States, the centre of postwar technological and commercial development of the computer, Kates's patent was rejected. In 1956, Canadian Patents and Development Limited decided to let these patents lapse because "this vacuum tube [was] now obsolete."[93]

Despite all the time and energy spent pursuing this new switching device, it was never incorporated into any of UTEC Mark I's circuits. The only application of Kates's switching tube occurred at Toronto's 1950 Canadian National Exhibition (CNE). After working on the binary adder tube for nearly a year, Rogers Majestic wanted to publicize some concrete use of this tube. Kates came up with a tick-tack-toe game called "Bertie the Brain," possibly the world's first

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[90] Jan Rajchman, Letter to J. Katz, 22 March 1949, Gotlieb, box 001, file UTECS. Ironically, the American patent examiner tried to used Rajchman's prior patents to disqualify certain claims in the Kates application.

[91] Britain's National Research Development Council also expressed an interest in obtaining licensing rights to Kates's invention. The National Research Development Council's substantial patent holdings centred on entire, or major subsystems of, computing machines. Though the NRDC had very little interest in vacuum tube patents, it was interested in licensing any specific circuits that were included as part of Kates's patent.

[92] Lewis, Memorandum to the Director of Electrical Research, 3 January 1950.

[93] Minutes of the 141st Meeting of the Committee on Patents, 19 December 1956, 10, CPDL, vol. 40, file L14-1220-3.

computer game.[94] Paid for by Rogers Majestic, Bertie the Brain was finished just in time for the CNE. Quite compact because of the use of the binary adder tube, Bertie was quite an attraction.[95] However, Bertie was the only consequence of Kates's ambition to design a faster and better electronic digital computer using his invention. Development of the switching tubes advanced too slowly for them to be seriously integrated into UTEC's design and testing. Without an early resolution of the patent process, there was little incentive for small Canadian firms such as Rogers Majestic to pursue extensive development of all the switching tubes. The window of opportunity for the switching tube concept was quite narrow; by the early 1950s it had closed.

The switching tube is not the only example of the non-conservative design ethos which dominated the UTEC project. Another, and probably more fatal, example was the advocacy of parallel, electrostatic memory based on new principles. Fascination with ultimate performance led the inexperienced University of Toronto design team to pursue a parallel rather than serial architecture. In serial machines, data moves in and out of memory one bit at a time along the same channel. In parallel architectures, all the bits of a word move simultaneously, each along its own channel. The parallel machine promised much faster processing speeds, but it was far more complex and costly to design, build, and test. For a computer using 40-bit long words, as was the case with IAS computer, a parallel architecture required a 40-fold increase in the number of logic circuits and fast memory units.[96] The design of IBM's first commercial venture, in 1951, into the electronic computers was deeply influenced by von Neumann's idea of parallel architecture.[97] Called the IBM 701, this computer was originally conceived of as a "Defence Calculator" for the

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[94] Rogers Majestic, *Bertie the Brain*, circa 1950. Promotional pamphlet in the possession of John Vardalas. Six years later, on 13 March 1956, a story ran in the New York Times that "the Bell Telephone Laboratories received a patent this week for a machine that plays tick-tack-to. The machine was invented by William Kesiter, director of switching engineering at Bell."

[95] One amusing anecdote has it that Danny Kaye, a well known celebrity, was coaxed into playing Bertie. Playing at the easiest level, he reacted badly after losing to Bertie.

[96] During the early development work on the IAS computer many questioned the wisdom of pushing the existing technology by going parallel. Julian Bigelow, one of the principal engineers in von Neumann's project later wrote: "Since an item of data was to consist of 40 binary digits handled in parallel...it was abundantly clear to us that the occurrence of a single undetected chance error anywhere in such 40-fold circuitry would produce numerical hash at unprecedented rates. Various reputable experts outside the engineering group at IAS made gloomy predictions that the attempt to produce a 40-place parallel computer was ill advised and...be more cumbersome and unreliable [than a serial machine]." Julian Bigelow, "Computer Development at the Institute for Advanced Study", in Metropolis et al., *A History of Computing in the Twentieth Century*, 293.

[97] For a period of time von Neumann worked as a consultant for IBM. See Aspray, *John von Neumann*.

American military.[98] Except for one installation at IBM's World Headquarters in New York, all of the nineteen 701s were delivered to customers within the swelling American military-industrial complex.[99] The explosion of defence spending that accompanied the Korean War provided the financial climate to justify the $8,000 per month rental fee for the IBM 701. Ultimately, the American military enterprise's willingness to push the limits of performance at any price provided the deep pockets needed to sustain the early development of parallel architectures.

Despite the performance advantages of parallel machines, serial computers, because of their simplicity, were still being actively pursued. In Britain, for example, all the contemporary projects of UTEC, such as the Pilot ACE at the National Physical Laboratory, EDSAC at Cambridge University, and the Mark I at University of Manchester were serial machines. The first computer to be commercialized in Britain in 1950 by Ferranti Limited was a serial machine. In the United States, J. Presper Eckert and John Mauchly, who pioneered the design and development of ENIAC, the first full-scale electronic computer, used a serial architecture for their first commercial venture -- the UNIVAC. Engineering Research Associates ERA 1101 was another commercial serial machine that appeared in 1950. The machine that first secured IBM's dominance of the commercial, general-purpose computer market was the IBM 650. While its predecessor, the IBM 701, was a large parallel machine, the IBM 650 was a serial machine designed as a low cost alternative. The 650 proved to be a gold-mine for IBM throughout much of the 1950s and established IBM as the leader in the computer business.[100] In the context of 1949, a serial architecture offered a relatively inexpensive and rapid technological solution to Canada's search for computational capacity.

The high risk of the parallel design choice was compounded by Kates's new approach to electrostatic memory. During the 1946-50 period, considerable effort was devoted in Britain and

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[98] Cuthbert Hurd, "Computer Development at IBM", in Metropolis et al *A History of Computing in the Twentieth Century*, 389-418

[99] For list of the nineteen IBM 701 customers see Cuthbert Hurd, "Early IBM Computers: Edited Testimony", *Annals of the History of Computing* 3 (April 1981): 163-182. This article is an edited version of testimony that Cuthbert Hurd gave in U.S. Federal Court, Southern New York District, in the 1979 antitrust trial of the U.S. Department of Justice versus IBM.

[100] "Approximately 1,800 were produced and delivered to customers. No other computer system at that time was produced in anything like that quantity. Accordingly, the 650 was described by Hurd as computing's Model-T because it was the first generation purpose computer system to be mass produced on such a scale." Franklin Fisher, et al., *IBM and the U.S. Data Processing Industry: An Economic History* (New York: Praeger Publishers, 1983), 17.

the United States to find a purely electronic method for fast memory, or what today would be called RAM. Mercury delay lines, which stored numbers as recirculating acoustic waves, undermined the performance gains proposed by the advocates of parallel machines. From the initial conception of the IAS computer, von Neumann insisted that fast access to memory would be critical to the project's success. Based on Rajchman's and Snyder's wartime work, RCA joined the IAS project proposing to design the first purely electronic memory. As delays in RCA's development of the Selectron kept increasing, von Neumann's group looked around desperately for an alternative and found the solution in Britain.

Unlike RCA's expensive custom-made Selectron, F. C. Williams's and T. Kilburn's approach to memory storage used conventional, inexpensive low voltage cathode ray tubes, such as those found in oscilloscopes.[101] The "Williams tube" stored binary numbers as electrostatic charges on the surface of the cathode ray tube's screen. With some difficulties, the IAS group adapted the Williams Tube to its parallel machine. Williams and Kilburn, on the other hand, used their electrostatic memory approach as the basis for a *serial* computer they were designing at the University of Manchester. This computer later became the basis of Britain's first commercial computer.[102] After some teething problems, Williams's and Kilburn's solution to fast memory became the mainstay of the world's computer industry well into the late 1950s.

Instead of simply copying the Williams electrostatic memory, Kates proposed a different and novel approach to the implementation of electrostatic memory on conventional cathode ray tubes (CRT) based on space charge.[103] Kates argued that the existing theoretical model used by his contemporaries to explain how electrostatic memory worked was wrong. Rather than looking to the properties of secondary electron emission to understand the limits of storage, he suggested that the physics of space charge was the critical factor. Kates contended that such a reinterpretation opened the way for faster, more reliable, and higher density storage systems.

The University of Toronto's Committee on Computing Machines had initially expressed concerns about the wisdom of trying to implement parallel electrostatic memory. But Kates, as

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[101] The first published technical description of this work is F.C. Williams and T. Kilburn, "A Storage For The Use With Digital Computing Machines", *Journal of the Institute of Electrical Engineers*, (London, England), 96, pt. II (April 1949): 183-200.

[102] S. Lavington, *Early British Computers* (Manchester, U.K.: Manchester University Press, 1980).

[103] Josef Katz, UTECS Report No. 53: Storage By Means Of Space Charge, February, 1950, Gotlieb, box 001, file UTECS. For a more comprehensive discussion of the approach see Josef Kates, Electrostatic Storage in Cathode-Ray Tubes, June 1950, Gotlieb, box 001, file UTECS.

Calvin Gotlieb later recalled, "convinced us and himself that the parallel cathode ray tube memory was possible."[104] After all, Kates was writing his physics doctoral dissertation in this area. No one on the Committee was in a position to seriously challenge the soundness of Kates's arguments, for he had made himself the *de facto* expert on memory tubes. Moreover, the experimental verification of the space charge concept at Los Alamos reinforced Kates's position.[105] J. Richardson's experimental collaboration with Kates contributed to Los Alamos's decision to abandon the IAS approach to Williams memory and "to pursue an independent course for memory, using a 2 inch tube rather than the 5 inch one considered by Princeton."[106] Los Alamos's success in developing a 40-digit memory, which made use of Kates's theoretical interpretation of electrostatic storage, gave Kates's approach considerable credibility.[107]

But could the University of Toronto team engineer a reliable, full scale, parallel computer, based on Kates's theory, soon enough to meet the growing pressure for a computational device? The Toronto group did not have the depth of engineering experience of Los Alamos. Furthermore, by its own volition Toronto did not benefit from the very close technology transfer that characterized the relationship between the Princeton group and Los Alamos.[108] It took the small Toronto team a year and half to go from a 1-digit stage of Kates's

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[104] *C. C. Gotlieb Interview*, 29 June 1971, Computer Oral History Project, Smithsonian, Washington, D.C.

[105] In Computation Centre Progress Report one reads: "the theory of storage systems was further investigated; and a series of experiments, conducted by Mr. Kates and Mr. Richardson at Los Alamos, has confirmed the theory of space charge and pointed in the direction of more reliable storage." Computation Centre Progress Report: April 1st, 1951 to June 30, 1951, July 1950, Sidney Smith (president of the University of Toronto) Papers, A68-0007, box 110, file 04, University of Toronto Archives. Henceforth the Sidney Smith (president of the University of Toronto) Papers, A68-0007, will be designated as Smith.

[106] N. Metropolis, "The MANIAC," in Metropolis et al., *A History of Computing in the Twentieth Century*, 461.

[107] In the Fall of 1951, Gotlieb pointed to the success of the Los Alamos electrostatic memory as evidence that the University of Toronto computer group was on the right track. See Computation Centre Progress report: October 1, 1950 to September 30, 1951, Gotlieb, box 001, file UTECS. However, twenty years later, in an oral history interview Gotlieb offered a different view: "[Kates's ideas] on the theory of storage, how to make a reliable storage, became literally his thesis, and he argued with [W. B.] Lewis about these. I don't think he ever convinced anybody about his theoretical work, and there may be several reasons for this. His English at the time was overlaid with a thick accent. He tends to be a steamroller in conversations, and this made people hold back. Even I would look at his arguments and I wasn't sure." *C. C. Gotlieb Interview*, 29 July 1971. What the interviewer never asked Gotlieb was why so much time and effort, and so many financial resources were committed to work whose theoretical basis found little support within the University of Toronto? Why didn't the university's Committee on Computing Machines insist that a more conservative and theoretical acceptable design course be taken?

[108] In all the documents John von Neumann's papers at the U.S. Library of Congress, the Institute of Advanced Study archives in Princeton, and the University of Toronto there is not one shred of evidence to suggest that the UTEC group ever tried to establish a close working relationship with von Neumann's computer group. In fact, one cannot find any reference to the Canadian group in the papers of the first two collections. The converse is also true.

memory to a 12-digit memory.[109] All the component parts of UTEC Mark I were finally assembled in the fall of 1951. And yet, even after two and half years of work on this small experimental prototype, a progress report stated that before one could bring UTEC Mark I to its full use further tests would still be needed to allow a careful assessment of its reliability.[110] Despite the slow progress, the computer group expressed confidence in its ability to build a full-scale computer. "The period of profitable development work on Model I is now at an end," wrote Ratz. "The work," he went on to write, "has gained for the project the experience necessary to produce a full-scale machine, and the time to start on this computer has arrived. A reliable and useful instrument can be produced in a reasonable length of time, if the project is suitably staffed and organized."[111] The university computer group estimated that it would take an additional two and half years to get a full scale computer designed, built and tested.[112] As long as the UTEC project was the only game in town, those people and institutions anxious for a computational tool had little to do but wait.

But new options for obtaining computational power finally overtook the UTEC project. Even as the University of Toronto computer group was confidently asserting its abilities to build Canada's first computer, W. B. Lewis, Director of Research at Chalk River, had set his eyes on the new British Ferranti Ltd. machine to meet the computational needs of Canada's atomic research project. In 1948, the British government issued Ferranti Limited, of Manchester, a five year contract, of about $510,000, to produce a commercial version of the computer that Williams and Kilburn were developing at the University of Manchester.[113] Ferranti Ltd.'s sales strategy consisted of (Lord) Vivian Bowden going on the road in search of orders while the Ferranti Board used its considerable contacts in the British government and military to promote sales at

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[109] News that a 1-digit stage memory had been built and tested with satisfactory results appeared in Computation Centre Progress Report: April 1st to June 30 1950, Smith, box 110, file 04. News that a "twelve digit memory for the model was assembled, along with the associated circuits consisting of the storage and location registers, the deflection generator, and reading and writing gates" was reported in "Computation Centre Progress Report: October 1, 1950 to September 30, 1951," October 1951, Gotlieb, box 001, file UTECS.

[110] *Ibid.*

[111] Alfred Ratz, "The University of Toronto Full Scale Computer," 20 September 1951, Gotlieb, box 001, file UTECS, 7. University of Toronto Archives. This report outlined the technical, manpower, and financial requirements needed to go on and build a full-scale computer. By the time the small experimental model, UTEC Mark I, had been built, the team had grown to six research engineers and four technicians. The engineers were L. Casciato, R. F. Johnston, J. Kates, A. Ratz, R. Stasior and H. Stein.

[112] "Construction Schedule: U. of T. Computer," November 16, 1951, Gotlieb, box 001, file UTECS. This document is a graphical depiction of the timetable for the development of the various subsystems of the computer.

[113] Lavington, *Early British Computers.*

home.[114] During the summer of 1951, Lewis learned from his old friend Bowden that Ferranti Ltd. was selling computers.[115] As Bowden wrote him, Ferranti would install a complete computer system anywhere in Canada for $220,000, plus freight charges from some British port.[116] Resorting to the usual salesman's ruse, Bowden wrote that, because Ferranti's production lines were being quickly tied up with future orders, if Canada wanted delivery within a year then Lewis had to act now.[117] Lewis was delighted with Bowden's offer. "This is better than I hoped for in the matter of price," wrote Lewis to K. F. Tupper, the Dean of Engineering at the University of Toronto. As the Chairman of the Committee on Computing Machines, Tupper no doubt sensed the disastrous implications for UTEC behind Lewis's excitement.

The lack of high-speed computation facilities had become a serious problem for Canada's atomic energy program. Efforts to develop a commercial reactor at Chalk River were creating ever-escalating demand for high-speed, large-scale, computational tools.[118] Lewis had warned C. J. Mackenzie, the President of NRC, that "unless we get a machine in the near future, Chalk River, at considerable inconvenience and expense, will have to arrange for needed calculations to be made in England and the United States."[119] He added that the university's punch-card machines were inadequate.[120] Lewis's patience with the university computer project had run out.

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[114] Geoffrey Tweedale, "A Manchester Computer Pioneer: Ferranti in Retrospect", *IEEE Annals of the History of Computing* 15:3 (1993): 37-43.

[115] Lewis and Bowden had both worked in the Cavendish Laboratory, at Cambridge University, during the 1930s. During the war Bowden worked on radar at Britain's Telecommunication Research Establishment, where Lewis occupied the position of Chief Superintendent.

[116] W. B. Lewis, Letter to K. F. Tupper, 3 August 1951, Gotlieb, box 001, Files UTECS. In this letter, Lewis gives several lengthy extracts from the letter he received from Bowden.

[117] Little did Lewis know that Ferranti was desperate for a buyer for the Ferranti Mark I, because its first commercial sale to Britain's Atomic Energy Authority had already fallen through. During the computer's construction, the newly elected Conservative government put a freeze on all large capital expenditures. This left Ferranti's chief computer salesman, Bowden, with a computer and no buyer. As to the other impending sales, Ferranti only managed to deliver one computer in 1953 in addition to the first Ferranti Mark I which went to the University of Manchester.

[118] Andrew Gordon, who was on the boards of NRC and DRB as well as being the head of the Chemistry Department, pointed out to the President of the University of Toronto that "the commercial development at Chalk River for the sale of plut,'Chalk River will want a lot of calculations. Therefore [they] could not wait for three years for the University-designed computer." Memorandum: Conference with Watson and Gordon, 12 midday, February 20th, 1952, re Computation Centre, 20 February 1952, Smith, box 110, file 04.

[119] C. J. Mackenzie, Letter to K.F. Tupper, 26 December 1951, C. J. Mackenzie (president of the National Research Council of Canada) Papers, MG 30 B 122, box 3, File: Correspondence 1951. Henceforth these Papers will called Mackenzie.

[120] By the end of 1951, the University of Toronto Computation Centre was still using IBM602 -- A relay-based multipliers. See item 3, Minutes of 5 October 1951 Meeting of Computation Centre Committee, Gotlieb, box 001,

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Mackenzie was very sensitive to Lewis's complaint. The success of Canada's quest to commercialize atomic energy was paramount to Mackenzie. Canada had emerged from World War II as one of the best placed nations in the world to develop nuclear reactor technology. The United States and the United Kingdom were the other two. For Mackenzie, this capacity was an opportunity for Canada "to get on the ground floor of a great technological process for the first time."[121] From the beginning, Chalk River's computational needs had been a key motivating factor in NRC's support of the University of Toronto's ambitions to become Canada's centre for large-scale scientific computation. Until Bowden's letter, hardware development had been an organic part of the development of a computation centre. With the availability of the Ferranti machine, at a price that was less than the cost building a machine, Mackenzie wanted to remove hardware R&D from the Computation Centre's mandate.

In a telephone call to Dean Tupper, Mackenzie suggested the idea of buying the Ferranti computer and locating it at the university. "If acquiring a Ferranti machine meant an end to development work on electronic computers at the Computation Centre, and an indefinite postponement of the plans for a small scale machine," the university's Computation Centre Committee voted unanimously to reject Mackenzie's suggestion.[122] For the Committee, the Ferranti machine's performance paled before what UTEC could achieve if built. The Committee expressed its fears that the Ferranti machine would soon be inadequate, if not obsolete, and thus condemn the university to a role of secondary importance in the computing field.

By December of 1951, Mackenzie was exasperated with what he felt were the Computation Centre Committee's illogical and contradictory objections to purchasing the Ferranti computer. He once again emphasized the need for early access to computational power. As to the university's ability to build the computer, Mackenzie was unequivocal: "To be brutally frank, I don't think the group at Toronto have sufficient staff or experience to be able to guarantee a first class rugged, dependable, workable commercial machine in any where near the time contemplated, and I think it is certainly not in the interests of Toronto to court that sort of

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[120](...continued)
file UTECS.

[121] Cited in Robert Bothwell, *Nucleus: The History of Atomic Energy of Canada Limited* (Toronto: University of Toronto Press, 1988).

[122] See item 4, Minutes of 5 October 1951 Meeting of Computation Centre Committee.

disaster."[123] Since Mackenzie knew little of digital electronics and computer technology, his harsh criticism probably reflected the views of W. B. Lewis. Mackenzie, however, was also sensitive to Gotlieb's fears that the purchase of the Ferranti machine, with the needed cancellation of the UTEC project, would completely demoralize the electronics team and, in the end, lead to the group's dissolution. He suggested to Tupper that "Gotlieb's [electronics] group would be better employed doing more fundamental research than trying to manufacture production equipment."[124]

In arguing for the Ferranti computer, Mackenzie, as President of NRC, had to tread the fine line separating Chalk River's interests and academic freedom. He knew it would be very difficult to impose a solution on the university, particularly since funding had already been approved.[125] Mackenzie raised the Toronto dilemma with DRB's chairman. Solandt's initial response reflected DRB's view of the strategic importance of a digital design capacity. DRB, wrote chairman Solandt, was "more interested in having the electronics group carry on in the development of the machine as a computer as they would undoubtedly gain much electronics experience that might be useful in an emergency."[126] But at the same time, Solandt was sympathetic to Chalk River's needs. At a meeting of DRB's Committee on Extra-mural Research, on 8 December 1951, Solandt outlined the issues dividing Mackenzie and the Computation Centre. The Committee backed a compromise presented by Solandt. DRB had already promised $300,000 towards the construction of the university computer. If NRC agreed to pay for half of the Ferranti machine ($150,000), DRB would pay the other half. Furthermore, DRB agreed to allocate the remaining $150,000 to support basic research into computer components and digital electronics. In effect, NRC had to pay an additional $120,000 to get its computer and placate the university. To drive home its position to the University of Toronto, DRB's Extra-mural Committee recommended "that in the event that it was decided to continue with the construction

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[123] C. J. Mackenzie, Letter to K. F. Tupper, 5 December 1951, Mackenzie, box 3, file Correspondence 1951. In a subsequent letter to Tupper, Mackenzie underscored that his views on the abilities of the Toronto team to build a full-scale computer reflected the views of W. B. Lewis, B. G. Ballard (Director of NRC's Division of Radio and Electrical Engineering) and Brigadier Wallace, "all of whom have had extensive experience in the production end and whose opinions weigh a great deal more with me than do those of engineers an scientists without such experience." No doubt the last part of Mackenzie's remark was directed at the Computation Centre Committee and the university's computer development team.

[124] *Ibid.*

[125] DRB had already approved $300,000 for the design, construction and testing of the full-scale computer.

[126] This was how C. J. Mackenzie recounted his conversation with O. Solandt to K. F. Tupper in Mackenzie, Letter to K. F. Tupper, 5 December 1951.

of the Toronto computer, steps should be taken to ensure that the work was contracted out to industry, and not carried out by the university."[127]

As pressure mounted from without, those within Computation Centre who were interested in the art of machine-based, scientific computation, realized where their future interests lay. On 11 January 1952, the Computation Centre Committee concluded that "it was important to work with Chalk River since the theoretical physics group there would certainly become one of the largest customers for computation."[128] The Committee voted unanimously to accept the offer NRC and DRB made to buy the Ferranti Computer.[129] The moment this decision was taken support for the electronics group within the Computation Centre collapsed completely. Tupper informed Mackenzie that other than putting some finishing touches on its small experimental prototype computer, UTEC Mark I, the university would probably "not wish to continue electronic work under Computation Centre auspices."[130] Ratz's attempts to salvage the digital electronic research experience built up over the preceding four years fell on deaf ears.[131] A new ethos had taken over the Computation Centre: "From here on it will be computing rather designing, mathematics rather than machine."[132]

In his capacity as a member of DRB's Electronic Advisory Committee, Lewis asked Tupper to reconsider killing the digital electronics R&D program. "I feel it would be a mistake," wrote Lewis, "to disband the Toronto group when there is such a big future for the techniques they have learnt. Also there is a real defence interest in many applications of this technique."[133] Lewis went on to suggest that the electronics group broaden its R&D interests to include the very strategic area of digital communication.[134] Tupper was "distinctly cool towards the suggestion

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[127] Minutes of Seventeenth Meeting of DRB Committee on Extra-mural Research, 8 December 1951, 2, DND, vol. 11,996, file DRBS-1-0-43-2, pt. 5.

[128] Minutes: Meeting of the Computation Centre Committee, 11 January 1952, Gotlieb, box 001, file UTEC.

[129] *Ibid.*

[130] K. F. Tupper, Letter to C. J. Mackenzie, 12 January 1952, Gotlieb, box 001, file UTECS.

[131] A. G. Ratz, "A Two-Year Plan For The Electronic Section," 20 February 1952, Gotlieb, box 001, file UTECS.

[132] These were Tupper's words. Memorandum - Conference: Computation Centre, 20 February 1952, Smith, box 110, file 04. At this conference were Sidney Smith, the President of the University of Toronto, K.F. Tupper, the Dean of Engineering, Andrew Gordon, the head of the chemistry department and member of the DRB, and NRC boards, and W. Watson.

[133] W. B. Lewis, Letter to Dean K. F. Tupper, 11 March 1952, Smith, box 110, file 04.

[134] Canadian military enterprise had at the same time invested heavily in Ferranti Electric's development of DATAR -- a top secret digital computer/communications naval warfare system. This development will be the subject of the

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that [the Computation Centre's] electronics work should be tied to similar secret projects elsewhere....The Computation Centre should not fall under the dead hand of 'Security.'"[135] Tupper's aversion to soiling the Computation Centre's hands with secret projects may have been somewhat misplaced. After all, much of the Centre's future computational work would have its *raison d'être* in secret weapons development.

Installation of the British computer started at the end of April 1952. By October, FERUT (FERranti University of Toronto), as the computer became known was fully tested and operational. In his history of Canada's pursuit of atomic energy, Robert Bothwell writes that "in the United Kingdom, Lewis was regarded as a great Englishman, and his Chalk River laboratory was considered, at least in an intellectual sense and certainly in a sentimental one, to be an extension of British science."[136] The birth of Canada's first large-scale, high-speed computational facility was also an extension of British scientific establishment.

Epilogue: Life After UTEC

Despite its failure, UTEC provided a vital training ground to build Canada's first pool of expertise in computer technology. Though the cancellation of UTEC disheartened the young electronics team, it was surely the Computation Centre's refusal to entertain any further military-funded basic research program in digital electronic techniques that ultimately led to the group's abrupt departure from the university. In 1953, three of the team members -- Casciato, Kates, and Johnston -- set out to form a new company called Digitronics and to design their own commercial computer.[137] Their experience on UTEC had convinced them that they could design

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[134](...continued)
next chapter.

[135] K. F. Tupper, Letter to Sidney Smith, 13 March 1952, Smith, box 110, file 04.

[136] Bothwell, *Nucleus*, 108.

[137] The computer they proposed to build, called the Digitron Model-S, was to fit in two office desks. Taking their cue from the first UNIVAC computer, Casciato, Kates, and Johnston proposed in their business plan, to build a decimal-based machine because it would somehow seem less alien to business users than a binary one. As with UTEC they wanted to build a parallel machine using electrostatic memory. The internal memory was to hold 500 10-decimal digit long words, and mass storage was to consist of a 10,000 word memory drum. To simplify the arduous task of programming, they wanted to build in a large number of general purpose registers. Taken from notes on a prospectus and business plan of the proposed company Digitronics. The document was given to this author by Josef
(continued...)

and build a very compact general purpose computer for business, industry, and government.[138] They estimated that it would take twelve months and cost $100,000 to develop a production-ready prototype. The subsequent commercial units were to cost $50,000 to manufacture.

Armed with a business plan and letters of endorsements from K. F. Tupper (ironically the man who had killed any further digital electronic research at the university), the Director of the Computation Centre, and others, Casciato, Kates, and Johnston went looking for $246,000 of start-up venture capital to see their new company through the first eighteen months. Their supply-driven market previsions cast an ambitious net over all the sectors of the economy, private, civilian government, and the military. They argued that the potential use of computers in such areas as inventory control, automated reservations systems, accounting, automatic process control in manufacturing, and office filing systems represented in 1953 a potential for $50,000,000 of sales in Canada.

There is no record of all the potential investors Kates approached.[139] But it must have been quite frustrating to find investors for such radical venture. At some point they approached Sir Robert Watson-Watt, one of the pioneers of radar, who had a high-tech consulting company in Montreal called Adalia Ltd.. He did not bite either, but he did hold out a carrot. If they joined forces with him, he would find a way to carry out their ambitions to build and sell data-processing technology. Tired of knocking on doors and out of money, they went to work for Watson-Watt and became Adalia's expert computer consultants. After doing some important work on a feasibility study to introduce the world's first computerized systems in Trans-Canada Airline's operations, the relationship between Watson-Watt and the trio fell apart because they grew to feel that he had no intention of getting into computer hardware.

At about 1954 or early 1955, Kates and Casciato, along with a new partner Shapiro, formed KCS Data Control Ltd. (KCS) which became the most successful computer consulting firm in Canada in the late 1950s and early 1960s. KCS's know-how played an important role in the computer technology decisions taken by companies and government agencies. This company

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[137](...continued)
Kates.

[138] *Ibid.*

[139] Kates was the aggressive marketer of the group and the man who shaped most of the business plan.

also developed real-time process control for Canadian petrochemical companies.[140] But KCS's biggest prize was the design and deployment of the world's first computerized urban traffic control system for Toronto, in 1962.[141] In 1964, to celebrate the KCS achievement, The American Society of Traffic Engineers held its annual conference in Toronto, a milestone considering this was the first time this Society met outside the United States. Not only was the construction of the computerized traffic control system a superb technical achievement, but it was also a remarkable piece of urban political work for Kates, who later went onto become the Chairman of the Science Council of Canada. KCS Data Control was subsequently bought by the large Toronto firm of Peat Marwick. In the 1980s, Kates formed Teleride/Sage, a company that created digital systems for public transportation networks.[142] Also working in the designing computer/communications systems for transportation networks, Casciato played a central role in the design of the prototype TRUMP (Transit Universal Microprocessor) system to monitor the operation of the Toronto Transit Commission's buses in real-time.[143]

Equally important, the loss of the University of Toronto's ability to design computers, which the purchase of FERUT embodies, was more than compensated by the accelerated development of the capacity to design software and make innovative use of the computer. Although FERUT contributed to the demise of UTEC, it also accelerated the diffusion of computer technology in Canada. FERUT allowed the University of Toronto to become an important training centre and innovation pole in the application of computers.[144]

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[140] The British American Oil Company paid KCS $30,000 a month to design, install and run a computerized planning and scheduling allocation system. Josef Kates Interview, 15 August 1985, National Museum of Science and Technology, Ottawa, Canada.

[141] The technical documentation of this work can be found in two large studies done for Metropolitan Toronto. See KCS Data Control Ltd, "A Centrally Controlled Traffic Signal System for Metropolitan Toronto," 1959; and "The Control of Traffic Signals in Metropolitan Toronto with an Electronic Computer," 1961. This author is in possession of copies of these studies. The originals still remain with Casciato. For a historical overview of the project see John Vardalas and Ted Paull, "The Toronto Traffic Signal System," *Canadian Information Processing Society Review* 18 (March/April 1987): 34-5, 39.

[142] "The most sophisticated of Teleride's systems employ electronic odometers on each bus to measure its precise progress along the route. The bus' location is radioed every thirty seconds to the central computer, which calculates how long it will take for each vehicle to reach the next stop...Now [1983] riders in ten North American cities can call the computer to learn the next scheduled arrival at their stop." David Thomas, *Knights of the New Technology* (Toronto: Key Porter Books, 1983), 84.

[143] L. Casciato and H. White, *Monitoring System for Vehicles*, U.S. Patent no. 4,009,375, issued 22 February 1977.

[144] Though in charge of the University of Toronto's research in large-scale automated computational techniques, Dr. C. C. Gotlieb played, as the reader discovered in this chapter, a nominal role in the design of UTEC. But once FERUT was installed Gotlieb came into his own. Under his leadership, the computation centre grew into Canada's

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The most striking example of the skillful use to which the University of Toronto's Computation Centre put FERUT came within a year of the machine's installation. The Centre's development of sophisticated computer-based hydraulogical models served to advance Canada's territorial interests in negotiations with the United States. In 1952, both the Canada and the United States agreed that a massive public works program of dams, locks, and channels was needed to improve the navigability and efficiency of power generation stations along the St. Lawrence River from Lachine, Quebec westward. Because any modification in the hydraulic structure of the river was bound to flood some areas, it was important to understand the cause and effect relationship between a particular modification in the natural flow of the river and its consequences on the landscape. Naturally both countries wanted to minimize the negative effects of changes to their territories while reaping the most benefits from changes to the river's flow. Unable to agree on terms, the two nations submitted their case to an International Joint Commission. Effective presentations to the Joint Commission hinged on having prior knowledge of all of possible scenarios. Ontario Hydro went to Gotlieb's group for help. "Considerable political consideration was given as to whether the seaway would be an all-Canadian one or a shared [one with the United States]. The Hydro, with the aid of [FERUT] did massive calculations, more voluminous than anything done in New York," Gotlieb later recalled.[145] With FERUT, what would have taken twenty person-years of manual computations to complete needed only twenty-one days of machine time. Thus Hydro always had a calculation for a credible all-Canadian Seaway up its sleeve before the United States presented its various Seaway

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[144](...continued)
leading exponent on the use of computers. It was from this centre that data processing techniques and technology moved to Toronto's largest insurance companies in the late 1950s. With FERUT, Gotlieb was able to launch Canada's first department of computer science. Because of FERUT, a whole generation of Canadian scientists and engineers got to use computers at least two years before they otherwise might have, assuming of course that UTEC would have been ready in two years. See C. C. Gotlieb Interviews. See also C. C. Gotlieb, "FERUT - The First Operational Electronic Computer in Canada," *Proceedings of the Canadian Information Processing Society*, 9-11 May 1984, Calgary, Canada, 314-7. These papers as well as numerous others on FERUT can be found in the Gotlieb Collection at the University of Toronto Archives. Another source is *Calvin Gotlieb*, Interview with Ted Paull, 14 August 1984, National Museum of Science and Technology, Ottawa, Canada; and Prof. Michael Williams's Interviews with C.C. Gotlieb, 29-30 April 1992, available through Prof. Williams at the Department of Computer Science, University of Calgary.

[145] C. C. Gotlieb Interview, 29 July 1971, pages 22-3 of transcript. For a detailed retrospective of the calculations see H. W. Lea, "Hydraulic Problems In Connection With The Development Of The St. Lawrence River," *The Engineering Journal* 43:2 (February 1960): 50-4; H. M. McFarlane, "Backwater Computations For the St. Lawrence Power Project," *The Engineering Journal* 43:2 (February 1960): 55-60; and C. C. Gotlieb, "Backwater Computations For the St. Lawrence Power Project: Calculations on the Ferranti Digital Computer," *The Engineering Journal* 43:2 (February 1960): 61-6.

scenarios.

The interaction between Canadian military enterprise and academia went beyond the University of Toronto. As the computer became an important symbol and tool in the pursuit of academic excellence, universities tried, wherever possible, to couch their desire to own a computer in terms of reference that would elicit either direct or indirect funding from the military.[146] For example, in 1956, the University of British Columbia (UBC) applied to the Defence Research Board for a $62,250 grant to buy a computer and carry out "research into the most efficient methods of programming a digital computer for handling the types of problem which arise in the research activities of the University."[147] While the UBC Sub-Committee on Equipment, which studied the issue of acquiring a computer, made no reference to defence needs when it wrote its report to the President's Committee on Automation, the application that went out to DRB played, however, on defence interests.[148] The application pointed out that there was an urgent need on the west coast to provide a facility in which to train graduate students, scientists, and engineers in the techniques of high-speed automated computation for Canada's government and industrial defence laboratories.[149] More to the point, the application reminded DRB that the university was directly engaged in DRB-sponsored basic research programs, all of which would benefit greatly by direct access to a computer. As an added inducement, UBC pointed out that the computer would be made available to the Marine Physics and Seaward Defence Groups, in DRB's Pacific Naval Laboratory.[150] Back in Central Canada, the University

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[146] The military would either contribute to the purchase of the computer or promise to buy a given amount of time on the computer.

[147] Walter H. Gage (Dean of Administration and Inter-Faculty Affairs and Professor of Mathematics, University of British Columbia), Application To the Defence Research Board For A Grant For Research, 7 May 1956, DND, Accession 83-84/167, box 7593, file DRB 9931-04, pt. 1.

[148] Report of Sub-Committee on Equipment, 26 March 1956, and Memorandum to the Chairman of the President's Committee, 25 April 1956, DND, Accession 83-84/167, box 7593, file DRB 9931-04, pt. 1.

[149] No doubt having learned of DRB's openness to helping diffuse computational technology to the west coast, the Dominion Astrophysical Observatory in Victoria, B.C., also put out its hand for help. Without such a computational tool," wrote the Dominion Astronomer, C. S. Beals, "no Canadian scientific institution will be able to maintain any international level research without a computer. If Canada was to decentralize the scientific research then it had to do the same for computers," Beals argued. C. S. Beals, Letter to A.H. Zimmerman, Chairman, Defence Research Board, 9 July 1956, DND, Accession 83-84/167, box 7593, file DRB 9931-04, pt. 1. DRB never gave the Observatory any funding, but it surely must have pointed out to Beals that the proposed computer at UBC offered much more accessible computation time than the one at the University of Toronto.

[150] See the second grant application, Walter H. Gage (Dean of Administration and Inter-Faculty Affairs and Professor of Mathematics, University of British Columbia), Application To the Defence Research Board For A Grant For Research, 10 December 1956, DND, Accession 83-84/167, box 7593, file DRB 9931-04, pt. 1. Apparently, the

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of Ottawa also benefitted from DRB's indirect financial support for a new computer. Because of its location close to a several government defence labs, the university was able to subsidize the early introduction of a computer through selling machine-time to the military. The extent to which defence played a role in diffusing this technology to universities has yet to be studied, but its clear that military enterprise helped accelerate the process.

The Canadian military's support of university computation centres stemmed from its continued interest in promoting computational self-reliance. There was a need to ensure that an adequate number of Canadian mathematicians, scientists, and engineers were trained in the use of general purpose computers. Without such a national pool of expertise, the military knew that it could never launch or sustain and semblance of R&D self-reliance. The military also wanted to ensure that it had direct access to a sufficient amount of machine-time to meets its day to day computational needs. Related to these two factors was the need for an adequate regional decentralization of computational facilities to match the coast to coast geographical dispersal of military R&D centres.[151] Before 1952, the military's need for computational power required the promotion of an indigenous capacity to design and build computers. After 1952, access to computational power became a question of being able to buy or lease commercial computers, to ensure an adequate number of people trained in the use of computers for scientific research and experimental engineering, and to support university computation centres where needed. The disappearance of the military's interest in promulgating a domestic capacity to design and build machines to do large-scale, high-speed scientific computation did not mean that it abandoned interest in digital electronics. As the next two chapters will show, the purchase of FERUT did not remove the need to develop an indigenous capacity to design advanced weapons systems using digital electronics. The next chapter examines how and why, during the late 1940s and early 1950s, the Royal Canadian Navy became one of the world's leading promoters of automated digital warfare.

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[150](...continued)
first grant application's attempt to play the defence angle did not convince DRB. In the second application, UBC made more explicit and greater reference to the benefits of the proposed computation centre towards meeting Canada's defence needs.

[151] It appears that the spatial distribution of computational power later became a strategic concern in the event of war, because of the issue of vulnerability to a first strike. J. Jablonski (Operational Research Group, Defence Research Board), Memorandum to Emergency Measures Organization, Privy Council Office: Location of Computers, 28 March 1960, DND, Accession 83-84/167, box 7589, file DRB 9900-31, pt. 1.

Chapter 3

The Royal Canadian Navy's Pursuit of Digital Electronic Self-Reliance

Introduction

Through military support, in 1952 the University of Toronto became Canada's first high-speed, large-scale computational facility. The commercial availability of the Ferranti Mark I computer had removed the military's imperative to design and build high-speed computational devices. The intensive mathematical simulations and calculations needed to accelerate the prototyping of new weapons systems could now be done on an off-the-shelf commercial product. Yet, the purchase of FERUT did not diminish the military's desire to create a national competence in the design of digital electronic hardware, for the impact of the digital paradigm on military technology went far beyond the need for off-line, batch-oriented, scientific computation. During the 1950s, real-time digital electronic computation became embedded in the actual operation of navigation, communications, early warning detection, target tracking, and automatic fire control systems. The Royal Canadian Navy's efforts, in the immediate postwar years, to automate naval battle offers the most striking example of how "being digital" had become a vehicle to military self-reliance.

In 1948, as the reader will learn in the narrative that follows, the Royal Canadian Navy (RCN) turned to the yet unexplored world of digital electronics in an effort to assure itself a sovereign and important role in the postwar era. David Zimmerman's analysis of the wartime development of asdic suggests that the role of self-reliant technological pioneer had not hitherto been part of RCN culture.[1] And yet that is exactly the course of action that the RCN chose in the postwar years, 1945 to 1955. During this decade, the RCN became the western alliance's leading exponent of electronic, digital, information-processing systems in modern naval warfare. The reason for the RCN's sudden embrace of leading-edge research and development stemmed from

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[1] Zimmerman, *The Great Naval Battle of Ottawa.*

its wartime anti-submarine and convoy escort role. During the course of World War II, serendipity had brought Canada a historically unprecedented degree of autonomy in its military relations within the North Atlantic Triangle. After the war, the RCN looked to technological self-reliance as a way to make its wartime gains permanent. This chapter explores how the RCN, in pursuit of this research and development (R&D) agenda, played an important role in advancing Canada's industrial capacity up the fourth innovation wave. More specifically, the chapter's focus is on the RCN's part in the birth and subsequent nurturing of Ferranti Electric Ltd.'s electronics group. For over a decade, even after the relationship between the RCN and this company ended, Ferranti Electric (later to become Ferranti-Packard) remained Canada's best hope of creating an indigenous computer industry. Finally, this chapter's narrative explores the dilemma that Canada's small open economy faced when it tried to pursue military self-reliance through costly, complex, large-scale technological systems. The story starts in the naval battles of World War II.

The Submarine in the Digital Universe: The Axis of Canada's Naval Self-Reliance

In World War II, Germany reasoned that if it could choke-off all the transatlantic re-supply lines to Great Britain from Canada and the United States, then Great Britain's demise would be only a matter of time. The failure of Germany's surface fleet to sever Great Britain's life-line to North America, led to the promotion of the submarine as Germany's principal form of naval warfare.[2] "By the end of 1940," writes W. G. D. Lund, Germany's strategy of starving Britain into submission...became evident and the long struggle by Commonwealth forces to maintain the vital lines of communication began."[3] Unless they were one of the very fast luxury passenger liners, such as the Queen Mary, sending solitary supply ships across the Atlantic was sheer folly. Their slow speeds made them perfect prey for German submarines. To assign a naval vessel to escort each supply ship was also utterly impractical.

To counteract the threat of the submarine, the Allies instituted convoys. In these there was safety in numbers. Large convoys lost proportionately fewer ships. So like animals in a

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[2] Gerhard Weinberg, *A World At Arms: A Global History of World War II* (Cambridge, U.K.: Cambridge University Press, 1994).

[3] W. G. D. Lund, "The Royal Canadian Navy's Quest for Autonomy in the North West Atlantic, 1941-43", in *The RCN in Retrospect, 1910-1968*, ed. James Boutilier (Vancouver: University of British Columbia, 1982), 139.

herd, supply ships would be assembled and moved across the Atlantic by a small protective escort comprised mostly of corvettes. Despite this advantage, protecting slow moving convoys that extended over many square miles proved extremely difficult. By the end of 1942, the German submarine "wolf-packs" were exacting a devastating toll on Allied shipping. In November 1942 alone, 720,000 tons of supplies were sunk by German submarines. With the rate of shipping losses exceeding the rate of production, the Allied leaders gave the submarine problem top priority at their January 1943 meeting in Casablanca. "If the menace [from submarines] could not be conquered," explains historian Gerhard Weinberg, "the steady diminution of Allied tonnage would immobilize the Western Allies."[4] By 1943, the battle to control the shipping lanes had become World War II's pivotal "battlefield." For Hitler, the submarine campaign had assumed, next to the Eastern front, the most important role in Germany's war strategy.[5]

Canada devoted all its naval resources to the role of protecting the transatlantic convoys.[6] By the end of 1942, Canada provided 48 percent of all the convoy escorts.[7] And yet, despite this large contribution, Canada had no say in the strategic use of its considerable anti-submarine resources. The dismissive attitude taken by British and American naval authorities to Canada's views on the disposition of its own naval resources frustrated and angered senior RCN officers. "The British Admiralty," concluded Canada's Admiral Brodeur, "still looked upon the RCN as the naval child to be seen and not heard when no outsider [the American Navy] looked on or listened in."[8] American naval authority was no different, added Brodeur. Japan's entry into the war provided the RCN with unexpected bargaining leverage to pry the command of Atlantic convoy escort operations away from the United States because it forced the Americans to pour all their naval resources into the Pacific, leaving little for the Atlantic. The time was now ripe for the RCN to win important concessions from its patronizing allies.

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[4] Weinberg, *A World At Arms*, 380.

[5] Weinberg, *A World At Arms*.

[6] For more details about Canada's heroic contribution to the protection of convoys against submarines see W. H. Pugsley, *Sailor Remembers* (Toronto: Collins, 1948); G. N. Tucker, *The Naval Service of Canada*, vol. 2 (Ottawa: Kings Printer, 1952); James Lamb, *The Corvette Navy* (Toronto: Macmillan, 1977); John Swettenham, *Canada's Atlantic War* (Toronto: Samuel-Stevens, 1979); Marc Milner, *North Atlantic Run: The Royal Canadian Navy and the Battle for the Convoys* (Toronto: University of Toronto Press, 1985); and Marc Milner, *The U-Boat Hunters: The Royal Canadian Navy and the Offensive against Germany's Submarines* (Toronto: University of Toronto Press, 1994).

[7] Lund, *The Royal Canadian Navy's Quest*.

[8] *Ibid.*, 147.

The RCN decided to use the high level Atlantic Convoy Conference to push the British Royal Navy (RN) and the United States Navy (USN) for a primary command role in the Battle of the North Atlantic. The conference started on 1 March 1943. At its close on 6 March the RCN emerged with a historically unprecedented military role within the North Atlantic Triangle. Canada had won control of all surface and anti-submarine escorts in the western half of the North Atlantic. In addition, Canada now shared control, with the United Kingdom, of all convoys running between the British Isles and North America, including those originating in New York. The senior level of the RCN officer corps had achieved what the MacKenzie King government could not do: the assertion of Canadian autonomy in the military sphere. Through a commitment to anti-submarine warfare, Canada had gained a key command role in one of the most important theatres of war, the Battle of the North Atlantic. "No other small power," Lund argues, "enjoyed such a position."[9]

Determined to preserve its hard-won special status in the postwar era, the RCN wanted to cast itself in the role of the Western alliance's anti-submarine and escort navy. By 1947, the RCN realized that advances in submarine technology would soon render its World War II anti-submarine (A/S) equipment obsolete.[10] If the RCN wanted to be taken seriously in its efforts to be recognized as an A/S force, then it would have to embark on its own research and development program. The RCN understood that the intensive exploitation of science and technology had become the *sine qua non* of military competency in the postwar era. But in 1946, the RCN had yet to articulate its R&D ambitions. By the end of 1948, however, its R&D agenda started to take shape. The most daring item in this agenda was the proposal to move naval warfare into the electronic digital universe. The impetus for this R&D came from the technical, mid-level officer corps within the Electrical Engineer-in-Chief's Directorate (EECD). Yet it was a receptive senior officer corps who provided the essential political and financial support. These senior officers who had fought so hard to win military sovereignty in the Battle of the North Atlantic were ready to finance any bold technological undertaking that bolstered the RCN's claim to be the backbone of the Alliances' anti-submarine efforts.

The inability to capture, extract, display, communicate, and share accurate tactical information in a timely manner had been a central limitation of A/S operations. The movement

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[9] *Ibid.*, 157.

[10] Minutes of the 24th Meeting of the Research Control Committee, Item 24-6, The Future of A/S Research, Item 24-6, 5 September 1946, DND, Accession 83-84/167, box 139, file NSS-1279-33, pt. 2.

of large convoys across the Atlantic during World War II had presented monumental logistical and tactical challenges. Keeping track of the position of all the ships in a convoy that stretched over many square miles proved problematic. In a battle situation, the difficulty was compounded by the need to monitor the movement of all the enemy submarines. The long human chain needed to convert asdic, radar, and other tactical data into useful information for command-and-control was slow and often unreliable. While asdic signalled to the convoy the presence of attacking submarines, radar tracked enemy aircraft. With a new postwar generation of submarines and aircraft, the RCN realized that the slow, human-intensive chain needed to convert input data to a coordinated tactical response had become a serious weakness in anti-submarine operations.[11]

While the flow of tactical information *within* the anti-submarine ship was slow, precious little flowed *between* escort ships. The absence of inter-ship, real-time, tactical data exchange severely limited the ability of the escort fleet to respond as one unit. The RCN came to believe that there was an "urgent operational requirement" for new systems that would allow "for closely co-ordinated tactics by convoy escort and hunter-killer anti-submarine groups."[12] The Development Section of the Electrical Engineer-in-Chief's Directorate advocated an integrated and automated information system that could simultaneously provide the Command of each anti-submarine escort with a complete, concise, and up-to-date picture of the tactical situation, provide the necessary information to weapon-control systems to assist in target designation, and incorporate tactical information on all aircraft into one battle picture. Unless the RCN could automate the production, exchange, and use of tactical data, reasoned EECD's technical people, Canada's A/S escort would prove ineffective against the co-ordinated attacks of a new generation of submarines and aircraft. But how could one achieve this technological breakthrough? To the technically minded mid-level officers in the EECD's Development Section, the ENIAC computer offered the answer.

A top secret project during World War II, ENIAC had been built to accelerate the

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[11] The chain started with the radar or sonar detection of a target. The range and bearing of the target was then passed on by telephone from the Reporter to the Plotter, who would then place the information, with a wax pencil, on the back side of a vertical transparent plotting board. The Air Plot Officer, with a wax pencil, would then filter this information onto the other side of the plotting board. The Direction Officer and Gunnery Liaison Officer then decided whether to engage the target with guns or fighters. The Gunnery Liaison Officer then passed the approximate bearing and speed to another person sitting in the Gun Direction Room. Then the Gunnery Direction Officer would pass on target identification information to the TIU Operator who then tells the Director on what bearing to start pointing the gun.

[12] Deputy Minister of Defence, Memorandum to the Minister of Defence, June 1950, DND, Accession 83-84/167, box 3108, file NSS-7401-382-1.

calculation of ballistic and bombing tables. Still the only fully electronic digital computer in the world in 1948, ENIAC was an obscure technology known and understood by a very small circle of people. But the members of the Development Section had followed the military reports on ENIAC with great interest. The incredible speed and precision of electronic digital computation made a dramatic impact on their technical imaginations. They saw more than just a radical advance in calculating technology. In these officers' minds, the new electronic digital paradigm offered a revolutionary way to unify the collection, interpretation, communication, and representation of tactical information into one automatic, interactive, and decentralized network linking all the escort ships of a convoy. They called this first comprehensive digital perspective of naval warfare Digital Automated Tracking And Resolving -- DATAR.[13] Expecting pack attacks by fast submarines armed with sophisticated homing torpedos, the RCN proponents of DATAR argued that there was an "urgent operational requirement for an electronic system that will allow closely coordinated tactics by convoy escort and hunter-killer anti-submarine groups."[14]

The idea of applying digital techniques to automate warfare was not new. During the war, the Radio Corporation of America (RCA), for example, had worked on an electronic system that converted optical and radar target data into precise information that allowed a naval gun's servo-control unit to track the target. Because of the high-precision required, traditional analog computational techniques were inadequate. Digital techniques, as one 1943 RCA patent application explained, allowed "any required accuracy to be obtained with the numerical method of computation merely by using the proper number of digits. Therefore, the accuracy of one part in 10,000 needed in the computer with the present day optical and radar tracking instruments for the present day medium and long range guns can be achieved and easily exceeded....Furthermore, the great speed inherent in electronic devices makes it possible to perform complicated numerical

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[13] As the Deputy Minister of Defence later explained the matter to the Minister, "DATAR is expected to allow an automatic exchange of detection data within the escort group, in order to provide more effective command functions for group tactics that are not now possible, and coordinated assignment of weapons in all ships from detection information available to any one. By display on automatic screens of identical information in all ships, possible only with DATAR devices, commanding officers will have available target 'pointer' facilities and other operational devices of real value in team operations." *Ibid.*

[14] *Ibid.*

computations without setting any limit on the firing speed of the gun."[15] Within the DATAR framework, automatic fire control became one element in a more sophisticated, comprehensive, and global use of tactical information.

By the fall of 1948, DATAR was still only an idea. Eager to prove its technical feasibility, the Development Section of EECD grappled with the question of how to do the research and development. The RCN had neither the electronic laboratories nor technical manpower to tackle DATAR single-handedly. In fact, in 1948 few people in the world had any knowledge or experience with the digital electronics, communications, and computer issues raised by DATAR. There was no one in Canada; the pioneering UTEC project at the University of Toronto had not yet started. The search for an industrial partner for DATAR led the RCN to Ferranti Ltd. and its Canadian subsidiary in Toronto, Ferranti Electric Ltd. As the reader will discover in the next section, the meeting between the RCN and Ferranti Ltd was a serendipitous byproduct of the Defence Research Board's search for an industrial base on which to rest a national defence R&D capacity.

Any self-reliant program to develop new military equipment was contingent on the existence of a sophisticated industrial electronics sector equipped with the facilities and staff to carry out leading edge research and development. Immediately following the end of World War II, the Canadian military started to campaign for the inseparability of peacetime defence planning and national economic and industrial issues. Canada's Chiefs of Staff argued that peacetime military preparedness demanded a national capacity to create, build, and use science-based weapons systems. In 1947, the head of the Chiefs of Staff, Lieutenant General Charles Foulkes, placed the technological issue within a broader industrial and economic framework. Foulkes reminded Brooke Claxton, the Minister of National Defence, that it had taken four years before Canada's industrial mobilization was felt in the active, military theatres.[16] This experience convinced Foulkes of the necessity to establish a peacetime economic and industrial infrastructure around which the nation could mobilize rapidly in any future conflict.[17] "It is

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[15] Richard Snyder and Jan Rajchman, *Calculating Device*, United States Patent no. 2,424,289, filed 30 July 1943, issued 22 July 1947, 1.

[16] Lieutenant-General Charles Foulkes (Chief of the General Staff, to the Minister of National Defence) Memorandum on Canadian Economic Mobilization, from, 10 February 1947, DND, vol. 19,172, file 2130-30/3.

[17] Foulkes recommended that the Department of Trade and Commerce be given the new responsibility of peacetime industrial preparedness. "Transfer the remaining elements of the Department of Reconstruction and Supply, which
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highly unlikely," explained Foulkes to Claxton, "that we shall ever again have as long a period as we had before the last war to mobilize the resources of the nation."[18] If need be, Foulkes added, Canada had to be ready to "subsidize industry [in peacetime] when in the interests of National Security."[19] Though it is not clear if Claxton agreed with the organizational implications of this plan, he was receptive to the overall thrust of Foulkes's ideas on postwar industrial planning, despite King's strong anti-military sentiments.[20]

A year later, in a speech to the Canadian Manufacturing Association, the Chairman of the Defence Research Board, Omond Solandt, reiterated the military's concern for a postwar industrial strategy. "Industrial preparedness in peacetime," stated Solandt, "is just as important to victory as is military preparedness....If the full potential of Canadian victory is to be reached quickly in the event of war, we must start now to form plans for the use of industry to strengthen the research and development side of industry and foster the partnership of science, industry, and the Armed Forces that is so essential to victory."[21]

Victory in war was not the only issue underlying the call for a stronger industrial base. With much of Europe in ruins, Canada had emerged from World War II as the third strongest nation in the industrialized world. Ahead of Canada were the United States and the United Kingdom, the other two vertices of the North Atlantic Triangle. Canada could not pursue anywhere near the spectrum of military R&D that the United States and the United Kingdom could. Even so, if Canada did not at least "pull its own weight" in the triangular alliance, the Americans and the British would surely shunt it aside in postwar planning. Marginality within the alliance would have seriously jeopardized Canada's access to the latest military equipment.[22] In the minds of the Chiefs of Staff, if Canada wanted to dip into the weapons reservoir of its

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were associated with war production during the last war, to the Department of Trade and Commerce...and reorganize this department in such a way that it may efficiently plan in peace for economic mobilization." Foulkes, Memorandum on Canadian Economic Mobilization, 10 February 1947, DND, vol. 19,172, file 2130-30/3.

[18] *Ibid.*, 2.

[19] *Ibid.*, 6.

[20] Minister of National Defence, Memorandum to the Chief of the General Staff, 17 February, 1947, DND, vol. 19,172, file 2130-30/3.

[21] O. M. Solandt, Brief on Research, Defence and Industry, 28 March 1948, p. 5. DND, box 11983, file DRBS-1-0-43.

[22] Of course there was no guarantee that Canada would be given an effective voice even if it did try to carry its fair share. World War II was ample proof of this possibility.

allies, then it would itself have to pour money into weapons design, development, and testing.

This strategy, however, had little chance of success if Canada could not cultivate an indigenous industrial capacity to do peacetime defence research and development. The Canadian military hoped to entice industry to invest in a more self-reliant research and development capacity by hinting at broader commercial spin-offs for them. Peacetime industrial preparedness, Solandt told Canada's manufacturers, was not only "desirable from the military point of view but also for the normal expansion of industry."[23] However, he added that "from the Defence point of view there is a need to accelerate the process, especially where the civilian interest is not great."[24] While DRB realized the need to raise the nation's industrial R&D capacity, it did not comprehend the extent to which Canadian industry was completely unprepared to develop and apply the state-of-the-art electronics needed for national defence.[25]

The seriousness of the problem became apparent, however, in the summer of 1947, when, after comparing their wish list of defence-oriented electronics research with Canadian capabilities, the Armed Forces concluded that the paucity of corporate research and development compromised the nation's postwar military preparedness. [26] The Electronics Advisory Committee recommended immediate action:

> *It is essential to the Canadian defence programme to enlist the services of Canadian industrial laboratories...Since few Canadian industries are now equipped with the necessary laboratory facilities, it is believed that the Defence Research Board should foster and support the establishment and maintenance of such laboratories by appropriate means with the industries...[DRB must] emphasize the imperative demand for such facilities and recommend a mutually satisfactory basis for a solution of this problem. Such laboratories*

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[23] Solandt, Brief on Research, Defence and Industry, 28 March 1948, DND, box 11983, file DRBS-1-0-43.

[24] *Ibid.*

[25] Minutes of the First Meeting of the Electronics Advisory Committee, 22 May 1947, DND, box 4233, file DRBS-3-640-43.

[26] The Services identified fifty-nine specific R&D topics which were grouped under three broad categories of electronics R&D: control and computation, detection, and communications. Under the category of control and computation, the Services included work in "radio aids to navigation and automatic piloting devices, automatic plotting and display equipment, automatic weapon control and prediction systems, telemetering, servo-control and computing devices, etc." The topics under detection included work on a broad range of frequencies: "sound, radio frequencies, heat, infrared-red, visible light, ultraviolet, nuclear radiation, etc." Under the heading of communications the Services included "manual and automatic printing code, voice and video transmission over wire, radio, light, underwater sound, infra-red or other suitable media, involving various grades of security." Memorandum to Secretary, Joint Communications Committee: Canadian Armed Services Electronic Research Requirements, June 19, 1947, 2, DND, Box 4233, File DRBS-3-640-43.

would form the nuclei of highly qualified groups so essential in the event of future conflicts, and without which Canada was so handicapped in World War II.[27]

Soon after the appearance of the electronics research and development wish list of the Canadian Armed Forces, the three industrial representatives on the DRB's Electronics Advisory Committee -- Northern Electric, Canadian Marconi, and RCA Victor -- advised it that their industry could develop the capacity to tackle these problems if assured adequate defence contracts.[28] They tabled a proposal showing how the military's electronic research and development requirements could be neatly partitioned out to what they called Canada's "primary" and "secondary" electronics industries.[29] Their self-serving proposal conveniently distributed all R&D contracts to their own three companies. Their industrial representatives on the Electronic Advisory Committee then convinced their colleagues to recommend that "DRB give immediate consideration to placing the [high priority] projects upon these firms in order that these important requirements for research and development may be undertaken without further delay."[30]

DRB, however, was unwilling to give Northern Electric, RCA Victor, and Canadian Marconi any contracts without open tendering. In August 1948, DRB asked for proposals from fifty-three Canadian companies.[31] In a letter to each of these companies, E. G. Cullwick, DRB's

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[27] *Ibid.*, Appendix B. B. G. Ballard, who was also Director of NRC's Radio and Electrical Engineering Division, "stressed the present lack industrial research laboratories in Canada, and doubted the present ability of industry to tackle the 'Research Requirements.' He agreed, however, that such encouragement of the development of research in industry was most desirable." See Item 2.3, Minutes of the Ninth Meeting of the Electronics Advisory Committee, 10 August 1948, DND, vol. 4233, file DRBS-3-640-43.

[28] See Item 3, Minutes of the Seventh Meeting of the Electronics Advisory Committee, 28 April 1948, DND, vol. 4283, file DRBS-3-640-43.

[29] The "primary" group were considered electronic and communications companies which had facilities for applied research, development and production. The secondary group embraced "those who are not primarily concerned with electronics and communications development and manufacturing. This group, however, has facilities capable of considerable expansion in time of emergency and is considered capable of development in some cases and of manufacture in other cases under the guidance of the primary industries." The three companies represented on DRB's Electronics Advisory Committee designated themselves as "primary." The only other companies listed as "primary" were Canada Wire and Cable, and Exide Batteries of Canada who posed no technological or market threat to the other three. Radio Valve, Rogers Majestic, General Electric, Westinghouse, Philco, Electrohome and CAE were some of the more notable companies labelled as "secondary" category. Minutes of the Eight Meeting of the Electronics Advisory Committee, 15 June 1948, Appendix A, DND, box 4233, file DRBS-640-43.

[30] *Ibid.*, Item 26.

[31] DRB presented four broad areas of research: precision servo-systems for computers including automatic following devices for radar systems; frequency control, including crystals; unattended power supplies; and radar systems. Each of these general areas was accompanied by a list of more specific research topics. See Appendix B, Minutes of the

(continued...)

Director of Electrical Research, announced that "the Defence Research Board intends to initiate a programme of applied research in Canadian industry in fields related to the use of electronic equipment in the Armed Services. Such a programme would balance the Board's programme of basic research in Canadian Universities, and would, it is felt, prove a valuable foundation for the Canadian production of Service equipment."[32]

Accompanying Cullwick's letter was a description of the electronics problems that DRB wanted industry to tackle. Four broad classes of electronics R&D were listed: precision servo-systems for computers including automatic following devices for radar systems; frequency control, including crystals; unattended power supplies; and radar systems. For each of these classes, DRB specified a number of more specific problems. This list, however, comprised the thirty-four highest priority items from the Armed Services' original electronics requirements. Of the fifty-three companies solicited, only nine responded, submitting proposals for sixteen R&D problems. It was this call for industrial assistance that drew the delegation from Ferranti Ltd. to see if it could set up an electronics group in its Canadian subsidiary to respond to DRB's R&D needs. [33]

Enter Ferranti-Canada

The Canadian subsidiary, Ferranti Electric Ltd., had started in 1908 as a simple distribution agency, run by the prominent Royce family of West Toronto Junction (who also owned the Toronto Suburban [Electric] Railway) to sell the watt-hour meters of the British

(...continued)
Ninth Meeting of the Electronics Advisory Committee, 10 August 1948, DND, vol. 4233, file DRBS-3-640-43.. The figure of fifty-three companies appeared in Item 3.1, Minutes of the Tenth Meeting of the Electronics Advisory Committee, 14 September 1948, DND, vol. 4233, File-3640-43.

[32] The letter was signed by Cullwick in the name of the Chairman of DRB. For the complete letter see Appendix A, Minutes of the Ninth Meeting of the Electronics Advisory Committee, 10 August 1948, DND, vol. 4233, file DRBS-3-640-43.

[33] After examining the proposals, the Electronics Advisory Committee recommended that the sixteen R&D problems be divided among four companies: Smith and Stone Limited, Canadian Marconi Limited, RCA Victor Limited, and Northern Electric. Then at the last moment, the British firm Ferranti Ltd. (Ferranti U.K.), through its Canadian subsidiary Ferranti Electric (Ferranti-Canada), submitted its own substantial proposal. Consequently, A. B. Cooper, the President of Ferranti-Canada, forwarded the letter from DRB to [Sir] Vincent Ziani de Ferranti who was the president, Chairman of the Board, and principal owner of Ferranti U.K.

electrical manufacturer, Ferranti Limited (Ferranti U.K.).[34] The rapid and widespread adoption of hydro-electric power that accompanied Canada's rapid economic expansion during the 1896 to 1912 boom period created an enormous potential for electrical capital goods. In 1912, at the peak of this buoyant electrical market, the agency created by the Royce family was succeeded by a full-fledged trading company, Ferranti Electrical Co. of Canada Limited (Ferranti-Canada). Over the next eighty years, three factors shaped the growth of the Ferranti-Canada: the need to survive in a North American electrical capital goods market dominated by the large American multinationals General Electric and Westinghouse; the Canadian subsidiary's continual pursuit of greater manufacturing and design autonomy; and the transfer of the parent firm's technology-driven corporate culture to the subsidiary. As of 1948, other than an X-ray department, which produced machines for industrial inspection and small portable units for the field hospitals, Ferranti-Canada had no experience in electronics. But its parent firm had made considerable inroads in this area and was interested in getting a foothold in the burgeoning North American defence market.

Considerable discussion ensued within the parent firm over how to respond to DRB's call for R&D proposals. What electronics technology should Ferranti go after? What would be the best corporate response to achieve this? Senior managers and engineers convinced Ferranti U.K.'s CEO, chairman of the Board, and owner, Vincent Ziani de Ferranti, to propose an R&D program in precision servo-systems for computers, including automatic following devices for radar systems. The second question the Ferranti group had to resolve in response to DRB was one of corporate strategy. This question was a bit more complex because DRB had stipulated that "the value of such work to the problems of defence will of course depend on the degree to which the programme can be carried out with Canadian facilities and personnel."[35] The Canadian subsidiary had neither the financial, managerial, nor technical resources to undertake defence electronics research and development. While the parent firm was willing to offer the necessary technology transfer, it was unwilling to underwrite the capital and operating costs of such an endeavour. These would have to be written into the defence contract. Confident that Canada had good defence contracts to offer, Sir Vincent Ziani de Ferranti and his people sailed for Canada to meet with DRB.

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[34] Ball and Vardalas, *Ferranti-Packard.*

[35] Minutes of the Ninth Meeting of the Electronics Advisory Committee, 10 August 1948, Appendix A.

The 18 October 1948 meeting, between DRB and the Ferranti delegation, which consisted of senior executives from both the parent firm and its Canadian subsidiary, was a dismal failure. While DRB's Electronics Advisory Committee supported the British company's proposal to transfer a vital defence R&D capacity to its Canadian subsidiary, DRB's management rejected the Ferranti bid.[36] Dr. Solandt, the Chairman of DRB, explained to Ziani de Ferranti that the Board had not "yet reached the stage where we could undertake to support a research venture such as the one which [Ferranti] propose[d] which ha[d] no direct commercial value but is entirely dependent on government support."[37]

Ferranti-Canada's response to DRB's non-offer was scornful but prudent: "Solandt leaves a small loophole for us to be associated with the Board, provided we will work for nothing," wrote A. B. Cooper, president of the Canadian subsidiary, to Ziani de Ferranti.[38] Behind this unwillingness to fund R&D at Ferranti-Canada lay the reality that in 1948 DRB did not have adequate financial resources to foster industrial research and development effectively.[39] The General Manager of Ferranti-Canada, Dr. John Thomson, was inclined to "discredit" the value of DRB contracts to Ferranti-Canada. With funding limited and already allocated to Northern Electric, Canadian Marconi, and RCA Victor in Montreal, DRB had nothing left for Ferranti-Canada. However, Cooper shrewdly acknowledged that it was perhaps in the company's "general interest not to ignore Solandt's suggestion of unpaid co-operation."[40] Increasing international political tensions, Cooper intimated, would no doubt lead to expanded defence spending in the

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[36] Lieutenant Colonel D. A. Waldcock, from the Army's Division of Electrical and Communications Development, welcomed Ferranti U.K.'s offer to transfer its British effort in "magnetic amplifiers" to Canada. "Servo-mechanism," Waldcock told the Electronics Advisory Committee, "will occur in almost all new applications for the Army." After discussion, the Committee agreed that Magnetic Amplifiers and Remote Position Servos over long distances were a high priority and endorsed undertaking this work at Ferranti-Canada. Magnetic amplifiers were one of the problems of interest to DRB under the broad research requirement of "precision Servo-systems for computers including Automatic Following Devices for Radar Systems." Minutes of the Eleventh Meeting of the Electronics Advisory Committee, 23 November 1948, 6, DND, box 4233, file DRBS 3-640-43.

[37] O. Solandt, Letter to Vincent Ziani de Ferranti, 7 January 1949, Ferranti plc Archives, Manchester, England. E. G. Cullwick, however, continued to champion the Ferranti cause within DRB. Cullwick wrote Sir Vincent Ziani de Ferranti privately that "the question of asking Ferranti of Canada to undertake a research contract is not dead." Though the Board had rejected the Electronic Advisory Committee's recommendation to give Ferranti-Canada a contract, Cullwick assured Sir Vincent "that the Committee intends to pursue the matter further." E. G. Cullwick, Letter to Sir Vincent Z. de Ferranti, 6 May 1949, Ferranti plc Archives, Manchester, England.

[38] Letter from A. B. Cooper to Vincent Ziani de Ferranti, 7 February 1949. Ferranti plc Archives, Manchester England.

[39] DRB only had $200,000 for the total industrial research program. See item 4.9, Minutes of the Tenth Meeting of the Electronics Advisory Committee, 14 September 1948.

[40] *Ibid.*

future. Richard Davies, from Ferranti's New York office, who also attended the 18 October meeting, best zeroed in on the contradictions of DRB's approach: if the venture had direct commercial value why would any company approach the military in the first place?[41]

Sustaining a strong industrial defence capacity posed serious problems because Canada lacked the peacetime military economies of scale of its allies. In the United States and the United Kingdom, observed Solandt, "the productive capacity of industry is adequate both quantitatively and qualitatively to meet the needs of the Armed Forces. It is therefore possible to have a very close relationship between industry and the Armed Forces since the Armed Forces are virtually the only customer of war industry."[42] Unable to completely sustain a Canadian defence industry, DRB strategy rested on the hope that civilian spin-offs could underwrite a healthy portion of military research and development. DRB never elaborated on how this strategy would work in practice.[43]

E. G. Cullwick, the Defence Research Board's Director of Electrical Research and a former RCN officer, was aware of the EECD's search for an industrial R&D base from which to build DATAR. In October 1948, Cullwick called Lieutenant Jim Belyea, who was one of the leading advocates of the DATAR concept within the EECD, and informed him of the Ferranti Ltd. delegation's visit. Ferranti U.K.'s experience in digital R&D dovetailed well with technical challenges raised by DATAR. Ferranti U.K. had supplied 30 percent of the British Army's requirements in servo-control equipment, which is an integral part of the automated fire control

[41] "It is not necessary to point out," observed Davies in a letter to Ziani de Ferranti, "that if research and development facilities exist and are supported on a purely commercial basis, there is no need for any government subsidy to make them available for defence purpose." R. H. Davies (Ferranti Electric Inc., New York), Letter to Vincent Ziani de Ferranti, 14 February 1949. Ferranti plc archives, Manchester, England.

[42] *Ibid.*, 4.

[43] National economic policy also shaped DRB's rejection of the Ferranti U.K. offer. DRB was under considerable pressure from the Canadian electronics manufacturers to support an industry hit hard by demobilization. An industry presentation to the 1955 Royal Commission on Canada's Economic Prospects noted that "prior to World War II, government contracts played little part in the development of the electronics industry in Canada. However, the rapid growth of the electronics industry after the outbreak of the war was largely the result of government contracts....As a result of the large-scale cancellations of government contracts upon the termination of hostilities, the output of the electronics industry shrunk considerably in 1945 and 1946." Canadian Business Service Limited, *The Electronics Industry in Canada*, prepared for the Royal Commission on Canada's Economic Prospects, April 1956, 37. Defence contracts were desperately needed to maintain the employment of valuable technical personnel. In this kind of economic climate, DRB felt that it would be counterproductive to encourage any R&D in companies that did not have an existing capacity to translate prototype design into actual production. The chairman of DRB's Electronics Advisory Committee, Mr. F. F. Fulton, who also represented Northern Electric Company, had received assurances from Solandt that DRB would give preference to companies with existing manufacturing facilities when it came to issuing research contracts. Minutes of the Ninth Meeting of the Electronics Advisory Committee, Defence Research Board, 10 August 1948, Item 2.3.5.

technology.[44] After the war, Ferranti U.K. took up the "design of naval fire control equipment involving electronic computers, regenerative tracking & automatic following" for the Royal Navy.[45] Ferranti U.K.'s work on the "Admiralty Flyplane" embodied electronic computing.[46] Dr. Prinz, an eminent research scientist on staff at Ferranti UK, was studying methods of high speed data transmission.[47] Finally, Ferranti UK had just received a contract from the British government to do the necessary design and production engineering to turn the Manchester University Mark I computer into a commercial venture.[48] After hearing Cullwick's profile of Ferranti U.K., Belyea seized the moment and visited the delegation at the Chateau Laurier .

It is not known whether Belyea went to the see the Ferranti group with the clear plan to enlist its help. But during the meeting, Belyea became convinced that the Ferranti organization was the company to develop DATAR. At the same time the RCN's project appealed instantly to the technology-driven Ferranti group. Not only did the work fit well into the company's current R&D activities, but nothing in England came close to the scope of DATAR. "It seemed to our group," reflected Kenyon Taylor, who was a member of that delegation, " that what [Belyea] had in mind was very much the proper thing to be doing....It was a first step in push-button warfare. Lt. Belyea was thinking 15 years ahead of his time and Sir Vincent de Ferranti and the rest of our party were well in tune with him."[49] With RCN support, Ferranti was ready to assemble Canada's first leading-edge industrial R&D group in digital electronic computers and communications.

The Development Section understood that unless it could prove that tactical information could indeed be exchanged reliably between two distant points through digitally encoded radio communication, there was little hope that an understandably sceptical RCN hierarchy would embrace this radical concept. Belyea offered Ferranti-Canada the challenge to develop the completely novel digital electronic circuitry based on a concept first proposed by H. A. Reeves in

[44] Minutes of the Eleventh Meeting of the Electronics Advisory Committee, 23 November 1948, 6.

[45] *Ibid*; and Present Government Development Work Coming Within The Scope Of The Canadian Defence Research Board's Requirements, September 1948, Ferranti plc Archives, Manchester, England.

[46] Eric Grundy, Memorandum to Sir Vincent de Ferranti: Research in Electronics Industry, Canada, 20 September 1948, Ferranti plc Archives, Manchester, England.

[47] *Ibid*

[48] Lavington, *Early British Computers*. The contract was for an estimated £35,000 per annum over five years.

[49] Kenyon Taylor, Autobiographical Notes, 15 February 1970, Ferranti-Packard Archives, Provincial Archives of Ontario.

1939 but never really explored. The idea behind Reeves's Pulse Coded Modulation, or PCM, was to convert analog signals into a series of binary values for the purpose of communication. Today PCM is an ubiquitous element in all communications technology, but in 1948 it was unexplored territory.

Too late to obtain a formal budget, Belyea funded the first year's work by siphoning money from other projects.[50] What should have been one relatively large contract was instead broken down into smaller contracts. By keeping each contract under $5,000, and thus within the realm of his discretionary spending authority, Belyea bypassed the need for formal spending approval from outside the EECD. In a span of three weeks, the Development Section issued four contracts. The first dealt with the study of digital transmission methods and devices; the second, with the design and construction of binary digital components for transmission systems; the third, with the design and construction of PCM components and devices; and the fourth, with the design of an experimental PCM transmission system.[51]

Though Belyea's contracts were quite modest, they did demonstrate the RCN's good faith to Vincent Ziani de Ferranti. In January 1949, Ferranti sent Kenyon Taylor, his most imaginative inventor, to set up an electronics R&D team in Canada.[52] Taylor had started working for Ferranti in 1931 as a "lab boy" when textile machinery still occupied an important place in the pantheon of Ferranti technological interests. The company's founder Sebastian Ziani de Ferranti had devoted considerable effort to designing high-speed textile machinery.[53] Taylor's success in applying electronic techniques to improving the operation of Ferranti textile machines not only led to his first patent,[54] but it also brought his inventive talents to Sir Vincent's attention. Over the years, they had become close friends. By the time Taylor set sail for Canada, he had acquired

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[50] "The contract position has been somewhat confused on account of adequate funds not having been made available for this project during this financial year, we have been kept going on funds originally intended for other projects - this accounts for the bittyness' of the contracts." Arthur Porter, Preliminary Report, 15 October 1949. Ferranti plc Archives, Manchester England.

[51] The first three contracts were issued on 18 November 1948 and were each worth $4,000. The fourth was issued on 5 December 1948 and was for $5,000. See attached table to Chairman, Defence Research Board, Letter to R. B. Bryce, Secretary of the Treasury Board, 18 December 1952, DND, Accession 83-84/167, box 3108, file NSS-7401-382-1.

[52] The team consisted of M. K. Taylor, D. F. Walker, J. F. Harben and G. Ross. *Ferranti Journal* (March 1949), 25.

[53] K. G. Ponting, "The Textile Innovations of Sebastian Ziani de Ferranti," *Textile History* 4. Exact year and issue number not indicated on reprint.

[54] Kenyon Taylor, *Dynamic balancing while in motion by means of weight spirals*, British Patent no. 399,845, application date, January 1932.

fifty-five patents that covered both consumer and military electronics. As the leader of the new Ferranti-Canada electronics group charged with the responsibility of turning the RCN DATAR concept into concrete engineering, Taylor offered the invaluable combination of great inventive talent and a wealth of practical experience.

Though the RCN had nothing to do with the Ferranti visit to Canada, it was quick to seize the opportunity. While the inability to fund Ferranti's proposal underscored the financial limitations on DRB in executing its mandate, Belyea's ability to issue contracts in rapid succession revealed that the Services had a stronger hand to play and could nurture industrial R&D capacity. The RCN's independent support of the DATAR project also reveals that the line demarcating DRB and the Armed Services's responsibilities in weapon's research was not as clear-cut as Solandt may have wished. Motivated by the Mackenzie King government's fear of wasteful duplication, DRB's mandate was to coordinate all the basic research common to all the three other Services. However, each Service could initiate research that was unique to its own particular military requirements. Despite this rationalization, the Services still guarded their R&D territory quite jealously, wherever possible. After all, the desire of each Service to protect its autonomy, which had been a factor in the Army, Navy, and Air Force's initial reluctance to create DRB as a fourth Service, did not just evaporate with the policy of R&D consolidation. Where the difference between what R&D was unique to the Service and what was common to all Services became blurred, there were bound to be jurisdictional conflicts. In the case of DATAR, the project was framed in the context of naval needs, but digital information processing had obvious and far-reaching implications for all the Armed Services.

Since Ferranti-Canada's initial contract arrangements with Belyea were carried out without DRB's knowledge, the company's management worried that its secret dealings with the RCN would prove to be the source of future conflict with DRB. Their fears did not materialize; after Solandt had learnt about DATAR, he rationalized DRB's non-participation on the grounds that the project entailed "engineering development" rather than "research," the latter being DRB's actual mandate.[55] With regards to DATAR, Solandt's linguistic distinction between "engineering development" and "research" was nothing more than face saving. The research for DATAR was as basic as, if not more basic than, any of the electronics research DRB was currently funding in university and industry.

[55] Solandt expressed this view to Arthur Porter in October 1949. *Ibid*

The money from Belyea's four small initial contracts to Ferranti-Canada quickly ran out. The Development Section squeezed out an additional $15,000 in May 1949, but considerably more money was needed to demonstrate the technical feasibility of PCM.[56] To release more funds, the Electrical Engineer-in-Chief's Directorate now had to seek more formal approval of the project from higher levels within the RCN. The series of small contracts to Ferranti-Canada had already given DATAR a momentum of its own that made it difficult for senior RCN officials to refuse the additional funds needed to complete the demonstration. On 7 October 1949, Chiefs of Naval Staff approved this initial phase of DATAR. Three weeks later, an additional $50,000 was awarded to complete the final design and construction of the experimental PCM transmission equipment.[57] However, any further financial support for DATAR hinged critically on the success of the proposed communications demonstration.

The idea of the demonstration was to transmit simulated tracking data reliably from Ferranti-Canada's laboratories, via radio PCM, and display the targets' movements in the RCN's Ottawa laboratory. Computing Devices of Canada was to develop the CRT display equipment for the experiment.[58] Founded in 1949 by George Glinski, a professor of electrical engineering at the University of Ottawa, and P. E Mahoney, Computing Devices of Canada became the other strategic industrial element in the RCN's efforts to enter the digital age.[59] The demonstration held in February 1950 made a vivid impression on the RCN's senior staff. A small Canadian team had shown the technical feasibility of digitally sharing target information in real-time among a fleet of A/S escorts. Euphoric over the success of the small PCM demonstration, the DATAR group decided to take the giant leap and call for the development of a large-scale, naval weapons system. On 5 April 1950, Captain Roger, the Electrical Engineer-in-Chief, went to the RCN's Research Control Committee with a request for a $1.5 million, thirty month program, to design,

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[56] See attached table to Chairman, Defence Research Board, Letter to R. B. Bryce, Secretary of the Treasury Board, 18 December 1952, DND, Accession 83-84/167, box 3108, file NSS-7401-382-1.

[57] Reference to date and money made in Item 1, in attachment to Chairman (Defence Research Board), Memorandum to the Minister of Defence Production, 25 July 1951, DND, Accession 83-84/167, box 3108, file NSS-7401-382-1.

[58] Arthur Porter, Preliminary Report, 15 October 1949.

[59] Computer Devices of Canada was created expressly to design and build a real-time interactive digital simulator to train officers in anti-submarine warfare. The "Tactical Battle Simulator" was to be the first of its kind in the world.

develop, build, and test a DATAR system prototype.[60]

The Road From Concept to Prototype: A Journey That Took Too Long

Roger's belief that one could jump from a small PCM transmission experiment to a large scale production version for only $1.5 million was naïve. DATAR called for far more research and development than just PCM transmission. Digital displays, servo-control elements, miniature digital circuitry, data-processing units, digital trackers, special input devices, digital storage devices, digital computer units, and navigational devices all had to be designed *de novo*. Then there was the question of systems integration. With digital electronics still very much in an embryonic state, it is understandable that the Committee was cautious about jumping into a full-scale development program when no one had a clearer picture of the technical hurdles that lay ahead. Roger's proposal also failed to show how RCN needs should inform the specifics of DATAR's design program. Short on details, Roger's proposal left the design of DATAR wide open. There were no functional specifications describing the operation of DATAR's subsystems. An even more serious flaw in Roger's request for $1.5 million was the absence of any specific analysis of how the design was to dovetail with RCN operational requirements. The issue for the Committee was not the generic concept of DATAR, but rather the specific form of DATAR technology appropriate for the RCN. Until the RCN's DATAR requirements were clearly understood and delineated, the Committee saw no point in talking about prototypes ready for production. Thus while the Research Control Committee accepted the view that some form of DATAR technology had become an operational necessity for the RCN's A/S operations, it nevertheless considered Roger's proposal poorly conceived.[61]

Six weeks after his first submission, Roger returned with a humbler and more methodologically incremental proposal which the Research Control Committee quickly approved. Instead of jumping directly into full-scale prototype, Roger's directorate received

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[60] Captain W .H. G. Roger (Electrical Engineer-in-Chief), Memorandum to Chief of Naval Tactical Services, 5 April 1950, DND, Accession 83-84/167, box 3108, file NSS-7401-382-1. The Research Control Committee was established in 1944 to coordinate the RCN's research and development programs. Funding approval for major R&D initiatives needed this Committee's prior approval.

[61] Item 40-1, DATAR Development Contracts, in Minutes of the Research Control Committee, 14 April 1950, DND, Accession 83-84/167, box 139, file NSS-1279-33, pt. 2.

$279,000 for a thirteen month detailed engineering study. Most of the money went to underwrite Ferranti-Canada's further experimental exploration of the digital circuit design issues raised by DATAR.[62] The new proposal also responded to the Committee's call on a co-ordinated and comprehensive analysis of the RCN's future DATAR requirements. As an automated information processing system, the DATAR concept required the close harmonization of needs and practices across several RCN command jurisdictions. And yet surprisingly, Roger's original submission made no reference to any intra-service co-ordination. At the Research Control Committee's insistence, the elaboration of the RCN's specific DATAR requirements was to be a collaborative effort between the Electrical Engineering, Telecommunications, Weapons, and Tactics Directorates.

The cornerstone of Canada's postwar military self-reliance was to avoid head-on competition with either the United States or the United Kingdom in the research, development, testing, and production of new defence systems. Within this policy framework, Canada sought to spin an R&D thread that both suited national needs and complemented the work of its allies. Despite the more modest nature of Roger's proposal, by its very nature DATAR promised in the long-term to be a large, complex and costly undertaking that was to challenge British and American R&D programs.

A proposal of this magnitude required a ministerial buy-in. The RCN assured the Minister of Defence that DATAR fitted very well within these constraints of Government policy on military R&D. Not only was it a pivotal technological component of a specifically Canadian responsibility, anti-submarine warfare, and convoy escort, but it was also a uniquely Canadian concept in its scope. As the Deputy Minister of Defence explained to Claxton, no one in either the United States or Great Britain had yet to embark on anything resembling DATAR.[63] Canada stood apart, continued the Deputy Minister, in its vision and achievements in the area of digital, naval, tactical information systems. But the Deputy Minister reassured the Minister that the RCN's program to develop an automated, tactical information system would nevertheless be carried out in close co-operation with its allies to ensure that no wasteful reinvention of the wheel took place. But underneath this commitment to co-operate was the RCN's firm conviction that

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[62] Minutes of the Research Control Committee, 17 June 1950, DND, Accession 83-84/167, box 139, file NSS-1279-33, pt. 2.

[63] Deputy Minister of Defence, Memorandum to the Minister of Defence, June 1950, DND, Accession 83-84/167, box 3108, file NSS-7401-382-1.

because of DATAR's superior technical vision, any transnational harmonization of R&D in this area should be on Canadian terms.

By the time of the successful PCM transmission in February 1950, Ferranti-Canada had already recruited a few bright young Canadian electrical engineers. Going from small contract to small contract made it very difficult for the company to nurture a stable design team. Accordingly the company advised the RCN that any further efforts to build the kind of development engineering staff required by DATAR called for a more substantial and long-term commitment from the military. Ferranti-Canada demanded a minimum of $250,000 worth of contracts annually over three years.[64] Instead, Roger's proposal assured them only $234,000 for one year.[65] However, by October of the following year, Ferranti-Canada was able to extract an additional $200,000 from the RCN to continue the engineering study and circuit experimentation.[66] One factor that contributed to the contract increases was the unexpected extension of Ferranti-Canada's technical responsibilities.

The Electrical Engineer-in-Chief's Directorate had originally wanted Ferranti-Canada to explore all but one aspect of DATAR -- the computer unit. Since Computing Devices of Canada had already been assigned the contract to design and build a digital computerized battle simulator, it seemed only natural that it design DATAR's computer. The RCN allocated $45,000 to Computing Devices of Canada to do a nine-month preliminary engineering study of DATAR's computer units. The simulator turned out to be a very complex and all-consuming undertaking for the small Ottawa-based company.[67] Fearful that Computing Devices of Canada could not handle both projects, the RCN asked Ferranti-Canada, in early 1951, to build a small 12-bit experimental computer as part of its DATAR work.

This new role had a dramatic effect on Ferranti-Canada's subsequent technological and corporate objectives. Suddenly the design and manufacture of electronic computers became a powerful and pervasive ambition among Ferranti-Canada's electronics engineers. Parallels were

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[64] Captain W. H. G. Roger (Electrical Engineer-in-Chief), Memorandum to Chief of Naval Tactical Services, 9 January 1950, DND, Accession 83-84/167, box 3108, file NSS-7401-382-1. In addition, Ferranti-Canada wanted patent rights concessions similar to those granted by the British Ministry of Supply to the parent firm in order to pursue any future non-military commercial options.

[65] Of the $279,000, only $189,000 was designated to Ferranti-Canada for the new thirteen month engineering study.

[66] At this point, Roger's rather unrealistic original estimate that $1.5 million was needed to get a production version of DATAR ready had jumped to $3.2 million.

[67] In the end, the Tactical Battle Simulator turned out to be the RCN's single most expensive digital electronic project. Whether it deserves the label of pioneering effort or fiasco remains an unanswered question.

made between Ferranti-Canada and its parent firm in the United Kingdom. In 1951, Sir Vivian Bowden from Ferranti U.K., while visiting Canada's atomic energy project, asked his friend, W. B. Lewis, "if there was any possibility that Ferranti, Toronto, might be given a contract to build a computer on the same sort of terms as Ferranti UK had."[68] With a contract from the British government, Ferranti U.K. had transformed the prototype computer developed at Manchester University into a commercial product. Could Ferranti-Canada do the same with the research going on at the University of Toronto? The subsequent collapse of the UTEC project abruptly ended this prospect.[69]

A year later, buoyed by the rapid progress being made on DATAR, Arthur Porter[70] boasted to E. L. Davies, the Vice Chairman of DRB, that the Canadian subsidiary "could produce a computing machine as efficient if not better than the present Ferranti equipment [Ferranti Mark I], in approximately twelve months for roughly $150,000."[71] Davies offered Porter an opportunity to make good on his boast. "I am suggesting a method by which Ferranti-Canada could effectively and cleanly cut the throat of Ferranti England." He went on to elaborate:

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[68] Vivian Bowden, Letter to Dr. Arthur Porter, 4 January 1951, Ferranti-Packard Collection, Provincial Archives of Ontario.

[69] Ironically, it was the sale of Ferranti U.K. computer to the University of Toronto that accelerated the demise of UTEC.

[70] In the fall of 1949, the Research Department was created within Ferranti-Canada to pursue the DATAR project and any other future defence R&D contracts. Taylor remained the Department's hands-on engineering mentor. But in a move calculated to give the Canadian group greater scientific credibility and prestige, Vincent Z. de Ferranti asked Dr. Arthur Porter to head up Ferranti-Canada's Research Department. A respected British physicist, Porter had done pioneering work in analog computers, i.e., differential analysers, and was a noted authority in control theory, servo-control mechanisms and operations research. Porter had been associated with the famous British wartime group "Blackett's Circus" that first demonstrated how mathematical and scientific techniques could be applied to military operations. Operations Research, OR as it was commonly called, became a key element in the postwar quest for military strategic advantage. In later years, Porter created the Department of Industrial Engineering at the University of Toronto.

[71] R. Davies, Letter to Arthur Porter, 30 June 1952, Ferranti-Packard Collection, Provincial Archives of Ontario. Arthur Porter had replaced Kenyon Taylor as the head Ferranti-Canada's DATAR development program. In a collection of papers acquired by this writer from the late Kenyon Taylor, there is a fascinating three-page document entitled "Notes on the Cost Estimates for a Digital Computer." No date is given but reference to DATAR technology strongly suggests that this document was written before 1955. What is intriguing about this document is that Ferranti-Canada appears to be bidding to sell a computer in competition with its parent firm. In this document, Ferranti-Canada makes cost comparisons to the British "Ferranti (Moston) computer," indicating that Canada could manufacture a serial computer with electrostatic memory more cheaply than its parent firm. The cost given was $100,000 (including 83 percent average overhead, 3 percent administration fee and 10 percent profit, subject to certain other exclusions). The fact that the document states that the cost of installation in Switzerland was not included suggests strongly that Ferranti-Canada was going after a Swiss client.

This depends on whether or not your statement at the very pleasant lunch last Thursday was affected by the liquid refreshments! ... We do not have in Canada, at present, any need for a further computer but we have heard that Dr. Ellis Johnson, Director of Operations Research [in Washington, D.C.]...is considering purchasing one of the Ferranti machines for roughly $300,000. This is your chance to go to it and earn some U.S. dollars for Canada, our contribution being the know-how we paid for in your development of DATAR.[72]

Ferranti-Canada never built this computer. Porter's belief that Ferranti-Canada could make a full scale, general purpose computer for only $150,000 constituted wishful thinking: the giant engineering leap from a small experimental 12-bit computer to a general purpose computer would have required far more than $150,000. Nevertheless, by replacing Computer Devices of Canada, Ferranti-Canada's engineers had tasted the excitement of participating in a new and revolutionary technology. Nothing less than building computers would now satisfy their future ambitions.

Although the Electrical Engineer-in-Chief's Directorate had succeeded in clearly articulating a consensus view of what Canada's antisubmarine DATAR requirements should be, and Ferranti-Canada had made considerable progress in its development work, the RCN seemed content to precede in a very slow and conservative manner. Then in the fall of 1951, a new sense of urgency invaded the DATAR project. The RCN's Electrical Engineer-in-Chief's Directorate learned that the British Royal Navy's Automatic Surface Plot (A.S.P.) system, which was a rival to DATAR, would be ready for testing as early as 1953.[73] The RCN's schedule for DATAR called for field tests in 1954-55. Roger asked the Research Control Committee for substantial funding increases to speed up the program in order to field test DATAR at the same time the British planned their tests.[74]

The Committee balked at Roger's request and increased spending by only $100,000. Roger reminded the Committee what was at stake. Britain was pushing hard to get its allies to accept the A.S.P. system. If Canada did not field its own demonstration prototype to coincide with the British field trials, the DATAR program could well collapse. Unless Canada sold the

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[72] *Ibid.*

[73] Minutes of the Research Control Committee, 24 October 1951, DND, Accession 83-84/167, box 3169, file NSS-7407-382, pt. 1.

[74] Roger asked to double the money the Navy had planned to spend on DATAR from November 1951 to April 1953; i.e., from $400,000 to $800,000.

DATAR technology to its allies, the RCN had little hope of underwriting the costs of DATAR through its own procurement. By allowing the British field trials to go unchallenged, ran Roger's argument, the A.S.P. system would become the *de facto* standard. What galled the RCN's DATAR proponents was the prospect of having to buy a technology which they considered to be intrinsically inferior in versatility, capacity, accuracy, and operational performance to the Canadian system.[75] Roger's arguments eventually found resonance within the RCN's nationalist senior officer corps and the race between the Canadian and British systems commenced.

With the new pressure of a June 1953 deadline, the pace accelerated and the costs climbed.[76] By January 1953, the cost of designing and building the demonstration DATAR equipment had climbed to $1.57 million.[77] Despite the RCN's technological nationalism, this kind of expenditure would not have been possible had it not been for escalating political tensions and the outbreak of the Korean War. Following the outbreak of the Korean War, Canada committed itself to an accelerated rearmament program. From $387 million in 1949-50, the Department of National Defence's budget more than doubled to $784 million in 1950-51.[78] The following year, 1951-52, the military expenditures doubled again to $1.6 billion.[79] In the 1949-50 fiscal year, Navy appropriations stood at $73 million. By 1953-54, they had swelled to $332

[75] W. H. Roger, Memorandum to the Director of Scientific Services, 13 December 1951, DND, Accession 83-84/167, box 3108, file NSS-7401-382-1. W. H. Roger, Memorandum to the Director of Weapons and Tactics, 5 April 1952, DND, Accession 83-84/167, box 3169, file NSS-7407-382, pt. 1.

[76] News of the Canadian progress on DATAR started to attract the curiosity of the United States and British Naval authorities. The pressure to meet the 1953 deadline became so great that the increasing number of visitors wanting to visit the project became a hindrance. On one occasion, when two large American delegations wanted to be shown the progress being made on DATAR, Canada's Naval Secretary recommended that the Canadian Joint Staff, in Washington, politely refuse the request. Naval Secretary, Memorandum to the Naval Member of the Joint Staff (Washington), 24 November 1954, DND, Accession 83-84/167, box 3169, file NSS-7407-382, pt. 1. When the Director of Scientific Services got wind of this, he quickly reminded the Chiefs of the Naval Staff of the error in any such refusal. "DATAR is one of the few projects in which we have a lead on the Americans," he wrote, "requests are usually the other way, that is for Canadians to visit the U.S. It would be most unfortunate if the Americans were to adopt the attitude that they were too busy to receive Canadian visitors." Director of Scientific Services, Memorandum to Scientific Advisor, Chiefs of Naval Staff, 6 December 1952, DND, Accession 83-84/167, box 3169, file NSS-7407-382, pt. 1.

[77] Minutes of the Research Control Committee, 24 July 1953, DND, Accession 83-84/167,Box 139, file NSS-1279-33 pt. 2. To this total one should also add the over $400,000 worth of R&D work that preceded the decision to accelerate the DATAR program.

[78] Appendix C in Major G. W. Goodspeed (Historical Section, Army Headquarters), The Canadian Army, 1950-1955. Part I: Canadian Defence Policy, Report No. 93 (1961), DND, Volume 6928, file 93.

[79] *Ibid.*

million.[80] In this huge swell of defence spending, the RCN had considerable room to fund its single most daring weapon system development.

Even with the deeper military pockets of the early 1950s, the continual procession of cost increases to the DATAR contracts raised eyebrows within the RCN. Stan Knights, the project's technical officer, questioned Ferranti-Canada's ability to manage the large project. Ferranti-Canada's costs were excessive, Knights told the Research Control Committee, because the company "had been lax in the preparation of its estimates and has not exercised due economy in its methods."[81] Yet, committed to getting a demonstration ready by the Summer of 1953, the RCN felt it had little choice but to pay for what it considered inefficient management.

The demonstrations of DATAR took place on Lake Ontario from September into November. Originally three Canadian Bangor class minesweepers were to be used in the demonstration, but pulling three ships out of service at the height of the Korean War proved impossible. Instead, the demonstration outfitted a shore station to simulate the third ship. All asdic and radar data, which came in as analogue signals, was immediately filtered and converted to digital information. Sophisticated cathode ray tube (CRT) displays on each ship depicted aircraft and submarines as distinctly different graphical icons. Information about any of these targets could be called up instantly by placing a cursor over its image on the screen.[82] All, or any portion, of the information stored in the computer was shared via pulse coded modulation transmission techniques to all or any selected ships of the escort. By taking into account the relative motions of all the escort ships, DATAR presented the complete picture of the tactical situation appropriate to each ship's own reference frame, even though the asdic or radar data displayed on one ship may have been collected by another. If the target was masked by such things as sea turbulence, rain, clouds, or radar windows, DATAR's computer supplied clues as to the probable location of the target.[83]

In the rush to get a DATAR demonstration ready quickly, compromises were made to the

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[80] *Ibid.*

[81] S. F. Knights, DATAR Contract F.E. 109,069 P33-40-881 With Ferranti Electric, 19 January 1953, DND, Accession 83-84/167, box 3108, file NSS-7401-382-1.

[82] A novel innovation developed by Ferranti-Canada to allow the operator to quickly position the cursor over the moving targets on the CRT was the trackball, which today is an ubiquitous element in the information technology landscape. Sometimes it appears in its inverted form, as the "mouse." Surprisingly no patents were taken out on the "track ball." Whether this was due to military secrecy is not known.

[83] This predictive ability required storing and using past data inputs.

design of the electronic digital computer. The Ferranti-Canada design team chose a magnetic drum over more elaborate memory technologies as the computer's main memory. The reliability problems of electrostatic memory systems would have unnecessarily risked the overall success of the demonstration. Given the overall complexity of the project, drum memory offered the most reliable option for the demonstration. Even so, both the RCN and Ferranti-Canada knew that the final DATAR prototype had to find a better solution to memory. Drum memory was too slow and electrostatic memory too bulky. Both of these memories were also quite vulnerable to a ship's vibrations and motion. Ferranti-Canada's desire had been to pursue Forrester's idea of ferrite cores. But this idea still required considerable development work and the race to get a demonstration ready did not permit this luxury.

The Battle of the Systems: Canada's Effort to Set Standardization

As one would expect, the Canadians and British had different interpretations of the results of the DATAR demonstration results. The RCN was elated. Though the demonstration equipment was small in scale and experimental, it nevertheless proved that DATAR technology had the ability to coordinate, with remarkable speed and accuracy, the collective actions of escort ships and aircraft in an anti-submarine operation.[84] Commodore Lay, who had played a key role in Canada's quest for military autonomy in the Battle of the North Atlantic, announced to his fellow members on Permanent Joint Board on Defence (PJBD) that DATAR had proven the superiority of the Canadian naval digital, tactical, information system.[85] On the other hand, while impressed with the technical advances in data handling made by DATAR project, representatives from the British Admiralty concluded that the United Kingdom's A.S.P. system was still

[84] Commander John Charles (Director of Naval Communications), Memorandum: Report on Visit to DATAR Demonstration, 10-11 September, 15 September 1953, and Lieutenant Commander W. R. Howard, Report of Trip to DATAR Project in Toronto, 23 September, DND, Accession 83-84/167, box 3169, file NSS-7407-382, pt. 2. Commander A. R. Hewitt (Director of Supplementary Radio Activities), Report of Visit to Scarboro Bluffs, NRC Establishment, 30 September 1953, DND, Accession 83-84/167, box 3108 file NSS-7401-382-9. Commodore Lay (Assistant Chief of Naval Staff ,Warfare), Conference of Demonstration of DATAR, 9 November 1953, Record of Proceedings, 13 November 1953, DND, Accession 83-84/167, box 3169, file NSS-7407-382, pt. 2.

[85] Minutes of the Permanent Joint Board on Defence, September 1953, 19, DDP, vol. 20,780, file CSC-6.5 pt. 1. The Permanent Joint Board on Defence was created in 1940 as a result of Franklin Roosevelt and Lyon Mackenzie King's desire to provide the necessary co-operation at the highest military levels to ensure the defence of North America. After World War II, the PJBD continued to play an important role in defence co-ordination.

cheaper, simpler, and more effective than DATAR.

The British criticism of DATAR reflected a fundamental disagreement with Canada over the role of air defence. The Royal Canadian Navy (RCN) insisted that any naval tactical information system would have to integrate air defence and anti-submarine data seamlessly. The modern convoy escort, the RCN felt, had to defend against both aircraft and submarines. If the escort ships' weapons could not directly attack enemy aircraft, DATAR could at least co-ordinate the use of friendly aircraft to fend off an enemy attack. The Royal Navy, on the other hand, saw the two as different problems requiring different systems. While the Canadian Navy was committed to a digital system, the Royal Navy's still pushed the more conventional analogue approach to asdic technology. A.S.P. was effective against submarines to the extent that it kept track of a relatively small number of targets. But the A.S.P. analogue approach became overly complex and unwieldy when it came to handling a larger number of targets, as would be the case with air defence. The digital approach not only allowed the easy merger of air and submarine tactical data, but the use of a computer gave the system a flexibility the British A.S.P. could never have. Under DATAR, each ship's computer could extract, from a common pool of data, the information appropriate to its needs in a given context. The A.S.P. system, on the other hand, presented information in a pre-set and rigid manner.

The Royal Navy also argued that because of Canada's insistence on a comprehensive air/antisubmarine system, DATAR had become too large to fit on anything but a large battle cruiser. But many escort vessels, the British pointed out, fell into much smaller classes. The RCN countered that DATAR's design was based on a modular concept. Different sizes of DATAR could be installed on different ships. In today's terms, DATAR used a kind of open system philosophy. The key was a standardized digital protocol for information exchange. A key feature that distinguished DATAR from A.S.P. was the former's decentralized network, in which each ship used its own criteria for information extraction. Sinking one ship, along with its computer, did not disable DATAR. The British A.S.P. system, however, offered a very centralized approach to co-ordinating the protection of a convoy during attack.

Despite the superiority of DATAR, there was little likelihood that the British Navy could escape from its colonial paternalism to adapt the Canadian system. But for Canada what mattered most was the position of the United States Navy (USN) on the standardization issue. As the kingpin of the alliance, the United States could make or break any proposal to standardize naval tactical information systems. Because the USN had done very little to develop it own tactical, information-handling technology, Canada worried that the British would be able to persuade the USN to adapt the A.S.P. system. After the success of the DATAR demonstration, there was little likelihood of this. The pivotal issue for the RCN then became the intentions of the USN. Would the USN, which still lagged considerably behind Canada in the area of automated, tactical, information-handling technology embrace DATAR? Canada lobbied intensely to bring the United States onside. On the 9 November, the Minister of Defence, Brooke Claxton, three Rear Admirals, the heads of various RCN directorates, the RCN's principal scientific advisers and the RCN's officers in charge of DATAR all gathered to sell the Canadian system to a high ranking American Navy delegation, headed by Rear Admirals W. G. Schindler and M. E. Miles, and Dr. E. Piore, Deputy Chief of the Office of Naval Research.

After a demonstration of DATAR, the Canadians outlined the operational capacity of the full-scale version of DATAR they intended to build. DATAR was to be the state-of-the-art in automated naval warfare, with each ship equipped with high-power, air-search radar, high surface search radar, high-definition navigational radar, an airborne early warning system, attack-and-scanning asdic, radio-direction finding equipment, and UHF radio communications. In a sixteen-ship escort fleet, DATAR would allow the simultaneous sharing of the input from all the above devices on all the ships. Each ship's computer was to have the speed and power to keep track of 128 targets simultaneously; to process an additional 1,000 possible messages for each target; to compute automatically, on demand, the course and speed of any target; and to produce specialized plots for tactical control and target designation.[86] To overcome the performance, size, and reliability limitations arising from dependence on a memory drum widespread use of vacuum tubes, the memory in the final version of DATAR was going to be all ferrite core.

The American delegation was impressed by the Canadian achievement, particularly by

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[86] Appendix B in Lay, Conference of Demonstration of DATAR, 13 November 1953. The great volume and diversity of displayed information planned for the DATAR system raised the issue of information and cognitive overload. How well could humans digest displayed information in a rapid unfolding battle situation. On 26 November 1953, the RCN called in the Applied Experimental Psychology Section of Canada's Defence Research Medical Laboratories (DRML) to answer this question. B. Bromily, Memorandum : DATAR Tests and Discussions at Defence Research Medical Laboratories, 25 January 1954, DND, Accession 83-84/167, box 3108, file NSS-7401-382-6; Department of National Defence-Canada Research and Development Project, 26 January 1954, DND, Accession 83-84/167, box 3108, file NSS-7401-382 The Navy asked DRML to study how humans interacted with DATAR's complex displays. Did this interaction stress or confuse the user, and thus mitigate the effectiveness of DATAR's sophisticated information handling? With its vision of high speed electronic naval warfare, the RCN introduced the earliest studies in Canada, if not the world, on the role of the man/machine interface raised by complex information processing systems. The first use of the term man/machine interface came from the U.S. efforts to develop fighter analogue based training simulators.

the Canadian claim that the equipment cost-per-ship for DATAR would be only $400,000. Dr. Piore had expected it to be closer to $1 million per ship. Canada had much riding on the American reaction to DATAR's techno-economic merits. If the Americans did not standardize on DATAR, Canada would have a very difficult time financing the further development and production engineering, and the cost of procurement. Worse if the USN did not agree to the Canadian data exchange protocol, the RCN would be forced to drop DATAR, regardless of whether the RCN could pay for DATAR or not. The RCN realized that unless it retained the initiative and organized international talks on standardizing the contents and protocol of naval data exchange, DATAR technology would be useless to Canada regardless of its superiority.[87] Commodore Lay pressed the Americans to embark on a collaborative undertaking. Though American Rear Admiral Schindler endorsed the idea of drawing up common requirements, it was still too early to know how close to DATAR the USN was willing to move its weapons systems.

Faced with a nationalist Pentagon reluctant to buy a foreign weapons system, particularly one as critical as automated electronic naval warfare, and a powerful American defence industry lobby anxious to block foreign equipment programs, the only possible hope Canada had to sell the Americans on DATAR was to build and test a full scale version before the USN had a chance to initiate a serious program of its own. And yet without some form of standardization assurances from the USN, investing heavily in a large scale production version of DATAR could prove impoverishing. Caught in a chicken-and-egg dilemma, the RCN fell back again into its slow and cautious approach.

Time was of the essence. Yet nearly a year elapsed after Canada's high level meeting with USN representatives before the Electrical Engineer-in-Chief's Directorate felt it was ready to issue contracts for the construction of the first full-scale prototype of DATAR. Through most of 1954, the RCN's DATAR group re-examined, in great detail, the scope of the operational specifications it had already defined in 1952, and then again in 1953. In part, this process was driven, as are many military development projects, by the tendency to seek every possible strategic advantage by pushing the state-of-the-art to its limits. Increasing DATAR's marketability was another equally, if not more, important factor behind the expanded operational specifications. In 1953, the RCN had told the USN delegation that DATAR would eventually be

[87] Minutes From the Project Committee on DATAR, 30 September 1953, DND, Accession 83-84/167, box 139, file NSS-1279-33, pt. 1.

able to handle 128 targets simultaneously. However, by November 1954, the specifications for DATAR had risen to include tracking 500 aircraft, plus other ships and submarines. But no escort role could justify a 500-target air defence information system. Only a major battle group could. DATAR's increased capacity to handle many aircraft lay in the RCN's desire to make the technology attractive to Canada's Royal Canadian Air Force (RCAF) and the USN.

Air defence had become the dominant concern of the Canadian military. Driving this concern was the knowledge that Americans saw the defence of Canada's northern air space as essential for their survival. Canadians feared that unless they took a more active role in continental air defence, they would lose effective control of their northern territory to the American military. It was within this political climate that Canada agreed to participate in the construction of various early warning systems, and that the RCAF received the lion's share of defence spending. The pressure for Canada to assume a stronger role in continental air defence also favoured efforts of A.V. Roe's and the RCAF to design the now legendary CF-105, all-weather fighter and interceptor. Though early warning radar and a new generation of fighter planes were essential factors in countering long-range Soviet bomber attacks, sound air defence also needed a sophisticated real-time, tactical, aerial information system to track enemy bombers, analyse their flight paths, suggest probable targets, and coordinate counter measures. In the United States, the Air Force was working on a computerized information system called the Semi-Automated Ground Environment, or SAGE system.

The RCN wanted the RCAF to adopt DATAR technology for its air defence system. In the event that the United States Navy did not buy into the DATAR development, then the burden of the high development and procurement costs could be shared with the RCAF. When the RCAF proposed to develop its own automated data-processing, transmission and display system, the RCN objected.[88] Despite inter-Service differences in tactical information requirements, the RCN felt there was sufficient overlap to warrant close collaboration along the framework of DATAR. To coax the RCAF closer to DATAR, the RCN offered it the equipment used in the 1953 demonstration. To what extent the RCAF was willing to cooperate with the RCN is unclear. In 1954, the RCAF did contract Ferranti-Canada to do a preliminary study on how high-

[88] William Ford, Secretary (RCN Research Control Committee), Memorandum to the Secretary, Committee on Development, Defence Research Board: Naval comments on Army and RCAF 1955-56 R&D Estimates, 1 October 1954, DND, Accession 83-84/167, box 139, file NSS-1279-33, pt. 2. The RCN argued that the RCAF intended program would be a wasteful duplication of R&D already successfully completed by the Navy.

speed digital data-processing techniques could be applied to Canadian air defence.[89] Ferranti-Canada's study proposed a decentralized system and stressed the importance of rapid automatic dissemination of all data rather than the automation of the control and guidance systems. Though called the Canadian Air Defence Automatic Reporting (CADAR) system, Ferranti-Canada had actually offered up a version of DATAR. But USAF plans to press ahead with the full-scale production of its own system forced the RCAF to contemplate purchasing American equipment.[90] In the end, trans-national standardization with the USAF proved more of an imperative than national harmonization of R&D with the RCN.

An awareness of USN interest also explains the expansion of the initial 1951 specifications of DATAR into a generic naval tactical information system. How else can one explain the jump from 128 aircraft tracking capacity to 500? Although the integration of air defence and anti-submarine tactical information seemed reasonable for a convoy escort navy, the need to track 500 aircraft made no sense, unless of course, one envisioned DATAR for an American aircraft carrier fleet.

The early success of the DATAR project permitted Canada to play an important role in defining trans-alliance standardization. The RCN managed to convince the U.S.N that binary, rather than decimal, was the best format for naval data exchange systems.[91] Canada's insistence on error detection in the data communication process, as well as the use of the UHF bandwidth for greater throughput, was slowly being accepted by its allies.[92] Canada's espousal of an open, decentralized, network architecture also appealed to the USN. The British approach, which was now known as the Comprehensive Display System (CDS), called for a centralized architecture in

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[89] See item 1.1.4 in Electronics Branch, Department of Defence Production, Activity Report for the Month of June, 1955, DDP, vol. 329, file 152-16-2, pt. 18.

[90] The U.S. system was based on the Badge prototype developed at the Bedford Laboratory, Cambridge Research Centre, Massachusetts. If Canada could not design its own system, the Department of Defence Production pushed to have Badge prototyped and manufactured in Canada. But the U.S. pushed ahead with its own production engineering program. See page 7, Electronics Branch, Department of Defence Production, Monthly Report, December 1955, DDP, vol. 329, file 152-16-2, pt. 20.

[91] W. H. Roger, Memorandum to the Director of Scientific Services: Brief on DATAR, 12 January 1955, DND, Accession 83-84/167, box 139, file NSS-1279-33, pt. 2.

[92] RCN Proposal For International Automatic Radio Message, 7 February 1955, DND, Accession 83-84/167, box 3108, file NSS-7401-382-6. The framework for the standardization of the data communication protocol was the CAN-UK-US Naval Data Transmission Working Group. The philosophy behind Canada's approach to communication protocol was shaped by the role the computer played in DATAR. The meanings conveyed by various groups of digits depended on values found elsewhere in the data stream. This technique resembles the idea of index registers in computer programming.

which all the processing was done on one ship and the required tactical information then broadcast to each ship. In DATAR, although each ship contributed to common pool of tactical data, information extraction was a local process determined by each ship's own computational capacity and needs. While the British approach reinforced the military tradition of hierarchical and centralized systems, the Canadian approach highlighted the advantages of a fluid, flat, and less vulnerable organizational structure.[93] By empowering each ship, the DATAR philosophy maximized the survival of the entire system. If any one ship was destroyed, the ability of other ships to share and extract information would not be jeopardized, as would be the case in the centralized British system. When the United States had finally committed itself to the Canadian position that air defence and anti-submarine concerns form one integrated information system, the RCN knew it had finally triumphed over the RN. Members of the RCN's Research Control Committee were no doubt pleased with the news that "the USN's wanted to adopt a modified version of DATAR for the next phase of its own development program" because it was convinced that the Canadian approach was the right solution for the modern warfare of the next decade (1960s).[94]

The RCN's victory, however, proved an empty one. The slow pace of DATAR's development not only jeopardized any possible export sales, but it also made the project more vulnerable to the flagging Canadian political will to pay for costly defence R&D programs. Nearly eighteen months passed between the successful demonstration of the experimental version of DATAR and the contracts being approved to start the design, development and manufacture of the large-scale prototype. [95] The RCN had divided the DATAR prototype program into two contracts: data processing and display, and the radio data link subsystem. When the specifications for the full scale version of DATAR had finally been set in November of 1954, the plan was to have the prototype ready in two years. Over a year had come and gone and the basic

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[93] Canada's and Britain's very different technological choices in the area of naval tactical systems raises an important question. Did these two technical trajectories reflect important differences in the "cultures" of the RCN and the RN? Britain focussed on battleship groups. The lack of capital ships, however, benefited Canada and spurred innovation.

[94] Minutes of the Research Control Committee, 4 May 1955, DND, Accession 83-84/167, box 139, file NSS-1279-33, pt. 2.

[95] The Research Control Committee had approved $1.95 million for this work; $910,000 to cover the data processing, communication, and display electronics; $1 million to cover the radar, sonar, navigational equipment, the installation, and testing. Royal Canadian Navy Research and Development Estimates, 1955-56, 28 September 1954, DND, 83-84/167, Box 139, File NSS-1279-33, pt. 2. At 24 percent of total estimated expenditures, DATAR represented the single largest item in the RCN's R&D program for 1955-56.

components of the system had not even been designed, never mind built and tested. A small part of the blame no doubt rests with bureaucratic inertia.[96] However, DATAR project's slow pace owed more to fundamental technical limitations than to bureaucracy lethargy.

As with the UTEC story, issues of design complexity turned the vacuum tube into a critical "reverse salient." The sheer size and power requirements of large-scale circuits made it increasingly more difficult to fit vacuum tube-based electronic equipment onto ships and airplanes.[97] Even more serious was the growing problem of reliability. As the number of tubes in military electronics grew into the thousands the mean time between failure (MTBF) became unacceptably short.[98] The Ferranti-Canada team had experienced first hand the urgency to miniaturize large-scale electronic digital systems and still improve reliability. About 15,000 thousand vacuum tubes comprised the DATAR system tested on Lake Ontario. Whenever DATAR was being demonstrated, it was not unusual to find Ferranti-Canada's young engineers, stripped down to the waist because of the heat and armed with cartridge belts of vacuum tubes, racing within the ship's interior locating and replacing faulty tubes.[99]

Even though the full scale version of DATAR was to have proportionately fewer tubes, the questions of reliability, space, and power consumption haunted the Electrical Engineer-in-Chief's Directorate. Throughout most of the 1950s, a considerable amount of money and effort was being directed to "ruggedizing" or miniaturizing the vacuum tube across the alliance. The RCN had even looked into dramatic redesigns of tubes, such as Josef Kate's "binary adder tubes," as a way of miniaturizing and improving reliability by minimizing complexity. But efforts to

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[96] About 4 months were needed to push the contract request through DND to the Department of Defence Production and then to Treasury Board for approval. Ferranti-Canada, wich was to do the first contract for $750,000, started around April 1955. It took a year to select the company to do the second contract Tenders went out in June of 1955. Five companies were chosen to compete for the "Automatic Radio Data Link": RCA Victor Co. Ltd. , in Montreal, Canadian General Electric, Canadian General Westinghouse Co. Ltd., General Electric Co. Ltd., and Northern Electric. S. I. Comach (Contracts Administrator, Electronics Branch, Department of Defence Production), Letter to Deputy Minister of National Defence, 18 August 1955, DND, 83-84/167, box 3168, file NSS-7404-20698. RCA Victor was finally chosen in December 1955.

[97] For example, the electronics in a destroyer contained some 3,000 tubes while the navigational equipment in a large bomber used 2,500. See C. I. Soucy, "A Survey of Electronics Equipment Failures Caused by Failures of Replacement Parts and Tubes and Improper Operation and Maintenance," 5 March 1954, internal Royal Canadian Air Force report, DND, vol. 4185, file 260-640-43.

[98] In a survey of 1050 USN fleet and shore station installations, it was found that one-third of the equipment was not operating properly, due to breakdowns. The U.S. airborne AN/APQ-24 radar bombing and navigation systems experienced, on the average, one failure per 21.5 hour interval. Soucy, "A Survey of Electronic Equipment Failures."

[99] This is based on anecdotal evidence from many of the engineers who worked on DATAR. Despite plans to use magnetic cores for the computer's random access memory, the vacuum tube remained the dominant device in DATAR's digital circuitry.

squeeze more tubes into smaller spaces only exacerbated the reliability problem. One senior RCAF officer had already warned in 1954 that "the rapid rise in the failure rate of electronic equipment coincident with the increasing complexity and miniaturization of that equipment is a cause for alarm ....The perfection of components would reduce failures in a ratio of only two to one whereas reduction in a ratio of fifty to one is required for acceptable reliability."[100] Unless the vacuum tube problem was addressed "the reliability problem [would] reach crippling proportions."[101]

The solution to the complexity problem resided in finding radically new electronic switching devices, and not in incremental improvements to existing components. It was during this crisis of the vacuum tube that the military looked to the transistor as a potential replacement for the vacuum tube. Still early in its development, the transistor was itself plagued with serious performance and quality control problems.[102] Its relatively slow switching speeds also limited the transistor's utility for data processing and communications technologies. Furthermore, the absence of tightly controlled transistor characteristics made it difficult to design high performance digital circuits. Despite these problems, the transistor's potential for far greater miniaturization offered the only hope of getting through the complexity impasse. The RCN was convinced that unless DATAR could be transistorized, it would never go into service.

Philco's 1954 surface barrier innovation seemed to offer the RCN the answer to DATAR's miniaturization imperative. The SB-100 transistor offered reliable, high-speed switching. Over the next few years, Philco used its SB-100 transistor as the basis of the world's first all solid state computer. As soon as news of the SB-100 became public, the RCN arranged for a team of Ferranti-Canada engineers to visit the Philco plant in Philadelphia with the mandate to explore the utility of the SB-100 transistor for DATAR.[103]

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[100] Wing Commander K. P. Likeness, Memorandum to the Chief of the Air Staff, 26 May 1954, 1, DND,, vol. 4185, file 260-640-43.

[101] *Ibid.*, 2. To dramatize his point, Likeness points out that by "statistical deduction," one can conclude that "the electronic equipment in fewer than four out of ten typical modern bombers will remain fully serviceable throughout a four hour mission."

[102] The issue of transistor performance and manufacturing is discussed in greater detail in the next chapter.

[103] Naval Secretary, Letter to K. G. Thorne (Ferranti Electric Limited), 19 April 1955, DND, 83-84/167, box 3168, file NSS-7404-20698. In their corporate study of Ferranti-Canada, Ball and Vardalas portrayed the company as the driving force behind the pursuit of the SB-100. But only after a closer look at naval records does it become clear that it was military enterprise, and not private enterprise, that brought the transistor into DATAR. However, it is important to underscore the fact that as a technology-driven group, Ferranti-Canada's digital electronic group

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Ferranti-Canada immediately began experimenting with the transistors and figuring out how to recast DATAR's circuitry into solid-state. While this course of action seemed straightforward, its execution proved difficult and slow. The young Ferranti-Canada design team had shown remarkable ingenuity in devising circuit techniques to minimize the number of tubes DATAR needed and to improve reliability. In the process they came to understand the subtleties of the vacuum tube's performance and how to use them to their advantage. Switching to transistors meant the abandonment of all this tube expertise and the re-invention of its digital circuit design know-how. Because transistors represented a paradigm shift in electronic design, miniaturizing DATAR went far beyond the mere replacement of tubes with transistors in the circuit diagrams. New principles were needed to exploit the strengths of transistors while minimizing their weaknesses.[104] Because no one in Canada (in university, government, or industry) had mastered digital, solid-state, circuit design, Ferranti-Canada literally had to create the learning curve it was going to climb up.

Time had now become the DATAR project's biggest enemy. For nearly seven years, Canada had held an unquestioned lead in the formulation and technical pursuit of automated naval tactical information systems. But by 1956, a shift in the Canadian political will to finance military self-reliance and the sudden awakening of the American Navy to the "urgency" of automated tactical information systems were about to ravage this lead. These two factors combined to bring about the collapse of the RCN's DATAR project.

Canada's small economy could support only modest levels of military procurement. In such a limited internal market for military equipment, a balance had to be struck between spending to nurture strategic indigenous design and manufacturing capacity, and importing less costly off-the-shelf foreign weapons systems. The Korean War encouraged much higher defence spending than otherwise would have been the case. In the process, the balance tilted more towards military and technological self-reliance. With the end of the Korean War, the political will to maintain high levels of defence spending weakened. Thereafter, every military expenditure was put under the microscope to reduce any duplication of Canada's development

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embraced the idea immediately. The RCN asked Ferranti-Canada to buy several hundred of these transistors for experimental purposes and charge them to the contract. With transistors selling for over $10 a piece, in 1955 prices, buying three hundred transistors represented more than just idle speculative experimentation.

[104] This theme is taken up again with greater detail in the next chapter.

programs with those of its allies.

In June 1955, Minister of Defence R. O. Campney announced Canada's plan to modernize the Canadian Navy's aging escort fleet with fourteen modern destroyer escorts.[105] At $23 million apiece, these escorts were to be, according to the Minister, the most formidable "submarine killers" in the world. With the cost of each ship's armaments and electronics at $6 million, DATAR was, no doubt, a key technological component in the RCN's proposed state-of-the-art escort fleet. This proposed expenditure of $322 million for ships in the post-Korean era was challenged by the Conservative opposition: "Canada is not a country," argued one Conservative member of the House Defence Committee, "that can afford much higher defence costs."[106] Careful not to appear to compromise national security, the Conservatives did not attack defence spending per se, but rather wasteful *overspending*. Whether the Canadian economy was capable of supporting the high pre-1954 levels of defence spending is a question that requires further study, but in 1956, St. Laurent's government concluded that "it would soon be impossible to maintain the existing defence establishment within the present budgetary limits unless strict economies were made and a list of priorities established and adhered to."[107] The Government was increasingly unwilling to bear the high costs of large, independent development programs, particularly in electronics, missiles and aircraft. The Government ordered DND to cut costs and reduce duplication, particularly in the development of new equipment.

Since 1950, the Treasury Board had usually rubber stamped RCN's development spending requests. But it approved only half of the RCN's $21.3 million R&D budget for 1956-57.[108] Though the refusal targeted the RCN's costly missile and anti-submarine helicopter programs, it nevertheless forced the RCN to rethink the funding of DATAR. The RCN had long justified the costs of the DATAR program on the grounds that neither the United States nor the United Kingdom had any comparable system to respond to Canada's unique anti-submarine role

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[105] Canada, House of Commons, *Debates*, Second Session-Twenty Second Parliament 1955 (Ottawa: The Queen's Printer, 1955), 4862.

[106] Wallace Nesbitt, Conservative member from Oxford. *Ibid.*, 4903.

[107] Summary of Remarks Made by Minister of National Defence, R. O. Campney, to Cabinet Defence Committee, 6 February 1957, OPC, vol. 2749, file Cabinet Defence Committee Conclusions, pt. XII.

[108] D. P. Hoyt (Acting Director of Scientific Services), Memorandum to Vice and Acting Chiefs of the Naval Staff: Naval Development Programme, 1956-57, 27 April 1956, DND, Accession 83-84/167 box 139, file NSS-1279-33 pt. 2. Treasury Board of Canada told the RCN that if it wanted any approval for any other additional R&D expenditures, then it would have to go through the Cabinet. Treasury Board Minutes TB-499572, Records of the Treasury Board, RG 55, National Archives of Canada.

within the alliance. But recent USN decisions had put this argument on very slippery footing.

Until 1955, the American Navy had done relatively very little work of its own on developing an automated, tactical, information system. That year the USN concluded that this technology was of paramount importance to its future effectiveness. Driven by a sense of urgency, the USN reached down into the deep pockets of American military spending and committed $10 million to a two year crash program to build its own supercharged version of DATAR, to be called the Naval Tactical Data System (NTDS).[109] The Chief of the American Naval Operations saw NTDS "as absolutely essential for the survival of a task force in the post-1960 era." American naval officials took the attitude that "in the future, if a ship did not have NTDS, then it should not leave the port."[110]

Having the benefit of the RCN's seven years of pioneering work and backed with considerable financial and industrial R&D resources, there was little doubt that the USN's proposed NTDS would triumph over DATAR. While the RCN had allocated $750,00 to Ferranti-Canada to design and build a transistorized, information-processing and display system, the USN gave Remington Rand, whose UNIVAC division was a recognized world leader in computer technology, $4 million, and Hughes Aircraft, $3 million, to undertake essentially the same challenge.[111] Given the scope and magnitude of NTDS, the advocates of DATAR knew that their program was extremely vulnerable to the cost-cutting imperative to eliminate duplication. If NTDS subsumed, or at least was congruent to DATAR, then why throw away any more money on a large-scale prototype when the Americans were already working on one? The only strategy open to the Electrical Engineer-in-Chief's Directorate was to try to weave DATAR into the NTDS project in a complementary manner.

From the outset, NTDS was designed to serve the needs of a large, carrier-based task force. Protecting destroyers, large battle cruisers, and aircraft carriers from enemy fighter planes was the prime function of NTDS. In designing NTDS, the USN had little interest in anti-submarine duty. Accepting NTDS as a *fait accompli*, the RCN argued that the USN system, as it

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[109] F. H. Sanders (RCN DATAR Sub-Committee), Report of the Sub-Committee Deputed to Prepare Recommendations to the Research Control Committee on DATAR, 26 October 1956, DND, Accession 83-84/167 box 139, file NSS-1279-33 pt. 4. This extensive report contains considerable information, given by the USN, on the estimated costs, schedules, contracts, and design specifications of its Naval Tactical Data System (NTDS).

[110] Sanders, Report of the Sub-Committee, 26 October 1956.

[111] For a fascinating look at UNIVAC's engineering role in the design and construction of NTDS see David Lundstrom, *A few Good Men from Univac* (Cambridge Mass.: The MIT Press, 1987).

was being developed, was not appropriate to Canada's anti-submarine mandate. The DATAR Sub-Committee recommended that the RCN use its expertise to embark on a development program to adapt NTDS to the needs of an anti-submarine navy.[112]

With the Cabinet Defence Committee pushing harder for more cost-saving co-operative ventures, the RCN tried to keep DATAR alive by proposing a joint Canadian-American. collaborative effort to design an anti-submarine version of NTDS. Offering Canada complete access to all the technical information on NTDS as it developed, the USN encouraged the RCN to continue on DATAR.[113] But with all its resources devoted to NTDS, the USN had little money to spare for the RCN proposal

Faced with spending restrictions and little political support for an independent program, the steam ran out of DATAR. The Government's decision in 1956 to retreat from its earlier commitment to build the fourteen destroyer escorts also contributed to the collapse of DATAR. These destroyer escorts were to be the state-of-the-art in anti-submarine warfare. Not only was the design of the destroyer itself a dramatic improvement in speed and manoeuvrability, but these ships were to be equipped with the most advanced sonar, radar, weapons, and fire-control. Individually, and collectively, the proposed anti-submarine destroyer escorts were truly a large complex technological system. DATAR was supposed to be the electronic nervous system and brain that made all the parts of the system work together harmoniously. With the collapse of the program to build a new fleet of advanced destroyer escorts, enthusiasm for any further costly work on an automated electronic naval battle system also waned. Canada did propose a three year, $450,000 study to come up with suggestions for a Tactical Data System based on whatever NTDS developed. After seven years of daring pioneering work in real-time, digital, information processing, communication and display, DATAR was abandoned. Unlike the AVRO Arrow which went out with a bang, DATAR died with not even a whimper, and along with it went the RCN's flirtation with military self-reliance.

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[112] Sanders, Report of the Sub-Committee, 26 October 1956.

[113] Minutes of the Research Control Committee, 20 December 1956, 3, DND, Accession 83-84/167 box 139, file NSS-1279-33 pt. 4.

Epilogue

The DATAR story calls for a re-examination of the historiography of the role of the Royal Canadian Navy in the immediate postwar years. Canadian historian Marc Milner has written extensively on the RCN's role during in the Battle of the North Atlantic.[114] Like others before him who have studied the subject, Milner portrays how the RCN stumbled into this critical wartime role. At the start of World War II, the RCN's officer corps dreamed of leading a fleet of aircraft carriers, destroyers, and battle cruisers into battle. The RCN looked down its nose at the idea of protecting convoys and hunting submarines. Canada's professional navy felt that this lacklustre job was better left to reservists. Where was the glory, they asked, in serving on small cramped corvettes that bobbed like corks in the water, and having to escort motley collection of freighters? Where were the career opportunities in serving on corvettes? While the RCN's officer corps trained for a fleet they would never have, reservists with little sea experience went to sea to guard the convoys. As the war against Germany's submarines became recognized in Ottawa as one of the most important theatres of war, Canada's professional navy was forced to take a greater interest in anti-submarine warfare (ASW). But to the end of the war, Canada's anti-submarine (A/S) contingency remained a navy apart.[115]

With the end of the war, Milner concludes in his latest book, the RCN reverted to the pre-war mentality of how a professional navy should look. "The post war RCN," writes Milner, "saw little of itself in the A/S and escort war in the Atlantic."[116] According to Milner, the RCN's professional navy, rejecting any postwar A/S role, continued to harbour ambitions of building a conventional naval fleet. Milner argues that ASW had never been part of the RCN's long-term plans during or after the war. Milner adds that the navy's postwar rejection of ASW was reinforced by a desire to distance itself from a wartime role that it considered an embarrassment.

The DATAR experience, however, contradicts Milner's conclusions on the RCN's

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[114] See Marc Milner, "Royal Canadian Navy Participation in the Battle of the Atlantic Crisis of 1943," in Boutilier, *RCN in Retrospect*, 159-174; Milner, *North Atlantic Run*; Marc Milner, "The RCN and the Offensive against the U-Boats, 1943-45," unpublished narrative, History Directorate, National Defence Headquarters, June 1986; Marc Milner, "Inshore ASW: The Canadian Experience in Home Waters," in *The RCN in Transition*, ed. W. A. B. Douglas (Vancouver: The University of British Columbia Press, 1988); Marc Milner, "The Dawn of Modern ASW: Allied Responses to the U-Boat 1943-45," *RUSI Journal* 134 (Spring 1989): 61-8; and Milner, *The U-Boat Hunters*.

[115] The fact that by the end of the war, of the 104 qualified A/S officers in the fleet, 99 were reservists underscores this cleavage. Milner, *The U-Boat Hunters*, 257.

[116] *Ibid.*, 58.

postwar ambitions. As this chapter has shown, ASW was the axis around which the RCN's entire pursuit of self-reliance revolved. ASW dominated the RCN's post war R&D strategy. Milner's conclusions were extrapolations of the Navy's attitudes and actions up to the closing days of the war. Because of the problems encountered in trying to mobilize a scientific and technological base to support its wartime weapons development program, where none existed before, the RCN realized in the last days of World War II that future peacetime military preparedness would demand the creation and maintenance of a military-scientific-industrial system complex. On this matter David Zimmerman observes that the navy's politically naïve ambitions to build a large, well-balanced naval fleet and maintain a moderate but respectable R&D program ran up against Prime Minister King's desire to dismantle the military. "Much of the accumulated wartime scientific and technical expertise," contends Zimmerman, "was lost as result of [King's] cutbacks and the return of most personnel to civilian life."[117] Zimmerman goes on to suggest that small R&D pockets remained. While Zimmerman points to bathythermographic and acoustical research for asdic development, from this thesis one can see that another more ambitious pocket emerged in the Electrical-Engineer-in-Chief's Directorate in Ottawa. With the King government's refusal to pay for the construction of a full-scale naval task force of aircraft carriers, battleships, cruisers, and destroyers, the Naval Staff faced the dilemma of how it could define a self-reliant role for the RCN within the postwar North Atlantic Triangle.

The potential of DATAR sparked senior officers to reappraise the value of ASW to the RCN's postwar naval ambitions. The advances in submarine technology in the immediate postwar years called for radical innovation in ASW. The DATAR concept offered a dramatic technological leap in ASW. The idea of DATAR did not arise from the senior levels of the RCN. Rather it was driven by the mid-level technical officer corps of the Electrical Engineer-in-Chief Directorate. Once the feasibility of digital tactical information exchange and processing became apparent by the end of 1949, DATAR started to win acceptance at higher levels because it represented a technological redefinition of ASW that promised to catapult Canada to the forefront of modern naval warfare.

The RCN's extensive R&D program in DATAR, the digital electronic A/S Tactical Trainer, the hydrofoil, missile development, the program to build the world's most advanced frigates all demonstrate that the RCN's drive for power and self-respect now ran through the anti-

[117] Zimmerman, *The Great Naval Battle of Ottawa*, 162.

submarine escort. A technologically advanced ASW fleet designed and built by Canadian know-how held out the prospect of a unique and important niche within the western alliance. Ironically, at the same time power in the American Navy was coming to reside in Hyman Rickover's program to introduce nuclear technology into the lowly submarine.

The failure to sell the Americans and British on DATAR underscores some of the contradictions the Canadian military faced in trying to advance Canada's technological and industrial capacity, even in specialized areas. This advancement hinged critically on the level of procurement that the Department of National Defence could guarantee. But the costs associated with the design, prototype development, production engineering, and deployment of very advanced large-scale defence systems were more than Canadian procurement alone could support. With Canada's relatively small peacetime Armed Forces, foreign sales were essential to underwrite any military flirtation with technological and industrial self-reliance. Commodore Lay knew that any efforts by Canada to fit the RCN with DATAR "would be largely nullified if the ships of other nations [its allies] were not so fitted also."[118]

The need to obtain Canadian industry access to the military markets of its allies was one of the driving forces behind Canada's push for transnational standardization -- first among its British and American allies, and later within NATO. Canada's pursuit of component standardization, and interchangeability across the entire alliance was a reasonable response for a small nation on the frontier of two empires: Great Britain and the United States. The standardization of screw threads, for example, was a remarkable Canadian-led initiative to ensure, among other things, that Canada's manufacturers could supply both the British and American military forces, without the wasteful duplication of machine tool setups.[119] Though the

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[118] Minutes of PJBD Meeting, September 1953. When Lt.-Gen. Foulkes had submitted the military's position on postwar technological and industrial development to the Minister of National Defence in 1947, a copy was also sent to Arnold Heeney for further review. As Clerk to the Privy Council, Heeney was well placed to comment on how Foulkes's plan did, or did not, correspond to Cabinet's immediate preoccupations. Heeney reminded Foulkes that any long term planning the needs of Canada's allies were probably more important that Canada's military needs. "Our wartime industrial pattern," observed Heeney, "[was] set, not by the needs of the Canadian Navy, Army and Air Force, but by the wartime industrial demands of our major allies." See Arnold Heeney, Memorandum for Chief of the General Staff, 26 February 1947, DND, vol. 19,172, file 2130-30/3.

[119] The drive to universalize screw threads presents a striking example of how Merritt Roes Smith's discussion of military enterprise can work within international alliances. Smith, has written quite extensively on how the military penchant for standardization and uniformity played a profound role in shaping early American industrialization. The American military's pursuit, in the early 19th century, to make standardized and interchangeable parts central to ordnance design and production was instrumental in the rise of the American System of Manufacture. See Smith,

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axis of Canada's economy had, by the end of World War II, dramatically shifted from an east-west, transatlantic orientation to a north-south, continental direction, Canada's military still had strong roots in British military practice and traditions. Consequently, in the early years following the war, the Canadian military still believed that Britain would, in any future war, remain an important destination for Canadian goods.

Standardization may have advanced the cause of Canadian mass-production manufacturers, but it did little to promote the sale of advanced large-scale military systems such as DATAR. For example, any early interest the Canadian Army may have had in DATAR-like technology was tempered by the realities of tripartite standardization. Of the three Services, the Army was the most committed to international standardization. Consequently, the Army was reluctant to undertake any R&D in this area until the details of Signals equipment standardization had been worked with the United States and United Kingdom.[120] Similarly the Royal Canadian Air Force backed away from CADAR and standardized around the SAGE system because the R&D and production costs of the former could never be covered by Canadian procurement only. Though the Air Force never gambled on CADAR, it did wager a lot on the AVRO Arrow intercept fighter. Canada's allies unwillingness to standardize around this large-scale, sophisticated, Canadian weapons system made the AVRO Arrow economically unfeasible. The Not Invented Here (NIH) syndrome that served to block the acceptance of systems like DATAR and the AVRO Arrow among Canada's allies was a reflection of more than mere national pride. It was also a manifestation of the relationship between global military and economic power. Both engendered an international struggle to control and appropriate the science and technology sustaining the long-term global expansionary period, which marked the postwar period until about 1970.

DATAR is as much a story of Ferranti-Canada's emergence as Canada's leading computer R&D group as it is about the RCN's quest to mould military self-reliance through technology. In 1948, the prospect of DATAR attracted the technologically-driven Ferranti U.K.

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Harper's Ferry. For a comprehensive discussion of the historical process leading from early 19th century armoury practice to Ford's mass-production see Hounshell, *From the American System to Mass Production*. For a valuable synthesis of the main themes in the American literature on the historic role of military enterprise in peacetime industrial development see Smith, *Military Enterprise and Technological Change*.

[120] Arthur Porter was told of the Army's "soft-pedalling...on their development until the question of standardization of equipment between U.S., U.K. and Canada has been resolved," at a meeting with Army Technical Staff officers in Ottawa. See Porter, Preliminary Report, 15 October 1949.

to establish an electronics R&D group in its Canadian subsidiary. This group was not to be any stereotypical "branch plant" affair with all the important research and development work carried out at the parent firm. Instead the parent firm left the technical, administrative, and financial modalities of this enterprise to its Canadian subsidiary. The Ferranti corporate structure resembled a collection of independent trading houses. Ferranti-Canada did not fall within some international, multi-divisional, hierarchical management structure. As a result, the Canadian subsidiary was given considerable autonomy.

In the end, Ferranti-Canada's forged the expertise to build DATAR on its own. Both Kenyon Taylor, the hands-on inventor, and Dr. Arthur Porter, the theoretically based engineer, aggressively sought out young Canadian scientific and engineering talent. At the time DATAR was demonstrated, the professional staff for this project had swelled to seventeen members; many of the engineers had masters degrees and there were three physicists with doctorates.[121] By 1955, Ferranti-Canada's electronics group had grown to thirty engineers and scientists.[122] DATAR thus allowed Ferranti-Canada to grow into Canada's leading industrial research and development centre in digital electronic information technology in the 1950s and 1960s. Military funding also fostered a technology-driven ethos within Ferranti-Canada's Research Department, an ethos which was reinforced by the parent firm's own corporate culture.

With collapse of DATAR Ferranti-Canada had to either pursue civilian markets seriously or dismantle the computer group. For the company to enter the computer business and survive, more than technical excellence would be required. Important questions had to be answered. How would the small Canadian subsidiary capitalize such an undertaking? What strategy would Ferranti-Canada adopt in order to compete in a North American market dominated by IBM, UNIVAC, and the Control Data Corporation? What would the markets be and how would the company address market needs? How would the subsidiary's aspirations to build and sell computers be reconciled with the parent firm's own ambitions? Would they be complementary or conflicting? Becoming a computer manufacturer also raised important internal management issues. How would the company's upper management, which was completely absorbed in

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[121] The number of professional staff on DATAR was ascertained from a prospectus that Ferranti Electric's Research Division put out in 1956. At the back there are short biographical sketches of all the professional staff. Document is in the author's collection.

[122] Electronics Branch, Department of Defence Production, Preliminary Statement of Engineering Facilities at Selected Plants in the Electronics and Telecommunications Industry, 7 March 1955, DDP, vol. 298, file 152-4-3, pt. 1.

surviving in the North American electrical capital goods sector, respond to the corporate needs of its small digital electronics group? Shaped by the exigencies of the electric power industry, could Ferranti-Canada's technological and management culture successfully embrace the engineering and business ambitions of the electronics group? During the DATAR project, the digital electronics group had worked in isolation and few demands had been placed on the company's management. But the collapse of military funding and the subsequent need to find commercial outlets for the company's digital electronic expertise brought the electronics groups under closer scrutiny from the electrical power group.

The subsequent story of how Ferranti-Canada became Canada's first commercial computer designer and manufacturer in the ten years following DATAR is taken up in Chapters 5 and 6. This part of the thesis's narrative underscores the importance of civilian public enterprise in the business and technical development of Ferranti-Canada's computer group. But before shifting the focus of Canada's quest for digital self-reliance from the military to the civilian sector, there remains a crucial facet of the military's quest that must be told. At the centre of this additional facet, and the next chapter, was the strategic importance of the transistor in breaking through the complexity/reliability problem that had hitherto undermined digital electronic design in both military and commercial systems.

Ferranti-Canada's difficulties in miniaturizing DATAR was indicative of how little the transistor had diffused into Canadian industrial engineering circles. The military understood all too well that a nation's capacity to design complex digital electronic had become inextricably linked to the capacity to miniaturize. The next chapter investigates the extent of the Canadian military enterprise's role in promoting a national core of transistor electronic know-how. But unlike these past two chapters, which saw the military turn to university and industry for R&D, Chapter 4 focuses on the role of government laboratories in advancing Canadian technological self-reliance and in moving the nation up the digital electronics learning curve.

Chapter 4

Complexity and the Military Imperative to Miniaturize

Introduction

The histories of digital electronics, computers, and transistor technology are inextricably bound to each other.[1] Each important advance in semiconductor devices has engendered a dramatic change in computer technology, which in turn has spurred further innovation in transistor technology. At the heart of this dynamic is the remarkable on-going miniaturization of the transistor, which has led to a three decade long exponential decrease in the cost per bit of electronic memory. During the 1970s, this very close coupling led to the invention of the microprocessor and the birth of the microelectronic revolution.[2] The subsequent ubiquitous diffusion of the microprocessor during the late 1980s and into 1990s turned electronic digital computation into a mass consumer phenomenon with far reaching societal implications.

The powerful civilian commercial dynamism that has characterised the mutually contingent growths of the computer and semiconductor industries conceals the crucial role that the military played in nurturing this interrelationship, particularly in the early stages when there was little civilian marketplace incentive to do so. As Ernst Braun and Stuart Macdonald have shown, the early development of the transistor was not propelled forward simply by obvious

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[1] This inseparability is reflected in the common periodization that technical, economic and social histories of the computer use. The introduction of discrete transistor components gave birth to the second generation of computers. The introduction of integrated circuits led to the third generation. The micro-miniaturization of transistors, such as Large-Scale Integrations (LSI) and Very Large Scale Integration (VLSI), led to the rise of the personal computer and a decentralized, networked, paradigm of computation. For example see Gerald Brock, *The U.S. Computer Industry: A Study of Market Power* (Cambridge, Mass.:Ballinger Publishing Company, 1975); John T. Soma, *The Computer Industry: An Economic-Legal Analysis of its Technology and Growth* (Lexington, Mass.: Lexington Books, 1976).

[2] Robert Noyce, one of the co-founders of the Intel corporation and co-inventor of the integrated circuit, presents a wonderful discussion of the demand-pull from the computer industry that drove the semiconductor industry and the supply-push from the semiconductor industry that simultaneously propelled the computer industry forward. "Microelectronics," *Scientific American* 237 (September 1977): 64-81.

commercially-driven opportunities or some internal, pre-ordained autonomous technical logic.[3] Rather, it was the interplay of technical, corporate, economic, and social factors that moved the transistor from being a curious invention to that of being the substrate of modern industrial development. In pointing to the military as the dominant force in this interplay, Braun and MacDonald reinforce Richard Levin's earlier comprehensive synthesis of the development of the American semiconductor industry. The American military services, according to Levin, were willing to support research and development (R&D), to subsidize engineering effort required to install production capacity, and to pay premium prices for procurement of new devices when the civilian market was incapable of doing so.[4] Similarly, Alfonso Molina reminds us that

> *the technologies and the industries behind today's microrevolution were shaped by the interests of a social constituency most heavily influenced by the military....A broad range of advances in electronic systems, between 1952 and 1966, originated from an equally broad range of military projects....The influence of the government-military constituents was wide-ranging, affecting all areas of electronics. Nowhere was this influence more decisive than on the development of the emerging technologies and industries of computers, industrial control, and above all, semiconductors, the technical base for the convergence of electronic systems.*[5]

Given the historical inseparability of computer and transistor technologies in shaping the postwar global innovation wave, any account of Canada's efforts to foster digital electronic self-reliance would be incomplete if it did not also weave in the military's efforts to promote a corresponding national capacity in transistors. In the preceding chapter, the reader discovered how the Royal Canadian Navy had tried to initiate this synergy by financially supporting Ferranti-Canada's efforts to miniaturize DATAR's design. The central theme of this chapter is the military's use of government laboratories as a source of innovation and as an agent of

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[3] Ernst Braun and Stuart MacDonald, *Revolution in Miniature* (Cambridge: Cambridge University Press, 1982). See also, by the same authors, "The Transistor and Attitude to Change," *American Journal of Physics* 45 (November 1977): 1061-5.

[4] Richard Levin, "The Semiconductor Industry," in *Government and Technical Progress: A Cross-Industry Analysis*, ed. Richard Nelson (New York: Pergamon Press, 1982), 58-9. Thomas Misra's examination of the U.S. Army Signal Corp's efforts to miniaturize field communications equipment offers a fascinating, more fine-grained detail of this process. Thomas Misra, "Military Needs, Commercial Realities, and the Development of the Transistor, 1948-58," in Smith, *Military Enterprise and Technological Change*, 253-288.

[5] Alfonso Molina, *The Social Basis for the Microelectronic Revolution* (Edinburgh: Edinburgh University Press, 1989).

technological diffusion to industry.

In recognizing the early strategic importance of the transistor, Canadian military enterprise faced the dilemma of how much transistor self-reliance it could afford. Was it strategically necessary and financially conceivable to promote a costly domestic transistor manufacturing capacity? Or was it more advantageous to concentrate time and money in nurturing a national core of expertise capable of designing military circuits using the transistor? The military's response to these questions was to have one of its own laboratories, the Defence Research Telecommunications Establishment (DRTE), embark on a five year, $400,000 program to design and build an electronic digital computer, even though the military had already concluded, with its cancellation of UTEC and the purchase of FERUT, that the commercial market offered acceptable access to computational power. Put into service in 1960, the DRTE machine was the first transistorized, general-purpose computer designed and built in Canada. This chapter examines the circumstances that led a government laboratory, with no prior experience in computers, to undertake such a project, and the role played by the DRTE in fostering digital electronics in Canada.

Digital Electronic Complexity and Self-Reliance

Fear that the very proliferation of electronics that was revolutionizing warfare also threatened to compromise effectiveness of weapons systems underlay the military's interest in the transistor. As the scope and diversity of electronic applications grew so did the scale of these systems. And as the number of electronic components in weapons systems grew well into the thousands, the spectre that greater design complexity would seriously undermine system reliability started to haunt the military mind. "I hope we have not created such complex machines," observed a former Assistant Secretary of the American Navy, "that we are in danger of contributing to our own ultimate destruction, for we are becoming so dependent upon automatic electronic brains for the conduct of modern warfare that their failure during combat could very well mean that difference between victory and defeat in an engagement."[6] The fear of

[6] Cited in Arthur Van Dyck, "Aviation Electronics", *Proceedings of the Institute of Radio Engineers* (November 1953): 1578. This paper gives an interesting, but not very developed, discussion of the American military's historical

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falling victim to electronic complexity led one USN officer to allude to the lessons of Mary Shelley's novel. "Like the creator of Frankenstein, we have produced devices which, in the hands of the operating forces, are so unreliable that they could lead to our ultimate destruction."[7]

The reliability issue spanned the entire spectrum of electronic components, such as vacuum tubes, resistors, capacitors, and batteries. However, because of their size, power consumption, and complex internal structure, and more complicated circuit mountings, vacuum tubes became the focus of the reliability debate. One way to try to counter the problem was to manufacture much higher quality vacuum tubes and circuit assemblies. Because such rigorous performance specifications far exceeded anything the commercial civilian market demanded, it was the military that had to finance the development of these more advanced and costly production methods. Project Tinkertoy and the United States Army's secret "Automatic Component Assembly System" thus strove to increase electronic reliability through automation.[8] Just as the American Army had promoted new levels of precision machining in then nineteenth century with its insistence on machine-made, interchangeable parts, military enterprise's obsession with stringent operational standards had again, in the case of electronic equipment, pushed the precision and quality of manufacture to new levels.[9]

The complexity issue pervaded all aspects of military electronic design, but its threat was particularly pernicious to the future growth of digitally-based weapons systems. Unlike analogue electronics, digital circuits invited extremely large-scale structures, which, when coupled to the military's singular preoccupation with greater performance regardless of cost, found expression in the pursuit of very complex circuits.[10] Even as a small experimental prototype, DATAR electronic components numbered in the tens of thousands. With such numbers, even very reliable individual components did not guarantee overall system reliability. The problem arises from the

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relationship to issues of complexity and reliability in weapons systems from World War I.

[7] Van Dyck, "Aviation Electronics," 1572.

[8] Alfred Gray, "Guided Missile Reliability and Electronic Production Techniques," *Institute of Radio Engineers, Convention Record*, Part 8 (1956): 79. From 1950-53, the United States Navy, in collaboration with the United States Bureau of Standards, spent $5 million on the Tinkertoy project. Levin, *The Semiconductor Industry*.

[9] On the role of the U.S. Army in advancing high-precision machining see Smith, *Military Enterprise and Technological Change*.

[10] In digital electronics, a given element is either off or on. Because the amplification or gain of any stage is unity, any number of these elements can be cascaded and the final gain will still be only unity. In analogue circuits, such as radio, the gain across any element is greater than one, typically of the order of ten. Thus if one cascades analogue circuit elements, voltages will quickly climb to unacceptably high levels.

statistics of large numbers. For example, suppose a manufacturer of an electronic component promised a MTBF (Mean Time Between Failure) of 87,660 hours; on average, that component would fail in 10 years' time. If an electronic system employed 10,000 of these components, then the system could on the average, fail every eight to nine hours.

Even if the reliability challenge were met, "packaging" problems posed an equally, if not more, important barrier in the race to deploy more advanced weapon systems. The vacuum tube's large size and high power consumption placed severe limitations on the performance and capacity one could design into digital electronic systems. Only through an aggressive miniaturization program could the military hope to exploit the potential strategic advantages of digital technology. If, as DATAR revealed, the task of deploying large-scale, digital electronic systems in ships was going to be difficult, then for aircraft it looked intimidating, and for missiles, impossible. Despite considerable efforts,[11] the vacuum tube paradigm offered no dramatic gains in miniaturization that could realize the military potential of large-scale digital techniques.

The transistor offered the possibility of dramatic miniaturization that was inherently impossible with the vacuum tube. But there were considerable barriers to the transistor's industrial development. On the demand side, the transistor's high costs -- eight times that of a comparable vacuum tube -- offered little incentive for the civilian electronics market to

[11] The "dynamic circuit" idea, for example, proposed cutting down the number of active vacuum tube elements required in computer circuits by shifting more of the computer's logic functions to passive gating, using much smaller and simpler crystal diodes. Similar proposals were first suggested during the EDVAC project at the Moore School at the University of Pennsylvania. See T. C. Chen, "Diode coincidence and mixing circuits in digital computers," *Proceedings of the Institute of Radio Engineers* 38 (May 1950): 511-514. Presper Eckert and John Mauchly raised the idea again in 1950 as a possibility for their early Univac computer. But it took U.S. government financial support, of which a good portion was from he U.S. Air Force, to build a computer based on "dynamic circuitry" techniques. The idea was to replace the conventional two tube Eccles-Jordan flip-flop with a one tube "dynamic flip-flop." While there was a nearly 50 percent reduction in tube complexity, "dynamic circuitry" posed important limitations on performance. The vacuum tube circuits could not provide the high pulse currents to drive the complex cascades of diode logic. To get around this problem, a new component, called the pulse current transformer, was used. But this device had disadvantages of its own. Limited switching times adversely affected performance. Sidney Greenwald and R. C. Haueter, "SEAC," *Proceedings of the Institute of Radio Engineers* 41 (October 1953): 1300-13; and Robert Elbourn and Richard Witt, "Dynamic Circuit Techniques Used in SEAC and DYSEAC," *Proceedings of the Institute of Radio Engineers* 41 (October 1953): 1380-87. Another approach was to seek radically new types of vacuum tubes for digital circuits. In this regard, Josef Kates's invention of the "binary arithmetic tube" is a striking example. The basic computer circuit needed to add two binary digits required six tubes, and multiplication entailed an even larger number of tubes. The reader will recall from the UTEC story in Chapter 2, that Kates's invention carried out these arithmetic operations within one small tube. The development and production engineering costs of Kates's invention were underwritten by Canada's military. The military also explored ways to develop much smaller ("sub-miniature"), reliable versions of existing tube types. Minutes of the First Meeting of the Electron Tube Development Committee, 18 September 1952, DND, box 4233, file DRBS-3-678-43.

incorporate it into their products.[12] Furthermore, for the civilian electronics market, which was dominated by radio and television manufacturers, there was no technical imperative to justify the high cost of solid-state miniaturization. Since radios and televisions used only a handful of tubes, complexity was a non-issue. On the supply side, very costly development and production engineering programs were needed before reliable and standardized transistors could be manufactured in large numbers. Until demand reached a sufficiently high level, there was little economic rationale for components manufacturers to rush into expensive R&D programs to improve the reliability and performance of transistors. Furthermore, as Braun and MacDonald noted, many electronics manufacturers were naturally reluctant to undermine their existing, sizeable, capital investments in vacuum-tube production by pursuing a semiconductor replacement. And on both the demand and supply sides, there was also a social resistance to any wide-scale diffusion of transistor technology. While the vacuum tube worked according to the laws of classical physics, the transistor was a product of the quantum mechanical revolution. Engineers needed a whole new set of paradigms to deal with the transistor. The tremendous intellectual and experiential investment that electronics engineers had in the vacuum tube paradigm thus became an important source of attitudinal resistance to the transistor.[13]

In a vicious circle, low demand impeded the crucial supply-side innovation required to make the transistor more attractive. No doubt the transistor would have eventually triumphed in the marketplace, but it may easily have taken a decade longer to do so.[14] American military

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[12] Braun and MacDonald, *Revolution in Miniature*, 50. The demand pull from the commercial computer industry would not kick in until the late 1950s and early 1960s. In 1957, tubes were still outselling transistors in the U.S. by a ratio of more than 13 to 1. Only in 1959 did transistor sales start to match tube sales.

[13] See Braun and MacDonald, "The Transistor and Attitude to Change," November 1977.

[14] It is important to remember that the idea of a semiconductor replacement for the vacuum tube triode had been around for nearly twenty years before there was any interest to develop it. The first patent of a semiconductor type amplifier was filed by the physicist Julius Lilienfeld on 8 October 1928; *Method and Apparatus for Controlling Electronic Currents*, U.S. Patent 1,745,175, filed 8 October 1926, issued 28 January 1930. The physicist Virgil Bottom argues that Lilienfeld's patent bares a striking resemblance to the modern NPN type transistor. Virgil Bottom, "Invention of the Solid-State Amplifier," *Physics Today* 17 (February 1964): 24-6. See also J. B. Johnson, "More on the Solid-State Amplifier and Dr. Lilienfeld," *Physics Today* 17 (May 1964): 602. As Lilienfeld's work reveals, physicists were aware of the implications of the new quantum mechanics to semiconductor theory. But the absence of pure semiconductor crystals made any practical electronic applications impossible. Bottom points out that nearly twenty years would pass before reasonable crystals became available. What he forgets to mention is that industry was unwilling to spend large amounts of money on R&D to develop semiconductor materials until military enterprise stepped in; first during World War II for the needs of radar, then after for the purposes of electronic miniaturization. Of course the advent of the electronic digital computer, also brought on by military enterprise, added a potential demand for solid-state amplification devices that did not exist during Lilienfeld's time. Thus it is safe to assume that without the visible hand of military imperative, the electronics industry may have let the idea sit for

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spending, however, boosted the weak, civilian demand-supply relationship and, as a result, greatly accelerated the rise of the powerful American semiconductor industry. The subsequent improvement in the transistor's performance-to-price ratio then initiated the synergy between digital electronics and semiconductor technologies.

Through much of the 1950s, Canadian military enterprise, like its American counterparts, grappled with the problems of reliability and size arising from the increasing complexity and scale of military electronic equipment.[15] "The rapid rise in the failure rate of electronic equipment, coincident with the increasing complexity and miniaturization of that equipment, is cause for alarm," warned Wing Commander K. P. Likeness, of the Royal Canadian Air Force's Air Material Command.[16] "It is apparent," he added, "that the severity of the reliability problem may reach crippling proportions unless it is given immediate attention." Again DATAR underscored that large-scale, electronic miniaturization had become critical to Canada's pursuit of military self-reliance. Although the Royal Canadian Navy's inability to convert DATAR's vacuum tube design quickly into solid state was not the cause for the project's collapse, it was an important contributing factor in closing an already small window of opportunity. Canada's efforts to develop a short-range missile and plans to design one of the world's most sophisticated all-weather interceptor fighter planes further underscored the critical importance of miniaturization to military self-reliance. With the transistor holding the strategic key to reliable miniaturization, electronics experts in the Canadian defence establishment worried over what could be done to get an ill-prepared national electronics industry to jump quickly on to the semiconductor learning curve. The barriers to accelerating the diffusion of transistor technology in Canada were far more formidable than in the United States. The disincentives to the commercialization of the transistor found in the United States were even more exaggerated in Canada. Foreign owned subsidiaries,

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another quarter century.

[15] "Equipment designed to perform complicated functions," wrote the Chairman of DRB's Electronic Component Development Committee, "tends to become complex and bulky. On the other hand, in many military application, size and weight must be kept at minimum. Consequently, a demand has been created for components not only of the highest quality but also of very small size." M. L. Card, "Electronic Component Development For The Canadian Armed Services," this is the final copy of an article prepared, during the latter part of 1954, for publication, sometime in 1955, in the journal *Electronics and Communications*. DND, Accession 83-84/167, box 7368, file 170-80/E5, pt. 1. M. L. Card was both the Deputy Director of the Canadian Military Electronics Standards Agency and the Chairman of the newly created Electronic Component Development Committee.

[16] K. P. Likeness, Memorandum to the Chief of the R.C.A.F Air Staff, 26 May 1954, DND, vol. 4185, file 260-640-43.

which dominated the Canadian electronics industry, were even more reluctant to embark on expensive product development programs than their parent firms.[17] Canada's considerably smaller civilian market further reinforced this reluctance.[18] Furthermore, the Canadian military did not have the procurement levels of its American counterpart to intervene as broadly and deeply in the promotion of the transistor.[19] As a result, the Canadian approach to the role of transistor technology in military self-reliance became a financially driven trade-off between the capacity to produce transistors and the capacity to use them.

From the moment in 1948 when the Canadian military first took an interest in the transistor as a possible electronic component to use in the harsh Arctic climate, the military debated the importance of being able to manufacture the transistor in Canada.[20] The experience of World War II had convinced the national defence planners that undue dependence on foreign sources for vital electronic components compromised Canada's military sovereignty. Even trusted allies would, in the event of a war, look after their own needs before responding to Canada's. Canadian military planners believed that, unlike the last war, there would be no time to develop, from the ground up, a national capacity to produce these items.[21] Thus from the Canadian

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[17] Canadian Business Service Ltd., "The Electronics Industry In Canada," prepared for the *Royal Commission on Canada's Economic Prospects*, April 1956.

[18] *Ibid.*

[19] The total American defence expenditure to develop and bring the transistor to mass production level has not been calculated, to the knowledge of this author. But the size of it can be inferred from the fact that the U.S. Army Signal Corp alone spent over $50 million, from 1956 to 1964 to do the necessary production engineering work needed to bring the transistor to standardized mass production level. Levin, "The Semiconductor Industry."

[20] After the war, the Department of National Defence started to form a comprehensive vision of Canada's northern flank. One facet of the military's study of northern defence was a re-examination of the kind of weapons needed to operate in the Arctic's harsh physical environment. In the context of the Arctic defence, the technically-oriented mind started to speculate if the transistor could produce more robust and portable electronics. Minutes of the Eleventh Meeting of the Defence Research Board Electronics Advisory Committee, 23 November 1948, Item 7.3.4.3., DND, box 4233, file DRBS-3-640-43. For a fascinating view of the military's attempt to explore the technical, economic, environmental, and social issues of Northern defence, the reader is referred to the files of the Defence Research Board's Arctic Committee that had just formed in 1948.

[21] See the argument developed by M. L. Card, Electronic Component Development For The Canadian Armed Services, DND, Accession 83-84/167, vol. 7368, file 170-80/E5, pt. 1. M. L. Card was the Chairman of the Inter-Service Electronic Component Development Committee. This text was a final draft of an article prepared, during the latter part of 1954, for publication, sometime in 1955 in the journal *Electronics and Communications*. When the Canadian military wanted to start production of its own small field radios, it was faced with the problem that Canadian electronic component manufacturers did not know how to manufacture moisture-resistant diodes. Rogers Majestic had already started, of its own initiative, to develop diodes for the Canadian television market. But from the military's perspective, these devices were too bulky and susceptible to moisture problems. Rogers Majestic had attempted to develop subminiature, glass-enclosed diodes. The company quickly dropped its development program when it realized that there would be few commercial opportunities for these expensive diodes. The American firm

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defence perspective, dependence on foreign suppliers for components like the transistor was unacceptable.[22]

No sooner had the Department of Defence Production (DDP) been created in 1951 that it "expressed anxiety over the greatly increased use of electronic components in weapon development, while there [had] been no corresponding increase in Canadian development or application of more reliable components for increasingly severe operational load." DDP felt that "Canada [could not] benefit fully from the energetic component programmes of the UK and US unless Canada actively sponsor[ed] similar programmes to ease increasing dependence on foreign sources of supply of these critical items."[23] In 1954, in an effort to induce the domestic development and production of the new types of electronic components required by military technology, the Department of National Defence committed $660,000 to help underwrite the high-risk investment associated with such R&D.[24] The plan was to devote 20 percent of this investment to research, 30 percent to development, and 50 percent to establishing Canadian sourcing.[25]

The efforts of Canadian military enterprise to create an indigenous capacity to develop and manufacture transistors proved a failure throughout the 1950s.[26] By 1956, when the need to miniaturize the exploding complexity of military electronic systems had become urgent, electronics experts in the Department of National Defence (DND) realized how little progress had been made in producing this revolutionary electronic device in Canada.[27] Northern Electric and

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Hughes Aircraft had solved the problem for the U.S. Army, but the process was a trade secret and not available to the Canadian defence industry. Secretary of ECDC, Memorandum to L. M. Chesley (Assistant Deputy Minister, Department of National Defence), 4 October 1955, DND, Accession 83-84/167, box 7368, file 170-80/E5, pt. 1.

[22] Minutes: Ninth Meeting of ECDC Transistor Panel, 3 January 1956, DND, Accession 89-90/205, box 36, file 171-80/To.

[23] Extract From [Services] Joint Telecommunications Committee Technical Meeting, 10 November 1952, DND box 4233, file DRBS-3-678-43.

[24] DRB contributed $125,000 and $535,000 came from the Army, Navy and Air Force. Minutes of the 13th Meeting of the Joint Services Electrical and Electronics Committee, 17 September 1954, Item 17, DND, vol. 9285, file CSACS-2-70-67-1, pt. 1.

[25] W. J. Eastwood (Secretary of Joint Services Electrical and Electronics Committee), Memorandum to Secretary, Principal Supply Officers Committee, 19 August 1955, DND, box 9285, file SACS-2-70-67-1, pt. 1.

[26] Whether this also proved to be the case over the broader range of electronic components still needs to be studied.

[27] Concerns over the availability of transistors during an emergency even reached down to the question of ensuring a secure source of semiconductor material. The Electronic Components Development Committee's special Transistor Panel underscored, to the Department of Defence Production, Canada's very limited ability to produce electronic
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Canadian General Electric, two of Canada's most prominent electronics companies, had shown little or no interest to commit corporate resources to the transistor.[28] Canadian Marconi and Rogers Majestic showed an interest in producing transistors, but they had not yet articulated an R&D plan, let alone committed funds. The only bright light in an otherwise bleak Canadian transistor R&D landscape was RCA Victor Ltd. in Montreal. This company had already produced, at its own expense, prototype junction transistors for the Canadian military. This Canadian subsidiary's unique willingness to invest seriously in R&D reflected the desire of its Semiconductor Department manager "to break away from the general policy of following the American parent firm."[29] But RCA was the exception. Even efforts to get American manufacturers to set up transistor branch plants in Canada failed. Efforts to get the Philco corporation to manufacture transistors through its existing branch plant in Canada did not dovetail with the multinational's self-interests. Philco declined to manufacture its innovative, surface-barrier transistor in Canada, as it argued that the limited market made it uneconomical to invest $1 million in a manufacturing plant.[30]

By 1956, budgetary constraints and the changing nature of warfare created divisions among Canada's defence planners over the issue of domestic sourcing of electronic components. The Department of Defence Production and the Electronic Component Development Committee saw the promotion of Buy-Canadian as an essential part of their mandates. But L. M. Chesley, one of the Assistant Deputy Ministers in DND, questioned the extent to which defence money should be used to foster industrial development: "Is it appropriate for ECDC to make a decision to spend public funds for the development of a source of supply in Canada," he asked, "when one

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grade germanium and silicon. Only Consolidated Smelters, from Trail, British Columbia, was in a position to undertake the production of an acceptable grade of germanium. No one in Canada could produce the more strategically important silicon. The sole source of this material was from Dupont in the United States. Minutes: Ninth Meeting of ECDC Transistor Panel, 3 January 3, 1956, DND, Accession 89-90/205, box 36, file 171-80/To.

[28] Minutes: Fifth Meeting of ECDC Transistor Panel, 12 April 12, 1955, DND, Accession 89-90/205, box 36, file 171-80/To.

[29] *Ibid.* Evidence suggests that RCA Victor's interest in the transistor was not an isolated example of the Canadian subsidiary's independent approach to R&D. For example, the Canadian company designed and built the transponders on America's first communications satellite, Telstar. Three years later, the company was part of an all-Canadian bid to design, build, and operate the world's first national broadcasting satellite. The reasons behind this Canadian subsidiary's aggressive postwar R&D policy have yet to be studied.

[30] The reader will recall that, in the spring of 1955 the RCN sent Ferranti-Canada to the U.S. to bring back several hundred of these transistors to study in the hope that they could be used to miniaturize DATAR.

might exist for instance in Detroit or elsewhere on this continent?"[31] In the years following the Korean War spending boom, the Armed Services came under constant pressure to reduce their budgets. They became increasingly unwilling to subsidize any domestic production of electronic components. Their definition of military self-reliance shifted accordingly. Rather than worrying about manufacturing components, the thrust of self-reliance was narrowed to Canada's ability to fulfill an equipment design, testing, and construction role within the alliance based on the transistor. Furthermore, concern over being able to mobilize production of essential electronic components at the outbreak of war made less and less sense with the reality of nuclear war. What counted was the capacity to design and deploy advanced weapons systems before the outbreak of war.

Digital Electronic Self-Reliance: The Ability to Design Miniaturization

Although there was considerable debate within the defence establishment, over whether to pour money into the domestic manufacture of the transistor, there was unanimity over the importance of fostering a national capacity to use this new electronic paradigm in original ways. The DATAR experience showed clearly that by 1956 the challenge of miniaturizing large-scale digital circuitry had less to do with having access to transistors than with knowing how to use them. One could not simply pull out a tube from a circuit, and with some minor redesign, plug in a transistor. Ferranti-Canada's short-lived struggle to recast DATAR's complex circuitry into solid state electronics was a rare event in the Canadian industry of the day, not because of its difficulties, but because of its attempt. Not only did the Canadian electronic industry have little design experience in large-scale digital circuitry, but as Frank T. Davies, a Chief Scientist with the Defence Research Board, noted, Canadian industry still lacked the knowledge and experience design around a solid state amplifier.[32] As late as 1958, Norman F. Moody, a man who played a central role in DRB's efforts to advance transistorized digital circuit design, warned an audience

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[31] L. M. Chesley, Memorandum to the Chairman, Defence Research Board, 22 September 1955, DND, Accession 83-84/167, box 7368, file 170-80/E5, pt. 1.

[32] In 1955, Frank T. Davies, a Chief Scientist at DRTE, wrote to the Vice-President of the NRC about the need to eliminate this lacuna in the Canadian defence program. Frank T. Davies, Letter to B. G. Ballard (Vice-President, National Research Council), 12 July 12, 1955, DND, Accession 83-84/167, box 7368, file 170-80/E5, pt. 1.

of electronics engineers that:

> *[The transistor] is different from the vacuum tube in all important respects. It is true that both devices have one trivial property in common, for both give power amplification. To designers who are familiar with vacuum tubes, this trivial resemblance between the devices has been a trap. Many of their failures are strewn along the path of progress. The transistor is a nuisance because you must learn an entirely new circuit technique to use it satisfactorily. Even then you must avoid a tube-by-tube replacement by transistors*.[33]

As early as 1954, the DRB had decided that rather than waiting for industry to explore the use of transistors in military electronic design, it would create a special section within the Defence Research Telecommunications Establishment Electronic Laboratory (DRTE(EL)) to accelerate the process. DRTE(EL) was itself a product of the belief that to have an efficient equipment-development program, scientists, and development engineers had to be immersed in the military ethos. From the Services' perspective, "[electronic] experimental development, to be successful, should not be divorced from the applied research which is always incidental to it....Experimental development for Service use requires the continuous absorption of Service experience...particularly when a new solution to an operational requirement is being sought."[34]

In creating a new Transistor Section within DRTE(EL), DRB argued that Canada's Armed Services needed a source of new ideas on how to exploit the strengths of the transistor in military electronics. Within a year of its creation, the Transistor Section with Norman Moody at its head staged a dazzling demonstration in the foyer of Ottawa' elegant Chateau Laurier hotel as a way to raise awareness of the transistor within Canada's defence establishment. For most who attended the event, this was their first exposure to the new generation of semiconductor electronics. The circus-like unveiling of the transistor may have been a good piece of public

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[33] N. F. Moody, "The Present State of the Transistor and its Associated Circuit Art," *Nuclear Instruments* 2 (1958): 182-92, 182. Moody, as will be discussed below, came to lead a program to expand digital transistor circuit know-how within the Canadian defence research establishment.

[34] E. Cullwick, Memorandum to P. Nasmyth: Facilities for Applied Research and Experimental Development, 18 March 1948, DND, Accession 83-84/167, box 7327, file DRBS-100-22/0, pt. 1. Invitations from the British and American armed services to co-operate in joint electronic weapons development projects first provoked concern over the need for centralized in-house electronic laboratories. The Canadian Armed Services inability to accept the invitation underscored "the problem of the absence of adequate facilities within the Department of National Defence for experimental development of electronic equipment and systems, [as well as facilities] to do the applied research which arises from such development." *Ibid.*

relation for the Transistor Section, but it concealed the absence of a well-articulated program in transistor circuit innovation.[35] But the digital electronic miniaturization issue soon brought focus to the Transistor Section's mission.

The failure of Canadian industry to champion the military uses of the transistor prompted DRB and NRC in 1955 to call for the government to assume a more aggressive role in the creation and diffusion of transistor circuit design know-how to industry. Projects such as DATAR, the Velvet Glove Missile, and the AVRO Arrow underscored the urgency to improve Canada's capacity to miniaturize electronic design. The Arrow, a remarkable all-weather fighter interceptor, promised to be the flagship of Canada's aeronautical industry. For this new generation of fighter, the Royal Canadian Air Force needed a new generation of sophisticated electronics: a comprehensive system that would integrate radar data, navigation, communications, the fire-control computer, and flight control.[36] Because of the drive to maximize electronic sophistication while minimizing payload, miniaturization was a central factor in the AVRO Arrow's avionics, of which digital circuits were a major component. In the early stages of the project, the Department of Defence Production (DDP) anguished over the prospect that the electronic "brains and nervous system," of what was to be an all-Canadian fighter plane, would have to be American-made. The scope and size of the Arrow's integrated electronic system exceeded Canadian capacity. The DDP had estimated that if Canada tried to single-handedly develop the CF-105's on-board electronic system, the effort would easily absorb 25 percent of all of the country's electronics engineers.[37] But the problem was even worse than this estimate suggested. Simply counting the number of bodies needed to design and build the

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[35] For example, when spectators walked passed a certain point, they would interrupt a beam of light falling on a semiconductor photocell, which, by means of miniature transistor switches turned on various flood lights in the exhibit area. To augment the visual display, a pre-recorded description of what the exhibit was also switched on automatically. Although the tiny transistor's potential to miniaturize military equipment was self-evident, its reliability, however, was not. To dramatize reliability, the Transistor Section demonstrated that transistors could work well even when undergoing mechanical shocks, being placed in boiling water, or being embedded in ice

[36] CF-105, DDP, vol. 298, file 152-4-3, pt. 1. This document has no date, but it is reasonable to assume from its location within the file that it was prepared in March or April 1955.

[37] D. B. Mundy, Memorandum to D. A. Golden (Deputy Minister, Department of Defence Production), 6 December 1956, DDP, vol. 298, file 152-4-3, pt. 2. The general shortages of electronics engineers in Canada was compounded by the limitations placed on recruitment for reasons of military security. "Our electronics industries as well as government laboratories," explained one DRB memorandum, "are all within security restrictions because of their classified projects....We could recruit considerable numbers of well trained men from England, Holland and Sweden, where subversive elements are in a very small proportion and our risks of picking such types are small." F. T. Davies, Memorandum: Shortage of Research Personnel in Canadian Electronics, 12 July 1955, DND, Accession 83-84/167, box 7368, file 170-80/E5, pt. 1.

CF-105's electronic subsystems did not take into account that most of these bodies had still not started up the transistor learning curve.[38]

In 1955 DRB reacted to the problem with a more vigorous transistor R&D program that it hoped "would [in two years] provide a sufficiently broad basis of knowledge from which to guide industry."[39] In this plan, the Transistor Section bore the specific responsibility for developing, testing, and disseminating the fundamental transistor circuit techniques that would be needed to support the military's equipment development program.[40] While this mandate admitted numerous options, it was the interplay of the electronic complexity crisis and Moody's past inventive talents in atomic energy research that shaped the contents of the Transistor Section's R&D agenda, which by the end of 1955 had become: "to master the techniques of applying semi-conductors to military problems involving digital computation."[41] This program was to unfold in three stages: to study digital logic with particular reference to its implementation in terms of semiconductor circuits; to develop circuits suitable for digital computation; and finally to develop a digital computer as a test bed for logic and circuits.[42]

Moody's experience with digital electronics started during Britain's World War II radar program. Under F. C. Williams's direction, Moody participated in the development of the circuits needed to generate and detect the rapid sequences of pulses used in radar systems.[43] This

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[38] In the end the DDP had to recommend that Canada give the U.S. Hughes Aircraft a four-year, $15 million contract to develop the AVRO Arrow's electronic systems.

[39] W. A. Thomson (for Chairman, Defence Research Board), Letter to Dr. D.W.R. McKinley (Assistant Director, Radio & Electrical Engineering Division, National Research Council), 25 July 1955, DND, Accession 83-84/167, box 7368, file 170-80/E5, pt. 1. Silicon-based semiconductors were initially more expensive to develop. But their greater resistance to heat and radiation made them far more attractive to the military.

[40] Dr. F. W. Simpson's Electronic Material's Section undertook to develop a deeper understanding of the individual transistor's behaviour. After considerable difficulty in finding applied scientists in the field of semiconductors, NRC formed a small team to study single silicon crystal growth. DRB covered the costs of the expensive equipment needed to grow the crystals. D. W. McKinley (Assistant Director, Radio & Electrical Engineering Division, National Research Council), Letter to Chairman (Defence Research Board), 26 July 1955, DND, Accession 83-84/167, box 7368, file 170-80/E5, pt. 1.

[41] Progress Report: Research and Development Project No. D48-99-31-03, 31 December 1960, DND Accession 83-84/167, box 7593, file DRB-9931.11, pt. 1. Though this document is a progress report of the later stages of the DRTE computer project, it nevertheless carries over some of the basic information that appeared in the original project description.

[42] *Ibid*

[43] The reader will recall from Chapter 2 that F. C. Williams went on to pioneer the first purely electronic computer information storage device called electrostatic memory. He was part of the design team at the University of Manchester that designed the Mark I experimental prototype computer on which Ferranti U.K. then, under British government contract, did the production engineering. The first commercial sale of this computer went to the

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experience with electronic pulse techniques later led Moody into the problems of devising better atomic energy instrumentation circuits, research which also dealt with electronic pulse techniques. Finding his participation in Britain's postwar development of the atomic bomb personally distasteful, Moody wanted to be transferred to the Canadian program at Chalk River, which had a more acceptable mandate: the exploration of peaceful and commercial uses of atomic energy. Moody's bridge from Great Britain to Chalk River was physicist W. B. Lewis, Director of Research of Canada's nuclear program at Chalk River. During the war Lewis had headed up the radar project at the Telecommunications Research Centre in Malvern, in the United Kingdom, where Moody worked in the basic circuits group. Lewis not only knew of Moody, but as the only principal British scientist who had refused to become involved in the Manhattan Project, Lewis also understood Moody's desire to exit Britain's atomic bomb project.[44]

While at Chalk River from 1949 to 1954, Moody led his team in a program to push the performance of trigger circuits to the very limits of vacuum tube technology. Prior to their use in computers, scientists used electronic digital-counting circuits to measure the fluxes of the various radioactive particles emanating from nuclear reactions. Being able to quantify the number and energy of each component of radioactive emission was not only critical to understanding the physics of nuclear fission, but also essential to designing a bomb or a nuclear reactor. The accuracy of binary digital counters depended on how well these could discern the passing of a stream of radioactive particles separated by extremely short intervals of time. If the counter circuits could only react every one-thousandth of a second, then they would miss all the particles in the radiation beam that were separated by one-ten-thousandth of a second. The switching time of the counter's many trigger circuits set the limits of the radiation counters. Trigger circuits with very fast switching times meant faster, hence better nuclear instrumentation.

Moody faced two technical issues in speeding up trigger circuit performance. The first was to devise a circuit that could provide well defined, strong pulses to drive subsequent stages when operating at very high switching speeds. The solution to this problem was to incorporate a feedback element, a "trigger tube," to each binary counting stage. This technique, Moody wrote

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University of Toronto and became known as FERUT.

[44] Bothwell, *Nucleus*. According to Bothwell, it was Lewis's deep Christian faith that led him to preach the peaceful uses of nuclear energy. Though Moody did not start from the same deep religious convictions, he nevertheless felt uncomfortable contributing to such a murderous weapon.

in his 1952 patent application, provided "the large, steep-fronted surge current" to ensure the fast reliable triggering of each successive stage within the counter.[45] The second challenge Moody faced in his effort to increase the speed of trigger circuits was the vacuum tube's reliability, or lack thereof. Every vacuum tube was characterized by a fixed family of plate-current versus grid-voltage curves that were crucial to determining the details of any circuit design. Ideally, these characteristic curves were exactly the same for all tubes of a given type and remained constant over the tube's lifetime. Despite the manufacturer's claims, vacuum tubes were not produced with this kind of standardization and reliability. Tubes of a given type were not manufactured with exactly the same characteristics. Furthermore, as a tube aged, its characteristics changed in ways that were not quantitatively predictable. No two tubes of the same type displayed exactly the same variations with age. While these variations from the ideal were well within acceptable limits for conventional analog electronics found in radio and television, they posed serious problems when designers tried to speed up the switching speeds of digital circuits. Small variations in tube characteristics could easily throw off digital switching circuits that had been "tweaked" for maximum performance. In various patents filed while at Chalk River, Moody expressly tried to design high-speed trigger and binary counting circuits whose performance was resilient to variations in tube characteristics.[46]

Early pioneering work in electronic digital computers had drawn sustenance from the digital counters first developed for atomic energy research. As one technical study of digital circuit design explains: "a few scattered references began to appear on the use of flip-flops in counter circuits, where the applications in most cases was the counting of pulses from a Geiger-Muller tube."[47] John Mauchly, one of the two principal designers of the ENIAC, the first American electronic computer which was built in the closing days of World War II, later recounted the technology transfer he acquired from digital radiation counters: "Binary counters

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[45] N. F. Moody, *Electronic Counter*, 10 April 1952, Canadian Patent Application 629,620, CPDL, vol. 62, file L14-1495-2.

[46] For example see *Ibid.*, and N. F. Moody and W. D. Howell, *Electronic Counter*, Canadian Patent Application no. 590,852, 4 August 1949, CPDL, box 63, file L14C-1508-2; William Battell and Norman Moody, *Discriminator Circuit for Kicksorter*, Canadian Patent Application no. 619,148, filed 10 August 1951, CPDL, box 48, file L14C-1364-2; and Norman Moody, *Trigger Circuit*, draft of patent application 28 April 1952, CPDL, box 50, file L14C-1364-2.

[47] R. K. Richards, *Electronic Digital Components and Circuits* (Princeton, N.J.: Van Nostrand, 1967). The flip-flop has two states (one tube is on and the other off, or vice-versa). Once the circuit has assumed one state, it stays that way until an external trigger pulse initiates a changeover.

were already known to me; they existed in cosmic-ray labs [like my father's]. So I thought, see, if they could count at something like a million per second with vacuum tubes, why it's sort of silly to use the these [IBM] punch card machines, which can only do maybe a hundred cards, a minute and don't seem to do much at that."[48]

Though Moody had little direct knowledge of electronic computers, the strong technical affinity between radiation counters and computer circuit design led him to speculate, as early as 1950, that his techniques would offer important benefits to the designers of "high speed computers and multi-channel pulse communication systems."[49] Moody felt that his digital switches offered computer designers much faster and more reliable digital circuitry. No one in the computer world took-up Moody's vacuum tube switches, but neither did Moody make any effort to promote his invention. Nevertheless, the idea that computers offered an excellent technological forum in which to showcase his techniques continued to percolate in Moody's mind. Five years later, as head of DRTE's Transistor Section, Moody saw another opportunity to establish the value of his trigger circuit philosophy to the design of computers, this time, however, through transistor switches.

It is unlikely that Moody would have suggested an ambitious computer design program as a way to advance transistor circuit expertise, and even more unlikely that DRB would have funded such a proposal, had it not been for the complexity crisis that threatened to paralyse the deployment of new electronic weapon systems. Nowhere was the urgency of this crisis more acutely felt than in large-scale digital circuitry. Once again, it is important to recall that by the end of 1955, DRB had seen first hand how DATAR's full-scale technical elaboration was being handicapped by the very slow pace of miniaturization. DRB's ambitions to define an independent missile development role for Canada within the North Atlantic Triangle alliance hinged, in part, on designing complex, robust, and miniature electronic systems for its Velvet Glove missiles. The RCAF's development of airborne, digitally-based, automated fire control systems and data communications systems also called for a solid-state solution to the power consumption, size, and reliability problems arising from greater complexity. What better place to hone one's miniaturization skills than on the scale of computers? The fundamental transistor circuit

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[48] Cited in Joel Shurkin, *Engines of the Mind* (New York: Washington Square Press, 1985), 91.

[49] N. F. Moody, G. R. Maclusky, and M. O. Deighton, "Millimicrosecond Pulse Techniques", Lecture delivered at the Third Annual Joint AIEE-IRE Conference on Electronic Instrumentation in Nucleonics and Medicine, New York, October 25, 1950. Copy in CPDL, box 50, file L14C-1381-2.

knowledge gained from building the computer could then be transferred over to any digitally-driven weapon system.

Another compelling reason for the construction of the computer lay in the large and controlled statistical sample set that could be used to measure and test transistor performance. While it was clear by 1956 that the transistor offered the only hope of substantial miniaturization, the Canadian military was still very cautious, as was its American counterpart, about any sudden replacement of all its vacuum tube equipment. Because of germanium-junction technology, transistor reliability had come a long way from the early, unreliable, point-contact technology. Nevertheless, important limitations continued. The transition from the production of short, limited runs of experimental transistors to a standardized, mass-produced commodity was still not assured, particularly for the newer generation of silicon transistors. According to Braun and MacDonald, "it was difficult to design a transistor to give even an approximation of the characteristics required, and even harder to produce two transistors with the same characteristics."[50] By 1956, the advantages of transistor reliability had still not been proven. "It is my suspicion," observed one senior American Air Force officer in a speech to a conference on electronic components, "that the chief reason we have not been able to advance the production date for this highly important equipment is due to the erratic and undependable behaviour of transistors."[51]

There seemed to be little statistical data to confirm the transistor manufacturers' assertions that they were producing a more reliable product. As the Head of Computing Devices of Canada's Semiconductor Engineering Department pointed out to DRB's Chairman, "there is no large body of experimental evidence to prove the [reliability] claims, though all indications tend to support them. In consequence, many designers hesitate to introduce transistors into military equipments until they see adequate proof of this greater reliability than tubes."[52] Because of its inherently large scale, Moody saw the digital computer as an excellent framework within which

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[50] Braun and MacDonald, *Revolution in Miniature*, 49. In 1953, the price of the best transistors was eight times that of a vacuum tube. One electronics expert recalled that, with regard to consumer electronics: "for a decade or so, from 1953 to 63, we had no choice but to go with vacuum tubes because they did a better job, and up until that time they were cheaper." *Ibid.*, 50.

[51] Attributed to Major-General C. Irvine, U.S. Air Force, during an Electronic Component Conference in Los Angeles in May 1955, by CI Soucy, RCAF. See C. L Soucy, The Future Replacement of Tubes By Transistors and Magnetic Amplifiers, DND, Accession 89-90/205, box 35, file 170-80/To, pt. 2.

[52] E. F. Johnson, Letter to Chairman, Defence Research Board, 5 April 1956, DND Accession 89-90/205, box 35, file 170-80/To, pt. 1.

to establish the statistical basis of the transistor's performance. More than a testing platform, the computer project also served as a valuable training ground in which Canadian engineers could move up the solid-state, digital electronics learning curve.

Today, silicon is synonymous with the digital revolution, the self-evident material basis for the commercial computer/transistor synergy. Levin, however, shows very convincingly that the abandonment of germanium and the push to develop reliable silicon transistors had little to do with any self-evident civilian commercial opportunities and everything to do with the American military's pursuit of reliability and performance regardless of cost.[53] Unlike germanium, the semiconductor silicon was far more resistant to the high temperatures one expected to encounter in missiles and high performance fighter aircraft. It was also less susceptible to radiation damage. Considerable military spending on direct research and development, and on future procurement was needed to get industry to move onto the silicon trajectory.[54] But unable even to kick-start germanium transistor manufacture in Canada, its military could not even contemplate the far more expensive prospect of producing silicon transistors domestically. Even so the nation's defence industry could become an early adopter and adapter of this technology. Transistor Section's early and complete commitment to design around silicon illustrates that military needs, and not civilian spin-offs, infused this group's exploration of new computer circuits.

The success of DRTE's plan to serve as a pole of innovation-diffusion depended on the effectiveness of the mechanisms used to move information from the government laboratory to industry. In Japan for example, the government laboratory Electro-Technical Laboratory (ETL), worked in close, continual and interactive collaboration with industry.[55] The rationale of the

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[53] Levin, "The Semiconductor Industry."

[54] The U.S. Air Force spent $5 million on industrial R&D into the development of the silicon transistor. In 1956, the U.S. Department of Defence committed $14 million to develop a large scale capacity to manufacture silicon transistors. The development of this mass-production capacity, which became the engine of national economic growth, was not motivated by any "abstract desire to promote industry, but rather by concrete military needs." *Ibid.*, 67-8.

[55] During the mid 1950s, the Japanese also decided to use a government laboratory, the Electro-Technical Laboratory (ETL), as a pole from which vitally needed transistor know-how could diffuse to industry. After some doubt as to how best to focus its energies, ETL shifted from studying the transistor itself to pursuing the circuit applications of the transistor. Like DRTE, ETL decided to design and build the nation's first solid state computer as a vehicle for developing an indigenous capacity to apply transistors. "At the time," the leader of the ETL transistor group later recalled, "none of us were interested in computer architecture; our goal was to build a computer as an application of transistors." Sigeru Takahashi, "Early Transistor Computers in Japan," *Annals of the History of Computing*, 8 (April 1986): 147. But the fact that ETL confined its initial investigations to the older and cheaper

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DRTE laboratory, however, was to "broadcast" to industry the basic circuit innovations needed to apply the transistor to military needs. In this regard, DRTE Transistor Section intended to publish and disseminate its work through of technical reports and papers to all potential defence contractors. But using only this method, how could the military ensure that the techniques developed in the DRTE laboratory would become part of industrial practice? Furthermore, technical reports could never convey the wealth of subtle and unwritten design know-how that is generated in a problem solving environment in which engineers and scientists work in daily close proximity and share insights and experiences through countless informal discussions. Rather than trusting in the movement of printed information as the only mechanism of technology transfer, DRTE also decided to move people.

In 1955, the Transistor Section set up a training program in which engineers from defence-related industries worked in Moody's laboratory for a minimum of six months.[56] The hope was that these engineers would, like good disciples, go back to their respective companies and teach the secrets of transistor circuit design to others. Equally important, the trainee represented someone who could be counted on to champion the Transistor Section's techniques once back in the company. The training program offered no government subsidies. Each company had to bear all its trainees' expenses. Even so, the response from Canada's electronics industry was overwhelming: Canadian Westinghouse, Northern Electric, Canadian Marconi, Computing Devices of Canada, Canadian Aviation Electronics, AVCO of Canada, and Rogers Majestic Electronics, all expressed an interest in sending one or more engineers for training.[57] Clearly, the initiative responded to a real need. Without extensive military procurement, most Canadian electronics firms were either unwilling or unable to embark on a costly transistor R&D program. In the absence of any contract, DRTE's proposal offered these companies the opportunity to share in a large, sophisticated R&D environment. No doubt the electronics firms also felt that by participating they increased their chances of winning future contracts.

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germanium transistor, while DRTE immediately explored the use of the embryonic and more costly silicon transistor, further illustrates the direct role that military enterprise plays in shaping both the rhythm and direction of technical change.

[56] The information on this training program was gathered from correspondence contained in, to this writer's knowledge, the only file on the subject. See DDP, vol. 303, file 152-14-5C3.

[57] Only two companies turned down DRTE's training proposal: Ferranti-Canada and RCA Victor of Montreal. Each of these companies was already pursing its own R&D program. Canadian General Electric never responded.

Moody's New Transistor Switch Drives Computer Innovation

Ready to exploit the transistor on its own terms, Moody nevertheless still made creative use of his prior innovative and unique work with vacuum tube switches. As with tubes, Moody set out to push the limits of transistor-switching circuits, both in terms of speed and load capacity.[58] Again, as with tubes, Moody tried to design high-performance, transistor circuits that would be fairly insensitive to the unwanted variations in component characteristics that marked transistor manufacture of the day. Positive feedback had been an important design element in Moody's earlier tube-based trigger circuits. The regenerative PNPN complementary structure was Moody's answer to feedback in the semiconductor realm. The tube-based flip-flops used in computers in the 1950s were based on the Eccle-Jordan symmetric arrangement of two vacuum tubes. When the flip-flop was transistorized, circuit designers simply replaced the two identical tubes with identical transistors, thus maintaining the symmetry. Looking at transistor circuits as vacuum tube equivalents missed a fundamental difference. There was only one basic vacuum tube structure, but two kinds of transistor structures: npn and pnp. It was this asymmetry that Moody exploited in his regenerative PNPN complementary structure.[59]

The construction of a computer became a showcase for the Transistor Section's rather unique approach to high speed, transistorized, digital circuits: the "controlled saturation" technique embodied in the PNPN structure.[60] Moody's contention that the PNPN trigger circuit's good performance "in the face of wide transistor and component variations" meshed well with the military's search for reliable high-performance. His claim that the PNPN approach allowed for the development of switching circuits capable of driving many other stages was also attractive

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[58] Patents from the trigger circuit development work at DRTE were: Norman F. Moody and David Florida, *Two-State Apparatus*, Canadian Patent no. 584,379, filed on 24 January 1957, issued 6 October 6. Norman F. Moody, *Two-State Electronic Circuit*, Canadian Patent no. 603,345, filed on 26 March 1957, issued 16 August.

[59] In more technical terms, the PNPN trigger was able to run the transistors at saturation without sacrificing speed. Moody argued that the symmetric transistor adaptation of the conventional vacuum tube flip-flop was not well suited for heavy loads. As its current output increased, performance deteriorated. The PNPN structure's regenerative loop minimized the storage time delay. N. F. Moody and C. D. Florida, "Some New Transistor Bistable Elements For Heavy Duty Application," *Institute of Radio Engineers Transactions on Circuit Theory* (1957).

[60] The PNPN structure consisted of a complementary pair of PNP and NPN transistors joined to form a regenerative feedback loop. N. F. Moody, *The General Properties of the P-N-P-N Structure As Applied to a Trigger Circuit*, 1954, DRTE Electronics Laboratory Memorandum 5059-54. During the 1980s, a similar principle was used to develop CMOS (Complementary Metal Oxide Silicon) technology. Today, CMOS technology underlies a large segment of microchip design.

to the military mind because it implied greater digital miniaturization without any sacrifice in performance. The design and construction of a computer was to be the litmus test of Moody's claim that the PNPN concept offered the military electronics designer significant reduction in digital circuit complexity without any sacrifice in performance.[61]

Beyond his invention of the PNPN structure, Moody played no further role in the design of the DRTE computer. Instead, he gave his most senior engineer, David Florida, the responsibility of being the project's manager and the computer's chief architect. In Florida's hands, the project's philosophy very quickly took on an entirely new dimension. In early 1956, Florida suggested to a DRB audience that military preparedness demanded a deeper understanding of the design of electronic, information-processing technology.[62] While Moody saw the computer as a vehicle to explore the potential of the PNPN flip-flop, Florida was inclined to see the latter as a means of expanding Canada's capacity to build and use data-processing systems. In 1956, with only a handful of electronic digital computers in operation in Canada and with Ferranti-Canada struggling to be the first computer hardware designer in Canada, Florida recognized there was a need for more computer design research in Canada.

Florida transformed the mandate to showcase the PNPN invention into an opportunity to explore computer hardware complexity. After a year of experimentation, Florida and Moody had shown, on a sample of forty transistors, the validity of "controlled saturation."[63] It was the ability to achieve high-pulse currents, with very fast switching, that, according to Moody and Florida, made the PNPN ideal for computers. By exploiting the PNPN's high fan-out capabilities, it was possible to transfer much of the computer's digital circuitry to passive diode logic without losing any overall speed.[64] Thus for a given level of performance, the PNPN approach promised a

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[61] In 1957, Florida described how the "controlled saturation concept" had been tested on only a small sample of transistors of forty transistors. Florida points out that building a computer which uses saturated trigger circuits would provide the large statistical sample to support Moody's circuit technique. See Florida, *An Analysis of a P-N-P-N Structure*.

[62] C. D. Florida, *Digital Computers (I)*, Transcript of a Talk Given at DRTE(EL), February, 1956. Computer History Archives, University of Calgary. "To paraphrase Mr. Moody's remark that unless we learn about transistors we shall be extinct as electronic engineers," Florida once explained, "I would say that unless we learn about computers, we shall be extinct period!" (p. 2).

[63] Florida, *An Analysis of a P-N-P-N Structure*.

[64] Florida's "passive routing" circuit architecture was not a new idea in computer technology. The American SEAC vacuum tube computer project had already pioneered similar principles between 1949 and 1953 under the name of "dynamic circuit techniques." The circuit design philosophy behind the SEAC computer ."..was to minimize the number of tubes by performing all the logical operations of 'and', 'or' and 'not' between pulses in circuits comprised of

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greater economy of transistor, hence even greater miniaturization. Ironically, the PNPN flip-flop's ability to maximize digital circuit performance reliably with a minimum number of transistors encouraged Florida to expand the number of features he wanted to design into hardware. Stimulating Florida's fascination with hardware sophistication was the desire to build an improved computational tool for scientists.

Examples of how, in resorting to greater circuit complexity, Florida wanted to take the computer from a mere test bed to a computational tool for scientists are manifold in the design decisions made from 1957-59. For example, at a time when fixed-point arithmetic was the standard feature in computers, Florida added floating-point capabilities as a way to ease the scientist's programming burden.[65] Another way to simplify the scientific programming environment was to eliminate doing arithmetic against an accumulator. Rather than using the then standard one or two-address command word structures, Florida proposed the more elaborate circuitry of the three-address architecture.[66] This method made an arithmetic operation resemble more closely the familiar "pencil and paper" method of computation of A+B=C.[67] The two addresses specified the memory location of each operand, and the third address gave the location to which one wanted to transfer the result. Greater hardware sophistication thus created a

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germanium diodes and resistors." Elbourn and Witt, "Dynamic Circuit Techniques Used in SEAC and DYSEAC," October 1953, 1380. However, vacuum tube circuits could not provide the high pulse currents to drive the complex cascades of diode logic. The SEAC project got around this by incorporating newly-developed miniaturized transformers: "transformer-coupled dynamic circuitry." See also Sidney Greenwald and R. C. Haueter, "SEAC," *Proceedings of the Institute of Radio Engineers* 41 (October 1953): 1300-13. J. Felker adapted similar principles in his proposal to design of a germanium point-contact transistor computer in 1952. J. H. Felker, "The Transistor as a Digital Computer Component," *Review of Electronic Digital Computers*, A.I.E.E. Special Publication, S-44, (February 1952): 5-109. Cited in Elbourn and Witt, "Dynamic Circuit Techniques Used in SEAC and DYSEAC," 1380. Whether Felker actually built a full scale transistor computer on these principles is not known. The Japanese government laboratory, ETL, however did use the technique in its exploration of transistor application. The motivation to reduce the complexity, i.e. to minimize the number of transistors, in this first Japanese effort to design and build a transistor computer was the simultaneous high cost ($8) and reliability problems of the germanium point contact transistor. Takashi, "Early Transistor Computers in Japan," 146. But unlike other "dynamic circuit" approaches, the DRTE computer's passive circuitry did not sacrifice performance to reduce complexity.

[65] C. D. Florida, *A Floating Point Arithmetic Unit*, Defence Research Telecommunications Establishment Electronics Laboratory Report No. 5083-7, February 1959. The first commercial scientific computer to incorporate floating-point was the IBM 704. R. Moreau, *The Computer Comes of Age: The People, the Hardware, and Software* (Cambridge, Mass.: The MIT Press, 1986), 66. First delivered in 1955, the design of this vacuum-tube computer benefited from IBM's experience in the U.S. Air Force's SAGE project.

[66] The three-address architecture was not new, but its implementation was rare. The first commercial system in Europe to use a three-address system was Ferranti U.K.'s ORION model.

[67] David Florida, "The DRTE Solid State Digital Computer," *Proceedings in the Second Canadian Conference for Computing and Data Processing, June 1960, Toronto, Ontario* (Toronto: University of Toronto Press, 1960), 299-310.

environment in which the scientist programmed arithmetic operations directly against the entire memory, rather than always passing through intermediary accumulators. In so doing, Florida reasoned, programs would be shorter and take less time to write. Shorter programs also meant faster computational times.

In other areas, Florida tried to reduce the programming complexity by relegating to hardware tasks that would normally have been left to software subroutines. Decimal-to-binary and binary-to-decimal conversion, division, and even square-root were to be all hardwired into the DRTE computer.[68] The Converter alone, which was designed by George Lake, contained 128 PNPN trigger circuits.[69] Fred Longstaff, who at the time was Ferranti-Canada's chief computer designer, later recalled coming to Ottawa to see the DRTE computer and feeling that "Florida was trying to build more fanciness into the hardware than was really viable at the time."[70]

From the military's perspective, the purpose of the DRTE computer project lay in the transistor circuit design know-how to be gained. Florida, however, wanted to advance the state-of-the-art of computer design by producing a machine that would significantly reduce the scientist's programming burden. But his design philosophy was nevertheless shaped by Moody's view that the computer was a vehicle to prove the merits of his PNPN trigger circuit. In the end, Florida's efforts to improve the utility of the computer as a tool for scientists meant creating greater circuit complexity to showcase the PNPN trigger.[71]

While the military funded the DRTE computer project as a means of advancng Canadian transistor circuit-design expertise, those working on the computer quickly came to see it as a end in itself. Florida's ambitions would have gotten nowhere had there not been a need for another military computer. To sell the construction of a sophisticated general purpose data processing machine, Florida played on the growing computational bottleneck in Canada's defence laboratories.

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[68] C .D. Florida, *A Non-restoring Method for the Extraction of the Square Root, and it Mechanization*, Defence Research Telecommunications Establishment Electronics Laboratory Report No. 5083-6, February 1959. George Lake, *A Digital Decimal to Binary and Binary to Decimal Converter*, Defence Research Telecommunications Establishment Electronics Laboratory Report No. 1044, 1960.

[69] Lake, *A Digital Decimal to Binary*.

[70] *Fred Longstaff, Gordon Lang, Les Wood, and Ted Strain*, group interview with Ted Paull, 14 August 1984, Computer Oral History Project, National Museum of Science and Technology, Ottawa, Canada.

[71] Though the absence of a good programming environment contributed more to the burden of using the computer than hardware inadequacies, Florida gave scant attention to software development.

From Computer Hardware Development to Computation Centre

In 1954, Canada had only two computers. Both had their origin in military needs: the British-made FERUT at the University of Toronto, and the American-made Computer Research Corporation CRC102A computer at the Royal Canadian Air Force base in Cold Lake, Alberta.[72] These two computers met most of the computational requirements of Canada's defence research until 1955, when the military's in-house defence research and development program started to run up against the limits of this restricted computational capacity.

In the fall of 1954, the Chief Superintendent for the Canadian Armament Research and Development Establishment (CARDE) argued that his department's research simply could no longer rely on using the University of Toronto's FERUT computer.[73] Since the purchase of FERUT, observed the Superintendent, "work in ballistics has shown that heavy computational programmes will become more frequent as Canada's dependence on U.K. and U.S. technical work is reduced, and as Canadian work in armaments matures."[74] Rather than expanding the facilities at the University of Toronto, CARDE wanted to acquire its own computer. Direct access to more computer time was not CARDE's only concern. The scarcity of programmers was another.[75] "The principal value of a local digital computer, in the long run," argued CARDE's Superintendent, "will be the indoctrination of CARDE staff and the training of programmers." It is now obvious," he went on to add, "that one of the main obstacles to the application of computers to scientific and technical work is that scientists do not think in terms of computers

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[72] N. W. Morton, Memorandum: Review of DND Computation Facilities, 30 November 1954, DND, Accession 83-84/167, box 7589, file DRBS-9900-31, pt. 1. By 1956, Canada's aircraft manufacturer A.V. Roe had acquired a CRC102A computer as well, and about ten orders for computers had been placed by various Canadian universities, companies, and government agencies, some of which were again partially financed by the military. See Computation Centre, University of Toronto, *Submission to The Royal Commission on Canadian Economic Prospects*, October 1955, No. 165. Library of Parliament. The world of computational technology was so small in 1955 that it was easy for Dr. Gotlieb, the Director of the University of Toronto Computation Centre, to keep abreast of all activity in Canada.

[73] E. W. Greenwood (for Chief Superintendent of CARDE), Memorandum to Chairman, Defence Research Board: Digital Computer, 20 October 1954, DND Accession 83-84/167, box 7593, file DRBS-9931-05, pt. 1.

[74] *Ibid.*

[75] In a visit to CARDE in October 1954, G. D. Kaye, the head of DRB's Operations Research Group, observed: "The shortage of programmers is the critical point. CARDE are already employing outside programmers, which is expensive, and trying to train their own men as programmers, which is inefficient when the computer for which they are trained is a long way away. It seems to me that purchase of a machine at CARDE would be the best way to remedy this shortage. The mathematicians are there and so are the problems, and experience would be rapidly gained on such a machine." G. D. Kaye, Visit to CARDE - October 15, 1954, DND, Accession 83-84/167, box 7593, file DRBS-9931-05, pt. 1.

except in general as mysterious devices used far away by specialists. Only the availability of a machine directly accessible to the individual scientist will overcome this difficulty."[76]

In the spring of 1956, CARDE acquired the American ALWAC III computer. Within a few months after installing the computer, a Defence Research Board memorandum noted that "even with this increased potential for solution of scientific problems by digital machine methods, facilities are being used at almost full capacity while the computation program has been kept of manageable size only by the exercise of restraint on the part of the larger users."[77] CARDE had been the largest single user of computer time on FERUT. After the purchase of ALWAC III, CARDE's demands on FERUT were reduced considerably.

In CARDE's place, DRTE became the principal military consumer of computational time on FERUT.[78] Much of this had to do with DRTE's intensive research into the problems of military radio communications in the Arctic. Modeling the propagation of radio waves in the ionosphere, which was crucial to Arctic communications, required considerable scientific computation. At the same time, other government defence research laboratories, because of the time-consuming inconvenience of having to deal with the geographically distant University of Toronto, started to ask for their own computational facilities. The Naval Research Establishment (NRE) in Dartmouth, Nova Scotia and the Pacific Research Laboratory (PRL) in Esquimalt, British Columbia, wanted their own computers. As with CARDE, the call for local computational facilities from other defence laboratories was not only a matter of fast and convenient access, but also an expression of the need to expose scientists to this new technology as rapidly as possible.

The Superintendent of DRTE suggested to the Chairman of DRB that "considerable annual savings might be made by establishing computer operating staff in Ottawa to utilize the [DRTE] computer [when built] rather than expand DRB support of the Computation Centre in

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[76] Greenwood, Memorandum to Chairman, 20 October 20, 1954. In addition to training more programmers, a computer on CARDE's premises was also needed to analyze the vast amounts of data generated directly by doppler, radar, kinetheodolite, telemetring, wind tunnel, and V.T. fuze experiments.

[77] A. S. Shore (Grants and Contracts), Memorandum to Chief Superintendents, Superintendents, and Directors: Computation Requirements, 29 October 1956, DND, Accession 83-84/167, box 7589, file DRBS-9900-31, pt. 1.

[78] In a document to Treasury Board's Interdepartmental Committee one finds that DRTE accounted for 40% of computation time for defence research and development purposes. The next biggest user was the Operations Research Group, with 22%. DRB Annual Report 1956: Computation, TB, box 632, file 1501-22.

Toronto."[79] The Superintendent boasted that not only would the DRTE computer represent a significant technical advance over the American Philco transistor computer, but it would also provide superior computational power when compared to FERUT. He also recommended that the proposed DRTE computer play an integral role in formulating DRB's future computational needs.[80] Florida even lobbied to have his machine become the mould from which other medium-sized computers could be produced for wider government service.[81]

After nearly five years of work and $400,000 in R&D investment, the DRTE computer finally went into service in the fall of 1960. Despite Florida's quest for a high performance, scientific computational tool, the DRTE computer still had serious drawbacks when it was put into service. It had a fast parallel memory linked to a slower serial arithmetic unit. There were also crippling input/output bottlenecks. Then as now, fast computation was fine, but if getting data in and out of the computer weres extremely slow, then the computer's utility to scientists was seriously compromised. Even more critical was the question of programming, as little manpower had been devoted to developing any kind of software to encourage use of the computer. From 1962 to 1964, the DRTE computer group designed and installed a new parallel arithmetic unit to replace the serial one, expanded the memory to 4,000 words, built a new magnetic tape system, and developed the circuits and logical design for new punched input-

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[79] James Scott, Letter to Chairman (Defence Research Board), 7 November 1956, DND, Accession 83-84/167, box 7593, file DRBS-9931.11, pt. 1.

[80] For example, in the summer of 1958, David Florida convinced representatives from the Pacific Naval Laboratory (PNL) that copies of the DRTE computer could be made available to other Defence Research Board laboratories. By this time, PNL's management was starting to complain that sharing the University of British Columbia's (U.B.C.) computer was not working out to its satisfaction. In 1957, DRB had paid for an ALWAC IIIE to be installed at U.B.C. in the hope that it would meet the PNL's urgent computational needs. Complaining that PNL had outgrown the U.B.C. computer facilities, the PNL superintendent lobbied to get another copy of the DRTE. Superintendent (Pacific Naval Laboratory), Letter to Chief Superintendent, Defence Research Telecommunications Laboratory, 29 April 1959, DND Accession 83-84/167, box 7593, file DRB-9931.11, pt. 1. But the deal collapsed when DRTE refused to sell the computer at the low price PNL was calling for. PNL offered $60,000, but DRTE wanted a minimum of $106,000. O. A. Sandoz (for Chief Superintendent, D.R.T.E.), Letter to Superintendent (Pacific Naval Laboratory), 8 June 1959, DND Accession 83-83/167, box 7593, file DRB-9931.11, vol. 1.; Frank Davies (Chief Superintendent), D.R.T.E., Letter to Superintendent (Pacific Naval Laboratory), 14 August 1959, DND Accession 83-84/167, box 7593, file DRB-9931.11, pt. 1.

[81] This view was expressed to G.D. Kaye, from DRB's Operations Research Group, on a visit to the DRTE computer group. G. D. Kaye, Letter to Chairman, Defence Research Board, 11 December 1956, DND, Accession 83-84/167, box 7593, file DRB-9931.11, pt. 1. The public record does not allow one to discern if Florida put his group's work to wider application in order to ensure continued funding for his project.

output devices.[82] Work started on the development of an easily accessible, scientific programming language.

These enhancements were still funded under the terms of the project's 1955 mandate. However, from the point of view of "mastering the techniques of applying semiconductors to military problems involving digital computation," the improvements to the DRTE computer were of marginal utility.[83] The continued availability of military funds stemmed instead from the immediate need of a machine to handle DRTE's ever expanding computational requirements. Research in military communications systems, radar detection systems, and satellite technology called for an adequate in-house computation centre.[84] The Alouette satellite project especially called for enormous data-processing capabilities.

From 1961 to 1964, use of the DRTE computer increased by 400 percent.[85] The capacity of the machine had reached its limit. DRTE found itself having to rent additional time on IBM 7090 and 7074 machines which proved to be far superior to the DRTE as the statistics easily proved: in 1964, 1,300 hours of processing time were used on the DRTE computer, while 60 hours were used on two large IBM computers. But because of the superior throughput of these large IBM installations, the amount of actual processing done by these machines surpassed that done on the DRTE computer. The latter, scarcely capable of handling the data generated by the Alouette I project, clearly would not be able to cope with the new ISIS satellite program to which Canada had also committed itself.[86] A new computer was needed.

George Lake, who had helped design and build the DRTE computer, became in charge of the DRTE computation centre when the computer went into service in 1960. In 1965, he estimated that in one year's time, that is, by 1966, DRTE's computational requirements would increase twelve-fold. Convinced that the existing DRTE computer would soon outlive its

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[82] G. T. Lake (for Chief Superintendent, DRTE), Memorandum to Chairman, DRB: Future Research Programme for DRTE Computing Centre, 22 February 1963, DND, Accession 83-84/167, box 7593, file DRB-9931.11, pt. 1.

[83] Progress Report: Research and Development Project D48-99-31-03, 31 December 1962.

[84] In 1963, the administrative pretence ended. The DRTE's Chief Superintendent, Frank Davies, recommended to the Chairman of DRB that funding be approved specifically "to provide a computing service for the establishment and to encourage its use." Frank T. Davies, Memorandum to Chairman of DRB, 28 January 1963, DND Accession 83-84/167, box 7593, file DRB-9931.11, pt. 1.

[85] G. T. Lake, Proposal for a New Computer in DRTE, 29 December 1964, John Chapman Papers, MG 31, J43, box 12, file 17. National Archives of Canada

[86] DRTE had started work on Alouette II. Canada had also committed itself to build four satellites for the ISIS program.

usefulness, he supported the purchase of a large IBM computer. The original DRTE computer continued to play an ever decreasing computational role until about 1967. The following year, this military exercise in digital electronic self-reliance was sent to its final resting place in Canada's National Museum of Science and Technology.

Epilogue

Today, stripped of any historical context, the DRTE computer sits in eerie silence, on display under a spotlight in the museum's dimly lit Computer Hall. Only a nameplate identifies it. On occasion, tour guides point to it and say: "Canada's earliest solid state general purpose computer." They pause, letting the visitors absorb the impact of this revelation, and then, with little to add, they move on to another exhibit. But as one stares at what appears to be a prop from a 1950s grade B science fiction movie, one is tempted to ask: Was there any point to this derelict machine? Linda Petiot speculates that the DRTE computer project may have been "motivated by attempts to create a high-speed, code-breaking machine."[87] "Was information learned at DRTE being passed back to a 'more secret' group doing decoding and encoding work?" she asks.[88] Though she offers little evidence to support her suspicion, the code-breaking scenario does, at first glance, offer a fascinating hypothesis to explain why a computer was ever designed and built within a military laboratory, particularly when, with the availability of commercial machines, the Canadian military had previously decided that the capacity to compute no longer demanded a capacity to build computers. Furthermore, Petiot's hypothesis is reinforced by the computer's close, historic ties to code-breaking.[89] But as this chapter has shown, the origins of the DRTE computer project awere more prosaic than Petiot's cloak-and-dagger scenario.[90] Although less dramatic than Petiot's suggestion, when cast into a broader technical, industrial, political, and

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[87] Linda Petiot, Dirty Gertie: The DRTE Computer, *IEEE Annals of the History of Computing* 16 (Summer 1994): 43-52. This article offers the reader a good overview of the DRTE computer's architecture and operational specifications.

[88] *Ibid.*, 50.

[89] Colossus, the first digital, electronic, information-processing machine built in Britain, was specifically conceived for code-breaking. Colossus's wartime success in breaking the German Enigma code provided the Allies with an invaluable strategic advantage. After the war, the computer became the essential tool for code-breaking.

[90] Despite an exhaustive examination of the primary sources, this author was not able to uncover even the smallest shred of evidence to substantiate Petiot's suggestion.

military context, the DRTE computer takes on more historical significance: the material artifact of Canada's unprecedented flirtation with military self-reliance and the ancillary pursuit of a capacity to design on the leading edge of technological change.[91] Simply put, the DRTE computer's purpose was to move Canada's electronic miniaturization know-how rapidly up the global innovation wave. In the process, the DRTE computer contributed to Canada's early emergence as an international leader in satellite communications technology.

The imperative to deal with the rapidly rising complexity of electronics used in weapons systems, which was sustained by ambitions of self-reliance, led the military to think of ways in which it could promote a domestic capacity to miniaturize. While complexity was a widespread problem in military design, it promised to be particularly crippling to the development and deployment of digital electronic military applications. As the DATAR story reveals, the military's abandonment of indigenous computer R&D in 1952 as a way of assuring access to data processing equipment did not extend to the broader area of digital electronics. But without reliable miniaturization, Canada's future ability to apply digital electronics in its weapons development program would be nonexistent.

Offering potentially dramatic advances in miniaturization, the nascent transistor became a new element in the military's perception of self-reliance. Faced with an electronics industry that was unable to champion the transistor, Canada's military grappled with how to get the nation more quickly up the transistor learning curve. With the limitations of Canada's small economy, self-reliance in all aspects of transistor innovation wave was impossible. Instead, the Canadian military tried to foster the capacity to design with transistors rather than to manufacture them. Moody's Transistor Section became the pole of innovation diffusion. From DRB's perspective, the ultimate rational for building the DRTE computer was to create a national expertise in digital electronic miniaturization that could bolster Canada's peacetime military preparedness.

Did the Transistor Section prove an effective source of innovation diffusion? From the point of view of computer technology, the answer is a categorical no. As a computational tool, the computer never found application beyond DRTE's walls in Ottawa. Florida's predilection for hardware sophistication, reinforced by the military's experimental mandate, served to lengthen

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[91] In fact, it may well be the only physical symbol of this flirtation still in existence. UTEC was turned to scrap, as was DATAR. The AVRO Arrow was systematically and purposely dismembered into minute unrecognizable parts. As with the destruction of any heroic icon, legends persist that one AVRO Arrow was secretly saved from government destruction by the plane's followers, and waits for the right day to emerge from hiding and reassert Canada's lost technological promised land.

the project.[92] By the time it was ready, the developments in the computer industry had removed any of the technical advantages the DRTE computer may have had. Perhaps if the computer had been completed by the end of 1957, as DRTE's Superintendent, James Scott, had confidently predicted to the Chairman of DRB, the diffusion of this technology within government operations might have met with some success.[93] Once this window of opportunity was lost, the price tag for DRTE's transistor computer technology became too high to attract government users away from commercial systems.

Throughout the life of the DRTE computer project, there was little collaboration between the Florida team and other groups in Canada working in computer technology. There is no evidence to suggest that the DRTE group during its design of the computer ever interacted with the University of Toronto Computation centre. In the period from 1956 to 1960, when Ferranti-Canada represented Canada's most advanced computer design group, no technology flowed from Moody's government laboratory to this company. While Moody sang the praises of his novel PNPN techniques, Ferranti-Canada continued to develop DATAR with the more expedient Philco techniques based on the SB-100. While Ferranti-Canada believed the PNPN to be too complex, Moody argued that Ferranti-Canada's Philco based techniques were unreliable.

Having neither advanced the general state-of-the-art of computer technology nor transferred any computer design expertise to industry, did the Transistor Section nonetheless succeed in some way in accelerating the ascent of Canada's industry up the transistor learning curve? Whether it successfully diffused fundamental circuit techniques to industry cannot be answered from the known public record, but there is no doubt that DRTE played an important role in raising the defence contractors' awareness of the transistor. The industrial trainee program that brought engineers from Canada's electronics industries into Moody's Transistor Section was a clear attempt to facilitate the transfer of technology from government laboratories to corporate product development. The success of this training initiative has still to be evaluated. How long did this program last? How many engineers were involved? From which companies did they

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[92] Fred Longstaff, the central figure in Ferranti-Canada's computer design team and Florida's contemporary, later recalled thinking that DRTE group "was building too much fanciness into the hardware than was viable at that time....For example [Florida] was building a square root as an instruction, not even a modern computer does that now. There is a sub-routine for it." *Fred Longstaff, Gordon Lang, Les Wood, and Ted Strain*, group interview with Ted Paull, 14 August 1984, Computer Oral History Project, National Museum of Science and Technology, Ottawa, Canada.

[93] Scott, Letter to the Chairman, Defence Research Board, 7 November 1956, DND, Accession 83-84/167, box 7593, file DRBS-9931.11, pt. 1.

come? What was the nature of the transistor know-how taken back to the company after the training? Did these trainees become effective champions of the transistor within their respective companies? A great deal more evidence and research is needed at the corporate level before one can even start to answer these questions.

Yet, despite its defects, DRTE's experimentation with solid state digital electronic techniques and the construction of the computer did play an important role in shaping the rhythm and direction of technological change in Canada. This digital transistor work contributed to Canada's ability to become the third nation in the world to design and deploy complex electronic satellite systems. From the outset, military enterprise drove Canada's interest in space and satellite technology. The Transistor Section supported the military's interest in space. In other words, this government laboratory bolstered public enterprise more than it did private enterprise.

The military's interest in space-related research arose from two distinct sources: remote sensing and the very unique problems of radar and Hertzian communications in Canada's northern latitudes. The first time DRTE computer group's know-how contributed to the study of these problems was in 1958. That year, Canada's military decided to launch a research program into the effects of the ionosphere on the detection of missiles launched from the Soviet Union. For this project, a two million dollar radar unit,[94] borrowed free of charge from the United States Air Force, was refitted with specially designed equipment and installed in a new facility in Prime Minister John Diefenbaker's riding of Prince Albert, Saskatchewan.

Preprocessing the vast amounts of data that the Prince Albert Radio Laboratory (PARL) was to receive called for fast parallel core memory facilities. The development of the digital electronics to drive this memory relied on exploiting the advantages of Moody's PNPN structure. Richard Cobbold, who was part of Florida's team in designing this memory, faced the challenge of having transistor circuits deliver one-half ampere currents at very fast speeds, in the order of a microsecond. Here again was Moody's favourite inventive challenge: to develop a high-speed trigger circuit that could also reliably produce high currents. The solution of this problem led Cobbold and Moody to patent a new monostable trigger circuit based again on the complementary PNPN transistor pair.[95] In building the two 40,000 bit core memory units for

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[94] Doris Jelly, *Canada: 25 Years in Space* (Montreal: Polyscience Publications, 1988).

[95] "The limitations involved with using either saturated or unsaturated switching circuits are firstly, that unsaturated circuits are limited to current output which they can sustain although switching time is quite slow fast; and secondly, that saturated circuits, while providing adequate current output, are very slow to switch from the

(continued...)

PARL, Cobbold also patented innovations that simultaneously overcame limitations in the performance and manufacture of core memories.[96]

On 6 June 1959, at the inauguration of PARL, Diefenbaker received greetings from American President Dwight Eisenhower. The historic moment marked the first satellite communication in the world. The radio message was transmitted from the United States into space where it bounced off the moon, and back to Canada. The irony of the ceremony lay in the fact that Diefenbaker had killed the AVRO ARROW, an icon of Canadian technological self-reliance, but with the inauguration of the PARL he inadvertently participated in the creation of a new icon: Canada's entry into the space age and satellite communications. The launching of Alouette I on 29 September 1962 made Canada the third nation into space, after the United States and the Soviet Union. The top-side sounding experiments carried out by Alouette I were an extension of PARL's earlier mandate: to understand how ionospheric disturbances, unique to Canada's far north, affected electro-magnetic-based communications and detection systems.

Not only did the DRTE computer play a vital role in processing the data from Alouette, it was also the knowledge and techniques gained in designing the computer's transistor circuits that helped to build this satellite. Minimizing payload size and weight was essential. And once a satellite was launched, there was little one could do about improperly-operating circuits. Since miniaturization and reliability were critical elements in the design of satellites, the considerable expertise in silicon transistor techniques developed by Moody's group proved a timely and

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[95](...continued)
conducting to the non-conducting state. The present invention combines the high-switching speed of the unsaturated circuit with the high current output of the saturated circuit using controlled saturation." From Norman Moody and Richard Cobbold, *Monostable Transistor Switching Circuit*, Canadian Patent no. 636,768, filed 1959, issued 1962, 2. This patent built on the monostable device described in Norman Moody and David Florida, *Monostable Two-State Apparatus*, Canadian Patent no. 595,885 filed 27 April 1957, issued 12 April 1960.

[96] "The voltages induced in the read-out winding by the half-excited cores on the selected lines did present a problem, as these 'disturb' voltages are additive and may mask out the desired read-out signal, particularly in large arrays. Direct pick-up from the exciting windings also adds to the disturbs." J.A. Rajchman, "Computer Memories: a Survey of the State of the Art," in Proceedings of the Institute of Radio Engineers 49 (January 1961): 104-127, 108. The most common approach to this problem was to thread the read-wire by zig-zagging back-and-forth diagonally through the core. The idea was to have the small disturb voltages cancel each other rather than reinforce each other. In a survey of memory technology, Jan Rajchman concluded in 1961 that this "cancellation [was], in general, not a sufficient remedy to the problem of disturb voltages," *Ibid.*, 100. The threading precision needed to minimize the disrupt voltage was, from the production side, very time consuming, and from the technical side, not completely satisfactory. Cobbold's idea to thread the read-wire to the drive wires eliminated the disrupt voltage problem completely. See Richard Cobbold, *Magnetic Core Memory*, United States Patent no. 2,995,733, filed 1959 issued 1961. See also "Discovery Improves Computers," *Financial Post*, October 1959. R. S. Cobbold, "Novel Magnetic Core Memory," *Electronic Equipment Engineering* 8 (February 1960): 73-79.

valuable experience for DRTE's subsequent work on satellite electronics.[97] Alouette's electronics designers had collaborated closely with Moody's group. Colin Franklin, for example, who spearheaded the design of Alouette I's electronic systems, had worked with Moody and others in the Transistor Section to develop miniaturized, self-contained navigational systems for use by Canada's fighter planes in the Arctic.[98]

Alouette I became the starting point of an ambitious Canadian space program. Alouette I was followed by Alouette II. After leaving the DRTE computer project, David Florida led the ISIS I and II satellite projects. When the Department of Communications was formed in 1969, it took most of DRTE's satellite R&D people, along with the electronics expertise that had grown out of the earlier transistor work. Under the Department of Communications, Canada launched the Hermes satellite in 1975 as one of the earliest experiments in direct broadcasting. Canada later led the way with MSAT, a mobile communications satellite, and RADARSAT, one of the world's most advanced remote sensing satellites.

Of course, one can exaggerate the contribution the contribution of the Transistor Section's early experimentation on silicon transistor, digital circuit techniques to Canada's subsequent space program. Nevertheless, it is clear that the Transistor Section did serve as an important pole of technical knowledge diffusion within military enterprise, and did help Canada move up the transistor innovation wave. Among the principal heirs of technical knowledge acquired by DRTE's early transistor research was the Department of Communications and the civilian-based space program which helped Canada move up the transistor learning curve. DRTE's experimentation with the use of transistors in digital electronics was another important facet of how military enterprise promoted the creation of a national core of experts who in turn

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[97] The same reasons that made silicon the semiconductor material of choice by the military -- resistance to heat and radiation -- also made it ideal for space electronics.

[98] With a good portion of Canada's Arctic beyond radio range, the Canadian military was interested in developing self-contained navigational equipment for its long range fighter aircraft. Furthermore, it was reasoned that any self-contained system would not be vulnerable to enemy radio jamming. The development of a lightweight transistor system made deployment of such equipment feasible. Working with other sections of DRTE(EL), Moody's group played a leading role in the development of a self-contained airborne navigation system. A good deal of work went into applying transistors to Doppler navigational radar and analog computation. However, this hybrid system also integrated a digital-based positional computer to the analog electronics. A patent was taken out for the electronic analog computational sub-system. See R .K. Brown, N. F. Moody, P. M. Thompson, R. J. Bibby, C. A. Franklin, J. H. Ganton, and J. Mitchell, "A Lightweight and Self-contained Airborne Navigational System," Proceedings of the Institute of Radio Engineers 41 (May 1959): 778-807. Bibby, Franklin, and Florida were also key engineers in the development of Alouette II and the ISIS satellite program

kept the digital electronic revolution within Canada's reach.[99]

Though the DRTE computer project helped Canada jump on the transistor innovation wave at a relatively early stage, it did little to help Ferranti-Canada develop and sell solid state computers. No technology transfer between Moody's government laboratory and Ferranti-Canada's computer design team was possible when both groups were entrenched in different transistor circuit philosophies. As the next chapter reveals, cut off from military funding by the collapse of DATAR, Ferranti-Canada funded its way up the solid state computer learning curve by adroitly exploiting opportunities created by civilian public enterprise.

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[99] The legacy of the DRTE digital transistor work also reached out into the nation's medical research. In 1959, just before the installation of the DRTE computer, Moody and Cobbold left DRTE and took the wealth of their experiences to the University of Saskatchewan. It was no coincidence that the Dean of Engineering at the time was Arthur Porter, the man who headed up Ferranti-Canada's work on DATAR. Porter had asked Moody to head up the Department of Electrical Engineering. Together, Moody and Cobbold turned their knowledge of transistor electronics to, among other things, the problems of medical research. Moody then went on to became Director of the Institute of Biomedical Engineering at the University of Toronto. Cobbold again followed his mentor, and later he also was to become the Director of the Institute. Moody and Cobbold became the nucleus around which research in the use of digital electronics in biomedical engineering developed at the Institute. By this time, microelectronics had replaced discrete transistors with integrated circuit silicon chips.

Chapter 5

Moving the Mail and People: Civilian Public Enterprise Encourages Domestic Digital Electronic R&D

The demise of DATAR symbolized the military's post-Korean War retreat from the high cost of technological self-reliance. As the Royal Canadian Navy's ambitions to develop its own digital electronic warfare systems stalled and then collapsed, Ferranti Canada scrambled to keep its digital electronic group employed. One part of the group went into electronic nuclear instrumentation. The digital computer expertise built up during the DATAR project, however, perched precariously on the edge of a precipice. Unless Ferranti Canada could find immediate civilian opportunities to underwrite further computer research and development (R&D), this critical mass of digital electronic engineers would disintegrate. This chapter explores how Ferranti Canada exploited civilian public enterprise to sustain computer R&D at the critical moment when military enterprise pulled away. An important theme in this chapter is that the interplay of Ferranti Canada's computer ambitions with the automation agenda of two public enterprises - Canada Post and Trans-Canada Airlines -- shaped the face of innovation.[1]

The Politics of Moving the Mail: Opportunities for Digital Electronic Innovation

At the start of 1951, a climate of severe federal government fiscal restraint created an opportunity for digital electronic innovation within the Canadian Post Office Department. As one of the largest government employers, the Post Office became a prime target in the Liberals'

[1] In a corporate history of Ferranti Canada, Ball and Vardalas briefly discussed the Post Office and Trans-Canada Air Lines computer projects Ball and Vardalas, *Ferranti-Packard.* Their study, however, did not explore in any detail the circumstances of why and how these two public enterprises supported new technological developments. Neither did they examine the interplay between Ferranti Canada's own technological ambitions and those of these two public enterprises. Such a wider and deeper elaboration is the purpose of this chapter.

program to slash 10 percent of the public service.[2] The letter carriers were the first victims. Twice-a-day mail delivery became once-a-day, and one thousand jobs were eliminated.[3] The Opposition, which had for so long attacked the Government's inability to reduce expenditures, now criticized the Government for trying to destroy this vital national institution. The public wanted cost-cutting but was unhappy when its cherished twice-a-day mail delivery ended.

Criticism that the Government's elimination of twice-a-day home delivery would slow the mail was not only blatant political opportunism, but also misplaced. The real bottleneck in mail service did not arise from the reduced frequency of home delivery. Rather, delays in sorting the mail for the carriers were the primary source of slow service. The delays arose fromm the physical process of manual sorting, which consisted of men standing before an array of pigeon-holes, reading the addresses, then placing each letter into the appropriate hole; and from the sorters' mental burden of having to memorize a very large number of geographic-based sorting distinctions. These physical and mental obstacles placed important limitations on the volume of mail a labour force of a given size could process in a day.

The constantly-growing volume of mail, coupled with intense postwar urbanization and suburbanization, were undermining the efficacy of manual sorting methods.[4] The continual redefinition of geographic sorting distinctions, arising from postwar growth, pushed the mental burden of sorting to its limits.[5] In forward sortation, the postal workers had to memorize the relationship between Canada's 13,000 agglomerations and the transportation system that served them. As the landscape of towns changed and new transportation routes were established, postal

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[2] See comments from James Sinclair, the Liberal member of parliament from Coast-Capilano. Canada, House of Commons, *Debates*, Fifth Session - Twenty-First Parliament 1951, (Ottawa: The Queen's Printer, 1951), 15 December 1951, 1990.

[3] Work force reduction figure cited by the Postmaster General, Gabriel Rinfret. See Canada, House of Commons, *Debates*, Fourth Session - Twenty-First Parliament 1951, (Ottawa: The Queen's Printer, 1951), 15 December 1951, 3899.

[4] The total number of pieces of first-class mail that the Canadian Post Office handled for the years 1948-49, 1949-50, 1950-51, 1951-52, and 1952-53 is 1,287,556,498, 1,321,172,583, 1,412,252,979, 1,413,988,068, and 1,518,279,701 respectively. See *Report of the Postmaster General*, for each of the years in question. Similar figures for earlier years are unavailable because volume of business was measured by weight. Joseph Noseworthy brings up the issue of the increasing resignations in the Toronto area. Canada, House of Commons, *Debates*, Fourth Session - Twenty-First Parliament 1951 (Ottawa: The Queen's Printer, 1951), 30 May 1951, 3562.

[5] An indication of the postwar boom in construction can be gleaned from the statistics on "dwelling starts." Five years after the end of World War II, the number of dwelling hit historically unprecedented highs. The 91,600 starts were easily double those of the 1920s, 1930s and war years. During the 1903 to 1913 boom years and the massive immigration that accompanied them, dwelling starts never went beyond the 60,000 and that was only for a few years. *Historical Statistics of Canada*, ed. F. H. Leacy and M. C. Urquhart (Ottawa : Canadian Government Publishing Centre, 1983, Second Edition), Series S198-202.

clerks struggled to keep pace with the ensuing sorting revisions. The rapidly evolving landscape within large cities, engendered by postwar growth, was even more problematic for sorters. In "city sortation," which was a physically distinct process from "forward sortation," the sorter had to memorize the addresses served by each letter carrier. Deciding on which letter carrier's "walk" a letter should be assigned was not at all evident from the address. In Toronto, for example, there were 700 walks covering 10,000 distinct city sections. A walk could consist of just one building, limited sections of primary streets, and/or entire secondary streets. "With the constant growth of population in Canada and the expansion of buildings," observed one Post Office Department expert in the early 1950s, "the strain on the sorters is increasing and officials fear an ultimate breakdown."[6]

One obvious solution would have been to employ more sorters. But in a climate of downsizing, this option was not politically acceptable. Automation, if less costly than labour increases, was the preferred solution. Technology did exist to increase the physical reach of each sorter. Purely mechanical devices allowed the sorter to place mail into several hundred pigeon holes as opposed to the maximum 108 then being used for manual sorting.[7] This technology did nothing, however, to alleviate the critical memorization bottleneck. If anything, it exacerbated it.

In December 1951, a bold automation plan that seemed to address the memory issue percolated up from an unlikely source within the Post Office bureaucracy. O. D. Lewis, a senior clerk within the postal bureaucracy in Ottawa, looked around and saw the great productivity gains and efficiencies that mass production had wrought in industry.[8] For Lewis, the road to

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[6] Maurice Levy, "The Electronic Aspects of the Canadian Sorting of Mail System", reprinted from the *Proceedings of the National Electronics Conference*, 10 (February 1955), 3. The breakdown lay at urban nodes on Canada's postal distribution system. In 1952, for example, Canada's seventeen largest cities processed over 70 percent of the nation's mail. "Thinking Machine Will Speed Mail", *Popular Science* (October 1953): 114-7. Of this volume, 50 percent was destined for distribution within each urban centre. City sortation was thus the most time-consuming and costly phase of sorting mail. O. D. Lewis, Memorandum to W.J. Turnbull, 29 January 1952. Records of Canada Post, RG 3, Accession 90-91/257, box 274, file 78-2-10 pt. 1. National Archives of Canada. Henceforth, the Records of Canada Post, RG 3, will be designated as PO. Postal workers underwent considerable training and testing to learn the details of their particular sorting task. With every new office building or housing development came modifications to the boundaries of a letter carrier's walk. Relearning new geographical distinctions was time-consuming and created important bottlenecks in mail processing. Another important limitation to postal efficiency was the time-consuming process of having to learn and relearn sorting categories. Keeping up with change proved quite stressful for shift workers.

[7] "Electronic Mail Sortation," *The Postmark* (September-October 1960): 8-9, 15, 20.

[8] Other than being a "Clerk, Grade 4" in 1951, very little is known about O. D. Lewis. In 1952, Lewis was promoted to "Administrative Assistant." Director of Organization and Classification (Civil Service Commission), Memorandum: Reassignment and provision of a terminable allowance for Mr. O. D. Lewis, 16 October 1952. PO,

(continued...)

more efficient, cheaper mail sorting was clear: embrace Fordism.[9] But until one could overcome the reliance on the sorters' memory skills, the logic of the assembly line held little value to the Post Office. Lewis had no formal, or informal, technical experience. Yet, the technological frontier of postwar electronics had seized his imagination. He was convinced that the miracle of electronics could eliminate the postal services' dependency on human memory, and thus clear the bottleneck in the Post Office's sorting operations.

Lewis looked to IBM's card technology for inspiration. Why, Lewis asked, could not technology capable of processing pencilled-in cards and questionnaires at very high speeds not sort mail?[10] If one could "read" addresses electronically, Lewis reasoned, then one could sort mail "without human direction." Realizing that reading handwriting electronically at high speeds was an impossibility, Lewis suggested representing the address as "a code of vertical bars [using conductive ink] on the back of the letter. Or if a virtually colourless conductive marking fluid could be developed then the front cover could be used."[11] In Lewis's mind, once the bar-coded translation of the address had been read electronically, the appropriate gates could then be actuated directly to sort mail, from a high speed conveyor system into the appropriate destination bin. The Government's push to reduce non-defence expenditures, the growing inability of postal workers to keep up with the volume of mail, and mounting Opposition criticism, made the Deputy Postmaster General, William J. Turnbull, receptive to this clerk's adventurous idea.[12] Turnbull also knew nothing of technical matters. Yet Lewis's tale of moving greater volumes of mail at less cost started to resonate with ever growing intensity in Turnbull's mind. Lewis's

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(...continued)
Accession 90-91/257, box 275, file 78-2-10 pt. 2.

[9] At Adamson's request for written elaboration, Lewis prepared a four page memorandum outlining his ideas. Adamson was a superintendent in the Post Office Department and Lewis's superior. O. D. Lewis, Memorandum for Mr. Adamson, 4 December 1951, PO, Accession 90-91/257, box 275, file 78-2-10 pt. 2.

[10] Everyone is familiar with the examinations where one chooses the correct answer by filling in, with pencil, the appropriate space. The existence of a mark is noted when a current is produced as a small metal brush passes over the mark. The detection occurs because the marking can conduct current.

[11] Lewis, Memorandum for Adamson, 4 December 1951

[12] This receptivity was no doubt shaped by the growing political, very public attacks on the post office's efficiency. For example, a few days after the Christmas of 1951, George Drew, the Leader of the Opposition, seized on the public's heightened sensitivity to mail delivery during the holiday season to attack what he saw to be the accelerated decline in the efficiency of Canada's postal service. Demanding to know why it took a week for mail delivery between Toronto, Ottawa, and Montreal, Drew reminded the Government of the important place that efficient postal services had come to occupy in our whole economic and social structure of the nation. Canada, House of Commons, *Debates*, Second Session - Twenty-First Parliament 1951, 29 December 1951, (Ottawa: The Queen's Printer, 1951), 2511.

assertion that "a good half of the existing sortation staff would be displaced by [his proposed] machines" surely made an impression on Turnbull. Exploiting obvious gender bias in wages, Lewis added that "their salaries would be replaced by a series of lesser and lower wages for typists."[13]

Investing heavily in new technology to achieve productivity gains and savings in labour costs made economic sense only because of the existing economies of scale and geographic concentration in Canada's mail sorting operations. Sixty percent of the nation's three billion pieces of annual mail were sorted in just ten processing stations.[14] This concentration also had important political consequences. Despite the vociferous protests from the rural areas calling for equal postal services for rural communities, over 75 percent of complaints aimed at the post office came from large cities.[15] Urban needs drove the economics and politics of mail service. The most difficult, time consuming, and costly task in each of these ten stations was the sorting of mail for local, city delivery. Investing in technology to reduce the time that mail lingered in these urban centres made good political sense.

Lewis and Turnbull quickly discovered the gulf between a vague technological desire and implementation. When Turnbull and Lewis looked to Europe and the United States to see if anyone had developed any electronic mail sorting system, they came up empty-handed. Lewis's assumption that "the basic devices required for [an electronic sortation] machine are already in existence and patented" proved naïve. Few if any of the existing patents directly addressed the specifics of designing fast and standardized methods of encoding postal addresses. Neither did they offer any useful designs for address-code printers and reliable readers capable of scanning the coded envelopes accurately at high speeds. The question of how the bar-coded address information, once read, would determine the appropriate sorting decision remained untouched.

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[13] O. D. Lewis, Memorandum to W. J. Turnbull, 9 February 1952, PO, Accession 90-91/257, box 274, file 78-2-10 pt. 1. Since no electronic system could read handwriting at high speeds, someone was needed to read the addresses and type them into an apparatus that would then print the corresponding bar codes onto the envelope. Typing required little if any decision-making. The typist did not have to memorize complex geographic grids. For this redefinition of the labour process to be effective, the act of typing each address had to be a faster than the mental act of sorting it. Lewis suggested, after some rough calculations, that "150 lower paid typists could do in four hours, the work that 160 higher paid sorters did in eight hours." *Ibid.*

[14] Walter Turnbull, Deputy Postmaster General, Transcript of radio address, Recorded at CARTE Radio Bureau, on 28 February 1957, CP, Accession 86-87/402, box 33, file Publicity 1953-57.

[15] Turnbull, Radio Transcript, 1957. Criticism of postal services in Parliament reflected this crucial urban dimension. Criticism of the Post Office was undertaken by those members of Parliament representing the fast growing metropolitan areas, such as York West and York South, which comprised the Toronto metropolitan area, and Montreal.

How would a machine know to which sorting category, from thousands upon thousands of choices, a given coded address belonged?

In 1952, the world had no off-the-shelf solutionsfor the Post Office's automation needs. Turnbull was unwilling to wait for the right technology to be created and proven elsewhere in the world. He had the bureaucratic astuteness and courage to gamble large sums of money on this risky enterprise.[16] But he needed someone capable to give this ambition the technical foundation it lacked. He turned first to Canada's most respected public R&D organization, the National Research Council, but discovered that it had little to offer.[17] Turnbull's search came to end when Dr. Maurice Moise Levy unexpectedly quit Canada's Defence Research Board in order to set up an R&D group at Federal Electric Manufacturing Co. (FEMCO), a Canadian affiliate of International Telephone and Telegraph (IT&T).

While FEMCO itself was located in Montreal, Levy's group was located in Ottawa to pursue federal government contracts. It was in within this context that Levy learned of Turnbull's interest in electronic mail sortation.[18] No sooner had Turnbull met Levy in April 1952, the Deputy Postmaster General asked him point-blank: "Can you do electronic sorting of mail by putting code marks on envelopes?"[19] Without hesitation Levy replied, "Yes." The extent of Levy's scientific achievements, IT&T's acknowledged experience in automated mail-sorting, as well as the weight of IT&T's vast technical resources, gave this affirmation considerable credibility.[20] If Levy could put a sound and practical R&D proposal on the table, Turnbull was ready to push it through. During the next three to four months, Lewis and Levy fleshed out a detailed contract proposal. Lewis provided the know-how on postal operations and needs. Levy

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[16] At the age of nineteen, Turnbull joined the federal civil service as clerk in the post office. By the age of 27, Turnbull managed to get a new position created for him as the Post Office Department's first Head of Public Relations. Then in 1936, Turnbull came to the attention of the recently elected Prime Minister, William Lyon Mackenzie King. For the next nine years, until the end of World War II, Turnbull worked as King's principle secretary. In 1945, Turnbull wanted to return to the Post Office. As a reward for loyal and excellent service, King saw to it that Turnbull was named Deputy Postmaster General.

[17] After visiting with National Research Council officials, Lewis concluded that they could not take on the problem O. D. Lewis, Memorandum to W. J. Turnbull, 29 January 1952, CP, Accession 90-91/257, box 274, file 78-2-10 pt. 1.

[18] Whether Levy found out about the Post Office's automation ambitions through the grapevine, or through Lewis is not known. Furthermore, it is not clear if Levy went directly to Turnbull, or was introduced by Lewis.

[19] Levy's recollection of the incident is taken from Levy, Memorandum to Boyd, 19 March 1954. Levy wrote that he was surprised that Turnbull was already thinking along these lines. But he failed, or refused to recognize, that Lewis had already sparked interest in this issue some four months earlier.

[20] IT&T had already designed and built the "Transorma," the mail sorter prototype for the Belgian postal authorities.

was the scientific and technical expert. By the end of May 1952, Levy had cast the notion of electronic mail sorting into a comprehensive design paradigm.

Levy was quick to have IT&T lawyers examine the potential for future patentable ideas from the Canadian postal proposal.[21] He discovered, one can assume to his dismay, that the general idea of using coding marks to sort electronically was far from new.[22] A dozen or more patents, some going back to the 1930s, had laid claim to many of the facets surrounding this broad concept. Laying claims to a principle, however, was a lot easier than building a useful prototype. Few, if any, of these patents offered any concrete solutions to the array of formidable technical problems specific to mail sorting. Many of these patents presupposed very tightly controlled conditions for code reading that could not be realistically created in postal operations.[23] An efficient and economic sorting technology, adapted to the realities of postal operations, would require considerable R&D. Levy was convinced that there was still important patentable territory to claim.[24]

The most novel aspect of Levy's approach to mail sorting was to convert the scanned

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[21] J. D. Stewart, Letter to R.P. Morris, 8 July 1952, Maurice Moise Levy Papers. Dr. Levy donated many of his personal papers to this author. After using these papers for this thesis, I hope to find a suitable public archival home for these papers. Henceforth these papers will be referred to as Levy Papers.

[22] In 1936, IBM had patented claims surrounding mail coding and sorting. See Ayres et al., U.S. Patent 2056382. 6 October 1936. But these were quite narrow. IBM's bid to win very broad patentable rights to the idea had failed. J.D. Stewart, a Washington, D.C. based patent lawyer wrote back to IT&T representative, R. P. Morris, in New York, that IBM tried and failed to expand its 1936 patent to include a "method of sorting mail in accordance with postal districts which comprise marking parcels of mail with code indications in accordance with various postal districts, analyzing the code markings with a light sensitive device and distributing the articles to various sorting machines under the control of an analyzing device." The claim, according to Stewart, was refused because the U.S. Patent Office felt that a combination of older patents dealt with the general idea of marking and sorting. Stewart, Letter to R.P. Morris, 8 July 1952. Westinghouse had already obtained marking and sorting patents which they used in a commercial billing system sold to electrical utilities. Electrical bills were sent as postcards, on which was also printed, in a coded form, the customer's address. When the customers mailed their payments, they inclosed the card. Then for the purposes of recording and statistical compilations, the utility passed the cards through special sorters. Friedman had a patent on bar-code scanning. U.S. Patent no. 2,224,646. IBM. had also obtained a wide range of patents dealing with the use of photoelectric techniques to sort cards. See U.S. Patents 1853443, 2000403, 2000404, 285296, 2231494, 2268498. GE had patented the idea of scanning fluorescent markings, which were invisible to the human eye, by means of ultraviolet light for identification purposes. See Short, U.S. Patent no. 2,593,206.

[23] In IBM's 1936 patent, Levy noted, one could not make allowances for errors in placement of the code on the envelope or in the position of the envelope relative to the reader. The patents on fluorescent reading assumed a tight control on the paper's colour. But these conditions did not exist in the world of postcards and envelopes. Great variations in colours and the possible intermingling of printed or handwritten characters with the flourescent marks made reading unreliable. Levy concluded that "all pertinent patents described very elementary systems which cannot give any reasonable performance or do not satisfy Post Office requirements." Maurice Levy, Memorandum, 24 September 1952, Levy Papers.

[24] The generic idea of coding and electronic sorting was not new. Nevertheless, there was still some latitude of originality because the Canadian letter sorting scheme did not infringe on any patents. Stewart, Letter to Morris, 8 July 1952.

coded address into binary information and to use a digital memory to store every minute, sorting distinction.[25] Previous approaches to electronic sorting used the analog output signal from scanning to activate the appropriate mechanical sorting gates directly. Given the complexity of postal sorting decisions and the need to alter constantly the geographic distinctions for sorting, the prior state-of-the-art was limited, inflexible, and cumbersome. Flexible sorting, in Levy's mind, required that binary address information be compared to routing information in memory. Once a sorting decision was made, the memory could then know which mechanical switches to activate in order to route the letter to the right sorting bin. Memory had the marvellous advantage of being easily updated every time changes in sorting categories were needed.[26]

The Federal Electric Manufacturing Co. (FEMCO) pushed Turnbull and the government to sign a $100,000 contract for a detailed engineering study.[27] Convinced of the need for radical innovation, Turnbull nevertheless still needed more assurance that Levy's approach could produce a usable technology. When Turnbull turned to Canada's National Research Council (NRC) for guidance, its president, Dr. Steacie, claimed "that almost anything could be done with the aid of electronics."[28] B. G. Ballard, the Director of the NRC's Radio and Electrical Engineering Division, provided more useful assurance. After a thorough analysis of the Levy-FEMCO proposal, Ballard concluded that the proposal was sound and that such a machine could be developed.[29] Whether $100,000 would suffice to build a prototype depended, according to Ballard, on the sorting speeds required.[30]

Increasing Opposition criticism of the postal service pushed Turnbull to act. Conservative Joseph Noseworthy underscored the sorters' inability to keep up with the growing

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[25] IT&T's American patent lawyer admitted the originality of the idea, but he felt it could never be patented.

[26] It is ironic that the conversion of the code to binary data and the use of a digital memory, the two most novel features of Levy's proposal, were not in themselves patentable. See opinion in Stewart, Letter to Morris, 8 July 1952.

[27] T. P. Leddy (Vice President, Federal Electric Manufacturing Co.), Letter to W. J. Turnbull, 15 May 1952, Levy Papers.

[28] Cited in E. J. Underwood (Acting Deputy Postmaster General), Letter to R. B. Bryce (Assistant Deputy Minister, Department of Finance), 9 June 1952, Levy Papers.

[29] B. G. Ballard, Letter to O. D. Lewis, 16 June 1952, Levy Papers. No copy exists of the Technical Proposal written by Levy and presented by the Federal Electric Manufacturing Co. to Turnbull. However, a detailed summary of this proposal can be found in OD Lewis's memorandum to E. J. Underwood. This summary accompanied the post office's request (See Underwood, Letter to Bryce, 9 June 1952) to the Finance Department that a $100,000 be allocated, in 1952-53, towards the development of an electronic mail sorter prototype.

[30] Electronics itself was not the issue. Rather, it was the importance of precisely controlling the aerodynamic forces which would affect letters as they moved at very high speeds.

volume of mail.[31] Stress and uncompetitive wages were producing resignations in Toronto, Canada's largest sorting station. These staff losses only made the problems of moving the mail worse.[32] To counter the growing criticism, Postmaster General Alcide Coté proclaimed to a Calgary audience in July 1952, that the Post Office was going to introduce "electronic marvels to sort the mail, instead of it having to be sorted by fallible hands."[33] The *Calgary Herald* was not impressed. Scientific marvels, the newspaper feared, could do little "to change the three or four days it sometimes takes Mr. Coté and his considerable staff to deliver a letter which is mailed within, and directed to an address within the Calgary city limits."[34] Still, with the electronic sorter now in the public and political arena, Turnbull had to move quickly. But before the Post Office Department could sign the deal with FEMCO, IT&T fired Levy.[35] Having come to identify the electronic sorter with Levy the man, rather than with IT&T the corporation, Turnbull dropped FEMCO and instead immediately hired Levy to co-ordinate the electronic sorter project from within the Post Office.

Levy immediately pushed to create a research and development team. There was resistance from within the postal bureaucracy to such a move. But Levy promised Turnbull that with a stable, in-house R&D team of four engineers and four technicians there would be a prototype ready for commercial manufacture in three years.[36] Turnbull approved Levy's staffing requests.[37] But to Levy's surprise, Turnbull also insisted that the post office immediately approach industry for technical assistance. Turnbull accepted the need for some sort of in-house research group. But in his mind, its role was simply to demonstrate, in a laboratory setting, the technical feasibility of the contentious facets of the electronic sorter. Anxious for quick results,

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[31] Canada, House of Commons, *Debates*, Fourth Session - Twenty-First Parliament 1952 (Ottawa: The Queen's Printer, 1952), 11 June 1952, 3901.

[32] *Ibid.*, May 30, 1952, 3562

[33] Editorial, "Will Gadgets In Post Office Speed Delivery", *Calgary Herald*, 23 July 1952. Found in CP, Accession 86-87/402, file Publicity 1953-57.

[34] The editorial went on: "Electronic sorters are no doubt satisfying to dream about. But for ourselves, we should be more content if some of the Post Office's surplus energy were devoted to prosaic problems like trying to cut down local delivery time from the occasional four days to a maximum of say one." *Ibid.*

[35] T. P. Leddy, Letter to W. J. Turnbull, 29 July 1952, Levy Papers.

[36] The staffing requirements are given in O. D. Lewis, Memorandum to W. J. Turnbull, 11 September 1952. Levy Papers.

[37] In a letter to the Civil Service Commissions, the Deputy Postmaster General underscores the urgency of staffing Levy's R&D team as quickly as possible. W. J. Turnbull, Letter to Secretary, Civil Service Commission, 11 October 1952, Levy Papers.

Turnbull wanted to turn industrial experts loose on the challenge of designing, building and testing a full scale model in either Toronto or Montreal. The completion of new automation technology, as he wrote the Assistant Deputy Minister of Finance, had become an urgent matter if Canada were to avoid a complete breakdown in the movement of mail.[38]

The central feature of Levy's novel approach to sorting automation was the use of a binary-based memory. The design of this memory had to be a compromise between capacity and speed. A great deal of memory was needed to hold all the extensive details on forward and city sortation. If the letters were to move through the system at high speeds, then the memory also had to make its sorting decisions equally as fast.[39] Under pressure to demonstrate the feasibility of fluorescent or optical reading of encoded letters, the question of developing a memory was one area that Levy was ready to hand over to industry. Optical scanning was pivotal to the project, and the central reason for the creation of his new lab. If his mail sorting "robot" could not see, then the question of memory would become a moot issue.

In early 1953, Levy made his rounds of Canada's electronics industry looking for the right company to design and build the digital memory and associated electronics for the small experimental model of the electronic mail sorter. When he met with Dr. Arthur Porter, the head of Ferranti Canada's digital electronic R&D group, Levy's conception of memory implementation was still quite indeterminate. Porter, whom Levy described to Turnbull as an expert on memory, immediately recast the Post Office's automation needs into the framework of DATAR's technology.[40] Not only was Porter's move an astute transfer of technology, but it also played on the high credibility that the DATAR project had conferred on Ferranti Canada.

For reasons of reliability, real-time performance, and miniaturization, Ferranti Canada and the Royal Canadian Navy (RCN) had agreed in 1952 that DATAR's memory would be based on the core memory technology being developed by Jay Forrester at the Massachusetts Institute of Technology. When, in response to the British Royal Navy's announcement of an early demonstration of its own anti-submarine, tactical information system, the RCN accelerated the

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[38] W. J. Turnbull, Letter to R. B. Bryce (Assistant Deputy Minister of Finance), 19 December 1952, Levy Papers. Turnbull asked that $300,000 be allotted for the 1953-54 fiscal year.

[39] In the Spring of 1952, when Levy had first articulated his vision of the electronic sorter to the post office, he referred to the idea of "cold tube" memory. Whether he was thinking of electrostatic memory, or some other tube variant is not known.

[40] This reference to Arthur Porter was made in Maurice Levy, Memorandum to W. J. Turnbull, 6 December 1952. PO, Accession 86-86/402, box 6, file 71-2-1. Levy met Porter only in February of 1953.

DATAR program. In the ensuing rush, short-term compromises had to be made. Core memory was still too experimental to use, so Ferranti went with the easier magnetic drum memory option. From the RCN's perspective, magnetic drum memory had many disadvantages, but it was an expedient that assured an early demonstration date. With his pitch to Levy, Porter took this unwanted, but necessary compromise, and turned it into an asset.

Porter pushed Levy to see the proposed electronic sorter as a special purpose computer built around magnetic drum memory. The electronic letter sorter, like DATAR, would entail continual requests to a look-up table in memory. Comparisons with data in the look-up table required an immediate decision and action. In DATAR, it was a question of keeping track of many aircraft, ships, and submarines, and then displaying their positions within the reference frame of each ship in the escort. The mail sorter had to keep track of each letter that flew by the scanner and then, at the precise moment, activate the appropriate switching gates to send each letter to its respective sorting track. In DATAR, radar and asdic were the "eyes and ears" sending input data to memory. In the mailsorter, the flying spot scanner would be the "eyes" reading fluorescent bar codes. Porter no doubt argued that a high-speed magnetic drum offered a more than adequate memory for the post office. Not only did it offer an acceptable balance between memory capacity and real-time response, but more importantly, the Post Office would be getting access to technology being developed for DATAR.

Postal Automation: An Opportunity for DATAR Technology

By April 1953, Ferranti Canada seemed the perfect candidate to design and build the "brain" for the small demonstration model of the mail sorter.[41] There were no domestic rivals to Ferranti Canada's technological approach and DATAR had given the company's views immeasurable credibility. Levy started by giving Ferranti Canada a small contract to produce a small experimental drum to be used in the Post Office's own laboratory. Despite this contract,

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[41] Canadian Marconi, however, actively campaigned to design and build a system using a different approach based on conductive ink scanning. This company argued that the use of memory unnecessarily complicated the design of the mail sorter. O. D. Lewis, Memorandum to W.J. Turnbull, 9 January 1953, PO, Accession 90-91/257, box 274, file 78-2-10 pt. 1. Canadian Marconi was confident that it could come up with a system more or less ready for manufacture. While Levy had no interest in non-memory approaches, others did. Lewis, the man who first put the ideas of electronic sorting in Turnbull's head, lobbied strongly for Canadian Marconi.

Levy's thinking on memory was still quite malleable. So when Dr. Louis Ridenour, a highly respected American physicist and Vice-President of the International Telemeter Corporation, proposed the radical idea of photographic, or optical, memory, Levy started to vacillate on the Ferranti Canada option.[42]

The long-term theoretical potential of optical memory captivated Levy. Optical memory promised potentially far greater storage capacity than Ferranti Canada's magnetic drum. Levy was also convinced that optical memory would lead to a reduction in digital circuit complexity. If vacuum tube circuits could be made simpler, then reliability would increase and maintenance costs decrease. Ridenour's proposal was appealing, but completely unproven. To pack a lot of information into a small space required that the spot of light be of very small dimensions. Scanning with such a small light spot, however, raised serious technical problems: the reader would mistake minute scratches and pieces of dirt for data. Considerable R&D was needed to eliminate this problem.[43]

Levy wrote to Ridenour suggesting ways to tackle the problems of optical memory.[44] The considerable length and detail of Levy's written response attest to the extent to which optical memory had captured his imagination. Levy was inclined to give Ridenour's company a preliminary research contract to investigate the idea further, but Turnbull was "dubious about allotting $10,000 to develop a theory."[45] Turnbull had a more practical response to Ridenour's proposal. If he has such faith in his idea, reasoned Turnbull, then let International Telemeter Corporation pay to produce a experimental version that the Post Office could then test. But Levy persisted. At every occasion, Levy argued that optical memory, with its greater information

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[42] Ridenour proposed an approach to memory based on photographic storage that would place postal information on a glass disk 15.5 inches in diameter and 3/8 inch thick. The names of all of Canada's 10,757 postal stations and the nearly 6,000 mail routing distinctions would be stored digitally as dark spots and empty spaces. To read this memory, a spot of light, analogous to a television tube beam, would scan the appropriate track. Photographic Storage System For The Post Office of Canada, March 1953, prepared by the International Telemeter Corporation, Levy Papers. For further technical discussion of this memory see G. W. Brown and L. N. Ridenour, "Photographic Techniques for Information Storage," *Proceedings of the Institute of Radio Engineers* 41 (October 1953): 1421-1428.

[43] Another weakness was the optical memory read-only capabilities. For Levy this was not a big disadvantage. Unlike a computer system, where one is constantly writing to memory, the postal computer needed only to read the memory.

[44] Maurice Levy, Letter to Louis Ridenour, 7 April, Levy Papers. This seven page single-spaced letter was accompanied by a whole set of hand-drawn illustrations.

[45] See Turnbull's own handwritten comments which appear at the end of Levy, Memorandum to W.J. Turnbull, 8 April 1953.

storage capacity, would be needed for the large urban sorting centres.[46] Had it not been for Turnbull's desire to get a practical system into the public view as soon as possible, Levy surely would have steered the project completely over to a longer-term R&D effort in optical memory.

In the matter of memory, Levy was forced to reconcile his quest for the optimal system with Turnbull's impatience. The latter was anxious for a tangible sign that the idea worked, albeit in a small experimental model. Furthermore, the public relations and political value of an early successful demonstration was not lost on Turnbull.[47] It would announce to the public, political opposition, and Turnbull's political masters, that the Post Office had innovative answers to the question of moving the mail efficiently and economically. In Turnbull's mind, Ferranti Canada's magnetic drum approach presented the fastest route to demonstrating the overall effectiveness of electronic sorting.[48] On 14 July 1953 the Treasury Board approved the Postmaster General's request "to enter a contract involving the expenditure of $56,855.70 [with Ferranti Canada] for the development of an Electronic Information Handling Equipment consisting of digital circuits and a digital storage system."[49]

Despite this intended commitment, Levy continued to flirt with other memory options and manufacturers. Turnbull also expected Levy to nail down the most appropriate technical options for each component of the sorting system and let industry get on with the final design and construction. Instead, Levy kept talking about the long-term significance of new developments on the horizon. In early July, Levy went to the United States to meet with RCA, Bell Laboratories, IBM, and Remington Rand. One of the main topics of these meetings was "the

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[46] Levy, Memorandum to W. J. Turnbull, 8 April 1953.

[47] Turnbull understood the value of effective public relations. In 1923 Turnbull created the public relation's group at the post office. He stayed as Head of Public Relations until 1936. In his retirement years, Turnbull spoke very fondly of his success in promoting, in film and print, the Post Office's public image. Throughout the 1953-56 period, the electronic sorter received more coverage in the foreign and domestic media than any other single Canadian digital electronic innovation. Articles appeared in *Popular Mechanics*, *Popular Science*, *The Financial Post*, and *The New York Times*. Turnbull and the electronic sorter were featured on the radio and the Canadian Broadcasting Corporation. Turnbull personally delivered talks in two engineering conferences held in Canada.

[48] Levy expressed concern over the difficulties Ferranti Canada had with the small magnetic drum it was to deliver to Levy's laboratory. Levy's worries were heightened by the pessimistic feedback he was getting back from the Royal Canadian Navy. The reader will recall that Ferranti Canada was in the midst of trying to get DATAR ready for field tests, which were scheduled to take place in the late summer. On the issue of getting the magnetic drum memory to work properly, Levy wrote Turnbull that "Dr. Porter is extremely optimistic but the Navy is rather disappointed." Maurice Levy, Memorandum to W. J. Turnbull: Comments on Photographic Storage Memories, 8 April 1953, Levy Papers.

[49] Postmaster General, Submission to Treasury Board, 26 June 26 1953, PO, Accession 86-87/402, box 6, file 71-3-5E. Treasury Board approved the request on 14 July 1953. See Authority To Enter Into Contract, TB, vol. 184, T.B. # 454222.

latest progress in storage memories."[50] Levy's hesitation to freeze the design concept worried Turnbull. "I have quite early in the development," Turnbull reminded Levy, "stressed that after preliminary investigation we would have to decide the direction to take and then go ahead without being diverted by new developments or after thoughts."[51] Levy's persistent reference to the advantages of optical memory prompted an impatient Turnbull to ask: "Are we committed to the magnetic drum or will it be photographic memory?"[52]

In trying to reconcile his desire for the optimal technical solution with Turnbull's political and economic need for a speedy demonstration, Levy pushed to have two parallel memory efforts. While Ferranti Canada worked on the drum memory computer, Levy hoped that Ridenour's group would work on the longer term problem of optical memory.[53] "By backing the development of this type of memory [i.e., optical]," Levy explained to Turnbull, "we are pioneering in the right direction....Unless new progress is achieved in magnetic drums, I believe the photographic memory will be the best."[54] Levy underscored his request by warning that "if we do not pioneer in backing this development of photographic memory, we risk to have to use a much more complicated design." Turnbull did not buy Levy's suggestion. One week later, on 10 August, Ferranti Canada formally started work on the contract to develop an "Electronic Information Handling System."

In February 1955, the experimental prototype was unveiled to the world's electronics experts. At a national conference in the United States, Levy proudly announced that the Canadian Post Office Department had pioneered a digital electronic mail sorter that could process 200,000 letters per hour.[55] Based solely on a extrapolation of the computer's processing speed, this assertion was more an act of hope than a statement about the sorter's actual operation. Levy's optimism concealed a project that was composed more of components parts whose design had still not crystallized, than a harmoniously integrated system. The problem lay not with Ferranti Canada's computer, but with the scanning, encoding, code printing, mechanical, and sorting

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[50] Maurice Levy, Memorandum to W. J. Turnbull: Visits to U.S., 3 July 1953, PO Accession 86-87/402, box 4, file Visits (Reports).

[51] W. J. Turnbull, Memorandum to Dr. Levy, 24 July 1953. Original in Levy Papers. Copy can be found in PO, Accession 86-87/402, box 6, file 71-2-1.

[52] *Ibid.*

[53] Levy, Memorandum to W.J. Turnbull: Photographic Memory, 4 August 1953.

[54] *Ibid.*

[55] Levy, *The Electronics Aspects of the Canadian Sorting of Mail System.*

technologies, that is, with the non-computer aspects of the project.[56] Despite these problems, Turnbull and Levy decided to push ahead to a full-scale prototype of the system for Montreal or Toronto.

From Vacuum Tubes to Semiconductors: the Post Office Pays the Way

No sooner had Ferranti Canada delivered its vacuum tube electronic brain for the small experimental electronic sorter system than it proposed jumping directly into a transistorized full-scale prototype. The potential technical benefits of building a solid-state computer, however, did not come cheaply or easily. Though in 1955 transistors offered the most promising prospect for the reliable miniaturization for large-scale digital circuitry, only military enterprise could justify the high development costs associated with transistorization. Turnbull might well have asked: Was a breakthrough in miniaturization imperative to the success of the Post Office prototype? After all, vacuum tube technology was still the accepted electronic component in all the commercial computers of the day. Not until 1957 did Philco Corporation come out with first solid state general purpose computer. Higher costs were not the only drawback of transistorization. The technical problems of moving up the transistor learning curve were bound to introduce additional uncertainty into a project already fraught with technical problems of a non-computer nature.

Given Turnbull's concern over costs and his desire to get a working prototype out quickly into the field for testing, it is surprising that he did not go with a vacuum tube machine, which, in 1955, offered the most cost-effective approach to building the full-scale prototype. Instead, convinced that the Post Office was getting a bargain, Turnbull, on Levy's advice, went with the Ferranti Canada proposal. In early 1955, the Royal Canadian Navy had just given Ferranti Canada a contract to develop the circuits techniques needed to transistorize DATAR.

[56] The overall management of the project was in disarray. Conflicts raged between the Post Office and Pitney Bowes over who should obtain exclusive rights on any patent developments surrounding the mechanical sorters. IBM refused to get involved in the coding desk and printer aspects of the project because of the post office's refusal to grant them exclusive ownership over any patents that arose during the project. The technical feasibility of flourescent scanning was still unresolved. Visible light scanning was pursued as a temporary measure. Maurice Levy, Confidential Memorandum to Turnbull, March 1955, Levy Papers. See also J. MacDonald (Comptroller), Memorandum to the Deputy Postmaster General, 13 April 1955, PO Accession 90-91/257, box 275, file 78-2-10, pt. 2; and Budgets, Costs & Estimates Division, Electronic Project, 19 May 1955, PO, Accession 86-87/402, box 4, file (untitled).

The company argued that all the digital transistor know-how gained from the Royal Canadian Navy project could simply be transferred over to the special-purpose computer for mail-sorting. When the Post Office signed a letter of intent, in August 1955, to pay only $65,000 for Canada's first solid-state computer, Levy no doubt believed that his project was getting a free technological ride on military spending.

When the Royal Canadian Navy pulled back from DATAR, in late 1955 or early 1956, Ferranti Canada now faced the daunting problem of having to do all the costly transistor circuit development work for the Post Office computer, as well as to manufacture and test it, at a cost of $65,000. To make matters worse, Ferranti Canada's decision to base its computer design on the Philco surface barrier transistor was proving problematic. Ferranti Canada had overestimated the maturity of Philco's SB-100 and Transac circuits. Considerable variations in Philco's transistor made the Transac circuit unsuitable for reliable high-performance applications in computers.[57] Making the SB-100 transistor work proved far more difficult than expected. The difficulties were already manifest while the company was working on DATAR. However, Ferranti Canada never revealed any of these difficulties when it pitched its transistor computer proposal to the Post Office. Fearful of losing a contract opportunity, Ferranti Canada put on a confident face to Levy on the matter.[58] But the budget was less easy to gloss over. Ferranti Canada's engineers quickly ran up against the financial limits of the contract's $65,000 budget. By early 1956, Ferranti Canada had exhausted most of the $65,000 contract allocation and was still a long way from the final product and meeting the summer deadline.

In the months that followed, Ferranti Canada returned to the Post Office on several occasions to ask for more money. The Post Office had little option but accede. It had already invested a substantial amount of time and money on both the computer and non-computer aspects of the mail sorter. Moreover, with the publicity surrounding the electronic mail sorter and the Opposition's call for greater postal efficiency, there was political pressure on Turnbull to show that the Post Office could indeed modernize. The Opposition insisted on knowing the state of Turnbull's electronic miracle. Without the computer there could be no sorter. And by 1956, it had become unrealistic to think that any other company could replace Ferranti Canada.

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[57] Fred Longstaff, Letter to Maurice Levy, 27 August 1956, PO Accession 86-87/402, box 3, file - Ferranti Electric, 1956.

[58] Maurice Levy, Memorandum to Turnbull: Visit to DRB and Discussions With Moody and His Collaborators on Transistor Circuits for Our Computer, 19 September 1956, Levy Papers. This information was subsequently revealed to Levy in conversations with K. G. Thorne, Ferranti Canada's former Business Manager.

Though the details of how Ferranti Canada rationalized its requests for more money are not available, it is clear that the company had kept Levy in the dark about the problems it was having with the transistor circuits. But when, in August 1956, the cost of the contract had reached 300 percent of its original value and there was still no clear completion date in sight, the Post Office demanded an explanation. Ferranti Canada's principal key computer designer, Fred Longstaff, was forced to reveal that the company still could not get the necessary reliability and performance from its Transac circuit approach. Ferranti Canada had therefore decided to embark on its own design approach to digital circuits, one that would overcome the manufacturing limitations associated with the SB-100. In addition to having to develop and test entirely new circuit techniques, abandoning the Transac circuit also meant that all of Ferranti Canada's previous circuit board layout had to be rethought. The new circuits were bigger than the Transac, and problems were encountered in trying to cram everything onto boards produced for smaller circuits.[59]

Delays and cost over-runs, which plagued both the computer and non-computer aspect of the Post Office's electronic mail sorter project, put Levy under a great deal of strain.[60] Levy's excuses only provoked Turnbull, who by now was exasperated at the slow pace of his project: "What I want is action not criticism of other people who are trying to help us put of a situation which is becoming embarrassing," demanded an angry Turnbull.[61] His determined commitment to the automation project was starting to hurt him politically. He realized that unless the project was finished soon, his adversaries in the Conservative opposition party would call for heads to roll. "You have spent one million dollars and taken three years," he complained bitterly to Levy, "and so far we have nothing to show for this except a lot of bits and pieces, none of which seems to be finalized."[62] Turnbull had reasons to fret.

Six months later, in August 1956, William Hamilton, the Conservative critic for postal operations, demanded that a parliamentary committee be allowed to inspect the progress of the

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[59] *Ibid.*

[60] For a detailed account of the delays and cost overruns see, for example, the handwritten table entitled "Successive Estimates By Ferranti," dated 20 November 1956, found in PO, Accession 86-87/402, box 3, file - Ferranti Electric 1956.

[61] Turnbull, Memorandum to Maurice Levy, 7 March 1956.

[62] *Ibid.*

electronic sorter project.[63] Hamilton reminded Hugue Lapointe, the new Postmaster General who now had inherited Turnbull's project, that in the spring Lapointe had promised the House committee examining the Post Office's budget estimates of the post office that the project would be finished by the end of the summer. Hamilton explained that he was not against "modernizing many functions of the post office," but wondered " when is this million dollar monster going to get into operation so that we can see it in use?"[64] Lapointe clumsily responded that the delays arose from the Post Office's burden of having to advance postal research singlehandedly in Canada.[65] His prediction that "a machine will be installed in Ottawa by the end of the year," turned out to be wishful thinking, as Ferranti Canada had to ask for additional money and time in November 1956. Levy warned the company that this was absolutely the last time the Post Office would go to the Treasury Board to amend the contract. Fortunately, Ferranti Canada's "Route Reference Computer" was delivered in January 1957.[66]

In the summer of 1957, the Post Office demonstrated its entire electronic sorter prototype at the annual meeting of the Universal Postal Union Congress held in Ottawa. Over its long history, the Congress had never before met in Canada. For Turnbull, the meeting represented a crowning moment in his career with the Post Office. The fact that a completed prototype of the electronic sorter could be demonstrated to this international gathering made the moment that much sweeter. But his taste of the electronic sorter soon turned bitter. The "million dollar monster" had now grown to $2.5 million. John Diefenbaker's Conservatives had come to power, and William Hamilton, the former Post Office critic, was now the Postmaster General. Unable to work with the Conservatives, Turnbull quit as Deputy Postmaster General within the year.

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[63] Canada, House of Commons, *Debates*, Third Session - Twenty-Second Parliament 1956 (Ottawa: The Queen's Printer, 1956), 13 August 1956, 7530.

[64] *Ibid.*, 7547.

[65] *Ibid.*

[66] In the end, the cost of the computer had gone up nearly 400 percent from the original cost specified in the August 1955 contract.

Epilogue

Canada's electronic mail sorting system received international attention. Britain and Germany sent delegations to Ottawa to see the new technology in operation. A group of American Congressmen came to Ottawa to examine the Canadian project first hand.[67] What they saw no doubt facilitated Congressional approval for $5 million to set up a research laboratory in Washington D.C. to look into the computerized automation of American postal sorting. Even as the United States invested heavily to computerize the movement of its mail, enthusiasm for the idea seemed to wane in Canada. It is tempting to conclude as J. J. Brown did, that the demise of the Post Office's computerized sorter project another example of "a melancholy procession of golden opportunities which we [i.e., Canadians] have let slip through our fingers....because we have not the vision to see their potential."[68]

Armed with a small amount of anecdotal evidence, Brown concluded that the newly elected Diefenbaker government by, killing this pioneering effort, deprived Canada of some $300 million a year in exports. Despite his self-admitted lack of evidence, Brown puts the blame on the Conservatives. After killing Canada's almost mythic technological exploit, the AVRO Arrow fighter plane, Diefenbaker's government made a good target. For Brown, the collapse of the electronic sorter, which happened at about the same time as the AVRO Arrow's demise, was another illustration of how "[Canadians] tend to be terrified little men, clutching frantically at what we have and afraid to take any risk whatsoever even for large rewards."[69] Brown's assessment was simplistic. It naïvely assumed that invention is the better part of successful innovation, and glossed over Turnbull and Levy's role in the failure.

The Conservatives did not intend to kill the project; the new Postmaster General, William Hamilton, wanted to implement this technology. He inspected the prototype in early August 1957. During that time, Levy again boasted that the prototype could be ready for commercial production in a little over six months. With his expectations raised, Hamilton advised Turnbull: "I would like to see this in practical operation in Post Office work as soon as

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[67] *Ibid.* If one looks at operating deficits, the imperative to automate sorting was greater in the U.S. than in Canada. Throughout the immediate post war period the U.S. Post Office's budget deficits climbed at an alarming rate. The first computerized mail-sorting system in the U.S. went into operation in 1960 in Rhode Island. Great Britain followed in 1966. See P. Harpur (ed.), *The Timetable of Technology* (New York: Hearst, 1982), 168.

[68] Brown, *Ideas In Exile*, 339.

[69] *Ibid.*, 340.

possible."[70] To accelerate the deployment of this technology, Hamilton was willing to expand the size of Levy's laboratory and he was even willing to consider higher contract fees.[71] But Levy's prediction of the completion date, which was no doubt an effort to garner support from the new Postmaster General, was ill-conceived, because it concealed all the problems that still remained before all the components would be ready for commercial production.[72]

Though Hamilton had warned Turnbull in August 1957 that he would not tolerate the litany of postponements that marked the project to date, work on the prototype dragged on until the project faded into obscurity and Levy's Electronics Laboratory was finally shut down in 1958.[73] The failure of Canada's computerized mail sorting project was not due to some flaw in the nation's psyche, as Brown intimates. There was no in-grained "pre-adolescent" Canadian fear of innovation. To the contrary, there was courage and daring. What the project lacked was good management and organization.

The electronic sorter was a costly and complex undertaking. Its potential impact on postal operations was far-reaching. Yet Turnbull and Levy managed this project by the seat of their pants. There was little, if any, consultation across Post Office management to help guide the innovation process. A detailed cost-benefit analysis was never undertaken. No one ever presented a cogent analysis of the estimated costs to see the development to completion. It boggles the mind to think that for an undertaking of such risk, cost, complexity, and import, no intra-departmental committee was ever set up to monitor the project's progress. The Post Office never evolved an explicit departmental policy or procedure to assess the merits of industrial contract bids. From the outset, Turnbull isolated Levy and his group from the rest of the Post Office.[74]

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[70] Bill Hamilton, Letter to W. J. Turnbull, 7 August 1957, PO, Accession 90-91/257, box 275, file 78-2-10, pt. 3. Turnbull, who was on the verge of quitting, warned Levy that "the new Government [was] prepared to support this project if it [was] kept down to a practical level and the present not sacrificed for the remote future, that is, a search for perfection should not be carried to the point where long delas result." W. J. Turnbull, Memorandum to Maurice Levy 15 August 1957, PO, Accession 90-91/257, box 275, file 78-2-10, pt. 3.

[71] *Ibid.* Director (Organization and Classification, Civil Service Commission), Memorandum to Post Office: Fourteen Additional Positions, 30 September 1957, Levy Papers.

[72] For example, the computer's reliability still had to be established. The coding desk had to be completely redesigned. The reader's performance was still unacceptable. Maurice Levy, Memorandum to W. J. Turnbull: Report on the work at hand, 6 September 1957, PO, Accession 86-87/402, box 4, file Untitled.

[73] In the process, Levy was let go. Frustrated and disillusioned, Levy did a little consulting for the U.S. Post Office and tried to build a business around some of the bits and pieces of the electronic sorter.

[74] Very early in the project Turnbull had warned Levy about seeking advice from others in the department. ..".It could be taken as a general principle that you should not pick up suggestions made by anyone in the Postal Service

(continued...)

Levy was to report to no one else but Turnbull. Why Turnbull did this remains an open question. Did he believe that internal opposition would sabotage the project if given a chance? Did Turnbull's approach reflect an institutional structure and ethos in which consultation had little, or no, role? Or was it simply a manifestation of Turnbull's personality? Whatever the reasons, Levy was left alone to navigate through a bewildering number of competing interests.

In the end, Levy's and Turnbull's mismanagement reflected the absence of a corporate culture of innovation within the Post Office that could have provided the institutional structure to manage radical technological change. While the electronic mail sorter project never translated into direct automation gains for the postal service, it nevertheless served as a crucial opportunity for Canada to move up the digital electronic learning curve. The design and construction of the "Route Reference Computer" allowed Ferranti Canada to be the first Canadian company to jump on to solid-state digital electronic innovation wave. In the next section of this chapter, the reader will learn that public enterprise could support digital electronic R&D and still produce successful institutional outcomes. Trans-Canada Air Lines (TCA), another public enterprise, turned its digital electronic R&D ambitions into an unqualified success. The key difference between the Post Office and TCA's patronage of R&D was the technological sophistication of the latter institution's senior management. While TCA's management of radical technological change differed in significant ways from the Post Office's approach, both shared a common impetus in their pursuit of digital electronic solutions to automation: the political pressure to lower the cost and increase the quality of service. In the Post Office, it was to move the mail. For TCA it was to move people. Political pressure, in TCA's case, was tied to threats to the airline's state-sanctioned monopoly. The next section of this chapter further explores TCA's decision to champion radical technological change, the airline's management the process, and the interplay of public and private enterprise needs as a source of the final design.

(...continued)
other than this office. This is the real danger I mentioned to you. Various officers will want to tempt you into bypaths and, while this at the start may not involve any great loss of time, still the net result will, in the long run, be a dissipation of energy." W. J. Turnbull, Memorandum to Maurice Levy, 30 September 1952, Levy Papers.

State Monopoly and Competitiveness: Trans-Canada Air Lines and Digital Electronic Automation[75]

By 1937, Canada's regional airlines had successfully linked metropolitan centres to their regional hinterlands, but the nation had yet to forge a nationally integrated air service. C. D. Howe, Canada's first Minister of Transport, was appalled that "many Canadians when travelling from one point to another in Canada find that they have to use airlines in the United States."[76] To the degree it siphoned the trans-Canadian flow of people, goods, and services, the emergence of American transcontinental air service weakened Canada's own east-west economic and political axis. As one example, Howe suggested that America's air transportation network undermined an important Canadian institution: the postal service. Airmail stamps were sold in Canada, and yet, he explained to Parliament, most domestic Canadian airmail was routed through the United States.[77] For Howe, the absence of a scheduled transcontinental air service clearly stood as a significant obstacle to national development. Public monopoly was the Canadian government's institutional response to the revolutionary change in transportation unleashed by aviation technology. In 1937, the Liberal government created the state-owned Trans-Canada Air Lines (TCA).[78]

The years 1945 to 1965 were a period of remarkable growth for commercial aviation and TCA in particular. Advances in aviation technology, first sparked by World War II, sustained

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[75] Alan Dornian's article, "ReserVec: TransCanada Air Lines' Computerized Reservation System," *IEEE Annals of the History of Computing* 16 (Summer 1994): 32-42, added an internalist perspective to the previous work of Ball and Vardalas's. Dornian's work, however, missed the fundamental importance of distributed online, real-time technology, within the TCA context, and the institutional forces that shaped its design.

[76] Canada, House of Commons, *Debates*, Second Session - Eighteenth Parliament, 1937 (Ottawa: King's Printer, 1937), 2041.

[77] *Ibid.*

[78] TCA was established as a wholly-owned subsidiary of Canada's state-owned railway Canadian National Railways (CNR). The belief that the CNR could provide the airline with a well established national reservations and communications infrastructure was a central factor in creating TCA under CNR. In 1964, TCA was renamed Air Canada. Only four books have been written on Air Canada: Gordon R. McGregor, *The Adolescence of an Airline* (Montreal: Air Canada, 1970); David Collins, *Wings Across Time: The Story of Air Canada* (Toronto: Griffin House, 1978); Philip Smith, *It Seems Like Only Yesterday* (Toronto: McClelland and Stewart, 1986); and Susan Goldenberg, *Troubled Skies - Crisis, Competition, and Control in Canada's Airline Industry* (Whitby, Ontario, Canada: McGraw-Hill Ryerson Ltd., 1994).

high economic growth, and a vast landscape all helped to heightened demand for air services.[79] TCA responded to the soaring postwar demand by investing heavily in fleet modernization. This progressive response reflected the technically-driven brand of management that came to characterize TCA management during the 1950s and 1960s. A transcontinental service to span Canada's vast landscape needed new aircraft that could carry more passengers at higher speeds, and with more comfort. TCA's older DC-3s were progressively replaced by fifty-one Viscounts, ten Super Constellations, twenty Vanguards, six DC-8s, and some North Stars.[80] TCA management bragged that the purchase made the airline one of the first in the world to use pressurized equipment.[81] TCA embarked on a program to convert its entire fleet of aircraft to turbine power. With the purchase of the British Viscounts in 1955, TCA became the first airline in North America to use turbo-propeller equipment.[82] In 1957, Gordon McGregor, the President who oversaw TCA's postwar growth, proudly told the Minister of Transport that "on the basis of orders now in the hands of manufacturers, TCA will be the first airline in the world to operate an all-turbine powered fleet."[83] Fleet modernization was a costly undertaking; for the period of 1956

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[79] In comparison to railways, the rise in the demand for air service was dramatic. In many respects the postwar years heralded the decline of the railway and the ascendency of air transport. In 1946, Canada's railways moved 43 million passengers. By 1965, this figure had plummeted to 24 million; a decline of 44 percent. In the same period, the railways' gross earnings from passenger service fell from $100 to $65 million. The number of passengers on scheduled flights rose from 0.8 million in 1946 to 8.1 million in 1965. This ten-fold increase in passenger volume translated into nearly a twenty-four-fold increase in revenue for Canada's civilian aviation industry; from $11.4 million to $283.5 million. Similar large growth rates occurred in the air transport of goods and mail. In absolute numbers, railways still dominated the movement of freight, much of which arose from the shipment of large volumes of bulky, staple products. But the tonnage carried by rail increased by a factor of only 1.5. This data was extracted from Series, T39-46, T59-73, and T195-198 in Leacy and Urquhart, *Historical Statistics of Canada*. The rate of growth in the number of civil aircraft even surpassed that of motor vehicle registration. While there was a four-fold increase in motor vehicle registration from 1946 to 1965, the increase in the total number of aircraft in Canada was eight-fold. *Ibid.*, Series T147-162 and T236-239.

[80] Gordon McGregor, Letter to Directors of Trans-Canada Air Lines, 2 March 1956, Appendix B: Capacity Program, 1951-65, Records of Air Canada (formerly called Trans-Canada Air Lines), RG 70, vol. 325, file 2-1C, pt.1, National Archives of Canada. Henceforth Records of Air Canada (formerly called Trans-Canada Air Lines), RG 70, will be designated as TCA. DC-3s, which were the work horses that built the airline industry before 1945, carried only some 21-25 passengers, and flew at 170 miles per hour. The North Star carried 52-62 passengers and flew at 230 miles per hour. The Viscount carried 44 passengers but with a higher speed of 310 miles per hour. The Super Constellation carried 65 passengers at 310 miles per hour; the Vanguard 92 passengers at 420 miles per hour; and the DC-8 122 passengers at 55 miles per hour. Gordon McGregor, Memorandum to Honourable Frank Ross, 4 December 1957, see untitled table attached to letter, TCA, vol. 325, file 2-1C, pt. 1.

[81] Gordon McGregor, Memorandum to the Honourable George Hees, 18 July 1957, TCA vol. 325, file 2-1 C, pt. 1.

[82] *Ibid.*

[83] *Ibid.*

to 1961 alone, TCA had committed $100 million to it.[84] TCA's modernization program, which enabled it to multiply the number of flights, greatly expanded the airline's capacity. Equally important, TCA's capital investment gave it greater flexibility in maintaining a profitable mix of long-, mid-, and short-range routes. As the size and flexibility of TCA's carrying capacity increased, so did the airline's ability to tap into the exploding market potential: in 1945, TCA had carried 183,121 passengers;[85] by 1960, the number had grown to 3,440,197.[86]

As is often the case, technological improvements in one sphere of an industry's operations accentuate the technological inadequacies in other spheres. TCA's growth concealed an important weakness in its sales operations that in the long term threatened to vitiate the airline's costly investment in carrying capacity. The problem was TCA's manual reservation system. Seats are the commodities that airlines produce and sell. The profitable clearance of this seat inventory rested on the speed, accuracy and cost of the reservation system. Through the modernization of its "production machinery" that is, the aircraft, TCA was able to "manufacture" seats that offered the consumer a greater variety of destinations and more flights between any two destinations. But could they be sold quickly?

TCA's reservation system consisted of a long chain of human links between the ticket agent and the seat inventory information. A passenger wanting to book a seat first called a local reservation office where an agent would book the seat on a "sell and record" system. Agents were permitted to sell tickets aboard any flight until told otherwise. When a booking was made, the local ticket agent filled out a reservations card. One copy of this card was sent, via an endless belt, to the teletype office, which then communicated the booking to the Central Space Control Office in Toronto. Another copy of the card was sent via another belt to the filing office. Clerks at the Central Space Control Office tallied the incoming bookings from all the TCA ticket offices. In addition to written records, the Central Office kept track of seat availability by means of a large Visual Space Indicator Board (VSIB) on which the availability of each flight leg (whether open, closed, or short-haul closed) was indicated by various coloured discs. As soon as a flight was full, a red disc would go up in the appropriate spot on the Central Control Office's

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[84] Gordon McGregor, Letter to Directors of Trans-Canada Air Lines, 2 March 1956, TCA, vol. 325, file 2-1C, pt. 1. A sum this large required the Board of Directors to consider asking for a modification of the Trans-Canada Air Line Act in order to increase the company's capitalization.

[85] Trans-Canada Air Lines, *Annual Report*, 1945.

[86] *Ibid.*

VSIB, and a "Stop Sale" order was sent out by teletype to ticket offices across Canada. Local reservation offices had their own smaller VSIBs where updates from the Central Office were also indicated by the appropriately coloured disc.

By 1953, TCA concluded that its manual reservations system was increasingly unable to provide ticket agents with the information needed to sell seats in a timely manner. The dependence on so many human links -- reservation agents, file clerks, teletype operators, and chart operators -- and on relatively slow communications created numerous errors. Often sales were not stopped or opened in time. If a flight were full, one cancellation could open up opportunities for bookings in many of the ticket offices across Canada. Yet by the time this cancellation reached the Central Office and was disseminated to all offices the opportunity was easily lost. The converse was also true: agents took reservations before they learned of the "Stop Sale."

Fifty percent of seat sales and most cancellations happened in the days immediately preceding flight departures. This high volume of booking requests over such a short period made the manual reservation system extremely unwieldy. This inflexibility translated into irrecoverable financial losses, for the seats in an airline's inventory were, and are, highly perishable and not easily interchangeable.[87] If there were an empty seat on a plane when it took off, that particular seat, along with the revenue it was supposed to generate, was forever lost. "No-shows" were a vexatious problem that further underscored the reservation system's increasingly sluggish response time as the volume and complexity of business grew.[88] Overbooking, an antidote to empty seats, was a bitter medicine that created angry customers and fuelled politically dangerous hostility to TCA's monopoly status in most markets.

During Gordon McGregor's tenure, TCA attempted to wrest more control of major corporate operational planning decisions from political interference. Until McGregor had become TCA's first full-time president in 1948, Canada's national air carrier was a "truncated" organization, for TCA was managed more as an appendage of the Government and Canadian National Railways (CN) than as a self-contained business entity with its own internal needs. "All

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[87] C. E. Amann, "Airline Automation: A Major Step," *Computers and Automation* (August 1957): 10-14, 30.

[88] In 1951, TCA had 31,378 no shows, with a resulting loss of nearly $1 million. Ronald Keith, "How TCA "Lost" $1 million," *Financial Post*, 20 September 1952, 10. A TCA commissioned study pointed out that the existing reservation system made it practically impossible to reallocate no show seats in the short time just before the flight's departure. The difficulty was not in giving the passenger the empty seat on the departing flight but in confirming seat availability on the subsequent legs of the passengers trip, particularly those legs on the return trip.

major [management] decisions," according to one McGill University study, "were made by government or CN officials. [TCA's] presidents, until 1947, were, in fact, the presidents or directors of the already large CN, with only limited time available for the small, fledgling airline. The CN also provided many of the airline's corporate functions in these years."[89] Furthermore, from 1937 into the 1950s, all important TCA management strategies were closely formulated by C. D. Howe.[90]

The new, and all-encompassing pursuit of techno-economic efficiency became the foundation on which TCA built its autonomy strategy.[91] Shortly after McGregor was appointed president, Howe's directive to him was short and blunt: "Keep your hands out of the taxpayer's pocket, and I'll keep the politicians off your back."[92] McGregor understood the message well: as long as TCA was not a financial or political liability, the Government would provide the airline with a protective domestic market environment, and refrain from interfering in its strategic planning. A commitment to "engineer-driven" efficiency was the manner by which TCA management sought to guarantee autonomy and all the privileges of monopoly.[93] By defining the "good' of TCA in terms of technologically-driven efficiency, the technical experts, rather than the

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[89] Henry Mintzberg et al.," Does Planning Impede Strategic Thinking: Tracking the Strategies of Air Canada from 1937 to 1976", *Advances in Strategic Management*, 4 (1986) (Greenwich Conn.: JAI Press): 14.

[90] According to one senior TCA executive, "What Howe said, went in those years." Cited in *Ibid.*

[91] TCA's quest for autonomy from the state and the associated strategic management issues were first raised in Taïeb Hafsi, "The Strategic Decision-Making Process in State-Owned Enterprises" (Doctoral Dissertation, Harvard University School of Business Administration, 1981).

[92] See McGregor, *The Adolescence of an Airline.*

[93] Hafsi, Kiggundi, and Jørgensen propose a management typology for state-owned enterprises. Taïeb Hafsi et al., *Structural Configurations in the Strategic Apex of State-Owned Enterprises*, Écoles Des Hautes Études Commerciales, University of Montreal, Report # 85-07, September 1985. They argue that, in the case of state-owned enterprises, Henry Mintzberg's notion of the "Strategic Apex" represents a corporate executive that is coalition of two groups: "commissars" and "engineers." "The commissars identify with the interests of the government or another external coalition, for example, the civil service, a political party or faction, the military, a geographical region or an ethnic group. Their utility, career paths, and rewards are bound to their ability to comprehend and represent the external coalition within the SOE [state-owned enterprise]. The SOE is a resource or means rather than an end....Engineers, by contrast, identify with the firm itself, its conventional economic function and its growth. Their utility, career paths, and rewards are linked to the technical economic performance of the firm....The engineers shoulder the economic legitimacy of the firm, embodied in their technical and commercial expertise, whereas commissars shoulder the forms socio-political legitimacy by serving as match makers between the enterprise and the government." Mintzberg et al., "Does Planning Impede Strategic Thinking," 4-5. It must remembered that Hafsi, Kiggundi, and Jørgensen use the term "engineer" in a broader metaphorical sense. The central idea in the term "engineer" is the pervasive ethos of technical efficiency in management. These authors characterise SOEs according to the whether the commissars, engineers, or both run the company. TCA's history until the early 1960s conforms to well to their typology. From 1937 to the close of the 1940s, TCA was in the "Infant" stage in which top management were commissars. During the 1950s, under McGregor, himself an engineer, TCA became an "Autonomous-type" SOE where top management was technically driven.

politicians, would be best placed to manage the public airline. McGregor and his executives argued that they could best serve the public's interest, "because they were the only ones to understand both markets and technologies relevant to the firm's business."[94] While TCA argued that "any interference from the [government] bureaucracy was dysfunctional because it lacked competence," Canada's national airline nevertheless still looked to the Government to maintain TCA's monopoly advantage.

The reservations problem not only compromised efficiency, but it also fuelled the kind of bad publicity that threatened TCA's monopoly status because, as TCA executives understood, the "secret to success within the government [was] to avoid the attention of the politicians."[95] Frank Ross, who sat on TCA's Board of Directors, wrote in 1954 warning McGregor of the public's growing dissatisfaction with TCA's service and anger over deplanings arising from failure to reconfirm or from overbookings.[96] Ross asserted that "the greatest immediate danger of a public demand for competition will come from dissatisfaction with our method of handling traffic."[97] On the issue of passenger anger over "deplanements" McGregor rationalized: "However much it is disliked, reconfirmation is a rule imposed throughout the continent to safeguard airlines as much as possible against empty seats resulting from 'no-shows.'"[98] Furthermore, McGregor downplayed the extent of customer dissatisfaction. Ross, himself a Vancouver resident, took exception to McGregor's suggestion that the customer dissatisfaction was an isolated phenomenon.[99] Ross warned that problems with service would only feed resentment that existed in the west over TCA's monopoly.[100]

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[94] Hafsi et al., "Structural Configurations in the Strategic Apex of State-Owned Enterprises", 15.

[95] Mintzberg et al., "Does Planning Impede Strategic Thinking," 37.

[96] "Ross was an engineer who collected company directorships like philatelists collect stamps." Smith, *It Seems Like Only Yesterday*, 40. Sitting on over twenty Boards of Directors, Ross travelled extensively from coast-to-coast. As one of TCA's most frequent users, he got quite an earful from the disgruntled passengers he met: "I have never been a member of any Board of Directors," he wrote to McGregor, "which has given me such an uncomfortable feeling because you can have no idea the endless number of complaints I receive." Frank Ross, Letter to Gordon McGregor, 1 November 1954, TCA, vol. 325, file 2-1C, pt. 1.

[97] *Ibid.*

[98] Gordon McGregor, Letter to Frank Ross, 4 November 1954, TCA, vol. 325, file 2-1C.

[99] Frank M. Ross, Letter to Gordon McGregor, 9 November 1954, TCA, vol. 325, file 2-1C, pt. 1.

[100] "Apparently I failed to convey to you what I think is the gravity of the situation." Ross went on to write: "I feel that unless the matter is dealt with now you are going to find steadily growing agitation for a competitive service. Time and time again when these errors occur, I listen to the expression with great embarrassment -- this is just what happens when there is a monopoly." *Ibid.* Ross then went on to document the valid complaints that had come to him

(continued...)

The seeds of western hostility towards TCA had been planted in 1937 when western entrepreneurs were shut out by the creation of TCA. In 1937, when Howe contemplated the creation of TCA, the western based airline, Canadian Airways, was slowly positioning itself as a national service. This private carrier represented the formal merger of the successful Western Canada Airways with four struggling eastern airlines. The consolidation, however, had not yet produced an integrated east-west service when Howe called for the creation of a national airline. Despite Canadian Airways willingness to participate in plans to create a transcontinental air service, Mackenzie King's Liberal government was determined, from the outset, that any national airline would have to be a public enterprise. The debate over private versus public air transport that ensued mirrored the struggle that pitted Canada's eastern-run, state-owned and western, private-owned airlines against each other.[101] From the time Canadian Pacific Railways established Canadian Pacific Air Lines (CPAL), it had tried to break the TCA's legislated eastern headquartered monopoly over transcontinental service.[102]

At every turn, TCA blocked any CPAL route application that threatened TCA's interests. The Liberal cabinet's rejection in 1952 of CPAL's application for transcontinental service fuelled western disaffection with the state's control over a significant portion of commercial air transport. McGregor dismissed anti-TCA sentiments as a conspiracy led by a group of disgruntled western "private enterprisers" who were angry at the Government's recent rejection of CPAL's application. This vocal dissatisfaction, believed McGregor, was not representative of the public's satisfaction with TCA service.[103] McGregor's dismissive attitude incensed westerners. The mayor of Calgary, D. H. MacKay, told the Canadian National Railways president: "McGregor starts off with the promise that nobody has any business to complain and besides there is nothing to complain about. He simply will not make any investigation on the ground and is content with alibis. He doesn't seem to realize that the important thing is that people in this area are

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(...continued)
in just one month, many of which were in some way related to an inadequate reservation system.

[101] Between 1940 and 1942, Canadian Pacific Railways bought Canadian Airways, and nine smaller airline airlines companies, then merged them to create Canadian Pacific Air Lines (CPAL). In 1949, CPAL moved its headquarters from Montreal to Vancouver. The shift of corporate power to the west no doubt reflected the strength of the western part of the operation and the CPAL's Pacific focus. Entry into the Pacific market occurred after TCA decided not fly those routes.

[102] The reader will recall that TCA was a wholly owned subsidiary of the state-owned railway, Canadian National Railways.

[103] McGregor, Letter to Frank Ross, 4 November 1954.

dissatisfied and fed-up and will do everything possible to break the monopoly so that we can get a competitive service to put [TCA] on its toes."[104]

If McGregor was dismissive of Ross's observation's then surely he must have sat up and taken notice when his boss, Donald Gordon, the Chairman and President of Canadian National Railways (CN), was completely caught off guard by the intensity of anti-TCA feelings among western business and political elite.[105] What was to be a good-will luncheon for the President of CN, attended by the Mayor of Calgary and some prominent members of city's business community, turned into a scathing condemnation of TCA. No one questioned the high quality of TCA's service in the air, but everyone objected to its service on the ground.[106] Most of the complaints could be traced back to TCA's reservation system: inaccurate bookings and frustrating delays in getting confirmations. Once again, westerners were charging that TCA's monopoly "produces indifference to the public needs and an absence of competitive spirit." Gordon went on to note that "allegations were made that many Canadians in Western Canada, and particularly on the B.C. coast, were turning to the United States because of exasperation with TCA ground service."

By 1956, the western-fuelled criticism that TCA's monopoly was at the root of the airline's poor service spilled on to the floor of the House of Commons. At every opportunity from March to through August, the Conservative opposition attacked TCA's monopoly status during meetings of a parliamentary committee examining transportation policy. They said that the airline's monopoly was a socialist evil that undermined efficient service to Canadians. For the Opposition, the political weak points in TCA's monopoly were pricing and ground service. Not even the Opposition could reproach TCA's engineering-driven use of the best aviation technology. While TCA may have been the "best in the air," the Opposition proclaimed TCA " worst on the ground."[107] Again, deplanements and problems with TCA's ability to monitor seat

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[104] *Ibid.*

[105] Donald Gordon, Letter to Gordon McGregor. Like Ross, Gordon was impressed enough with the seriousness of the criticism to write McGregor a lengthy narrative of the comments he had heard.

[106] It was common to hear TCA described as "a wonderful organization in the air but lousy on the ground." *Ibid*

[107] Canada, House of Commons, *Debates*, Third Session-Twenty-Second Parliament, 10 January - 14 August 1956, 6 March 1956, 1870.

availability were the common complaints.[108] "I cannot understand," exclaimed Defienbaker, the Leader of the Opposition, "the dog-in-the-manger attitude of Trans-Canada Air Lines in continuing an attitude antipathetic to competition....The time has come," Defienbaker concluded, "to take the hobbles off air development in Canada to remove the shackles of outgrown policy that denies competition, and to give Canadians those benefits that competitive enterprise will assure."[109]

While opponents bemoaned the lack of competition, McGregor saw state-backed monopoly in aviation as an economic advantage for Canada. In his mind, TCA was "a protector of the public interest, rather than as a money-hungry business. [He] argued that lack of competition actually benefited consumers."[110] McGregor's justification of monopoly rested on the notion that TCA was another form of public infrastructure. "Who would think of having a municipality with two sources of lighting supply, two sources of sewage disposal or two sources of garbage collection," asked McGregor rhetorically. "It doesn't make good economic sense," was his reply.[111] To the Royal Commission on Canada's Economic Prospects, McGregor again repeated that under the umbrella of monopoly TCA had not only maintained the highest pace of fleet modernization in the world but also offered the consumer the widest possible network of flights.[112] Though McGregor could say that "no airline in the world [was] better equipped with aircraft for the type of service to be operated,"[113] he was well aware for several years of the growing inability of TCA's reservation system to keep pace with the airline's rapidly expanding business. The modernization of the seat inventory system had not kept up with fleet.

At first it seemed that the only way TCA's existing reservation infrastructure could respond to the increasing demand for passenger service was through labour- intensive expansion.

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[108] Conservative Member of Parliament W. B. Nesbitt told the House: "I have received many complaints from constituents who have made reservations on Trans-Canada Air Lines but who, when they go to the airport after having confirmed beforehand, find that their seat is not there and that they have to miss the plane and go on the next flight." *Ibid.*, 1871.

[109] *Ibid.*, 1863. Not all westerners objected to TCA's monopoly status. Stanley Knowles, a leader of Canada's socialist Cooperative Commonwealth Federation (CCF) party, argued that a state-owned airline was essential to establish a first-rate and economically viable air service in Canada. *Ibid.*, 1851.

[110] Goldenberg, *Troubled Skies: Crisis, Competition and Control in Canada's Airline Industry*, 19.

[111] *Ibid.*

[112] G. R. McGregor, *Submission to the Royal Commission on Canada's Economic Prospects*, No. 115, 19 January 1956. Copy in the Library of Parliament, Ottawa, Canada.

[113] *Ibid.*, 12.

Throughout the early 1950s, TCA executives watched with "alarm" as the size of the reservations personnel grew proportionately faster than that of the passengers carried, and as the cost of the entire reservation infrastructure grew faster than passenger revenues.[114] It became apparent to McGregor that the existing manual reservation system not only hampered current operations, but that, at some point in the near future, it would hobble the company's service and profitability.

To the extent that the reservation system underlay weaknesses in TCA's ground service, TCA's critics were mistaken to believe that poor service was a product of monopoly alone. The inadequacies in TCA's manual reservation systems typified the state-of-the-art throughout the world's airline industry.[115] By the mid-1950s, the only airline that had actively sought a radical technological solution to the reservation problem was American Airlines.[116] In 1949, this company had started work on the "Magnetronic Reservisor," a small digital prototype that used a magnetic drum memory to handle seat confirmations. No sooner had American Airlines put its Reservisor system into limited operation in 1952 than it realized that it needed a better solution. The absence of a general purpose computer severely limited the scope of information processing, and better input/output devices were needed to make the ticket agent's interaction with the system much easier. Finally, the associated communications infrastructure did not provide a nationally-integrated, information-handling system. In 1953 American Airlines started extensive discussions with IBM to develop a new, far more advanced real-time airline seat inventory system that could overcome these limitations.

Like American Air Lines, TCA became convinced that incremental innovations could no longer alleviate the growing bottlenecks in its reservation system. TCA set out to avoid, with one technological leap, all the deficiencies of the Reservisor system. When TCA opted for radical innovation, two historical threads became intertwined: TCA's growth as Canada's national airline, and the emergence of an indigenous industrial capacity to design digital information systems. During the 1950s, while American Airlines and IBM started to collaborate, during the 1950s, on the design of the first computerized reservation system, TCA turned to Ferranti Canada. What

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[114] C. J. Campbell (Director of Telecommunications, TCA), Memorandum to W. H. Seagrim (General Manager of Operations, TCA), 27 July 1955, TCA, vol. 100, file 1620-10.

[115] See Amann, "Airline Automation."

[116] Amann, "Airline Automation" and Jon Eklund, "The Reservisor Automated Airline Reservation System: Combining Communications and Computing," *IEEE Annals of the History of Computing* 16 (no. 1. 1994): 62-69.

followed was a race to develop the world's first fully computerized real-time passenger information system. American Airlines's role may be symbolic of the risk-taking virtues and foresight of competitive private enterprise. But TCA's initiatives reveals that Canadian public enterprise could be equally daring and visionary in the defence of monopoly.

Despite McGregor's contempt for his western critics, he knew that unless TCA met the public's rising expectations for comfortable, fast, flexible, and cost-effective transcontinental service, his argument about the advantages of monopolistic air service would ring hollow. To this end, TCA had to create a supply of seats to match demand, had to run an efficient reservations infrastructure to convert a perishable inventory into profits, and had to develop an operations-research approach to long-term plans based on accurate forecasting methods.[117] The fleet modernization program addressed the first imperative, the supply issue. The second imperative dealt with the vital question of sales and the timely liquidation of the seat inventory. The third imperative represented the "engineer's" systems approach to techno-economic efficiency. As with the aggressive aircraft modernization program, the proposed daring computerization of its reservation system represented an important weapon in TCA's efforts to protect its transcontinental route from its western rival.

Shaping Design to Corporate Needs

The path to radical technical change was a long one, characterized by TCA's methodical scrutiny of how the process of computerization should be structured to meet corporate expectations and priorities. At a meeting in early 1953, McGregor and his senior officials decided that the time had come to pursue a new approach to reservations. Because automation meant venturing into unchartered organizational and technological waters, McGregor agreed that the undertaking should proceed methodically in four very distinct phases. The first phase, to start immediately, was a preliminary internal analysis, to define the problem, and to formulate, in very

[117] On the importance of long-term planning for TCA, McGregor explained to George Hees, Minister of Transport, that "accurate future planning is by far the most important of the activities of the management of an airline. Failure to foresee the extent of the future market will result in poor service and the loss of revenue which would otherwise be available, through inadequate capacity. Over-optimism with respect to future markets will result in redundant capacity, and considering the small margin of profit inherent to the industry -- corporate deficits. Incorrect choice of equipment will produce lack of market appeal, operating inefficiency, and financial losses." Gordon McGregor, Memorandum to the Honourable George Hees, 18 July 1957, TCA vol. 325, file 2-1 C, pt. 1.

general terms, the framework for automation. The second phase was to be a proper engineering evaluation by an independent consultant. Only after TCA had thoroughly digested the second phase did management plan to move to the third phase: to discuss with prospective computer manufacturers the technical and financial details of designing and constructing the new system. The fourth phase entailed the system's installation and operation within TCA's organizational structure.[118]

In 1953, responsibility for the TCA internal study fell to Lyman Richardson, a young radio engineer in the airline's Telecommunications Division who had received his first training in radio technology while in the Royal Canadian Air Force. Hired by TCA in 1949 as a transatlantic radio operator, by 1953 Richardson had risen to "communications engineer." Richardson's analysis found that the "majority of the manual operations in the reservations system were simple in nature and could be precisely defined by mathematical logic in such a way that they could be reduced to simple machine operations and done far more expeditiously with fewer personnel."[119] Although Richardson had never heard of computers when he started his preliminary analysis, in October 1953 he advocated the creation of a vast digital communications and computation network on a scale never before contemplated.[120] The proposed new electronic system was to encompass most of the simple manual operations needed to sell a ticket. Agents in TCA offices across North America, according to Richardson, would be linked interactively, in real-time, to a centralized seat inventory kept in a computer.

In twenty TCA ticket offices across Canada and in the United States, agents would do all bookings through a special input/output device, which Richardson simply called an "Agent Set."[121] "Agent Sets" in the same ticket office were to be routed into a "Local Store," a kind of

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[118] Among those who attended the meeting were Gordon McGregor, the president of TCA, W. F. English, the Vice-President of Operations, C. J. Campbell, TCA's Director of Communications, plus the Vice-President of Traffic, and the General Manager of Operations. W. F. English, Memorandum to Gordon McGregor: Automatic Reservations System, 16 December 1953, TCA, vol. 100, file 1620-10.

[119] Campbell, Memorandum Seagrim, 27 July 1955.

[120] The reader should recall that in 1953, Canada had only one general purpose computer: FERUT. This was the machine that DRB and NRC bought and installed at the University of Toronto in 1952.

[121] Richardson recommended a total of 300 "Agent Sets". No copies remain of Richardson's October 1953 report entitled "Automatic Reservations - Passenger Flow Systems". The description given here comes from another study, in which the main elements of Richardson's report are briefly recapitulated. See L. P. Casciato, R. F. Johnston, and J. Kates, *Preliminary Report of an Automatic Passenger Service For Trans-Canada Air Lines*, circa Spring 1954. One of the original copies of this report now resides with the author of this thesis.

buffer to keep and route information to and from the "Agent Sets."[122] All the geographically dispersed "Local Stores," would then pass on and receive seat information to and from a central computer that kept the entire TCA seat inventory.[123]

Richardson's report served its purpose well. It sketched, in broad strokes, the nature of the reservation system TCA should pursue. The second phase called for more concrete evidence that a cost-effective approach to the Richardson recommendation actually existed. TCA solicited bids from seven companies. The objective of the contract was to elaborate, without going down to the level of circuit design, on the equipment configuration that would best meet Richardson's requirements. Only then, believed TCA executives, could they "definitely decide whether or not an automatic reservation system [was] justified from the viewpoints of efficiency and economy."[124]

Of the six companies TCA approached in the fall of 1953, only three bid for the contract to do the technical study: Ferranti Canada, in Toronto; Computing Devices of Canada, in Ottawa; and Adalia Ltd., in Montreal.[125] Ferranti Canada jumped at the opportunity to do the technical study.[126] To the digital electronics group at Ferranti Canada, Richardson's proposal was tailor-made to the achievements of DATAR. Richardson's proposal called for the design of a real-time data-exchange system, which linked geographically-dispersed users to a central information repository through a digital communications infrastructure. Like DATAR, TCA's search for an automated passenger service called for the fusion of computation, communication, and human interface considerations into one large-scale information system.

Ferranti Canada's unrealistically low bid again represented the company's aggressive efforts to convert the technological advantage it gained from the military-driven DATAR experience into civilian opportunities. Just a few months earlier, Ferranti had started a campaign

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[122] Associated with "Local Store," Richardson called for an additional input/output device that would function as a "Master Agent Set." The device had to be able to examine passenger continuity on any flight.

[123] Richardson actually proposed two central computers working in parallel. Each would serve as a back-up to the other.

[124] English, Memorandum to Gordon McGregor: Automatic Reservations System, 16 December 1953 .

[125] The others were Cossor Ltd., Halifax, Canadian General Electric, Toronto, Canadian Aviation Electronics and International Business Machines, both in Montreal. To TCA's solicitation for bids to do an engineering study they replied that their "organizational structure would not allow them to participate, at the present time, in this study." *Ibid.* Computing Devices of Canada bid $24,000, Adalia bid $18,000, and Ferranti Canada bid $10,000.

[126] In fact, Ferranti-Canada had attempted an earlier unsolicited proposal the moment it learned of the contents of Richardson's report.

to win the contract to build a special purpose computer for the Post Office's first experimental electronic mail sorter. Underbidding was clearly an attempt to sacrifice in the short-term to gain a bigger and longer-term prize: the development and manufacture of an entire computerized national reservation system. If Ferranti Canada did the engineering study, it would presumably have an advantage in the subsequent contract bids to build the system. TCA, however, did not take the bait of Ferranti Canada's low bid.

Objectivity more than cost was TCA's prime concern. After some reflection, senior management recommended to McGregor that it would be unwise to entrust this crucial technical study to one of the companies that would be bidding to develop and manufacture it. They feared that Ferranti Canada, as well as Computing Devices of Canada, would "consciously, or unconsciously, promote their own preconceived solutions" instead of what best suited TCA's operational needs. Furthermore, TCA management was concerned that with a vested interested in building the system, these two companies would not do the "statistical analysis, informational analysis and operations research" TCA needed to help assess the cost-effectiveness of automation. In the end, the contract was given to Adalia Ltd., a consulting firm with no intention to enter the manufacturing field.[127] Adalia had been created after World War II by Sir Robert Watson-Watt, one of the pioneers of radar.

In 1953, a working knowledge of digital electronics, computers, and information processing was still a rare commodity in Canada, as elsewhere. Ironically, had it not been for the collapse of Canada's first effort to design and build a general purpose digital electronic computer at the University of Toronto, Adalia would never have had the know-how to tackle TCA's technical study. The reader will recall from Chapter 2 that after plans to build a full scale prototype of UTEC had been cancelled, its design team of Josef Kates, Leonard Casciato, R. F. Johnston eventually went to Adalia after their plans to form a new company to build computers had collapsed.

The Adalia study by Kates, Casciato, and Johnston filled in the technical details of a system that could meet the requirements in Richardson's report.[128] The report analyzed the data

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[127] *Ibid.* For the details of what Adalia proposed to do in the study see J. A. Richards (Executive Vice-President, Adalia Ltd.), Letter to C. J. Campbell (Director of Communications, TCA), 25 February 1954, TCA, vol. 100, file 1620-10.

[128] Casciato, Johnston, and Kates, "Preliminary Report of an Automatic Passenger Service For Trans-Canada Air Lines," Spring 1954. Some confusion is associated with the date of this study. No date appears on the document. This (continued...)

flows associated with processing, storing, and updating information in the seat inventory. It also examined communications issues needed to ensure easy and reliable real-time access to the inventory, and at time when all aspects of computer design were still very much in flux, the report also examined the various technical options for the design of the central computer. Adalia's study offered a technically-informed corroboration of Richardson's model for automation.[129] After their theoretical endorsement of the electronic reservations, Kates, Casciato and Johnston arranged to simulate the operation of an electronic seat inventory system on the University of Toronto's FERUT, which at the time was one of only two general-purpose computers in Canada.[130]

None of TCA executives who gathered on the morning of 25 August 1954 to watch the demonstration had ever seen a computer before. They watched with fascination as FERUT stored the airline's entire seat inventory, updated the inventory continually as simulated bookings were made, and instantly revealed the status of every seat on every leg of TCA's flight schedule. Following this demonstration, lengthy and meticulous internal analyses were carried out before TCA would commit money to phase three, the design and construction of the computer system. This detailed, systematic approach to innovation reflected the post-World War II emergence of TCA's new management ethos which put technical efficiency and innovation at the core of the company's business strategy.

Although the Adalia study had confirmed the engineering feasibility of Richardson's concept in August 1954, it was not until the spring of 1959 that TCA solicited offers from industry to design and construct the computer. TCA needed five years to resolve two issues that were critical to the overall design philosophy of its computerization. The first, and perhaps most

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(...continued)
author mistakenly attributed the report to 1953. Dornian, "ReserVec: TransCanada Air Lines'Computerized Reservation System," found a discrepancy in this date, see footnote on page 33. More recent findings within Air Canada Archives now show that this preliminary report had to have been written in the spring of 1954. Adalia Ltd. started the study at the end of February 1954, promised a preliminary report in three months, and a final report in six. To this author's knowledge, copies of the final Adalia Ltd. report no longer exist.

[129] "It is clear," concluded Kates, Casciato, and Johnston, "that such an A.P.S. [Automatic Passenger Service] can improve immediately the reservation problem, result in more sales with less delay and less human intervention...Existing techniques have proven sufficiently reliable so that such a task could be undertaken with certainty of successful conclusion...Such a system should fully match the benefits expected from better planes and better flight-control equipment." Casciato, Johnston, and Kates, Preliminary Report of an Automatic Passenger Service For Trans-Canada Air Lines, 1954.

[130] C. J. Campbell, Memorandum to H. W. Seagrim (General Manager of Operations, TCA), undated, TCA vol. 100, file 1620-10.

immediate, was the human/machine interface. Could one design an input/output technology that made access to information a fast, reliable, and transparently simple act for the ticket agent? Because of the large number, about 300 hundred, of Agent Sets that TCA wanted to install across the country, the price per unit for the human/machine technology became another important constraint.

The second issue to be resolved was the role of electronic automation in the broader context of TCA's future data-processing needs. Should the goal of automation be simply to produce an electronic seat inventory that could be queried and updated in real-time, or should it also serve to promote TCA's integrated system's approach to management? The prospect of building a computer provoked an examination of how this new technology could improve quantity, quality, and speed of information flow between all of TCA's interdependent operations so as to maximize efficiency, quality of service, and hence profits. The issue of introducing the computer into TCA operations engendered more than technical debate. It also touched on questions of power and control. Inter-departmental squabbles over who should manage this new technology had to be resolved. How all the above issues were resolved played a direct and indirect role on the final and detailed design concept that TCA eventually put out to industry for development.

TCA turned the development process on its head. Rather than starting with the biggest and most complex piece of hardware -- the computer -- TCA first focussed on the human/machine interface. For TCA management, the way the ticket agent communicated with the computer was the pivotal design issue.[131] An economical interface had to be created that would allow for easy, fast, but economical, and high-volume use of unscheduled interactions between a large number of users dispersed over a vast landscape using one central computer. This was a truly ambitious goal when one recalls that, with the exception of secret military projects, such as Royal Canadian Navy's DATAR and the United States Air Force's SAGE projects, real-time interactivity in an electronic digital information system with distributed users was still

[131] The Telecommunications Department, which was given the responsibility of formulating TCA's electronic reservations project, and the Sale Department, which was going to use the system when implemented, underscored the importance of first developing prototypes of the interface. In their eyes, the design of a new input/output technology was more problematic than that of designing the appropriate general purpose computer. C. J. Campbell, Memorandum to General Manager of Operations, 24 September 1956, TCA, vol. 100, file 1620-10.

unexplored territory.[132]

The dominant human/machine interface paradigm during the 1950s was batch data processing. Batch-oriented card readers, punched tape, and magnetic tape did not offer users the opportunity to seek information from the system on an immediate feedback basis.[133] Depending on the system load, the user would come back in an hour, a half day, or the next morning to collect the results. Flexowriters, which resembled teletype machines, and printers offered a more direct interaction between the user and the computer. But usually the system had only a few of these input devices and they resided in a centralized location to which only the system managers had direct access.

Uppermost in Richardson's priorities was the creation of an interface technology that adapted to the needs of the ticket agent rather than the other way around. In his mind, the existing flexowriter/printer interface was not only an uneconomical option, but also a cumbersome barrier between the ticket agent and the prospective customer. Richardson convinced his superiors that TCA could develop a relatively inexpensive interface that could be simply and naturally integrated into the ticket agent's existing patterns of work.[134] How? Richardson observed that ticket agents, as they talked to customers over the telephone, scribbled booking request information on pieces of paper. Why not somehow make the fast and simple act of scribbling the

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[132] To these, one should add the Royal Canadian Navy's Tactical Battle Simulator and the U.S. Air Force's flight simulators where the term man/machine interface was first coined.

[133] When the electronic digital computer first appeared, users were allocated time-slots during which they had sole use of the computer. This provided for an interactive environment between the user and the computer. Real-time response, however, depended on the machine and the task. As computers became larger, faster, and more expensive, this exclusive one-on-one relationship became an uneconomical use of computational resources. It was at this point that "the user was thrown out of the computer and his punched cards or tape became his sole input, yielding reams of paper output. This succeeded in efficient use of the computer at the expense of the highly inefficient use of the user, resulting in many hours of turn-around from when a job was submitted until it was returned complete." Leonard Kleinrock, "Computer Networks," in *Computer Science*, ed. Alfonso Cardenas et al. (New York: Wiley-Interscience, 1972), 242. It was not until the end of the 1950s and into the 1960s when "time-sharing," which allowed spatially dispersed users to share one computer's resources, started to make its appearance. The drive behind the development of time-sharing technology was to increase the efficiency of the programming process by allowing many programmers to share the computer's resources during the time-consuming debugging process. The precursors of this technology were SAGE, and the reservation systems being developed by American Airlines/IBM and TCA/Ferranti Canada in the 1950s. These three "time-sharing" systems, however, were focussed on very specialized tasks.

[134] "The success or failure of any system we may conceive," explained Richardson to a Canadian Conference of Electronics engineers in 1956, "depends largely upon this device [i.e., the interface], since to the user this device 'is' the computer, regardless of where it is, or what goes on behind the scene. Our requirements for this device were simply that it should be trivially easy to use, inexpensive...., and above all that it should not be a highly specialized device." Lyman Richardson, "Some Applications of Electronic Data Processing Equipment in the Air Transport Industry," Paper #4, delivered to the *Canadian Convention and Exposition of the Institute of Radio Engineers*, Toronto, Canada, 1-3 October 1956. Copy of the paper given to this author by Lyman Richardson.

basis for a new human/machine interface? pondered Richardson. To further ensure the simplicity and speed of the interface, Richardson wanted the same piece of paper to convey the answer to the ticket agent's booking query. In 1956, TCA solicited proposals from the electronics industry to develop the hardware that would embody Richardson's interface philosophy.

Of all the companies that bid, noted the Director of TCA's Telecommunications Department, "Ferranti [Canada] of Toronto have made us by far the best proposal both from the technical and economic aspects."[135] Called the "Transactor," Ferranti Canada's proposal offered a compact invention ingenious in its simplicity. All the information needed to update the seat inventory or to make any booking request was depicted on pre-printed, standard-sized IBM-type cards. Every possible piece of information was laid out within a 300 element matrix. During the course of a telephone enquiry, the ticket agent, with great ease and speed, would translate the customer's reservation request into short pencil strokes that went through the appropriate pre-printed entry. For example, if the flight booking was to be on a Monday, then a pencil mark was put through the word "Mon." Then, while still on the telephone with the customer, the ticket agent inserted the marked card into the Transactor through a neatly designed neck at the top. A movable plate would then, with 400 pounds of force, automatically press the card tightly against a reading plate. The reading plate consisted of a matrix of 300 sensing heads which fit exactly over every possible entry on the pre-printed card. Each sensing head was thus responsible for detecting the presence of a pencil mark over only one spot on the card.[136] Within seconds, the information on the card was sent to the computer. And if the routing equipment and computer were designed properly, the ticket agent would get an answer back in four to five seconds.

The Transactor's simplicity was two-fold. First, the use of a static 330 head reading mechanism eliminated the need for complex and more costly designs that involved either cards moving past conducting brushes or optical scanners. Static sensing offered a cheaper approach to good reading reliability. This placed less stringent requirements on how well the ticket agent blackened-in a precise area. As a result, data entry did not become an obstacle to efficient service

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[135] Campbell, Memorandum to General Manager of Operations, 24 September 1956. According to one TCA contract, Ferranti Canada presented a report on the design of the "Transactor" on 27 July 1956, in Ferranti Document No. L208, Terms of Contract Between Ferranti Electric Limited and Trans-Canada Air Lines, 5 March 1957, TCA, vol. 100, file 1620-10.

[136] While all the 300 sensor heads read the card in parallel, data from the heads was picked-off serially. For a schematic of the signal pick-up mechanism see Interdepartmental Electronics Committee (Government of Canada), Report On The Visit Of R. Ziola And N.G. Anderson To Ferranti Electric Limited, Toronto, For A Demonstration Of The Transactor, 12 December 1957, TB, vol. 632, file 1501-22.

while the ticket agent gathered information over the telephone from the customer.[137]

The second facet of the Transactor's simplicity resided in how information was conveyed back to the ticket agent. The same input card served as the output. On the edge of the card were, in pre-printed form, all the possible answers the system could convey. To indicate the computer's response, the Transactor used one of nine pins to punch out a mark next to the appropriate pre-printed answer. In this way, the need for complicated and expensive printing facilities in the interface were eliminated.[138]

The Transactor card represented a compromise between the costs of design and manufacture and optimal performance. The temptation to incorporate a large variety of input data had to be balanced by the cost of designing more expensive input systems. The economic and interface philosophy put a constraint on the diversity of information that could be transmitted from the ticket agent to the system. Richardson's challenge was to distill and then organize from all the operational information flows the data elements needed to run the entire reservation and sales operations efficiently and fit them on to the 300 matrix Transactor card.[139]

The Transactor's hardware simplicity was only possible because of innovations in how operational information was organized and embodied on the card itself. The final Adalia report had suggested viewing automation as part of an integrated, information-processing system, which it called a "Hybrid System."[140] "Consideration of the interdependency that exists between the reservations and scheduling structures," argued Richardson in a memorandum to the

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[137] The drawback to the Transactor technology was its inability to serve as an interface for batch processing. The manual process of inserting a card, the mechanical clamping and unclamping action of the plates, and the final ejection of the card was far too slow to read cards in bulk. But the booking transaction was not a batch process. One dealt with one customer at a time, in real-time.

[138] Another economic advantage was that agents could share a Transactor without impeding their work flow. Richardson also reasoned that the use of cards added flexibility. If the system went down, the ticket agents could nevertheless still make note of customer requests and easily process them in bulk once the system was back up again. Otherwise, the agents would have to write down the booking request information and then enter it again when the system came back on.

[139] One way around the constraint was to design different pre-printed cards for the various facets of the airline's operations: reservations, scheduling, flight operations, etc.

[140] W. H. Campbell, Memorandum to H. W. Seagrim (General Manager of Operations, TCA), 27 July 1955, TCA vol. 100, file 1620-10. Though no copy of the final report exists, we know that during the 25 August 1954 simulated demonstration of automatic reservations done on FERUT, Kates and Johnston lectured on the "Hybrid System". See the undated memorandum from Campbell to Seagrim in TCA, vol. 100, file 1620-10. The 27 July 1955 memorandum from Campbell to Seagrim lists the following design criteria for the Hybrid System: "service improvement; elimination of human linkages, improvement in routines that do not require much speed, accumulation and increased provision of statistical data for report and planning purposes; the system should be realizable as far as possible with known techniques and existing equipment, the system should be flexible and capable of expansion; and the system must be economical."

interdepartmental Automatic Reservations Committee, "[leads] to the conclusion that the most satisfactory automatic reservations system for use in TCA would be one incorporating a facility known as feedback."[141] In this way, the massive quantity of valuable data generated during the reservations process could be gathered easily, assimilated rapidly, and then used to improve future load demand forecasting, traffic scheduling, long-term resource allocation, and improved strategic performance evaluation. Richardson's recommendation tapped into the TCA corporate ethos that stressed a system's approach to efficiency.

On 24 October 1957, on the heels of its difficulties with the Canadian Post Office's electronic automation project, Ferranti Canada demonstrated the effectiveness of the Transactor interface to TCA's executive.[142] Ferranti Canada designed and built six Transactors, the "distribution unit" which polled the Transactors, and the communications interface to the University of Toronto's FERUT computer, where TCA's entire flight schedule had been loaded. From the Toronto's Royal York Hotel, six ticket agents, each equipped with a Transactor, independently queried and updated TCA's seat inventory in real-time. The performance of the Transactor concept convinced the Telecommunications and Sales Departments to prepare for McGregor the detailed design requirements, budget estimates, and cost-benefit analysis for a national system that would join TCA offices in thirty-nine cities in Canada and the United States into one integrated digital electronic system for selling seats. Another year was needed before these two departments would complete their analyses.

On 7 November 1958, W. Gordon Wood, TCA's Vice President of Sales, wrote McGregor that it was finally time to act on the electronic reservation system. The design requirements and advantages of an electronic reservation system had been studied thoroughly

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[141] Lyman Richardson, Memorandum to W. G. Rathborne (Chairman), Automatic Reservations - Report Function, 9 June 1955, TCA, vol. 100, file 1620-10. Reservations and scheduling were complementary facets of the same corporate objective: to move the maximum number of passengers throughout its transportation grid with a minimum of passenger disruption and expense.

[142] Ferranti Canada began to work officially on the $75,000 Transactor contract on 5 March 1957. Josef Kates, now president of his new consulting company called KCS, was hired as a consultant. Dr. J.C. Ogilvie was retained as a consultant on the "so called human engineering' aspects of the Transactor design and the layout of the necessary cards." As part of the contract, TCA let Ferranti Canada retain all patent rights but reserved the right to use the technology free of any royalty fees. Terms of Contract Between Ferranti Electric Limited and Trans-Canada Air Lines, 5 March 1957, TCA, vol. 100, file 1620-10. "Ticketing Handset Reads'Pencil Marks," *Aviation Week*, 11 (November 1957): 47.

with respect to all the details of TCA's sales and scheduling operations.[143] Action on automation was now urgent, explained Wood. Not only had the manual reservation system become unwieldy and slow, but it was now becoming too expensive to maintain. By eliminating most of the human links between the ticket agent and the seat inventory, Wood calculated that an automatic system would drop salary costs associated with reservations by at least five-fold. In the first year alone, Wood estimated that even after one factored in the cost of the automated system, the company would save $557,674. He estimated that in the second year the net savings would exceed over $900,000.[144]

The single most expensive item in TCA's estimated $3.2 million automated reservation project was the computer. The new computer system for reservations represented a spectacular increase in TCA's computational facilities. TCA had a small, vacuum-tube IBM 650 computer, which handled the airline's administrative, financial data-processing, and computations for the Operations Research Department. But it was the Accounting Department that administered the operation of the IBM 650. Would the computer be controlled by the Reservations Department and housed in Toronto, or would it be integrated into the existing data processing facility at Dorval? Territorial conflict broke out over which department would oversee the proposed computer's operation.

The question over the administration of the new computer centre was more than just a question of the prestige of controlling this postwar symbol of technological and corporate power. It was also a matter of influencing the design philosophy of the new computer. From the outset, the Director of the Telecommunications Department, Campbell, who shepherded the automated reservations project from its inception, always visualized the computer as being a tool for the Reservations Department.[145] At a meeting in McGregor's office with executives from other departments, Campbell argued that "if the Sales Department was going to be responsible for

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[143] W. Gordon Wood, Confidential Memorandum to G. R. McGregor, 7 November 1958, TCA, vol. 100, file 1620-10.

[144] In the first year of operation, 1961, salaries would drop form $1,172,547 to $246,087. In 1963, Wood estimated a drop in salaries from $1,394,207 to $246,087 *Ibid.* McGregor replied that these estimates needed more detailed elaboration (on such questions as depreciation, leasing vs. buying, cost of housing the computer etc) before he could use them to convince the Board of Directors. G. R. McGregor, Confidential Memorandum to W. Gordon Wood, 17 November 1958, TCA, vol. 100, file 1620-10. In his second estimate, Wood estimated the final total system cost to be $3,234,550. W. Gordon Wood, Confidential Memorandum to G.R. McGregor, 21 November 1958, TCA, vol. 100, file 1620-10.

[145] Minutes of Inter-Departmental Meeting in President's Office: Automatic Data Processing, 10 December 1958, TCA, vol. 100, file 1620-10.

reservations, they should be responsible for the tool they use, which would be the computer."[146] As a result, the specifications and costing of the computer's design, he argued, should revolve strictly around the reservation task: real-time interaction. Hence the capacity to do large-scale, off-line, data-processing should play a minor role in the design philosophy behind the computer.

Yet J. B. Reid, the Accounting Department's Manager of Electronic Data Processing and the acknowledged company expert on computers, objected that reservations would only consume 6 percent of the proposed computer's total capacity. With an excess capacity equal to twenty IBM 650s, Reid suggested that the proposed computer be reconfigured to solve all of TCA's data-processing needs.[147] The implication of Reid's analysis was that with so much excess capacity for data-processing, the new computer should naturally fall under the management of the Accounting Department. He proposed further studies to elaborate on those features in the computer's design that would be necessary to enhance the computer as a data-processing tool. In support of Reid, W. S. Harvey, the Comptroller, argued that only "one person should be responsible for all computers in the company."[148]

Campbell rejected Reid's estimates of excess capacity as being unrealistically high. W. G. Rathborne, the Director of Reservations further argued that "the Accounting and Reservations requirements could not be combined, according to the experience of every carrier which had tried it."[149] Pointing to the SABRE project, Rathborne suggested that American Airlines had under-estimated the difficulty of joining these two functions in one design. As a result, the American Airline/IBM effort had to compromise on the real-time performance of SABRE's reservation function.

Faced with an inter-departmental feud over the design specifications of the new computer, TCA president McGregor intervened. He underscored the centrality of the reservation problem. However, he acknowledged that there could be during off-peak hours some excess capacity. He agreed that a second set of design specifications and cost estimates should be drawn

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[146] *Ibid.*

[147] Some of the elements Reid wanted incorporated into the computer's design specifications were: batch oriented input/output devices; greater bulk storage capacity, specifically large magnetic tape units; an interrogate command, and enough auxiliary memory capacity to allow the Reservations programme to be dumped and another programme played in, and vice versa. *Ibid.*

[148] *Ibid.*

[149] *Ibid.*

up for a "multi-functional" computer.[150] Aware of the potential pitfalls of such an attempt, McGregor insisted that any multi-purpose design should not in any way compromise the speed of the reservation system. He also cautioned against letting the data-processing issue interfere with the scheduled appearance of the automated reservation system. "The company," he told his executives, "cannot face 1961 without this equipment."[151] On 3 April 1959, TCA solicited sealed bids to build the computer from nineteen electronics firms. The principal dimensions of TCA's computer requirements were to ensure real-time reservation response and reliability, expandable at some future date, and able to handle batch data-processing. The computer thus had to be a general-purpose, that is, programmable machine.

The TCA contract represented a pivotal economic and technological moment in the history of Ferranti Canada's efforts to enter the computer business. After a decade of important technological advances, Ferranti Canada's digital electronic group had yet to establish a viable commercial business. DATAR had suffered a premature death and with it had gone Ferranti Canada's hopes of long-term, lucrative defence contracts. Next came the Canadian Post Office computer. The powerful technological momentum generated by DATAR carried Ferranti Canada's digital electronic ambitions into the civilian sector. Computer-based automation technology for postal service, however, proved to be a commercial dead-end for Ferranti Canada. The project nevertheless did propel Ferranti Canada up the computer innovation wave by making it one of the first companies in Canada to gain design know-how in solid-state digital electronics and drum memory technology. There was also some hope that a profitable business in electronic cheque-sorting technology could be developed in the United States, but little had yet to materialize.[152] In bidding for the TCA contract, Ferranti Canada found itself in competition with seven of the most prominent computer and electronics firms: Burroughs of Canada Ltd., Montreal; Canadian Westinghouse Co. Ltd., Hamilton; E.M.I Electronics Ltd., Middlesex, England; IBM., Montreal; Minneapolis Honeywell Co., Montreal; and Philco Corporation,

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[150] G. R. McGregor, Memorandum to Comptroller, Vice-President of Operations, Vice-President of Sales, Director of Operations Research, and Director of Administrative Procedures, 24 December 1958, TCA, vol. 100, file 1620-10.

[151] Minutes of Inter-Departmental Meeting in President's Office: Automatic Data Processing, 10 December 1958. The year 1961 coincided with TCA's next round of aircraft modernization, which was to bring TCA into the jet age.

[152] Computer cheque sorting was a direct application of the post-office project. Instead of routing letters, one used a special purpose drum memory computer to route cheques. This will be discussed in the next section of this chapter.

Philadelphia.[153] But none of Ferranti Canada's competitors had computer design facilities in Canada.

TCA wanted a general-purpose computer. But all of Ferranti Canada's experience had, to that point in time, been in the design of hardwired, special-purpose computers. Ferranti Canada had to make this technological leap quickly if it did not want to be completely frozen out of the rapidly growing commercial market for general-purpose computers. The TCA contract offered Ferranti its first serious opportunity in ten years to develop general-purpose machines.

Ferranti Canada's chances of beating out the likes of Burroughs, Honeywell, IBM, and Philco would have been slight had TCA placed equal emphasis on the computer's ability to handle reservation and batch data-processing functions, as the latter companies had sophisticated off-the-shelf general purpose computer systems specifically designed for off-line, batch-oriented data-processing. Ferranti Canada's best hope was to exploit the real-time, interactive aspects of the specifications for the reservation system. Of all the competitors, Ferranti Canada was most in tune with TCA's thinking on this matter. After all, Ferranti Canada's digital electronic engineers had, since 1956, worked very closely with TCA's Telecommunication Department in the development of the Transactors and the auxiliary communications technology.[154]

Most of the bidders adapted standard data-processing machines for their proposals. The Honeywell, IBM., and Philco proposals tried to exploit the data-processing potential of their machines. While Philco proposed a fast machine, none of these three offered an attractive solution to the reservation problem.[155] "The Ferranti-Packard and Canadian Westinghouse systems," on the other hand, "were well matched to the Reservations requirements, but they could not be expanded into such useful general purpose systems as the Honeywell, IBM, and Philco computers," concluded TCA's "Committee on the Assessment of Electronic Data

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[153] Committee on the Assessment of Electronic Data Processing Equipment, Minutes of Second Meeting, 19 June 1959, TCA, vol. 230, file 1240-22-2. The companies that declined to bid were: Canadair Ltd., Montreal; Canadian Aviation Electronics Ltd., Dorval; Canadian Curtiss Wright Ltd., Montreal; Canadian General Electric Co., Toronto; Computing Devices of Canada; Metropolitan Vickers Electrical Export Co., Montreal; Remington Rand Ltd., Montreal; Sperry Gyroscope Co. Of Canada Ltd., Montreal; and Standard Telephones and Cables Manufacturing Co., Montreal. The RCA. Victor, Montreal, bid, submitted after the 1 June deadline, was not accepted. The value of the bids were as follows: Burroughs, $1,640,833; Canadian Westinghouse, $1,189,875; EMI, $1,853,700; Ferranti Canada, $1,299,277; Honeywell, $1,330,690; IBM. 1,189,620; and Philco, $1,400,962. Abstract Of Tenders For Central Computer: Automatic Reservation System, 23 July 1959, TCA, vol. 230, file 1240-22-2.

[154] This close working relationship was about to bear fruit in the second half of the reservation project. Ferranti Canada had become the clear favourite to win the $1.8 million contracts to build the 332 Transactors, and all the digital communication equipment linking all the Transactors to the central computer.

[155] Abstract Of Tenders For Central Computer: Automatic Reservation System, 23 July 1959.

Processing Equipment."[156]

Phasing in the automated system entailed eliminating most of the human chain needed to process the ticket agent's booking requests. Once in place, TCA would be utterly dependent on the computer. Expecting nearly 40,000 reservation related transactions a day, TCA could not afford to have the system go down without any back-up capacity. The Canadian Westinghouse proposal, like most of the others, did a poor job of designing adequate redundancy into the reservation system. Common to most of the proposed computer architectures was the use of two computers in series. The front-end computer, the faster of the two, handled the reservation function, while the back-end did data-processing and acted as the emergency back-up.[157] If the first computer failed, the second, much slower computer, offered a poor substitute for reservations.

Ferranti Canada's design approach to TCA's computer requirement was far more novel. It proposed the Gemini system: two identical computers operating in parallel. The twin computers were called Castor and Pollux. During peak-loads, both computers would share the work load. Each computer would independently poll the eight incoming communication trunk lines. Gemini's hardware design made Castor and Pollux into siamese twins joined by special registers, and sharing the same drum and tape mass storage. Each twin knew exactly which of the eight communications trunk lines the other was currently handling and which drum memory address the other was currently reading from, or writing to. In this way, the twin computers could work simultaneously and independently and yet avoid degrading system performance through conflicts. Through this parallel architecture, two smaller computers offered faster real-time performance than one large computer. Of course if one failed, the other could take over.

As far as TCA's Telecommunications and Sales Departments were concerned, Ferranti Canada's original design best addressed the airline's requirement for fast, distributed, on-line access to the seat inventory as well as adequate emergency back-up. Reid, on the other hand, felt that the proposal, as it stood, did not produce a computer system that could handle adequately the

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[156] Committee on the Assessment of Electronic Data Processing Equipment, Minutes of the Fourth Meeting, 30 June 1959, TCA, vol. 230, file 1240-22-2. McGregor had set up this inter-departmental committee, under the chairmanship of P. J. Sandiford, the Director of Operations Research, to select the best bid. The Burroughs proposal was rejected almost immediately because it proposed a vacuum tube design. The EMI proposal was poor in both categories.

[157] Abstract Of Tenders For Central Computer: Automatic Reservation System, 23 July 1959. The Honeywell and Philco bids that did not offer any emergency back-up. With three computers, EMI offered the best redundancy, but the computers were totally inadequate in all the other requirements.

future data processing needs of the TCA's financial and administrative services. As a concession to Reid and the Accounting Department, the Committee chosen to assess the bids, recommended to McGregor that TCA pay for an additional $400,286 in modifications in order to make the Ferranti Canada machine a useful tool for data-processing.[158] If there was sufficient excess capacity, then during periods when on-line demand was low, one of the parallel computers could be taken off-line for data-processing. Despite these modifications, there were no serious compromises made to data-processing. From beginning to end, the pursuit of fast on-line interactivity with the 330 Transactors framed TCA's view of its computer needs.[159] Fortunately

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[158] These additions included doubling the core store, adding three index registers, and using radix conversion circuitry. Other batch-oriented improvements were: four additional magnetic tape drives and buffers; a card reader, card punch; and the requisite control circuitry; and a Samatronic printer. J. B. Reid, Memorandum to W.S. Harvey, Comptroller, 23 July 1959, TCA, vol. 230, file 1240-22-2. The Gemini system that finally emerged consisted of a core memory of 4096 words for each computer. A word was 25-bits long plus a parity bit. The Gemini computers used a one-address architecture. Programming was carried out through an assembly-type language with 90 mnemonic instructions. In this language, addresses could be given names which would logically apply to the program. In all each computer had fifteen registers. The first eight served as intermediate storage in calculations and as index registers for instruction modification. The ninth and tenth registers allowed the Gemini computers to co-ordinate their access to mass storage by keeping track of which locations in drum memory both computers were accessing at any moment. The eleventh register recorded the settings to which the twenty-five switches on the console were set. The twelfth register recorded error in the output/input operations. The thirteenth register was used for paper tape operations. The remaining two registers were reserved for future expansion. Only two additional tape drives were added to the four already specified in the initial proposal.

[159] The jurisdictional disputes over the control of the new computer did not end with the triumph of the Telecommunication Department's design philosophy. The diffusion of the digital revolution into TCA raised the thorny issue of managing access to computer power. While the Sales and Telecommunications departments warned that the existence of any excess capacity for non-reservation tasks was still to be determined, others lobbied to have exclusive control over the computer's data processing functions. While the Comptroller and the existing Manager of the Small Data Processing Centre in Montreal, argued that access to this complex technology had to pass through experts, others wanted each department to carry out its own use of the computer. McGregor's willingness to entrust the management of all the non-reservations uses of the computer to the Comptroller provoked considerable opposition. G. R. McGregor, Memorandum to Comptroller, Vice President of Operations, Vice President of Sales, and General Manager of Purchases and Stores: Organization - Electronic Data Processing, 28 September 1959, TCA, vol. 100, file 1620-10. C. J. Campbell, the Director of the Telecommunications Department, saw this as clear evidence that "ever since the Comptroller added the Manager, Electronic Data Processing, to his staff, their plan was to create a central data processing group in TCA to perform operations for all Departments, including reservations." C. J. Campbell, Memorandum to Vice President of Operations, 13 October 1959, TCA, vol. 100, file 1620-10. He then warned: "we are obliged to be guided by the mistakes other airline organizations admit they made by trying to incorporate other off-line data processing on their on-line and automatic reservations systems." In a personal letter to McGregor, the Director of Administrative Procedures argued that "the fog and mystery, which has surrounded the electronic equipment for data processing, has somewhat dispersed. A new department of data-processing experts was not needed. I am persuaded that it is easier, quicker and less expensive to have the people who know and use the Company processes learn enough about the machine to program and use it, than to have those who know the machine inside out learn the work processes which have to be accomplished...the people with the greatest interest in a result should have the means to accomplish it." Director of Administrative Procedures, Letter to President, TCA, 8 October 1959, TCA, vol. 326, file 2-2, pt. 4. In the end, off-the-shelf computers were bought to fill TCA's data-processing needs. When ReserVec went into operation in 1963, TCA's Data Processing Centre in Dorval had an IBM 1401, and its Data Processing Centre in Winnipeg had two IBM 1401s. While a total staff of needed to run the ReserVec centre

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for Ferranti Canada, this was the only technical card it could play against the other computer manufacturers. And it played it well.

In August 1961, nearly two years after being given the contract, Ferranti Canada installed the Gemini computers at TCA's Toronto offices. But it was not until January 1963 that automated reservations went into full operation. Named ReserVec, TCA's $3.25 million computerized reservation system consisted of 10,000 miles of full-time, voice-quality communications lines linking some 330 Transactors spread over thirty-nine cities to an electronic seat inventory in Toronto.[160] In fewer than two seconds after the Transactor read the input card, any ticket agent could confirm or alter a reservation. Within a few months of operation, ReserVec was handling up to 80,000 transactions a day.[161] Almost immediately, management noted a dramatic improvement in efficiency and substantial cost savings from ReserVec. The number of bookings cancelled because of failure to reconfirm dropped immediately by 34 percent. There was a 250 percent drop in space cancellations due to record discrepancies. Productivity (as measured by reservation person-hours per passenger boarded) improved by 177 percent. All these improvements assured a much higher return on the airline's massive expenditures on new aircraft during the early 1960s.

Epilogue

At both the Post Office and Trans-Canada Air Lines the need to increase productivity turned these public enterprises into patrons of leading-edge engineering development in digital electronics. The story of the Post Office's "one million dollar monster" underscores how, despite Levy's technical brilliance and Turnbull's bureaucratic daring, this state agency was ill-prepared to manage the introduction of radical technical change. In contrast, TCA was prepared to

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in the first year was a modest ten people, the staff at the three Data Processing Centres was nearly 130. TCA Data Processing Coordinating Committee, A Review of Information System and Computer Planning in 1963, January 1963, TCA, vol. 100, file 1620-10, pt. 2.

[160] TCA held a contest among its employees to name the new automated reservation system. "Harry J. Simper, passenger office manager at Lethbridge, won $100 for coming up with the name ReserVec - from Reservations Electrically Controlled." Smith, *It Seems Like Only Yesterday*, 213. One wonders, however why the peculiar typographic form, with a capital letter v, for ReserVec.

[161] Reservations Division, RESERVEC REPORT, 15 May 1963, TCA, vol. 100, file 1620-10, pt. 2.

constrain and manage radical technological change to suit corporate ambitions. First of all, after World War II, TCA's operations were suffused with the postwar spirit of technical progress. From radar and telecommunications to the latest advances in aviation, TCA's business called for considerable technological sophistication. In tandem with this high-tech reality was TCA's "engineering-driven" strategic planning, a management style nurtured under McGregor's tenure as president. The overwhelming emphasis that TCA's senior executives placed on operating efficiency thrust this state-owned airline into a Schumpeterian role. For example, McGregor bragged how TCA was a world industry leader in the introduction of the most advanced commercial aircraft technology. To this author's knowledge, TCA was one of the first Canadian corporations, private or public, to make Operations Research an integral part of the strategic planning process.[162] Though TCA was uninnovative in the services it chose to sell, the airline nevertheless exhibited considerable technical innovation in how it delivered the services.[163]

TCA's carefully elaborated priorities framed Ferranti Canada's pioneering engineering work. TCA saw the need to promote radical innovation. But it was careful not to let the process get lost in the pursuit of ultimate performance. The SABRE system cost $30 million to develop; ReserVec, only $3.25 million. While IBM designed a $11,000 interface for the ticket agent, the Transactor cost only $2,633.[164] Except for IBM's STRETCH supercomputer, the two IBM 7090 computers that made up SABRE were IBM's most powerful commercial, data-processing computers and cost eight times that of the Gemini twin computers used in ReserVec I.[165] While the IBM 7090 could do 229,000 arithmetic additions per second, each of the Gemini twin

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[162] Of course it was already a part of military enterprise.

[163] TCA management's preoccupation, during the period leading up to the commitment of funds to an automated reservation system, was over "how to do things better" rather than "what kinds of activities to do." Mintzberg et al., "Does Planning Impede Strategic Thinking."

[164] These details on the SABRE come from a report from a Canadian government official to Treasury Board, after his visit to American Airlines. E. O. Landry, Notes on Visits to U.S. Commercial and Industrial Firms to Discuss Central Computer Operations, 13 December 1962. TB, Accession 80-81/069, box 179, file 1501-22, pt. 4. Transactor price in Wood, Memorandum to McGregor, 21 November 1958. As a comparison, the standard flexowriter interface to a computer cost about $6,600. Reid, Memorandum to Harvey, 23 July 1959.

[165] Two IBM 7090s cost about $7.2 million (excluding tax), not including the cost of mass storage facilities. See Richard Smith, "A Historical Overview of Computer Architecture," *Annals of the History of Computing* 10:4 (1989): 277-303. The Ferranti Canada's Gemini twin computers cost $0.9 million (excluding tax). Reid, Memorandum to Harvey, 23 July 1959.

computers could do only 17,800.[166] Despite the IBM 7090's faster computational performance, the Gemini computers processed three to four times the volume of transactions per day, and with faster on-line response times per transaction. The reasons for ReserVec's higher throughput were two-fold: Ferranti Canada's novel parallel architecture which optimized real-time reservation task, and TCA's careful efforts to keep to barebones the amount of information that the reservation system needed to work.[167] ReserVec offered a cost-effective, and hence relatively quick, answer to a pressing operational problem.

IBM's design of SABRE was an outgrowth of its experience building the real-time technology for the American SAGE and Dew-Line air defence systems.[168] Similarly, Ferranti's capacity to design the TCA system was to a great extent the legacy of the Canadian navy's DATAR project. DATAR and SAGE were the first defence systems that integrated issues of real-time, electronic, digital, data-processing, data communication, and human/machine interfaces into one system. Despite the high price American Airlines paid for the IBM 7090, the computer was an off-the-shelf item, whose development costs had been covered by the American Air Force's deep pockets.[169] Ferranti Canada used the much shallower pockets of Canada's Post Office Department to develop the digital transistor circuit and drum memory know-how needed to design and build the Gemini computers.

While IBM used its powerful reputation as a leading manufacturer of computers to get the American Airline's contract, Ferranti Canada hoped to use the TCA contract to become

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[166] P. N. O'Hara, "Know Your Data Processing Machines," *Office Automation* (May 1960): 59-71. This article provides an extensive catalogue of the commercial computers of the day. Dornian, "ReserVec: Trans-Canada Air Lines's Computerized Reservation System," 1994, also provides an interesting tabular synthesis of performance characteristics of the two computers.

[167] ReserVec I was extremely limited in the kinds of information it could process. No information about the passengers, other than the first four letters of their surnames, was kept. Other details still had to be filed by hand. SABRE on the other hand stored the passenger's full name, telephone number, special meal requests, and hotel and automobile reservations. It was this dramatic reduction in the kinds of information that ReserVec had to process that allowed the Transactor to be a cheap, but effective, machine interface. ReserVec II greatly expanded the variety of passenger information handled by the system. ReserVec II was designed for much higher throughputs than ReserVec I, from 4,000 transactions per hour to 40,000. Smith, *It Seems Like Only Yesterday.*

[168] For a history of SAGE see George Valley, Jr., "How the SAGE Development Began," *Annals of the History of Computing*, 7 (July 1985): 196-226.

[169] "In 1958, the U.S. Air Force issued a request for proposals for computers to be used in the DEWLINE air defence system. In response, IBM proposed a computer designated 7090 in December 1958....In late 1958 the Air Force ordered four 7090s, to be delivered starting in November of 1959. Components being built for STRETCH...and engineers working on STRETCH were diverted to the 7090." Cuthbert Hurd, "Early IBM Computers (Edited Testimony Given at antitrust trial of U.S. Justice Department versus IBM)," *Annals of the History of Computing* 3 (April 1981): 179.

Canada's first designer and manufacturer of commercial general purpose computers. Like Ferranti Canada, all the other bidders for the TCA computer were subsidiaries of foreign owned companies.[170] Except for Ferranti Canada, each proposal from the subsidiaries of American companies offered mere copies of existing parent firm know-how and products. Ferranti Canada's parent firm, Ferranti U.K., was a prominent builder of computers. And yet, the Canadian subsidiary chose to push its own design. Within seven months of signing the Gemini computer contract, Ferranti Canada announced that it was marketing an off-the-shelf, general-purpose computer.[171]

The $3.25 million TCA contract provided Ferranti-Canada's computer group with the cash, pivotal technological opportunity, and credibility so desperately needed to bolster its ambitions to design and manufacture computers in Canada. Despite this milestone, building a sustainable computer business remained elusive. For all the remarkable innovative tradition of Ferranti Canada's electronics group, it only managed to generate "one-off" sales. DATAR and the postal system computer were custom systems that never generated any repeat sales. Perhaps ReserVec would be different.

Who would be the next customer be? Efforts to market RESERVEC around the world proved to be a very frustrating experience for Ferranti Canada. Systems for national transportation carriers were invariably bought domestically. Ferranti Canada's efforts to sell on-line computer technology to Europe's various national railways failed for similar reasons. Furthermore, Ferranti Canada received little help from its parent firm Ferranti. Rather than promote the proven technology of its Canadian subsidiary, Ferranti U.K. wanted to develop and sell its own computerized airline reservation system to British Airways. Ferranti Canada's failure to get Ferranti U.K.'s co-operation, reflected the parent firm's inability to formulate a coherent corporate wide strategy. This inability, however, was a two-edged sword. It also permitted the Canadian subsidiary to slip through the rather large cracks in parent-firm control and follow its own R&D agenda.

ReserVec was the world's first fully operational on-line reservation system using a general purpose, that is programmable, computer. Nearly two years later the American

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170 Even Computing Devices of Canada (CDC) had given up on building its own general purpose computer business. By 1960, CDC was content to sell the computers of known American manufacturers. In 1960, CDC was selling Bendix computers. See O'Hara, "Know Your Data Processing Machines."

171 A Woods, Gordon & Co. survey of commercial computers for sale in Canada listed Ferranti Canada's Gemini computer, along with its parent firm's Serius and Pegasus computers. *Ibid.*

Airline/IBM SABRE system became the second such system. Though ReserVec was not as ambitious in scope as SABRE, the Canadian system did the job at a fraction of the cost. With some enhancements, ReserVec ran successfully for seven years before it was replaced, in 1970, by ReserVec II.[172] In the late 1980s, Air Canada (formerly TCA) installed another even more comprehensive computerized reservation system. Called "Gemini," the new system provided an important source of revenue diversification. Air Canada marketed the Gemini service to the entire Canadian air travel industry. The choice of "Gemini" as the name for the new reservation system was a fitting reminder that pioneering work in the 1950s gave Air Canada the experience and technical competence to be an important player in the computerized reservation business.[173]

In the early 1990s, nearly forty years after TCA and American Air Lines started to build computerized reservation systems, the direct descendants of ReserVec I and SABRE were at the centre of a fierce corporate struggle between Air Canada and Canadian Airlines (formerly Canadian Pacific Air Lines). At stake were the substantial investments in, and revenues generated by, these two systems. American Airlines would consider a merger with Canadian Airlines only if the latter switched to the SABRE system. Canadian Airlines merger with American Airlines, however, was being blocked by the former's contractual obligation to use Air Canada's Gemini reservation system. The long corporate struggle between Air Canada and Canadian Airlines became a battle over computerized airline reservation technology, and SABRE won.

Hope that the success of ReserVec would open up the world's transportation market to Ferranti Canada soon evaporated. To succeed in a maturing computer market, Ferranti Canada realized that it needed to develop and sell a standardized digital computer, rather than the highly customized one-of-a-kind products it had sold in the past.

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[172] ReserVec II also used parallel computers.

[173] By 1964, all the world's major airlines had some form of computerized reservation system. The problem now was how to share information between these independent computer networks. TCA tried to play a leading role in establishing international standards for inter-airline reservation data exchange. TCA's active role was again driven by the issue of operating efficiency. In this case, Air Canada's TCA's problem was to improve the selling of tickets when its passengers had to link up with other airlines. See "Some Considerations in the Exchange of Reservation Interline Information," 1964. The thrust of TCA's efforts was to define a standard format for communicating digital information. "The Communication of Data Between Systems," draft outline of an Air Canada presentation to IATA, in New York, circa 1964; "The Communication of Message Formats by Means of Field Defining Characters Using the Baudot Code," presented by Air Canada to the ATA-IATA Interline Communications Systems Working Group, 23-25 June 1964, Munich, Germany. Original copies of these documents were given to this writer by Lyman Richardson.

Chapter 6

In Search of a "Made-In-Canada" Computer Industry: The Birth and Death of the FP6000 Computer

From its inception, Ferranti-Canada's computer group existed practically in isolation from the rest of firm. Historically, the company had been, first and foremost, a manufacturer of electrical power products for Canada's utilities. In 1949, the parent firm, Ferranti U.K., grafted an electronics business on to Ferranti-Canada's power operations. For years, Ferranti-Canada's senior management, who were all trained in the electrical power business, knew little, if anything about digital electronic technology. But as long as the Electronics Division did not lose money, Ferranti-Canada's senior executives were content to let this group set its own research and development (R&D) priorities and commercial strategy.[1] The parent firm, whose own technology-driven ethos reinforced the Electronics Divisions ambitious R&D objectives, was also content to adopt a similar stance. This arms-length policy was a two-edged sword. With the independence that it provided came the reluctance on the part of senior management to share the Electronic Division's commitment to make the commercialization of computers a cornerstone in the Canadian corporation's existence.

As the Post Office and Trans-Canada Airlines stories reveal, Ferranti-Canada's Electronics Division aggressively pursued opportunities to convert its military-driven, digital electronic expertise into civilian products, even before the demise of DATAR in 1956. Once DATAR collapsed, these efforts to build new civilian markets became a matter of life-and-death for the Electronics Division. New sources of revenue were needed if the Division was going to keep intact all the expertise it had built up during DATAR. Not only did the Post Office and TCA projects help provide the Electronics Division with sufficient financial stability to maintain

[1] In 1949, the Research Department was specifically created to handle Ferranti-Canada's new digital electronic work. In 1958, after Ferranti Electric merged with Packard Electric to produce Ferranti-Packard, the Electronics Division was created to manage all digital electronic product development work. In the context of this chapter, the term "Electronics Division" is used to denote the computer group even in references prior to 1958.

a strong R&D program, but these projects also provided the Division with an opportunity to continue moving up the technical learning curve that was so essential to its ambitions of entering the commercial, general-purpose computer market. The mail-sorting computer project for the Post Office propelled the Division up the transistor learning curve and also allowed it to perfect its mass-storage technology. In the ReserVec I project for TCA, the Division perfected the basic logic circuitry needed to build commercial computers and also developed the experience in designing programmable computer architectures. Though unable to sell any turnkey computer reservation systems, the success of ReserVec I's Gemini computer intensified feelings within the Electronics Division that the time was ripe to commit greater corporate-wide energy and resources to establishing a niche in the commercial computer market. But there was a growing feeling of exasperation that the company's Canadian upper management had no real interest in building a computer business.

Faced with this increasing discontent and impatience, the manager of the Electronics Division assured his engineers that he was working on a plan to convince senior executives to let Ferranti-Canada manufacture the parent firm's existing advanced computers. With no indigenous computer manufacturing facilities in Canada, the federal government was receptive to Ferranti-Canada's request for financial assistance to set up production facilities. All that remained to be done was to receive the parent firm's approval and arrange for the necessary technology transfer. But overwhelmed by its own badly managed computer operations, Ferranti U.K. rejected the proposal. Angered at the news and the absence of any support from upper management, many of the senior computer engineers in Canada tended their resignations. After a long meeting, Tom Edmondson, the CEO and Chairman of the Board of Ferranti-Canada, managed to convince the engineers to reconsider their resignations and persevere a little longer. Although the CEO diffused the crisis, the central issue remained unaddressed: how and when would the company, building on its Gemini expertise, get into the general-purpose computer business?

While the R&D ambitions of Canadian military and civilian public enterprise had served to move Ferranti-Canada up the digital electronic learning curve, it was American public enterprise that gave the company the first opportunity to create a niche in the general-purpose computer business. This chapter explores how the United States Federal Reserve Banks' advocacy of digital automation as a way to keep up with the rising flood of financial paper transactions created Ferranti-Canada's first opportunity to sell general-purpose computers. The computer's design, as this chapter shows, was both a logical extension of the Trans-Canada Air

Lines's ReserVec I system and Ferranti-Canada's search for niche in a market dominated by large mainframe manufacturers such as IBM. Furthermore, the narrative that follows will illuminate the circumstances surrounding Ferranti-Canada's failure to turn the Federal Reserve Bank computer into a commercial success and the subsequent demise of the company's computer design group. Finally, this chapter will show that the memory of government inability to act swiftly to support Ferranti-Canada's bid to commercialize general-purpose computers played an important, but subtle, role in the Government's efforts during the 1970s to foster an indigenous computer industry.

Technical Know-How Finds Commercial Opportunity: The Role of American Public Enterprise

By the early 1950s, faced with the prospect of being buried under a mounting volume of paper cheques, the United States Federal Reserve System anxiously searched for new technologies to accelerate the "clearing" process. After a spate of bank failures, the United States Congress had created the Federal Reserve System in 1913 to ensure public confidence in the solvency of the American monetary system.[2] The reliable and timely clearance of cheques was essential for this confidence. For the thousands of small independent banks throughout the United States, the Federal Reserve System came to offer a fast, easy, convenient and secure way to clear each other's cheques.[3] While the Great Depression had reversed the steady climb in cheque transactions of the preceding decade, the volume of cheques handled by the Federal Reserve System resumed its growth with the start of World War II and accelerated in the postwar years. From 700 million per year in 1939, the number of cheques cleared annually by the Federal Reserve system had soared to 2.8 billion in 1956.[4] This expanding circulation of cheques in the

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[2] Reflective of the U.S.'s regional development, twelve regional banks made up the new Federal Reserve System, with overall co-ordination held by a Board of Governors in Washington, D.C.

[3] The reserve deposits, to which all members of the Federal Reserve System had to contribute, became the medium of adjustment during the daily clearing process

[4] *The Federal Reserve System*, (Washington, D.C.: Board of Governors of the Federal Reserve System, July 1954), 157. The figure for 1939 is very approximate because it was read off a graph. For the 1956 figure see Appendix B, "Selected Operating Data of the Federal Reserve Banks and Branches," in R. C. Amara and Bonnar Cox, *A Study of Check Handling Operations in the Federal Reserve System*, A Stanford Research Institute Study prepared for the

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economy showed no signs of slowing down in the postwar economic boom. One bank specialist at the Product Development Division of National Cash Registers suggested that the volume of cheques cleared by all banks in the United States would climb from 3.5 billion in 1957 to 14 billion in 1960.[5]

Since cheque clearing was a labour intensive process, the considerable expansion of clerical staff needed to keep up with the vertiginous growth of cheques in circulation troubled Federal Reserve officials. The Federal Reserve Banks (FRBs) found the prospect of large increases in its labour force economically unattractive. First, there was the high cost of salaries. Low birth rates during the 1920s and 1930s and low rates of unemployment during the 1950s had raised the price of labour. There were also indirect, but equally important, costs associated with a labour intensive solution to the cheque clearing problem. Any new army of clerical workers would require very large expenditures on new facilities to accommodate them. Rather than a large-scale expansion of its labour force, the FRBs preferred the path of increased labour productivity through technical innovation.

In the early 1950s, the FRBs had already foreseen the long-term need for high-speed mechanization. Under the leadership of H. H. Kimball, the Vice President of the Federal Reserve Bank of New York, the FRBs set up atechnical sub-committee to examine if the miracle of electronics could be applied to the cheque clearing bottleneck.[6] Since the automation of cheque handling was a problem that faced American banks and clearing houses outside of the Federal Reserve System, the American Bankers' Association (ABA) had also set up its own Committee on the Mechanization of Check Handling. From 1953 to 1957, the FRBs were content to let the

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Federal Reserve Banks, September 1957. Federal Reserve Bank of New York Archives. Henceforth this archive will be referred to as FRBNY.

[5] See pp. 5-6, "Banking Uses" in R. Ziola, Report on the Fourth Institute on Electronics in Management held at the American University, Washington, D.C. on 4-8 November 1957, 3 December 1957, TB, vol. 632, File 1501-22.

[6] This Electronics Subcommittee reported to the FRBs' Committee on Miscellaneous Operations. The FRBs also participated in the U.S. Treasury Department's efforts to promote the development of electronic equipment to process the paper cheques issued by the Federal Government. On 28-29 September 1953, the Treasury Department held a Symposium on "Utilization of Electronic Equipment in the Clearance, Payment and Reconciliation of Government Card Checks," which brought together its officials, those from the FRBs, and twelve leading electronics, computer, and business machine manufacturers. J. E. McCorvey (Assistant Vice President, Federal Reserve Bank of Atlanta), Memorandum to Lowell Myrick (Assistant Director, Board of Governors of the Federal Reserve System), 30 September 1953, FRBNY. Following this symposium, the Treasury Board set up the Joint Government Committee on Electronics to pursue the same question. Once again the FRBs participated. E. F. Bartlett (Fiscal Assistant Secretary, Treasury Department), Memorandum to H. H. Kimball (Vice President, Federal Reserve Bank of New York), Agenda of Meeting, 1 April 1954, FRBNY.

ABA Committee take the lead on the automation issue. During this period, the ABA Committee tried to raise manufacturers' awareness of the banks' technological needs. Central to the ABA Committee's strategy was the quest for a consensus across the banking community on how to encode information on cheques. Standardization, reasoned the ABA Committee, would accelerate the industry's development of suitable cheque-clearing equipment.[7] As with the electronic mail-sorting, a key technical challenge in automated cheque clearance was the proper encoding of the essential information needed to process cheques at high speeds, and then to scan this code electronically and convert it to a binary digital format. The ABA Committee advocated standardizing around a new technology called Magnetic Ink Character Recognition (MICR).[8] Despite the ABA's efforts, commercial equipment to mass process cheques remained elusive. All the technological pieces for electronic cheque-sorting were available, but no manufacturer had yet integrated them into a system.

As the nation's largest clearinghouses, the FRBs could no longer stay in the background and wait for a solution. Pressed to find an answer to the growing bottlenecks in their own operations, the FRBs decided in 1957 to take a more aggressive role in accelerating the development, manufacture, and implementation of electronic cheque-clearing equipment. In May 1957, after months of discussions, the FRBs engaged the Stanford Research Institute (SRI), in Menlo Park, California, to study "the check handling requirements of the Federal Reserve Banks with a view of isolating those problem areas to which special attention should be given and from which mechanization can be expected to yield the greatest returns."[9] The SRI study set out "to make a preliminary translation of [FRB's] operating requirements into electronic devices and systems which incorporate currently known techniques; and then to make an initial study of the economic feasibility of such devices and systems."[10]

SRI's four-month, $16,000 study examined the technological and economic issues of mechanization along two principal axes: the preparation of cheques for sorting and the actual sorting of cheques and settlement of accounts between banks. The first axis dealt with the

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[7] C. Edgar Johnson (Vice President, First National Bank of Chicago), Memorandum to John Hurts (Vice President, Federal Reserve Bank of New York), 19 February 1954, FRBNY.

[8] The MICR method called for the use of black magnetic iron oxide ink to print Arabic numerals. This was a departure from encoding information as bar codes. Today, all cheques have MICR printed numbers on the bottom.

[9] Oliver Whitby (Division of Engineering Research, Stanford Research Institute), Letter Proposal (E 56-39) to H. H. Kimball (Subcommittee on Electronics), 11 April 1957, FRBNY.

[10] Amara and Cox, A Study of Check Handling Operations in the Federal Reserve System, September 1957, 1.

problem of encoding the cheque with the amount and the identity of the bank on which it was drawn. If the amount and ABA number on each cheque were MICR-encoded, an electronic sorting system could "read" the cheque at very high speeds and sort them according to the banks on which they were drawn.[11] In the process, the electronic sorting system could keep a running total of the value of all cheques drawn from each bank. Using these totals, the FRBs could then settle any outstanding difference between their member banks by simply debiting or crediting their standing reserve accounts.

The economic feasibility of this electronic sorting depended on what percentage of the cheques sent to the FRBs for clearing that had already been encoded with the ABA Number and amount. A high percentage meant less manual encoding for the FRBs. If fewer than 50 percent of the cheques received had the ABA number and amount encoded on them, there would be no economic advantage to the electronic methods of sorting. Beyond the 50 percent level, savings became "significant." For example, with 75 percent of the cheques pre-encoded, the FRBs would save 35 percent of the cost of clearing.[12] More importantly from the FRBs' perspective, these savings could, according to SRI, be traded for a 100 percent increase in throughput.[13] Thus for mechanization to succeed, it was imperative for the FRBs promote the development and diffusion of Amount Encoding equipment based on the MICR concept.[14] Technologically, there were no obstacles to designing and building suitable Amount Encoders. The manufacture of MICR printing and reading equipment remained stalled, noted the SRI study, because standards had not yet crystallized. Unless simple standardization issues, such as where to locate encoded information on the cheque and what font to use, had unanimous acceptance in the banking community, equipment manufacturers would not risk any product development. SRI

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[11] The American Bankers' Association had drawn up an eight-digit code, called the ABA number, which uniquely identified each of the 21,000 banks in the United States. SRI's study reaffirmed that Arabic numerals printed in magnetic ink were the best approach to encoding the ABA number and amount. "Since dirt, overstamping, and other types of document defacement are a constant problem, reliance has not been placed on optical scanning methods, such as photocell pick-up or those using phosphorescent ink; consequently these and related condition have led to the choice of magnetic ink as the recording or printing medium. The early success with bar-code systems led to the investigation of means of reading Arabic numerals directly. Since such Arabic numerals must be printed in any case to convey information to the human reader, much less printing and duplication are required, and an enormous advantage is attained." *Ibid.*, 16-7.

[12] *Ibid.*, 54, Table VII.

[13] *Ibid.*, 4.

[14] For the ABA number there was a relatively easier solution: each bank would, when having its cheques printed, also print its ABA number in magnetic ink on the cheque.

recommended that the FRBs throw their considerable weight behind the standards proposed by the American Bankers' Association.

While the development and manufacture of MICR printing and scanning equipment were straight-forward matters, the same was not true of the digital electronic system that would control the sorting process and keep track of the running total values of cheques drawn on each bank. SRI proposed an electronic, digital, dictionary look-up approach.[15] Operating one cheque scanning/sorting operation, at ten to twenty cheques per second, with drum memory was in itself a challenge. But for economic reasons, SRI recommended having at least three scanning/sorting processes running simultaneously. Thus the challenge in designing this special-purpose computer was to allow several concurrent processes to access the memory independently and still keep each process moving at its top speed. In technical terms, the ability to field a cost-effective, high-speed, electronic cheque system required designing in real-time, time-sharing, or multiplexing features into the system's computer.[16]

"[With] little or no emphasis placed on research and production of [such systems]," SRI underscored the need for "the Federal Reserve System to take immediate action in the direction of playing an active role in directing business machine manufacturers toward such a development."[17] Either the Federal Reserve System would have to invest directly in research and development or it would have to incite industry to undertake this work by promising the whole prize to one company. The Federal Reserve System chose the second option. The Electronic Subcommittee asked the SRI to have more detailed specifications of the Federal Reserve System's equipment needs ready for widespread public distribution by 1 March 1958. "The subcommittee felt that such an announcement would induce competition in the development of equipment, not only among the recognized office equipment manufacturers, but also among

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[15] The ABA number of each bank was to be stored digitally on a high-speed magnetic drum. The moment the scanner converted the encoded ABA number into binary code, the system would look-up which bank the cheque was drawn on, and then control the mechanical sorter to ensure that the cheque went to the proper holding bin. At the same time, the amount of the cheque would be converted to digital data and added to the appropriate drawee bank's running debit total.

[16] "The availability of specific portions of sorting equipment capable of meeting the requirements of the Federal Reserve System is likely to lag behind. This is particularly true of the 'dictionary look-up' system capable of operating multiple Sorters which has been recommended in this report." Amara and Cox, A Study of Check Handling Operations in the Federal Reserve System, September 1957, 67.

[17] *Ibid.*

manufacturers of other precision equipment."[18]

Six months after SRI made its system specifications public, Ferranti-Canada submitted its proposal to the Federal Reserve System.[19] Thanks to the Canadian Post Office mail sorting project, which had just ended, and its ongoing work with Trans-Canada Air Lines, Ferranti-Canada had acquired the perfect blend of know-how needed to compete head-on with American computer and electronic manufacturers. Mail and cheque sorting were similar tasks. The key difference was the need to add accumulators to the special-purpose computer to keep running credit and debit tallies on all cheques drawn from any one bank and deposited to any other. The special-purpose computer built for the Post Office contained the necessary transistorized, digital-circuit design expertise, and the high-speed, drum-memory technology to serve as a cheque-sorting computer.[20] But equally important, Ferranti-Canada's work on DATAR and its 1957 contract with TCA to design, build, and multiplex six Transactors to FERUT gave the Canadian company a keen appreciation of how to get many concurrently running processes to share a computer's resources in real-time.[21]

The Federal Reserve System did not confer the field trials to one manufacturer nor to just one FRB. After all the proposals had been received and analyzed, the Federal Reserve System decided in 1959 to launch an extensive pilot study to evaluate the technical, operational, and economic aspects of the most promising proposals.[22] Five Federal Reserve Banks were chosen as

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[18] H.H. Kimball, Chairman (Subcommittee on Electronics), Memorandum of Meeting of the Subcommittee on Electronics in New York in November 6, 1957, 22 November 1957, FRBNY

[19] Standford Research Institute, Operational Performance Specifications For Check Handling Operations of Federal Reserve System, March, 1958; and Ferranti-Packard Electric Ltd., A Proposed Document Sorting System for the Federal Reserve Bank System, FRBNY.

[20] Prior electro-mechanical, office-automation technology, such as punched cards and pencil-marked cards, sorted one digit at a time. For example, if one were sorting cards by an encoded, three-digit, decimal number, the first pass through the sorter would arrange all the cards into ten pockets, one for each of the possible ten first digits. Then each of these ten piles would be sorted again by the second digit. The process would be repeated for the third digit. SRI's recommendation to use a special-purpose, drum-memory sorter was intended to eliminate the time-consuming sorting by digit. While multiple-pass sorting may have been workable in cheque sorting, it was totally unacceptable for postal-sorting. This was why Maurice Levy had from the beginning pushed for a stored-memory approach to sorting. In its contract proposal to the FRBs, Ferranti-Canada played up the fact that its computer for the Post Office had already demonstrated the idea that it was feasible to do reliable, high-speed sorting by the entire ABA number, as SRI had called for.

[21] The reader will recall that in DATAR, many sensing devices (radar and sonar) on several ships were connected on-line to one computer, and that users of different ships all had on-line, real-time access, to the special-purpose computer.

[22] For details on the terms of reference of this pilot project see Guideline to Pilot Planning, 21 December 1959, FRBNY.

test sites. In the Federal Reserve Bank of New York test site, Ferranti teamed up with firms Pitney Bowes and National Data Processing. Pitney Bowes was to build the mechanical sorter equipment and National Data Processing the MICR encoding equipment.[23] The contract drawn up between Ferranti-Canada and the Bank called for a monthly rental fee of $7,200 per month during a six-month test period, after which time, if the system performed to specifications, the Bank had to either buy Ferranti-Canada's Stored Reference Computer for $295,000 or continue to rent it for $7,200 a month for an additional four and a half years.[24]

By September 1961, the field tests at the Federal Reserve Bank of New York had been completed successfully. Estimating that its system would process some 500,000 cheques daily, the Federal Reserve Bank of New York received approval from the Board of Governors in Washington, D.C. to purchase the Ferranti-Canada computer.[25] But before the New York bank had taken this decision, Ferranti-Canada tried to sell it an improved design. Having just installed the Gemini computers for TCA, Ferranti-Canada tried to transfer this technical experience back to its Stored Reference Computer. The company proposed a computer that considerably simplified the multiplexing hardware, improved the memory drum, offered input and output buffers, and provided new circuitry for self-testing, arithmetic and control functions.[26]

If the Federal Reserve Bank of New York was interested, it said nothing. Ferranti-Canada meanwhile issued a press release that it had sold the only Canadian-made computer for cheque-sorting purposes.[27] The delivery of the ReserVec general-purpose computer to TCA had already produced a heady atmosphere within Ferranti-Canada's computer group. The successful performance of its cheque-sorting computer only intensified the feeling. Ferranti-Canada issued product literature and hoped that it could build a repeat business around cheque sorting.[28]

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[23] A. J. Stanton, Check Mechanization Department (Federal Reserve Bank of New York), Memorandum to Mr. MacInnes: Proposed Budget - 1960, 5 August 1959, FRBNY.

[24] M. A. Harris, Memorandum to W. F. Treiber (First Vice-President, Federal Reserve Bank of New York), 7 September 1961, FRBNY.

[25] W. F. Treiber (First Vice-President, Federal Reserve Bank of New York), Letter to the Board of Governors of the Federal Reserve System , 5 December 1961, FRBNY.

[26] Ferranti-Packard Electric, "A Proposal For A Modular Check Sorter Computer For High-Speed Sortation of Magnetic Ink Encoded Checks," Prepared For The Federal Reserve Bank of New York, August 1961, FRBNY.

[27] Ferranti-Packard News Release, 15 December 1961. Original in this author's possession.

[28] Ferranti-Canada's design approach was to make all aspects of the computer cheque-sorting system modular, to enable customers to expand the capacity of their sorting systems in an economical and flexible manner. These modules consisted of a central dictionary look-up reference unit, drum-load and print-out facilities, simulators,

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While computerized cheque clearance was an item high on the ABA's technology agenda during the 1950s, Canadian banks appeared uninterested. And yet, the growth in the volume of circulating cheques resembled the United States' experience. A Government report noted that "the annual fluctuations in cheques cashed from 1924 to [1948] followed rather consistently the cyclical movements [of the periods 1924-29, 1930-37, and 1938-48]."[29] The report also underscored that "the advance both in duration and magnitude in the cashing of cheques from 1938 to 1948 was without precedent."[30] The post war growth in the value of cheques cleared was just as impressive: from $68 billion in 1945 to $212 billion in 1957. Though inflationary factors contributed to this growth rate, it nevertheless reflected a considerable growth in the volume of paper cheques that Canadian banks had to handle. "During that period, the total number of cheques was almost doubled," explained a Royal Bank publication. "[In 1964] the yearly total has reached one billion and continues to increase at the rate of around 10 percent a year."[31] But it was not before 1964 that the Royal Bank admitted that "if [it] retained its present methods, this volume would soon become unmanageable....In short, existing methods, staff and premises are inadequate in the face of this increase in business."[32] Despite the claim that "the enormous increase in the number of cheques handled by the Canadian banks in the decade after the last war [World War II] prompted banks to search for faster methods of processing," it is difficult to find any reference in the literature during the 1950s to Canadian banks' trying to promote the development of electronic cheque-clearing. One can only speculate as to why it took so long for computerization of cheque clearing to develop in Canada. Perhaps it has something to do with the way cheques are cleared in a system dominated by handful of banks owning thousands of branches where a higher percentage of cheque clearing entails inter-branch account-settling.

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controls, and power supplies. Any one of these units could be replaced and upgraded, as needs changed. A fully expanded cheque sorting system, Ferranti-Canada argued, could process up to 135,000 cheques per hour.

[29] Dominion Bureau of Statistics, Canada, *Annual Report on Cheques Cashed, 1948* (Ottawa, Dominion Bureau of Statistics, April 1949), 13.

[30] *Ibid.*, 1.

[31] "Our Bank Enters the Electronic Age", *Royal Bank Magazine* (May and June 1964).

[32] *Ibid.*

Pushing Cheque Sorting From Special to General Purpose Computers

By 1962 technical advance had started to undermine Ferranti-Canada's approach to cheque-sorting. Despite its inflexibility, the special purpose computer had been an attractive option for a certain class of data-processing because of its lower cost and higher speed. But as the price-to-performance ratio of general purpose computers improved, they became, as Ferranti-Canada had earlier recognized, a competitive alternative to special purpose computers, even in very restricted applications. Furthermore, programmable computers allowed cheque sorting operations to be expanded to include a wider range of data processing tasks as circumstances warranted. Honeywell's efforts to introduce general purpose computers into the cheque sorting operations of banks made Ferranti-Canada realize how vulnerable its business plan was.

In January 1962, one of Ferranti-Canada's system engineers, Paul Dixon, proposed that the Federal Reserve Banks further improve their cheque-processing operations by purchasing a general purpose computer from Ferranti-Canada.[33] "The use of the [Ferranti-Canada designed] general purpose computer," argued Dixon, "marks an important step forward in the operating efficiency, reliability and flexibility, in the high-speed cheque sorting operation."[34] The use of a programmable computer, Dixon explained, would allow the Bank to determine the optimum sorting patterns and to change sorting patterns easily on demand; to prepare a greater number of more sophisticated control totals that would significantly reduce the manual work needed to maintain tight audit trails; and to make the system more adaptive to changing conditions. But the real advantage of the general purpose computer proposed by Ferranti-Canada was its ability to run several real-time applications at the same time. The computer could run three independent sorting runs simultaneously, each with its own optimal sorting pattern and audit trail. At the same time, the computer controlled a variety of peripherals: a high-speed paper tape reader and punchers, high-speed line printers, card readers and punchers, and magnetic tape units.[35]

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[33] Proposal for a General Purpose High-Speed Document Sorting System for the Handling of M.I.C.R. Encoded Documents for Federal Reserve Bank of New York, Ferranti-Packard Electric Proposal No. TY.100, prepared by Paul J. Dixon, January 1962, FRBNY.

[34] *Ibid.*, 25.

[35] "The distinguishing feature of the computer," claimed the Ferranti-Canada proposal, "is the provision of full range time-sharing and automatic interrupt facilities. This makes the computer particularly suitable for use in real-time applications such as cheque sorting. The interrupt facility enables the computer to respond instantly to any signal or request for action form the sorter and considerably reduces the timing accuracy of passing cheques for accurate

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Real-time "time-sharing" was an extension of the multiplexing features Ferranti-Canada had used in the special-purpose, cheque-sorting computer. But in the new design, the "time-sharing" concept expanded beyond hardware to include software. "The time sharing feature," wrote Dixon, "enables the computer to operate several programs concurrently, while providing full-store and computational protection to each program handled. Hence, in the course of cheque sorting, the computer will be able to monitor its own operations and the accuracy of control accumulations which actually sorting."[36] In both the special purpose and general-purpose computer designs, the economic necessity for the Bank to have several sorting processes going on in parallel shaped how Ferranti-Canada came to define its competitive advantage in terms of innovation based on "time sharing."

The computer, which was named the "F.P.-6," had not yet been designed in any detail, let alone built. But that did not stop Ferranti-Canada's computer engineers from boasting that the F.P.-6 was a "next generation general purpose computer" which "represented a genuine breakthrough in terms of performance."[37] This self-confidence, which rested on the successful transistorized logic circuit design Ferranti-Canada had used in the TCA Gemini computers, was reinforced when the parent firm asked Ferranti-Canada computer engineers to participate in crucial computer-development program known as ORION II.

Acutely aware of its diminishing share in the world computer market, Ferranti U.K. had decided to expand its product line downwards by launching a smaller machine called the ORION. In the design of the ORION, Ferranti U.K. gambled on a radically new circuit design. The ORION project was fraught with technical difficulties, cost overruns, and substantial delays. At one point in the project's life, Ferranti U.K. management worried that the technical and financial problems might prove to be insurmountable. As result, Ferranti U.K. started an alternate backup project, called ORION II. The parent firm decided to use Gemini's less sophisticated, but proven, transistor circuit techniques in the construction of ORION II. In 1961, engineers from Ferranti-Canada had gone to England to participate in the ORION II project. For a time two

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operation." *Ibid.*, 33.

[36] *Ibid.*

[37] *Ibid.*, 31. While the F.P. in F.P.-6 represented the company's name, Ferranti-Packard, one can only speculate why the number "6" was chosen. Perhaps because this was the sixth digital computer designed and built by the company; one for the Royal Canadian Navy, two for the Canadian Post Office (one tube and one transistor), one for Trans-Canada Air Lines, and one for the first FRBNY cheque sorter.

groups worked in parallel: the first in Manchester, U.K., building ORION, and the second in Bracknell, U.K., building ORION II.[38] Orion II was never needed, but the experience later served to reaffirm the Canadian computer group's belief in its design capabilities. So when, in March of 1962, the Federal Reserve Bank of New York (FRBNY) agreed to buy the F.P.-6 computer, the ORION II experience further convinced the engineers and management in Ferranti-Canada's Electronic's Division that they had the "right stuff" to build the "Next Generation" general purpose computer.[39]

Ironically, the technical advantages Ferranti-Canada promised to deliver in its new computer were not the determining factor in the Federal Reserve Bank of New York's decision to buy the computer. The special-purpose, cheque-sorting computer still worked quite well. But officials of the Bank feared that when the system reached its expected processing output of 500,000 cheques a day, any breakdown in the computer would prove disastrous: a mountain of cheques to clear for the next day and no back-up facilities. Paul Dixon, who was a systems engineer/salesman at Ferranti-Canada, had no doubt learned before he submitted his proposal that the Bank had already planned to buy a second computer as a back-up. The Bank's decision to go with Ferranti-Canada was in part based on the success of the existing system, but equally important, the Bank felt it advantageous to have one, rather than two, manufacturers responsible for the maintenance of its computer systems.[40] Dixon did not know that the Bank had already allocated $260,000 for a second system.[41] The fact that Ferranti-Canada was asking only $152,350 for this "Next Generation" general purpose computer turned necessity into a great deal for the FRBNY.[42]

The news of Dixon's sales coup transformed the festering discontent within Ferranti-Canada's computer group into euphoria. At long last, the company was in the commercial

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[38] ORION was finally completed. However, as an answer to Ferranti U.K.'s deteriorating computer business, ORION was a dismal failure. ORION only served to intensify the company's financial losses arising from its computer operations. The ORION became a significant contributing factor to Ferranti U.K.'s eventual withdrawal from the commercial, general-purpose computer business. From 1962 to 1964, the Ferranti U.K.'s Computer Division lost nearly $7.5 million. See "Annual Financial Statements of Ferranti Limited World-Wide Operations," Ferranti Packard Collection, Ontario Provincial Archives, Toronto, Canada.

[39] W. F. Treiber (First Vice-President, Federal Reserve Bank of New York), Letter to the Board of Governors of the Federal Reserve System , 5 March 1962, FRBNY.

[40] *Ibid.*

[41] *Ibid.*

[42] This was the price quoted in Dixon's January 1962 proposal.

computer business. In a more detailed draft of the proposal, the F.P.-6 was replaced by the "FP6000 High Speed Check Sorting System."[43] This system represented an entire product line of components. The computer itself was called the FP6001. However, by tradition this computer has come to be identified with the name FP6000.[44] Within a year, Ferranti-Canada had designed, built and installed the FP6000. Excitement was running high. In November 1962, while Ferranti-Canada was working on the Federal Reserve Bank's FP6000, it got another order for one from Canada's Naval Research Establishment in Halifax.[45] Several months after this order the Toronto Stock Exchange also ordered a FP6000 computer.[46]

The initial performance and cost considerations in the design of the FP6000 tried to exploit a specific opportunity with the Federal Reserve Bank of New York's cheque-sorting needs. At the same time, Ferranti-Canada's design philosophy was also a reaction to the problems of its parent firm's computer business. Although Ferranti U.K. produced remarkable, high-powered computers for scientific applications, the company had difficulties addressing the various levels of the burgeoning electronic data processing and office-automation market. Ferranti U.K.'s computer business was unable to find the right technical and marketing response to this still untapped market. Preoccupied with technical sophistication, the company lost sight of its customers and their needs. As Peter Drucker pointed out, "while the technological leaders in the early computer days...were product-focussed and technology-focussed, the punch card salesman who ran IBM asked: 'Who is the customer? What is value for him? How does he buy?

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[43] Ferranti-Packard, Draft Specification of the FP6000 High Speed Check Sorting System for the Federal Reserve Bank of New York, May 1962, FRBNY.

[44] Like the Gemini computers, the FP6000 computer used a 24-bit word length, with an additional bit for parity, and 1-address architecture. But the instruction formats were different. An instruction in Gemini was structured as follows: S, M, F, X, N; the Stop-Go, S, was 1 bit; reference to the register for indexing, M, was 3 bits; the operation code, F, was 6 bits; the accumulator registers, X, was 3 bits; and the address in core store, N, was 12 bits. FP6000 used only 2 bits for the index registers and but seven bits for a longer function code. The last difference was to accommodate a much larger order code. For details on the Gemini architecture see Ferranti-Packard Electric, *Gemini Data Processing System: Programming Manual*, 1963, in Canada's National Museum of Science and Technology collection. For details on the FP6000, the National Museums of Science and Technology's collection contains the complete circuit, programming and operating system documentation for this computer. The FP6000 also had fewer accumulator registers than Gemini (8 instead of 15). The late Fred Longstaff, the computer's chief designer, later recalled that it was big mistake to choose a 24- rather than a 32-bit word length. When this author asked him why he did so, Longstaff replied that it was more or less an arbitrary decision. But he failed to recall that he had already used 24 bits in the Gemini computers.

[45] Naval Research Establishment, Progress Report FP6000-2, 30 May 1963, DND, Accession 83-84/167, box 7589, file DRBS 9900-31, pt. 1. The computer was delivered in June 1963.

[46] This system was delivered in December 1963.

And what does he need?' As a result, IBM took over the market."[47] The loss of $450,000 in 1961 was clear indication of the commercial world's response to Ferranti U.K.'s computer business strategy.[48]

Meanwhile, Ferranti-Canada's computer group felt that its best chance to survive against the likes of IBM, Univac, and CDC was to aim at a mid-level market and to stay clear of big systems. The challenge then became one of designing a lower-priced, mid-sized computer. To make the FP6000 a more attractive option for the mid-level, data processing user, Ferranti-Canada migrated its "time-sharing" innovations for high-speed cheque-clearance into the advanced feature of multiprogramming. In batch processing, all the user programs queued up and ran one after the other. The programs could range from complex scientific modelling to large financial, data-processing applications. Each program made different demands on the computer system's central processing unit, core memory, magnetic tapes, magnetic drums and disks, printers, paper tape units, and so forth. When only one program was being executed, there were always some portions of the computer's resources that sat idle. For example, while writing to mass storage devices or to the printer, the resources of the central processing unit were being wasted. In allowing many batch programs to run concurrently, multiprogramming improved the throughput and economics of the entire computing centre. By the end of 1960, a small number of attempts were made to implement multiprogramming on very large systems, such as the IBM STRETCH computer.[49]

While the advance of multiprogramming had become more widespread by 1963, it still remained confined to very big and expensive machines. At a conference, which attracted North America's leading computer engineers, a Ferranti-Canada team explained how "time-sharing facilities normally only available on larger computer systems may be realized on a medium-sized system [on the FP6000] by an intermarriage of hardware and software for minimum cost yet still retain all the safeguards necessary for an operable system."[50] For multiprogramming to be a

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[47] Peter Drucker, *Management* (New York: Harper & Row, 1973), 61.

[48] Throughout the period from 1956 to 1964, Ferranti UK's computer operations were, from a profit perspective, marginal at best. See Ball and Vardalas, *Ferranti-Packard*, 255.

[49] F. S. Beckman and F. P. Brooks, "Developments in the Logical Organization of Computer Arithmetic and Control Units," *Proceedings of the Institute of Radio Engineers* 49 (January 1961): 53-66.

[50] M. J. Marcotty et al., "Time Sharing on the Ferranti-Packard FP6000 Computer System," *Proceeding - Spring Joint Computer Conference, 1963, of the American Federation of Information Processing Society*, 40. In the late 1950s and early 1960s one finds the terms multiprogramming, concurrent programming, parallel programming and

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success, not only did it have to optimize the integration of all the system's hardware, but it also had to make the entire process transparent to the user. In other words, from the user's perspective, a program was written and run as if it were the only job on the system. According to E. F. Codd, the biggest challenge that the development of multiprogramming systems faced in 1962 was the design of flexible storage allocation.[51] The approach taken by Ferranti-Canada was dynamic program and data relocatibility. Each program was allocated a range in the core store specified by a starting address called the "datum" and an upper address called the "limit."[52] All instruction addresses in the program were assigned relative to each program's "datum." As programs terminated, blocks of free memory would be created. In order to prevent any fragmentation in the available core store, each time a program terminated, the FP6000's supervisory program would temporarily stop the execution of all the other programs and recopy them hard against each other at the lowest end of core-store. The "datum" in each program would be changed accordingly, and then the FP6000's supervisory program would set them all running again.[53] In this way, at any given moment, all the system's available memory physically occupied one contiguous block at the top end of the core store.

The customer's ability to expand the system economically and flexibly was another important consideration in the design of the FP6000. The power and performance of the FP6000 could be expanded in a modular manner to accommodate a company's changing requirements and budget. The ability of the system's supervisory system, called the Executive, to accommodate various core-store and processor options with minimal additional software costs was an essential ingredient in Ferranti-Canada's modular strategy.

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time-sharing often used interchangeably. However, the FP6000, by today's standards was not a time-sharing computer; i.e. there was no online sharing of the system's facilities by remote users. The FP6000 allowed many batch programs to run concurrently.

[51] For a comprehensive technical review, as seen from the historical context of 1961, of the issues surrounding the optimal allocation of memory as well as other issues surrounding the implementation of multiprogramming see E. F. Codd, "Multiprogramming," in *Advances in Computers*, vol. 3, (New York: Academic Press, 1962).

[52] The "datum" and "limit" points occurred in multiples of 64 words, where a word was 24 bits long. The FP6000 used a priority system to allocate the system's resources. The computer's supervisory system, called the Executive, assigned each program a priority code based on its expected use, as measured by duration and frequency, of the system's hardware. Before each transfer of control, the Executive scanned its priority list for the active program with the highest priority.

[53] The task of dynamic memory allocation was even more complex because the FP6000's supervisory program, called the Executive, allowed the user to write a program in such a way that the different parts of the program could multiprogram among themselves.

In his history of the British firm, International Computers and Tabulators, Martin Campbell-Kelly suggests that the design of the FP6000 originated with Ferranti-Canada's parent firm.[54] This conclusion, however, assigns undue primacy to Ferranti U.K. technical knowledge in shaping the development of the FP6000. This computer was not an isolated technical and corporate event in the life of Ferranti-Canada. Neither was it a product of the parent firm's technological cast-offs. Instead, the corporate capacity to design and build the FP6000 was the culmination of a process that started in 1949 with DATAR.

The transistor circuit techniques used in the FP6000 were first honed in the computerized mail-sorting system for the Canadian Post Office. By the time Ferranti UK had installed its first vacuum-tube, Pegasus computer in 1956, the Canadian subsidiary had totally abandoned the vacuum-tube paradigm and undertaken an independent program to develop transistor-based, digital electronic, circuit techniques. Throughout the latter part of 1955 and early part of 1956, the digital electronic group at Ferranti-Canada worked closely with Philco in the United States to explore the digital electronic design implications of the latter's new, high-speed SB-100 transistor. It was during this period that the Canadian subsidiary gained first hand experience in the design and manufacturing issues associated with the construction of systems based on standardized transistor cards.

The Gemini computer's transistor logic circuitry, which formed the basis for the FP6000, was the culmination of Ferranti-Canada's early commitment to solid state electronics. The expertise needed to develop the real-time communication's aspect of ReserVec's information processing capabilities grew out of the DATAR experience. The Gemini computer's unique architecture was itself a direct consequence of Trans-Canada Air Lines' on-line reservation imperative. The FP6000's multiprogramming marketing feature was the technical culmination of the Ferranti-Canada's long experience (first with DATAR, then ReserVec, and finally the cheque-sorting computer) in multiple, on-line, real-time access to computer resources.

While it is important to recognize the important innovations that originated at Ferranti-

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[54] Campbell-Kelly writes: "The FP6000 had originally been specified in England as an overtly 'commercial' computer by one of Ferranti's salesmen, Harry Johnson; and the design had much common ancestry with the Ferranti Pegasus. But because Ferranti had most of its resources committed to the ORION and ATLAS, it was not developed in England. The design was picked up by the Canadian subsidiary, where it was developed during 1962." Campbell-Kelly, *ICL*, p. 221. A similar misunderstanding was expressed by Moreau, *The Computer Comes of Age*. Moreau suggests that the FP6000 was developed with "the aid of techniques developed in Manchester and used for the first time in Ferranti Packard 6000." *Ibid.*, 123 In footnote 13 on page 123, Moreau further suggests mistakenly that the FP6000 was a Ferranti U.K. initiative.

Canada, it would be foolhardy to push this argument too far and dissociate the company from the internationally available pool of ideas and techniques. Ferranti UK's experience no doubt had some influence on how Ferranti-Canada approached the task of designing a multiprogramming environment. After all in 1958 it was Dr. S. Gill of Ferranti U.K. who wrote the first comprehensive research paper on the question of multiprogramming.[55] Gill's work sparked widespread interest in the question of multiprogramming. Ferranti U.K. had also incorporated multiprogramming features in the ORION. Moreover, the subject of multiprogramming had become a widely discussed topic within the international, computer engineering community when Ferranti-Canada took on the FP6000 contract for the Federal Reserve Bank in New York.[56] Ferranti-Canada engineers were exposed to these discussions, particularly those within North America, as much as they were to Ferranti U.K. ideas.[57]

Innovative engineering is the art of compromise, balancing the realities of market and corporate constraints with the pursuit of technical artistry. The decision to design a mid-sized computer was in part, a consequence of the terms of the contract with the Federal Reserve Bank of New York and a conscious recognition that, as a small Canadian company, Ferranti-Canada's only chance to survive in the computer business dominated by IBM was to design a smaller, less costly computer for a mid-level user. In the early 1960s, the American firm Digital Equipment Co. (DEC) was pursuing a similar strategy to produce a line of relatively cheap, simple computers for specific situations. These computers, named PDP, were intended to provide the spectrum of functions of conventional, electronic data processing systems. From the success with its early line of PDP computers, however, DEC subsequently did create and dominate a new market of more general purpose data-processing machines called minicomputers.[58] Ferranti-Canada's approach from the start, on the other hand, was to create a mid-sized computer with larger mainframes features. The innovation in the FP6000 lay in finding the right "intermarriage

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[55] S. Gill, "Parallel Programming," *Computer Journal* 1 (1958): 2-10.

[56] Codd, "Multiprogramming," 1962

[57] When Ferranti-Canada engineers first described FP6000 in the technical literature, they situated their achievement within the context of Gene Amdahl's criteria for multiprogramming, which were published in the early phases of the FP6000's design. See Marcotty et al., "Time sharing on the Ferranti-Packard FP6000 Computer System," 1963. For more on Amdahl's criteria see, Gene Amdahl, "New Concepts in Computing System Design," *Proceedings of the Institute of Radio Engineers* 50 (May 1962): 1073-77.

[58] The market need for a smaller and less costly alternative to large mainframe technology is apparent from the meteoric rise of DEC. In 1957, $70,000 of local venture capital set up DEC in an old woollen mill in the suburbs of Boston. In 1966, when DEC went public, the worth of the company had grown to $228.6 million.

of software and hardware" that would allow multiprogramming on a less costly mid-sized machine.[59]

When Ferranti-Canada had first approached Ferranti U.K. with the idea for the FP6000 computer, the parent firm disagreed with the concept and wanted little to do with it. Technology-driven and immersed in technological elitism, the parent firm viewed the FP6000's design as too conventional and tainted by overtly "commercial" motives. But the FP6000 was a creative adaptation of leading edge technology to the competitive challenges faced by a small company in an industry dominated by very large corporations. The fact that Ferranti U.K. let Ferranti-Canada pursue its FP6000 strategy nevertheless reflects the remarkable degree of R&D autonomy that Canadian subsidiary enjoyed.

Within the span of one year, Ferranti-Canada had received three orders for the FP6000 computer system.[60] It was a modest, but promising beginning. Subsequent orders, however, for the FP6000 proved elusive. Despite Ferranti-Canada's sale of the FP6000 to the Naval Research Establishment in Dartmouth, Nova Scotia, two other attempts to sell to the Canadian military failed.[61] The sales team felt particularly discouraged by what it perceived to be an unwillingness of local and provincial governments to "Buy Canadian." During the early 1960s, the Ontario government ran an extensive advertising campaign urging people "To Buy Canadian." Ian Sharp, the man who headed up the FP6000's software development, later recalled that when Ontario's Treasury Department went shopping for a computer, it "did not give the FP6000 the time of

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[59] The resulting cost constraints naturally affected hardware and software design choices The choice of shorter 24 bit long words is one example of this compromise. One compromise which affected the design of the Executive was to use the central arithmetic unit to perform the addressing and counting during peripheral transfers. This was in contrast to the usual practice found on the large multiprogramming machines where these tasks were handled by independent logic in each peripheral control unit.

[60] These systems differed in core memory, mass storage capacity and in input/output facilities. As a result all these systems differed greatly in price.

[61] In the spring of 1962, the Canadian Armaments Research and Development Establishment (CARDE) wanted to buy, or lease, a new computer. Thirteen firms were approached, but only four bid: IBM., Canadian General Electric, Burroughs Corporations, and Ferranti-Canada. Ferranti-Canada's F.P.-6 bid, which was a clone of the computer they proposed to the Federal Reserve Bank of New York, proved too expensive. CARDE wanted a simpler and less costly machine, such as IBM's 1620. J. H. Morgan (Defence Research Board), Recommendations to the DRMC Concerning a New Digital Computer for CARDE, 18 April 1962, DND, Accession 80-81/069, box 179, file 1501-22, pt. 2. A month later, in May 1962, the Defence Research Telecommunications Establishment (DRTE) wanted to buy a computer to use in its Prince Albert Radar Laboratory, Prince Albert, Saskatchewan, for real-time antenna control and the scientific analysis of atmospheric sounding data. J. H. Morgan (Defence Research Board), DRTE Computer Requirement, 10 May 1962, DND, Accession 83-84/167, box 7589, file DRBS 9900-31, pt. 1. By 1964, DRTE had reduced the bidders to seven. Once again, Ferranti-Canada's bid, along with those of Control Data, Remington Rand, and General Electric, were ruled out as too expensive. O. S. Roscoe (DRTE), Memorandum to Chairman of the Defence Research Board, 21 September 1964, DND, Accession 83-84/167, box 7593, file 9931-11, pt. 1.

day."[62] Instead it bought American. Sharp also recalled his anger at the City of Toronto's decision to buy south of the border. In 1963, Metropolitan Toronto was about to become the first city in the world to computerize the operation of its traffic light system.[63] Univac, Control Data, IBM and Ferranti-Canada made bids to supply the computer. The Univac machine, which was Metro Council's choice, had no clear technical superiority over the FP6000, Leonard Casciato, who was the city's consultant, later recalled.[64] In its sales pitch, UNIVAC promised significant Canadian content, in Toronto, in the manufacture of this computer. Yet, in the end, Univac assembled the entire computer in the United States. Ferranti-Canada's failure to win the contract to build the computer for Toronto's traffic control system is but one small example of the failure of government to promote the implementation of an indigenous computer industry through the power of procurement. However, it was in the federal government, which was the single largest user of computers in Canada where this deficiency was most acute.

By the mid 1950s, interest in electronic digital computers started to grow across many departments in the federal government. The procurement, staffing and maintenance of computer centres represented considerable expenditures. But few in government had any working knowledge of this technology. Fearful that departments, if left to their own devices, would make unsound, or unnecessary purchases, in 1955 the Treasury Board instituted the requirement that it had to appraise all government expenditures on electronic digital computers. That same year, the Treasury Board set up the Interdepartmental Committee on Computers to advise on proposals to install new computers, to eliminate duplication and overlap in departmental expenditures on computer centres, and to advise departments on the application of computers.[65]

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[62] *Ian Sharp*, Interview with Ted Paull, 13 August 1984, Computer History Oral History Project, National Museum of Science and Technology, Ottawa, Canada. Copies of transcript available from this author.

[63] The system was designed by Josef Kates and Leonard Casciato, the same two who worked on UTEC and then went on to do the feasibility study on the computerization of Trans-Canada Air Lines' reservation system. This story, which blends municipal politics, the role of the car in the city, and the high-tech computer, has yet to be told in its entirety. A short note on this topic, however, was written by John Vardalas and Ted Paull, "The Toronto Traffic Signal Control System," *Canadian Information Processing Society Review* (March/April 1987): 34-6.

[64] Leonard Casciato, who along with Josef Kates had designed the Traffic Control System, was part of the group that advised the city on which proposal to use. He personally favoured the IBM bid, but recalls that the Univac computer was not in any way technically superior to the FP6000. But the weakness in the Ferranti-Canada bid, according to Casciato's vague recollection, was the high price for the "front end" of the system. *Leonard Casciato Interview*, 1985, National Museum of Science and Technology, Ottawa, Canada

[65] John Deutsch (Secretary of the Treasury Board), Memorandum to all Departments, 31 May 1955, TB, vol. 632, File 1501-22. The first meting of this Committee was held in March of 1955, see Minutes of the first Meeting of the Committee to Study Developments in Electronic Computing Machines and Their Applications, 9 March 1955, vol.

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Concern over the most cost-effective manner to introduce the computer into government operations became a central theme in the work of the Royal Commission on Government Organization. In the fall of 1960 the Government gave this Commission, chaired by the President of Brazilian Traction, the mandate to examine how to modernize and streamline the operation of the federal government along the best practices of the private sector management. The Commission emphasized the crucial role that computers were playing in transforming the productivity, scope, and efficacy of white collar work. By making vastly increased resources of information readily available, in whatever form required," wrote the Commission, "the new technology continues to enlarge the boundaries of effective action as a rapidly accelerating pace."[66] No doubt impressed by the accomplishments of automation in the secondary sector of the economy, the Commission looked to the computer "to create new administrative 'machine shops' -- data-processing centres which can respond to the demands of administrators and operators throughout the organization with increasing versatility."[67] If the government were going to modernize its operations and be more productive then it had to integrate the computer effectively into all it operations. Not only did the federal government have to readapt its administrative structures and practices to the logic of this new technology, but it also had to be a lot smarter in how and where it introduced data processing centres. Despite the Treasury Board's initiatives, the Commission underscored the "unco-ordinated," "hit-and-miss" manner in which data processing centres were being introduced.

The Commission was particularly scathing in its assessment of the role of the Interdepartmental Committee on Electronic Computers: "The Committee has not provided leadership and management guidance, or given adequate technical assistance to the departments....No formal reporting procedures have been set up to facilitate co-ordination of automatic data processing activities, and no attempt has been made to measure actual results against forecasts or to assess the impact on departments. Furthermore, the Committee has not taken the initiative in promoting and developing comprehensive plans and policies for the

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632, File 1501-22.

[66] Canada, Royal Commission, *Royal Commission on Government Organization*, vol. 1, (Ottawa: Queen's Printers, 18 July 1962), 45.

[67] *Ibid.*

introduction of automatic data processing."[68]

While the Government and the Commission grappled with the management and financial issues associated with the computerization of government operations, little attention was given to the industrial development question of whether the State through its purchasing power should promote the domestic manufacture of computers. On one occasion, however, the Commission did venture into the manufacturing issue when it stressed the importance of defence procurement in advancing Canada's overall technological and industrial capacity. "Those responsible for defence procurement," observed the Commission, "must therefore be more than skilled purchasing agents. The procurement effort must be guided by an adequate appreciation of the present and future potentials of the economy in fields of research, development, and technology which can, by proper stimulation and support, underpin the country's economic strength and potential economic growth."[69] Why the Commission failed to extend this argument to all those in the civilian government who procured data processing systems remains a mystery.

Not only did the absence of a suitable "Buy-Canadian" policy limit opportunities for the FP6000, but Canada's import tariff structure served as a disincentive to manufacture systems in Canada. Because the duty rate on components was higher than on complete systems, Canadian firms seeking to manufacture entire systems were at a disadvantage. Not only did the actual rates work against domestic manufacture, but the manner of their application exacerbated the disadvantage. Instead of applying the tariff rate on the fair market value of the data processing system being reported, Canada Customs applied the excise tax on the cost of manufacturing the system. This strange logic arose because American computer manufacturers claimed that electronic data processing systems were normally leased, and not sold, in the United States. "As cost of manufacture is generally 25% of sale price," noted the Department of Industry's Electrical and Electronics Branch, "the evaluation is correspondingly low, resulting in only nominal duty being paid with no incentives for subsidiaries to manufacture in Canada. Furthermore, Canadian subsidiary importers can take protection in their sale price of duty at arms length or sale price

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[68] *Ibid.*, Chapter 8 - Automatic Data Processing, 589.

[69] Canada, Royal Commission, *Royal Commission on Government Organization*, vol. 2, (Ottawa: Queen's Printers, 10 October 1962), 119. It is ironic that while Canadian military enterprise had abandoned its earlier ambitions of technological and industrial self-reliance, a civilian government Commission would now champion the cause. The Canadian defence establishment, argued the Commission, showed a "marked lack of confidence in Canadian science and technology as a whole." Canada, Royal Commission, *Royal Commission on Government Organization*, vol. 4, (Ottawa: Queen's Printers, 21 January 1963), 208.

evaluation which a private importer would have to pay on individual imports."[70] Faced with a tariff structure that encouraged Canadian subsidiaries of American computer manufacturers to import entire systems at far lower prices than anyone in Canada could sell for, it was only natural that Ferranti-Canada's systems would always be seen as too expensive. Try as they might, Department of Industry officials found that "there [was] no way of overcoming the problem under the existing legislation and regulations."[71]

It is important to underscore that the "Buy Canadian" issue is not a question of whether the large computer manufacturers had, or had not, a subsidiary in Canada. Most operated some sort of sales and service functions within Canada. However, during the 1950s and 1960s, only Ferranti-Canada maintained any R&D program in Canada. To make matters worse, the other subsidiaries did not even operate as manufacturing branch plants. Instead, they merely imported, or at best reassembled, the computer systems produced by their parent firms. In describing the tariffs of Canada's nineteenth century National Policy, Michael Bliss argued that they created a wall specifically over which American business was to supposed to jump.[72] While the tariff discouraged imports of manufactured goods, it encouraged the creation of branch plants.[73] The tariff structure on data-processing systems, however, eliminated the need for American computer firms to jump over any walls or to manufacture in Canada.

Ferranti-Canada's difficulties in selling the FP6000 were not only externally-generated. There were also internal impediments. While the FP6000 was an attempt to break away from its parent firm's technology-driven, product-development habits, Ferranti-Canada faced serious marketing obstacles. In its sales efforts, the Canadian computer group found it difficult to escape the dominant, technology-driven corporate culture that it had inherited from its parent firm. The Canadian firm sold computers to technically-sophisticated users more on the basis of design achievements than on an appreciation of the customer's operations and needs.[74] The dominant

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[70] Industrial Development Group (Electrical and Electronics Branch, Department of Industry), Quarterly Report: 1 July to 30 September 1965, IC, vol. 1728, File P1410-07, pt. 1.

[71] *Ibid.*

[72] Michael Bliss, "Canadianizing American Business: The Roots of the Branch Plant," in *Close the 49th Parallel*, ed. Ian Lumsden (Toronto: University of Toronto Press, 1974), 26-42.

[73] The word "encouraged" rather than "caused" is used because Canada's patent laws were also a crucial factor in the early rise of branch plants. This factor is not brought out in Bliss's article.

[74] In this regard, Peter Drucker's observation of the relationship between "product" and "customer" is noteworthy. "What a customer thinks he is buying, what he considers value, is decisive - it determines what a business is, what it (continued...)

mind-set seemed to be that technical achievement would somehow sell itself. Ferranti-Canada's previous sales had been to technologically-driven users: the Royal Canadian Navy, the Canadian Post Office, Trans-Canada Air Lines, and the Federal Reserve Bank of New York.[75] But selling to the mass business market was an entirely new experience for Ferranti-Canada. Fred Longstaff, the FP6000's chief designer, put the problem quite succinctly: "Our marketing was zip. We were poles apart from IBM."[76]

As one OECD study later concluded, the ability of a nation's manufacturers to compete against IBM was less a matter of technology and more an issue of marketing and management.[77] To be successful, domestic computer manufacturers had to develop the management/marketing mind-set that allowed them to design and build "the type of machines and services needed by the market, and in cases where the market is non existent or too small, to create and enlarge this market," which Ferranti-Canada did do in the case of TCA and the FRBNY.[78] The OECD Expert Group on Electronic Computers went on to emphasize that "manufacturers must sell a service, and not simply systems, however complex."[79] Designing and building the FP6000 proved much easier than selling it. Not only were new marketing skills required, but the company would also have had to invest a great deal money in expanding its marketing efforts if it were going to chip away at IBM's dominance of the Canadian market. Could any Canadian company have mounted an effective enough marketing effort? Probably not.

Proper marketing demanded considerable capital investments in an extensive sales and service network. The Ferranti corporate structure made it difficult for the Canadian subsidiary to mobilize large sums of money. From the time Sebastian Ziani de Ferranti regained control of Ferranti U.K. in 1923, he and his descendants were determined to keep the company under family control. Tradition played a powerful role in the family's refusal to go public as a way to

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(...continued)
produces, and whether it will prosper. And what the customer thinks is buying is never a product. It is always utility, that is what a product or service does for him." Drucker, *Management*, 61.

[75] Part of the Bank's sophistication came from the ongoing consulting role of the Stanford Research Institute.

[76] *Fred Longstaff, Les Wood, Gord Lang, and Ted Strain*, group interview with Ted Paull, 14 August 1984, Computer Oral History Project, National Museum of Science and Technology, Ottawa, Canada.

[77] Expert Group on Electronic Computers (Directorate of Scientific Affairs, Organisation for Economic Co-Operation and Development), *Gaps In Technology Between Member Countries*, Restricted Report-DAS/SPR/67.93, 4 October 1967. Copy in IC, vol. 1790, File IRA-9000-320/T2-5

[78] *Ibid.*, 11.

[79] *Ibid.*

raise capital. As a result, Ferranti U.K. relied only on profits or the British banks to finance long-term expansion. As the economies of scale and corporate concentration in both the electrical and computer-manufacturing sectors kept increasing, so did the capital investment needed to compete. Pursuing venture capital was not an option open to Ferranti-Canada. The Ferranti family's refusal to go public became an onerous financial handicap that crippled both parent and subsidiary.

Ferranti-Canada's own struggle to survive in the North American electric power market compounded the problems of raising capital. During the 1950s, offshore competition and dumping wreaked havoc on the entire Canadian electrical capital goods sector. In the early 1960s, excess electric generating capacity, which reduced the demand for new capital goods, further exacerbated the Canadian electrical industry's business hardships. The Canadian Electrical Manufacturing Association warned that unless the Federal Government acted to protect local manufacturers from unfair foreign competition, Canada would lose its industrial base. Other analysts not directly tied to the industry argued that Canada's problems arose from internal structural problems -- too many producers in a small market.

From the point of view of its historical traditions, revenues, profits and losses, capital investments, and labour, Ferranti-Canada's corporate existence was very much rooted in the design and manufacture of electrical capital goods. Thus it was understandable that Ferranti-Canada's struggle to survive as an electrical manufacturer was pre-eminent in the minds of the company's senior executives and Board of Directors.[80] In an attempt to overcome the limitations of the small fragmented Canadian electrical capital goods market, Ferranti-Canada committed much of its energy to going after the American market, an unprecedented move south for the Canadian electric power industry.[81] The deeply entrenched "Buy American" attitude of the American electrical utilities had long impeded selling south of the border, but Ferranti-Canada hoped to break this stranglehold. The "Electrical Conspiracy" litigation during the late 1950s, which saw the United States Department of Justice convict America's largest electrical

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[80] The merger of Ferranti Electric and Packard Electric in 1958 was a direct result of the fierce competition ravaging the Canadian electrical industry. Ball and Vardalas, *Ferranti-Packard.*

[81] Such a move, if successful, gave Ferranti-Canada an unusual, but rare, business advantage over its Canadian competitors. Since they were all subsidiaries of American electrical power manufacturers, they could not ship to the U.S. and compete against the parent firm. Ferranti-Canada could sell domestically and to the U.S. while its Canadian competitors could only sell locally.

manufacturers of price fixing had shaken the utilities' faith in their suppliers.[82] American utilities even launched their own $9 billion law suit against these companies; American utilities were now more open to Ferranti-Canada's sales pitch. Ferranti-Canada's success in the American market, however, depended on how effectively and quickly it could improve its capacity to design and manufacture larger, but more cost-effective power transformers. To achieve this improvement, Ferranti-Canada had to devote most of its human and financial resources to electrical power R&D. To underwrite any serious entry into the computer business would have entailed a considerable reallocation of capital away from Ferranti-Canada's unswerving plan to save its electrical business.

While Ferranti U.K. gave Ferranti-Canada more or less free rein to set its own research and development agenda, the parent firm balked at actively promoting the FP6000 in the U.K.. When a delegation from Ferranti-Canada had gone to England in the late fall of 1961 to get head office approval to enter the general purpose computer business, Ferranti U.K. responded coldly. Since Ferranti U.K.'s senior computer engineers disagreed with the design philosophy being proposed, they wanted nothing to do with the undertaking. As for the new Federal Reserve Bank opportunity, the parent firm consented reluctantly. Ferranti U.K. had originally agreed that, if the FP6000 project went well, it would help market the computer in Britain. In the two years that followed the first sale of the FP6000, the parent firm, however, never honoured this commitment. By 1964, unbeknownst to Ferranti-Canada, Ferranti U.K.'s unwillingness to market the FP6000 in Britain and the rest of the Commonwealth reflected the parent firm's decision to cut its own heavy losses and get out of the commercial, electronic data-processing business. In the end however, Ferranti U.K.'s unwillingness to promote the FP6000 in Britain was not the pivotal business issue for Ferranti-Canada's Electronic Division. The real market challenge for the Canadian subsidiary lay in wresting a small piece of the domestic data processing equipment market from the likes of IBM and Univac.

In 1964, Canada's Department of Industry started to examine the strategic economic importance of having an indigenous computer industry. In 1963, shortly after regaining political power, the Liberal government had created the Department of Industry. The new department's principal responsibilities were to improve the balance of payments, to foster the efficient development of the Canadian manufacturing industry, and to encourage industrial research and

[82] Ball and Vardalas, *Ferranti-Packard.*

development. The very terms of the new department's creation were a call for more nationalism in Canadian industrial policy. "In order to maintain Canada as a political entity," senior officials adopted the policy that "Canadians had to be prepared to pay a certain economic premium" in order to foster indigenous design and manufacture.[83] A political interest in technological and industrial self-reliance, which formerly had been promoted by the military in the early 1950s and abandoned by 1958, now reappeared under a civilian guise, as many of the more nationalistic electronic experts in the Department of Defence Production now transferred to the new department.

The Department of Industry perceived that computers had become a powerful engine of economic growth within the world economy. Anxious to push for a domestic capacity to manufacture computers, the department contemplated spending some $2 million per year to help Ferranti-Canada develop and market a commercial line of computers.[84] In seeking technical advice from the Defence Research Board's Chief of Computation and Analysis Branch, the Department of Industry explained that it wanted to focus on Ferranti-Canada because "it was the only company free of U.S. backing with the experience and knowledge to enter the general purpose computer field."[85] Since 1962, the Canadian government had already been engaged in an extensive R&D cost sharing program with Ferranti-Canada to develop data processing peripheral equipment for export.[86] But now with the FP6000, Ferranti-Canada had an entire system to sell. Before committing any funds to Ferranti Packard, the Department of Industry wanted to assure itself that the technical merits of the FP6000 warranted the investment. Knowing that DRB's Naval Research Laboratory, in Dartmouth, Nova Scotia, had recently bought an FP6000, E. A. Booth, the Chief of the department's Electronics Division, wrote to DRB on 15 July 1964 asking

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[83] Summary of the Twelfth Monthly Meeting with Directors, 5 November 1964, 8, IC, vol. 1727, File P.1115-19.

[84] Industrial Development (Group Electrical and Electronics Branch, Department of Industry), Quarterly Report: 1 January to 31 March 1964, IC, vol. 1728, File P1410-07, pt. 1.

[85] J. H. Morgan (Chief of COMANSEC, for Chairman of DRB), Letter to Chief Superintendent, Naval Research Laboratory, 20 July 1964, DND, Accession 83-84/167, box 7589, file DRBS9900-31, pt. 2.

[86] The initial impetus for this was to export magnetic drums to the American defence industry. Thus the Department of Defence Production first started this initiative, then, after its creation, the Department of Industry took over. By the time the Department of Industry had decided to consider supporting Ferranti-Canada in its bid to sell general purpose computers, "Ferranti had nearly completed the 3rd year of a 5 year 50/50 shared cost-development program. Items developed included tape readers and magnetic memory drums, some $3 million worth of which has already been sold to U.S. companies for less than $1.0 million development effort." Industrial Development Group, Electrical and Electronics Branch, Department of Industry, Quarterly Report: 1 JULY to 30 September 1964, p. 4, IC, vol. 1728, file P1410-07, pt. 1.

that it, as a user, evaluate the merits of the FP6000.[87] The contents of DRB's evaluation remain unknown. But no matter how glowing, no report could have helped. A corporate drama in the United Kingdom, over which Canada had no control, rendered irrelevant the Department of Industry's intentions to help Ferranti-Canada become the nation's first successful manufacturer of commercial data processing systems.

British Corporate Needs and the Death of Computers at Ferranti-Canada

In early 1963, Sir Vincent Ziani de Ferranti approached International Computers and Tabulators Limited (ICT) with an offer to sell Ferranti U.K.'s non-military computer operations. Behind this gesture was the visible hand of the British government's trying to consolidate the nation's computer business. Britain, like most of the industrialized nations of the day, was desperately seeking ways to strengthen its domestic computer industry against IBM. ICT expressed little interest in Sir Vincent's proposal. As technically sophisticated as Ferranti U.K.'s computer product line was, Ferranti U.K.'s product mix did not match ICT's perception of market needs.[88] Like IBM, ICT had its roots in punched-card machines and other office equipment.

Despite its rejection of Sir Vincent's first offer to sell, ICT nevertheless realized that it could benefit greatly from the R&D potential and manufacturing capability that Ferranti U.K. had to offer. The appearance of the FP6000 computer increased the attractiveness of Sir Vincent's offer to sell. ICT had already decided to move its product line upwards and develop its own mid-sized computer. The FP6000 offered a readily available, proven technology. An internal Ferranti UK report recognized the usefulness of the Canadian computer to ICT's plans. "Were we to begin designing now a machine in the same price/performance range as the FP6000," the report explained, "we would have in some 18 months time a system that would not be significantly better - if indeed it were any better - than the FP6000."[89] An ICT visit to Canada confirmed the Ferranti UK evaluation. In April 1963, ICT's upper management concluded that the FP6000 should serve as the technological basis for the company's thrust into the mid-sized computer

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[87] E. A. Booth, Letter to J. H, Morgan, 15 July 1964, DND, Accession 83-84/167, Box 7589, File DRBS9900-31, pt. 2.

[88] Campbell-Kelly, *ICL*.

[89] *Ibid.*, 222.

market.

With ownership of the design rights to the FP6000 central to the deal, ICT acquired Ferranti U.K.'s non-military computer operations in June 1963. This deal was premised on the guarantee that the design rights to the FP6000 would be included in the deal. John Picken, a former technical director and member of the Ferranti UK board, later recalled that "without the FP6000 we would not have gotten the deal we wanted from ICT. The FP6000 was the golden brick in the sale of our operations."[90] In the words of another Ferranti U.K. Board Member and director of the company's Edinburgh operations, the FP6000 was "the jewel in the crown that ICT had bought."[91]

It remains unclear whether Sir Vincent first consulted Tom Edmondson, Ferranti-Canada's President and CEO, before agreeing to sell the FP6000 rights to ICT. Over a quarter century later, Edmondson contended that the deal was contingent on the Canadian subsidiary's consent.[92] With FP6000 crucial to the ICT deal, it is doubtful that Sir Vincent, as the owner of all the Ferranti-Canada shares, would have agreed to sacrifice the deal to keep the FP6000 in Canada. If Ferranti-Canada's senior executives did indeed have a say in the matter, then the sale of the FP6000 to ICT reflected in part a preoccupation with saving their troubled electric power business. The $1 million compensation offered to Ferranti-Canada must have seemed very attractive to executives faced with several years of financial losses. But equally important, any Ferranti-Canada consent also reflected the realization within the Canadian company's most senior executives, who all had backgrounds in the electrical power industry, that the company did not have the capital resources to back a serious fight for market share with the likes of IBM, particularly since it would surely mean sacrificing much of the electrical business.[93] Immersed in

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[90] *John Picken*, Interview with author, 11 May 1989.

[91] *Sir Donald MacCallum*, interview with author, 9 May 1989.

[92] No documents have yet been found to corroborate or refute this claim. The $1 million compensation that Ferranti-Canada accepted from its parent firm was in exchange for the loss of the design rights to the FP6000. The technological and corporate legacy of the electric power revolution was also a powerful factor shaping decisions within Ferranti U.K. While the Ferranti family found it easy in 1963 to sell its money-losing, non-military computer operations, the sale of its money-losing transformer operations was continually postponed. The electrical revolution had become an integral part of the way the Ferranti family defined its *"raison d'être."* The founder of the company, Sebastian Ziani de Ferranti, almost single-handedly had pioneered the development of alternating current power generation and transmission in Britain.

[93] It must be remembered that most of Ferranti-Canada's capital investment was tied to the manufacture of electrical capital goods, and that this manufacture accounted for about 70 percent of total corporate revenues. While the 30 percent came from the Electronics Division, the majority of these sales were not general purpose computers. Much of (continued...)

the electrical power tradition, they still saw the company's mission statement in terms of the older, rather than the newer, technological revolution. Knowledge of the deal did not reach the middle management and engineers in the Electronics Division until 1964.

Although the deal permitted Ferranti-Canada to follow up sales leads that had been started in 1963, it nevertheless effectively killed the Canadian company's computer business. The computer group at Ferranti-Canada approached ICT with a proposal to design and manufacture ICT's proposed 1905 and 1906 computers in Canada. The group tried to convince ICT that it was not only technically well-suited for the task, but that Ferranti-Canada also offered the British company a gateway into the North American market. Unfortunately, Ferranti-Canada was not part of ICT's corporate strategy. By the summer 1964, it had become apparent to the computer group at Ferranti-Canada that a long journey had come to an end.

Most of the hardware development team -- Gord Lang, Fred Longstaff, Don Ritchie and Ted Strain -- resigned. This was quickly followed by the resignations of the entire software development team of David Butler, Brian Daly, Bob Johnston, Ted McDorman, Jim McSherry, Roger Moore, Audrey Sharp, Ian Sharp, and Don Smith. The hardware team formed a digital electronics firm called ESE. When ESE was acquired by Motorola Information Systems, Lang, Longstaff, and Strain moved into that company's top management. The software team meanwhile formed I. P. Sharp Associates, which went on to build a profitable on-line, global, database service, as well as to become one of Canada's largest software houses. In 1987, Reuters acquired I. P. Sharp Associates. Finally, those involved in Ferranti-Canada's high speed tape readers and drum memories -- Cliff Bernard, Rod Coutts, Lawrie Craig and Al Vandeberg -- resigned in 1967 to set up a digital electronic engineering company called Teklogix.

The success of ICT's 1900 series of computers, which strengthened the British computer industry, turned the FP6000 into another Canadian icon of lost technological and industrial opportunity. B. Van der Wijst asserted that the FP6000, which was "the first true time-sharing, multi-programmable computer on the world market back in 1961-1963," represented a lost

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[93](...continued)
the revenues came from memory drums, high-speed perforated tape readers, and other digital electronic products. The sale of the FP6000 did not prohibit the Electronics Division from this latter business. Sixteen years later, when Ferranti U.K. wanted to sell its Canadian operations to the British consortium Northern Engineering Industries (NEI), the Canadian management fought vigorously to keep certain electronic patents from being transferred. Ferranti-Canada's flip-disc displays had become an important business that promised to offer the company the market diversity it needed to cushion its business activities from the wide swings of the electric power market. Ball and Vardalas, *Ferranti-Packard*.

opportunity to develop an indigenous, general purpose computer industry.[94] D. H. Wilde, who had been the Manager of the largest FP6000 installation at the Saskatchewan Power Corporation, similarly claimed that the FP6000 was "certainly ahead of its time" and after eight years in operation the computer "still measure[d] up in many respects to current models."[95] In their book *Entering The Computer Age*, B. Bleackley and J. LaPrairie repeated the argument that the FP6000's multiprogramming capability "was a significant technological breakthrough [which] preceded similar capabilities later introduced in the equipment of other manufacturers."[96] And in more dramatic language, journalist David Thomas has contended that the sale of the rights to Canada's FP6000 to ICT "annihilated Canada's capacity to build major computers."[97]

Yet the FP6000 did not mark any radical breakthroughs in the art of computer design. The story of the FP6000 is one of creative adaptation. Endowing a mid-sized computer with multi-programmable capabilities became the technical solution to the problem of how a small Canadian company could carve out a niche for itself in a market dominated by IBM. No one can deny that the sale of the design rights to the FP6000 dealt a mortal blow to Ferranti-Canada's computer business. But the commercialization of the FP6000 faced many serious, if not insurmountable, problems even before its acquisition by ICT. Ferranti-Canada's inability to make a solid business of the FP6000 could not be simply laid at the feet of a branch plant economy that thwarts national interests. Neither was it a question, as J. J. Brown argued, of timid Canadian entrepreneurs unwilling to run risks. The demise of the FP6000 arose from a constellation of factors: the growing corporate concentration in the North American and British computer industries; the very high costs of marketing computers; the different technological cultures within Ferranti-Canada's management; the inability to sell to business users; the limitations of raising equity within a privately owned company; the precarious financial state of the parent firm; the British industrial policy; the Canadian tariff structure; and the absence of a timely and coherent Canadian policy to promote a domestic computer industry.

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[94] Bob Van der Wijst, "Saga of the FP6000: How Canadians built the first time-sharing computer but could not sell it," *Canadian Information Processing Society Computer Magazine* 3 (November 1972): 4.

[95] "Letter to the Editor", *Canadian Information Processing Society Computer Magazine* 3 (November 1972): 7.

[96] B. Bleackley and J. LaPrairie, *Entering the Computer Age* (Agincourt, Canada: Book Society of Canada, 1982), 52..

[97] Thomas, *Knights of the New Technology*, 110.

Epilogue: Indifference to Economic and Technological Nationalism

Canada's problems with the FP6000 were far from unique. During the 1960s, the major industrialized nations of the world all grappled with the problem of nurturing their own domestic computer industries in the face of American IBM domination. Attempts to rationalize the British computer industry, of which Ferranti U.K.'s withdrawal from its data processing business is one example, reflected the new global competitive realities of the computer business.[98] Two decades later, Harry Johnson, who was at the heart of Ferranti U.K.'s computer development program, remarked that "it was becoming clear that the business, particularly in the burgeoning commercial applications sector, was one in which only a small number of suppliers prepared to invest on an enormous scale could compete successfully."[99]

The story of the IBM 360 computer offers a striking illustration of the new competitive realities during the 1960s. Put on the market in 1964, the IBM 360 represented a truly ambitious undertaking, which one historian "compared with the massing of troops and equipment for the D-Day invasion of France during World War II."[100] No doubt this is how European and Japanese manufacturers must have felt about IBM's 360 campaign. With the 360, IBM was determined to ensure its domination of the market. Before the 360 computer program, IBM had never reported annual capital expenditures of more than $340 million. By 1966, two years after the 360 entered the commercial market, the figures had risen to an astounding $1.6 billion.[101] But equally telling, from 1961 to 1967, IBM's long-term liabilities rose by $1 billion.[102] IBM had increased the stakes considerably. The world's computer manufacturers seemed to have two options: invest heavily or fold.

By 1965, for the advanced nations of the industrialized world, the United States

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[98] The commercial failure of "Compagnie Bull" in 1965, underscored the problem in France. Finding IBM's dominance of the French market "intolerable," the French government "caused the formation of a private company, the Compagnie Internationale de l'"informatique, CII, as a joint venture of three electrical companies and contributed a grant of $80 million...CII was to develop a comprehensive (small to large) line of computers and software." Kristian Palda, *Industrial Innovation: Its Place in the Public Agenda* (Vancouver: The Fraser Institute, 1984), 130-1.

[99] Harry Johnson, "Involvement of Ferranti Ltd. in the Development of the FP6000 Computer," February 1988, 4. Private communication to Basil Ziani de Ferranti. Location of original unknown. Copy was sent to former CEO of Ferranti -Packard, and is now in this writer's possession.

[100] Robert Sobel, *IBM, Colossus in Transition* (New York: Bantam, 1983), 213.

[101] *Ibid.*

[102] *Ibid.*

dominance of the computer market became extremely troubling, if not a crisis. In 1950, the gap between America and European computer industry had been small, but by 1967, a huge chasm separated the two. In 1950, one could count the number of digital electronic computers in the United States on the fingers of one hand. By 1967, the number had exploded to 40,000, valued at $12 billion.[103] Starting in 1959, the number of computer systems in the United Kingdom and Europe's six Common Market countries grew at an annual compounded rate of 45 percent. Despite the growth of the European market, the diffusion of computers through the American economy was three to four times more intense.[104] Even more troubling to countries such as Japan, the United Kingdom, France and Germany, was the fact that two American multinationals controlled over 80 percent of the world market.[105] While these countries argued that it was imperative to establish a strong indigenous computer industry in order to regain lost revenues, the United States defended its monopoly by arguing that a national computer industry *was not indispensable.*[106] Narrowing the gap in utilization, suggested the United States, was the key to a nation's reaping the benefits of the computer revolution. It made eminent sense, for a nation that dominated world production of computers, to promote a greater geographic consumption of computer technology over its manufacture. Forced to make trade-offs in its R&D spending, Canada's military had, fifteen years earlier, reached the American conclusion.

After military enterprise's retreat in 1952 from the position that computational self-reliance called for a capacity to design and built general purpose computers in Canada, the issue of an indigenous computer industry ceased to be a central concern for government policy makers. Then after eighteen years of indifference, the state of Canada's computer industry suddenly became the quintessential measure of a nation's future economic well-being for government policy makers. In 1970, the recently created Department of Communications (DOC) and Science

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[103] Expert Group on Electronic Computers (Directorate of Scientific Affairs, Organisation for Economic Co-Operation and Development), "Gaps In Technology Between Member Countries," Restricted Report-DAS/SPR/68.3, 9 January 1968. Copy in IC, vol. 1790, file IRA-9000-320/T2-5.

[104] Europe had some 10,000 computer systems in 1967. On a per capita basis, or percentage of GNP, the United States had well over five times as many computers as Europe: 586 computer systems per million of working population vs 108 for Europe. Compiled from data on p. 7 of Expert Group on Electronic Computers, "Gaps In Technology Between Member Countries," 4 October 1967.

[105] Estimates had IBM holding 75 percent while Univac held 8 percent. See *Ibid.*, 6.

[106] This is how the OECD Group of Experts on Electronic Computers summarized its study of the American computer industry and discussions with U.S. government officials. This dichotomy between the U.S. outlook and the other industrialized nations is summarized in Expert Group on Electronic Computers, "Gaps In Technology Between Member Countries," 9 January 1968.

Council of Canada became the new champions of national self-reliance in computer technology. That year DOC appointed an independent task force to provide the Government with its first comprehensive and in-depth examination of the technological, social, economic, and political issues raised by the electronic digital revolution.[107] In its investigations, the Task Force stressed the need to foster an indigenous computer industry. "Without a domestic manufacturing and supply capability," the Task Force argued, "it is doubtful, in most instances, whether specifically Canadian needs would be met at all."[108] Looking back on the FP6000 as "Canada's most illustrious bid to enter the computer mainframe design and manufacturing field," the Task Force recognized that inadequate capitalization and the lack of support of the domestic market continued to frustrate the growth of a domestic hardware industry.[109] In its final 1972 report, the Task Force not only called on the Government to invest a great deal more money in the "support of all phases of innovation in the computer/communication," but also that the State use its power of procurement to bolster the commercialization process.[110]

Behind the call for a domestic hardware industry stood DOC's conviction that information technology was heading towards the "computer utility."[111] In this vision of the future, a network of large mainframes and minicomputers would bring the power of digital electronic information processing to every home through a vast, national, digital communications

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[107] Canadian Computer/Communication Task Force, *Branching Out*, Vols. I and II, Report of the Canadian Computer/Communication Task Force, (Ottawa: Department of Communications, May 1972). The report was, in the authors' words, "an attempt to sort fact from fiction; to differentiate between probabilities and promises; to take stock of the current situation; to determine the likely direction for future development; and to recommend fundamental policies to prepare for the future." *Ibid.*, vol. I, 1.

[108] *Ibid.*, 158.

[109] *Ibid.*, 14.

[110] Recommendation 32, *Ibid.*, 160.

[111] Spearheading this notion within DOC was Douglas Parkhill, the Director-General of the Department's Policy, Plans, and Programs. The idea was far from new to Parkhill. In 1966, he had published an extensive analysis of the subject . See D. F. Parkhill, *The Challenge of the Computer Utility* (Reading, Mass.: Addison-Wesley Publishing, 1966). Parkhill's efforts would not have gone far had Eric Kierans, the Minister of Communications, not decided to make the computer and digital communications a high profile focus of the newly created Department of Communications. For example see Eric Kierans, Canada and the Computer Utility, 14 January 1970, Speech to the Canadian Information Processing Society in Ottawa; The Computer - Some Canadian Options, 19 February 1970, Speech to Montreal Chapter of the Data-Processing Management Association in Montreal; and The Computer: Social and Economic Aspects, 23 February 1970, Speech to the Data Processing Institute, in Ottawa. Text of these speeches are found in SCC, vol. 4, , File 410/2.1. Kieran's decision took the lead on the computer issue, even over his Cabinet colleague from the Department of Industry, Trade and Commerce, when in June of 1970 "he tabled a paper suggesting the government may have to constrain forces before the Canadian computer industry is dominated by American giants." Cited in newspaper article entitled "Computer Flood Seen," dated July 10 1970. Copy of article can be found in SCC, vol. 2, , File 106/2.

network. Using an inexpensive terminal, users could dial up one of these computer stations and rent processing time. The "computer utility" which represented the first serious realization that the convergence of telecommunications and the computer held enormous commercial potential, was the forerunner of the present-day "information superhighway" and "Internet." But unlike the decentralized, flat, organizational logic of the present-day Internet, where all users have considerable computational power sitting on their desks, in the "computer utility," users were to be equipped with "dummy" terminals.[112] In other words, computational intelligence was more or less centralized and physically removed from the user's location.[113]

Like the railways, radio, and televison, the creation of a "computer utility" took on all the discourse of technologically mediated nation-building. The DOC identified Canada's future industrial well-being with the creation of a vast east-west digital communications network under Canadian control. Countering possible regional fragmentation along north-south lines with the United States became the DOC's *cause-célèbre*. At stake was Canada's economic, industrial, cultural, and political future. Under the nationalist renaissance of the early Trudeau years, the civilian government took up the banner of technological and industrial self-reliance that military enterprise had let fall at the close of the 1950s. A cornerstone of this self-reliance was greater political interest in the domestic ownership of strategic Canadian economic activities.

Concurrently with DOC's policy concerns over the state of Canada's computer industry, Herb Gray, then Minister Without Portfolio, started to lead a study of whether foreign investment was supporting or hindering national interests. While the Trudeau Liberal government recognized the historically important and necessary role of foreign investment in Canada's economic development, it also recognized, wrote the Minister of Finance, E. J. Benson, "that certain spheres of economic activity should be reserved for Canadians."[114] "This Government is not trying to buy back Canada," Trudeau told a *Time Magazine* reporter. He went to explain to *Time*'s American readership: "It's trying to make sure that we control that number of institutions which have a greater impact on our development as an individual society, and for the future, that

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[112] Ironically, the "computer utility's" hierarchical and centralized organizational structure vulnerability to enemy attack led the U.S. military to champion the Internet concept.

[113] The accuracy of "Moore's Law," a conjecture made by one of the founders of INTEL that the density of transistors on integrated circuits would double every one and half years, led to the personal computer and a dramatic increase in the computational power that could be placed directly at one's fingertips. In economic terms, the microelectronic revolution has turned the digital memory circuit from a scarce resource to a limitless resource.

[114] E. J. Benson, Letter to Eric Manning, 30 December 1969, SCC, vol. 2, file 106/2.

we divert our savings, our hard-earned investments, more and more, to areas which are areas of future potential greatness for Canada, rather than try to spread our ownership or our investment all across the board."[115] For the DOC, the Department of Industry Trade and Commerce, and the Science Council of Canada, the computer/communications industry was one of those strategic areas in which Canada had to overcome the almost complete absence of any form of domestic ownership.[116]

Like the DOC, the Science Council of Canada also underscored the vital economic, social, and political importance of a national computer/communications infrastructure. But unlike the DOC, the Science Council was a far more vocal proponent of the view that foreign ownership had stifled Canada's industrial capacity to carry out advanced research and development. "To an increasing extent," argued the Council, "technological capability is the basis of power in the advanced industrialized countries."[117] Viewing the ascendency of the digital electronic paradigm as a far reaching "transformative force," the Council warned that unless Canada had the capacity to design and manufacture within this technological revolution, the nation would compromise its economic, social and political development.[118]

The Council's nationalist approach to technology was in tune with the new generation of political economists who questioned the traditional models of Canada's development. Influenced by the Third World discourse of dependency and underdevelopment, the "New Political Economy" recast Canada's economic trajectory into a process of "de-industrialization" driven by the predominance of foreign-owned branch plants. Embracing the ideological framework of the New Political Economy, the Science Council pointed to the dangers of Canada's economic well-being and political sovereignty arising from Canada's scientific and technological dependency.

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[115] Dr. Leon Katz (Chairman of the Science Council of Canada Committee on Computer Applications and Technology), After Dinner Talk at the Regional Technical Conference on "Computer Applications - Canada's Opportunity" Sponsored by the Engineering Institute of Canada, 17 April, 1970, SCC, vol. 2, file 106/2.

[116] In addition to the issue of the nation's domestic technological and industrial capacity to provide the goods and services to build and run its computer utilities, came issues of public vs. private ownership, regulation, and issue of how to demarcate the role of carriers from information providers.

[117] Pierre Bourgault, *Innovation and the Structure of Canadian Industry*, Background Study for the Science Council of Canada, October 1972, Special Study No. 23.

[118] Science Council of Canada, *Strategies of Development for the Canadian Computer Industry*, Report No. 21, September 1973. While this report represents the Council's first in-depth, computer technology policy pronouncement, two years earlier, it had addressed the importance of building a national digital communications infrastructure to move data between computers. Science Council of Canada, *A Trans-Canada Computer Communications Network: Phase I of a Major Program on Computers*, Report No. 13, (Ottawa: Information Canada, August 1971).

For the Science Council, the absence of any industrial capacity to design and build products for the Information Technology Revolution underscored the grave threat to the future of Canada's well-being.

While large mainframe computers inspired much of the technological nationalism that arose in Europe and Japan during the late 1960s and early 1970s, the Council set its sights on "peripherals" and "minicomputers" as two product niches that could support a Canadian hardware industry. Because of the relatively low start-up costs, "peripherals" were seen as an attractive business opportunity for the smaller Canadian companies. Part of the market attractiveness of computer peripherals resided in their use as the interface to the computer utility. The Council also argued that "a Canadian minicomputer manufacturer offering a good product whose service was supported by Canadian-based hardware and software design teams, would be able to capture much of the domestic market and to establish a viable base for penetrating some foreign markets as well."[119] With neither any indigenous design nor manufacturing capacity of minicomputers in Canada, the Council urged the Government to act aggressively to create this capacity as part of a much needed national industrial and technology policy.

Bent on promoting some form of domestic computer hardware industry and determined not to let another FP6000 opportunity die because of Government inaction, the Department of Industry and DOC spent the next two decades looking to champion a "Made-in-Canada" product. They eventually settled on the all-Canadian owned company Consolidated Computer. With DOC's scenario of the "computer utility" in mind, the Department of Industry was convinced that Consolidated's innovative data-entry systems and small multi-function data terminals had great commercial potential. These devices offered flexible, easy-to-use, and low-cost replacements to keypunch machines, which would be essential if the computer utility were to become a widespread consumer reality. Determined not to let Consolidated Computer whither on the vine from inadequate capitalization, both the federal and Ontario governments pumped millions of dollars into the company's product-development program. To keep the company afloat, in 1976

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[119] *Ibid.*, 54. The Council believed that creating Canadian design and manufacturing capacity in minicomputers would bring "a greater responsiveness to the requirements of Canadian users of computers, minicomputers, and minicomputer-based systems; increased markets for Canadian-produced components; improved original equipment manufacture and end-user capability; and export potential." The Council also urged that Canada develop a computer communication peripherals industry. The capital requirements to enter and stay in the peripherals business were lower than the general purpose computer business. Ferranti-Canada also had a strong peripherals business, but it revolved around the company's computer ambitions. The glamour and excitement of general-purpose computers drove Ferranti-Canada's computer group. Once the FP6000 collapsed, peripherals held little attraction for its engineers.

the federal Government acted as venture capitalist and became the single largest shareholder of Consolidated stock.[120]

After years of stagnant revenues and soaring operating deficits, the once promising Consolidated Computer turned in 1980 into a "debacle" and underscored the stark reality that, in an international market controlled by a few large computer firms Canadian ownership was not an automatic recipe for success in the data-processing equipment business. For the Electrical and Electronics Branch, "debacles," such as Consolidated Computer, were the price other national governments had already paid, and would continue to pay, in order to foster indigenous computer industries. [121]

By the 1980s, Government's search for winners had shifted away from hardware. As a nation of sophisticated computer users, the Department of Industry officials reasoned that Canada could still build a strong domestic software industry. From the vantage point of hindsight, although failure in the hardware sector pushed Canada into this strategy, the decision nevertheless proved to be an eminently wise one. The exponential decrease in the cost of transistor logic led to a dramatic shift in the relative proportion of value added arising from hardware and software. With Intel engineer Marcian Hoff's invention of the microprocessor in 1969 and the subsequent advances in microelectronics, computation became a ubiquitous commodity, and with it a considerable decline in the earlier monopoly-like profits enjoyed by the Schumpeterian companies that launched the post-World War II computer innovation wave. IBM, which had been so successful in building an empire on mainframes, found it difficult to make the shift to the personal computer (PC) world of the 1980s. Of course one can only speculate if Ferranti-Canada had succeeded in carving out a niche in the computer business of the 1960s and 1970s whether it would have then survived into the PC world.

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[120] The same year, Fujitsu Ltd of Japan was given a share in Consolidated in return for technology transfer. Electrical and Electronics Branch (Department of Industry, Trade and Commerce), "The Canadian Computer Industry: An Economic and Industrial Perspective," July 1980. Copy in author's possession.

[121] *Ibid.* DOC's very costly Telidon program of the early 1980s again demonstrates that the government continued its search for the elusive "winner" around which to build an important domestic hardware industry. A great deal has been written on Telidon. Douglas Parkhill, "Some thoughts on the Information Revolution and Telidon," *Submission to the Royal Commission on Newspapers*, 1981; David Godfrey and Douglas Parkhill, *Gutenberg Two* (Toronto: Press Porcépic, 1982); Charles Kless, "Canadian Science and Industrial Policy: The Case of Telidon" (University of Guelph: M.A. Thesis, 1985); Ada Louise Forsythe, "The Politics of Technological Development: a Case Study of Telidon - the Problems and Prospects of Interactive Information Systems" (York University: Ph.D. Thesis, 1987); Destrier Management Consultants, *Telidon Research and Development* (Ottawa: Department of Communications Evaluation Division, 1988); Carla Mascoli, "Telidon: Hopes, expectations and Reality: a Historical Case Study" (Carleton University: M.S.S. Thesis, 1991); and Daniel Burke, *Telidon* (Ottawa: Canadian Centre for Management Development, 1991).

With computation so cheap, software innovation became the new area for the next generation of Schumpeterian entrepreneurs and high profits. The meteoric rise of Bill Gates and Microsoft dramatized the new software entrepreneur. Early in Microsoft's history, Paul Allen, Bill Gates's partner, wanted to follow the traditional route of IBM, DEC, and Apple and produce both hardware and software. Gates, however, argued that software rather than hardware would be the future source of monopoly profits. On this early decision, Gates later remarked: "When you have processing power doubling every two years, in a sense you can think of computer power as almost free. So you ask, why be in the business of making something that's almost free? What is the scarce resource? What is it that limits being able to get value out of that infinite computing power? Software."[122]

The development of electronic data processing equipment at Ferranti-Canada suggests a Schumpeterian vitality to the behaviour of foreign-owned branch plants that goes against the dominant view promulgated by "Nationalist" political economists that subsidiaries were agents of dependency and de-industrialization. To be sure, one can argue that Ferranti-Canada was an isolated case and that, as a British-owned firm operating under what Alfred Chandler called "personal capitalism," this company does not in anyway detract from the focus of the nationalist argument in which "arrested" development is identified with the domination of American owned subsidiaries. In the next chapter, the reader will learn that the Sperry Gyroscope Company of Canada, the subsidiary of a large American multinational, also acted as an agent of radical product innovation in digital electronics with its own ambitious global business agenda.

[122] Cited in Michael Cusumano and Richard Selby, *Microsoft Secrets* (New York: The Free Press, 1995), 5-6. Microsoft allowed this MIT-initiated study to view its internal engineering and management practices. This book offers the most rigorous look at how, as the sub-title claims, "Microsoft creates technology, shapes markets and manages people."

Chapter 7

The Sperry Gyroscope Company of Canada Limited: A Case Study in the Creation of Electronic Digital Automation Technology in the Canadian Context

In 1962, while Ferranti-Canada was trying to define a technological and commercial niche in the electronic data processing (EDP) market, a Montreal firm, the Sperry Gyroscope Company of Canada Limited,[1] set out to become the first company in the world to design and commercialize the fusion of the programmable computer and the machine tool. The development of computer numerical control (CNC) was not a case of simply taking an off-the-shelf computer and attaching it to a machine tool. The creation of CNC required significant adaptive redesign of existing mainframe oriented hardware, a completely new software environment to reflect the real-time needs of the machining process, and the design of appropriate servo-control technology. The key issues in this adaptive innovation process were how to match design goals with the available corporate research and development (R&D) resources and how to define performance specifications that would not make the new CNC technology prohibitively expensive for machine tool shops.

Despite the considerable adaptive innovation needed, none of the components of Sperry Canada's CNC system marked dramatic advances in the state-of-the-art. The technological and market boldness of Sperry Canada's 1964 innovation, which was called UMAC-5,[2] was to conceive the programmable computer and machine tool as one, integrated production unit on the shop floor. Each machinist thus directly operated his own computer/machine tool centre. This digital version of automation differs from the notion of a centralized mainframe, which sits in an air-conditioned office far removed from the harsh environment of the factory floor, and sends orders to all the numerical control (NC)-equipped machine tools on the shop floor. Acting as an

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[1] Henceforth called Sperry Canada.

[2] UMAC is the acronym for Universal Multi-Axis Controller. The number five in UMAC-5 signifies that this was the company's fifth model of controller. The first four -- the MARK, I, II, II, and IV -- were purely NC systems.

agent for parent firm technology, Ferranti-Canada also competed against Sperry Canada in the NC business. And yet, despite the expertise of Ferranti-Canada and Ferranti U.K. in computer technology, neither of them attempted, in the early 1960s, to make the conceptual jump to CNC.

Three years after the demise of the FP6000 in 1965, Sperry Canada's ambitions to be in the vanguard of computer numerical control technology faced a similar fate. Why and how did Sperry Canada, which was created in 1950 to serve primarily as a manufacturing branch plant and with little experience in computer technology, ever venture into this costly high-tech gamble? This chapter examines how, as part of a continual struggle to break away from its total dependence on military procurement, Sperry Canada drifted into computer design and CNC. In the process, the Canadian subsidiary created its own R&D agenda and aggressively tried to shape its own global product mandate. Sperry Canada's determination to develop and market CNC was the act of a classical Schumpeterian firm. Sperry Canada's entry into computer technology again shows, as the Ferranti-Canada case study did, that the nationalist historiography, which depicts subsidiaries in Canada as passive and subservient entities, has been rather one-sided. Another important element in this story will be the important role that the state played in assisting in the development of UMAC-5. Department of Industry support arose from a policy that sought not only to stimulate the use of this technology, but also to create a national capacity to design and sell it. The collapse of Sperry Canada's CNC business is a story of how, within the Canadian political economy, a Schumpeterian company was unable to make the monopoly-like profits usually associated with being an early innovator in the fourth innovation wave.

This chapter's narrative is organized into five sections. The first presents Sperry Canada as another offspring of Canada's 1945-58 flirtation with military self-reliance. The second looks at how, after the collapse of this self-reliance, Sperry Canada set out to articulate within the corporate realities of the parent firm its own civilian market strategy. The outcome was Canada's first and only company to pursue a design strategy in the leading-edge, digitally-based, machine-tool automation technology called numerical control (NC). The third section deals with Sperry Canada's efforts to create an appropriate, global technological and market niche in NC. The reader will see that Sperry Canada's jump into computer design and CNC was dictated by its commitment to a diversification strategy built around machine tool automation. The fourth section of the narrative examines the circumstances that led Sperry Canada to enter the computer design field and the techno-economic trade-offs that plagued UMAC-5's development. The section also investigates the decisive role the Department of Industry played in shaping Sperry

Canada's technology strategy. The fifth and concluding part of this chapter situates the Sperry Canada story within the broader historiographical debate on the nature of technological change in the Canadian context.

Sperry Canada: A Child of Canada's Flirtation with Military Self-Reliance

Sperry Canada was established on 8 November 1950 by the American company Sperry Corporation. Created on the eve of the Canada's greatest peacetime rearmament, the Korean War, its business mission was clear and very focused: to exploit the commercial opportunities of this new wave of defence spending. In 1950, forty-two percent of Canada's defence procurement was devoted to aircraft.[3] This high figure reflected the growing strategic role that the Canadian government assigned to the Air Force in continental defence. For the American parent firm, Canada's defence spending offered an excellent business opportunity in its major technological strength: aircraft instrumentation, particularly sophisticated military navigational systems.

In its charter, the Canadian subsidiary had a three-pronged mandate: "to do business in any aspect of gyroscopes or gyrocompasses; to design, manufacture, purchase, sell, lease, import, export and deal in any gunfire, bomb, torpedo and rocket control equipment appliances and devices, for use on or under the sea, on land, or in the air; and to export and deal in and with anti-aircraft guns."[4] Sperry Canada's creation was, first and foremost, driven by the mandate to sell the navigational technology developed by the parent firm. The second mission statement, however, held out the promise of some form of advanced research and development in Canada. Yet subsequent events revealed that the American parent firm, the Sperry Corporation (later to become Sperry Rand), was unwilling to risk any of its own capital to further this mission statement.

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[3] In a speech before the House of Commons, on 8 February 1951, C. D. Howe, then the Minister of Trade and Commerce, described the extent of military spending during 1950. Military equipment, supplies and construction contracts of $56 million, $88 million, $132 million, and $318 million were issued in the first, second, third and fourth quarters of 1950 respectively. Of this amount, $267 million was for aircraft. Right Hon. C. D. Howe, "Speech from the Throne," 8 February 1951, Canada, House of Commons, *Debates*, Session 1951, vol. 1, 179-87.

[4] A capital stock of the new company was set at $50,000, 500 shares at $100 pershare. Letters Patent: Sperry Gyroscope Company of Canada Ltd., 8 November 1950, Sperry-Rand Corporation Administrative Records, Accession 1910, Series 1, Minute Books, box 29, Sperry Gyroscope Co. of Canada Ltd, The Hagley Museum and Library. Henceforth the Sperry-Rand Corporation Administrative Records, Accession 1910, Series I will be referred to as Sperry-Rand.

Initially, Sperry Canada served simply as an sales agency. Working out of the International Aviation Building on Lagauchetiere Street West in Montreal, B. Wensley King, the company's Managing Director, marketed the parent firm's aeronautical instruments.[5] King, a Queen's University graduate in civil engineering, had obtained his expertise in aviation technology during World War II. Upon joining the Royal Canadian Air Force (RCAF) in 1940, King had attended its Aeronautical Engineering School. From Chief Engineer at the RCAF Station, Trenton, King had been promoted to the rank of Wing Commander at the 63rd RCAF Base in Britain.[6] Immediately following the war, King had gained valuable experience in government procurement in the aviation industry when Canadair Ltd. hired him as an Executive Engineer. When General Dynamics had acquired Canadair, King had been promoted to Manager of Procurement. In the winter of 1950, he had left Canadair to create Sperry Canada.

The scope of the Government's announced rearmament program created a propitious climate for Sperry Canada to expand it sales infrastructure beyond the one-room sales agency. Sperry Canada's Board of Directors passed a resolution to borrow $643,000 from the parent firm to buy the Ottawa based firm of Ontario Hughes-Owens Co. which had a long tradition in the precision engineering, architectural, and surveying instrument business.[7] For many years, the Ottawa company had also been the representatives for two American aircraft instrument manufacturers: the Sperry Corporation and Kollsmann.[8] The Ottawa based company provided an established sales infrastructure spread across the country in Halifax, Montreal, Toronto, Winnipeg, and Vancouver. This arrangement, however, did not yet give Sperry Canada a manufacturing presence.

The extant public and corporate records do not reveal if, when, and where the parent firm planned to set up design and manufacturing facilities in Canada. But whatever Sperry's plans, C. D. Howe's determination to ensure a greater Canadian defence production capacity was the

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[5] Sperry Canada also acted as an agent for the British subsidiary of Sperry in London and it very quickly became the Canadian representative for another American firm, Kollsman Instrument Corporation. R. E. Crawford, "Instruments to keep pace with today's aircraft," *Canadian Machinery and Manufacturing News* 66 (September 1955): 101-6.

[6] *The Canadian Who's Who*, Volume X, 1964-66 (Toronto: TransCanada Press, 1966), 579.

[7] Minutes of a Special Meeting of The Board of Directors, 20 February 1951, Sperry-Rand, Minute Books, box 29, Sperry Gyroscope Co. of Canada Ltd.. Except for a few Canadian representatives, the Board Directors of the Canadian subsidiary was predominantly composed of Americans. All meetings of the Board Directors took place in the American head office. Though any resolution passed by the Sperry Canada Board was, in effect, a decision of the American Sperry Corporation's most senior executives, Wence King was the principal force steering the growth of the Canadian subsidiary.

[8] B. W. King, "Instruments and Controls: Key Items in Air Power," *Canadian Aviation* 27 (June 1954): 82, 89.

catalyst that accelerated the timetable and expanded the scale of Sperry's manufacturing presence in Canada. In rearming, Canada risked a crippling outflow of currency to pay for imported military equipment. Fearful of the possible havoc that rearmament would wreak on Canada's balance of payments, the Government naturally wanted to ensure that military spending created as much business and as many employment opportunities for Canadians as possible. In a speech before the House of Commons on 8 February 1951, Howe argued that military preparedness called for the expansion of Canada's productive capacity.[9]

The absence of an indigenous capacity to manufacture sophisticated aircraft instrumentation stood as a glaring weakness in Canada's pursuit of a technologically advanced aviation industry. Whether at the instigation of Sperry Canada or the Department of Defence Production (DDP), the two had, by the spring of 1951, entered into negotiations to establish a Canadian manufacturing facility for aircraft instruments. Determined to promote the transfer of an important portion of the parent firm's production engineering capacity to Canada, the Government was prepared to underwrite the construction and equipment costs. In return, Sperry Canada was to lease the facility on favourable terms on the condition that it manufacture aircraft instruments for Canadian defence needs. Underlying this arrangement was the tacit assumption that the Government would, at some future date, offer the plant and its equipment back to Sperry Canada at an attractively depreciated value.

Sperry Canada's Board of Directors authorized King to submit an offer to sell the land and buildings on 45 Spencer Street Ottawa, to the Canadian government for $159,000.[10] This building had been part of the Ontario Hughes-Owens purchase. Whether this offer signified an attempt by Sperry Canada to get the Government to pay for the construction of aviation instrument manufacturing facilities in Ottawa is not known. "[But] the government," as King reported to the Board of Directors, "was not interested in buying the land and building."[11]

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[9] Howe, "Speech from the Throne," 8 February 1951.

[10] Minutes of the Board of Directors Meeting, 21 May 1951, Sperry-Rand, Minute Books, box 29, Sperry Gyroscope Co. of Canada Ltd.

[11] Minutes of the Board Directors Meeting, 3 July 1951, at Sperry Gyroscope Co., Great Neck, Long Island, Sperry-Rand, Minute Books, box 29, Sperry Gyroscope Co. of Canada Ltd. One immediate consequence of this decision was the creation of new company, the Sperry Gyroscope Co. of Ottawa, which fell under the direct control of Sperry Canada in Montreal. This facility was retained as an instrument overhaul facility. By 1955, the Sperry Gyroscope Co. of Ottawa had grown to 250 employees "overhauling 500 different types of instruments for aircraft, marine and industrial service in all fields, and manufacturing parking metres, range switches, range timers and coin metres of many different patterns." Crawford, "Instruments to Keep Pace With Today's Aircraft," September 1955, 101. The (continued...)

Instead, on 14 June DDP agreed to build the new facility in Montreal's Cote de Liesse area.[12] By the time the 90,000 square foot factory opened in the summer of 1952, the Department of Defence Production had poured a total of $3.3 million dollars into the new facility: $63,815 for the land, $1,790,000 for the building, and $1,496,185 for the equipment.[13]

In a little over a year after its opening, Sperry Canada's staff swelled to over 1,100.[14] Most of the staff were production workers engaged in high-precision manufacturing.[15] Airspeed indicators, altimeters, machometers, gyrocompasses, and gyro-horizons were the company's bread-and-butter. The Sperry machometer was a sophisticated piece of equipment that gave a continuous indication of a plane's Mach number. Because the Mach number relates to shock waves and aerodynamic stability, the machometer was considered essential for safety in high speed fighter jets. The Sperry gyrocompass consisted of a gyroscopic unit and a "flux valve" mounted on the fighter's wingtip. The flux valve sensed the Earth's magnetic field and used this information to keep the plane on course during turbulence.[16] By the time the defence-spending boom had passed in 1955, the Montreal Sperry plant had manufactured nearly 6,000 aircraft instruments.[17] In addition to its Canadian market mandate, Sperry Canada also obtained the North American mandate to manufacture air-driven gyrocompasses and gyroscopic horizons.

(...continued)
latter manufacturing activities represented this company's efforts to survive the contraction in military spending following the end of the Korean War.

[12] Until 1950, Côte de Liesse remained an undeveloped street. However, by the end of the Korean War considerable industrial location had taken place on the street, such as Canadian Aviation Electronics (CAE), Bepco Canada Ltd., RCA Victor, Hollinger-Hanna Shore and Labrador Railway Co. and the Standard Electric building, which housed the offices of Sylvania Electric, Chrysler, and Shell.

[13] These figures came out in the Minutes of the Board Directors Meeting, 20 July 1954, Sperry-Rand, Minute Books, box 29, Sperry Gyroscope Co. of Canada Ltd. In 1954, Sperry Canada gained ownership of its manufacturing facilities. The sale price was half the original cost. In addition, the Department of Defence Production agreed to build in an accelerated depreciation rate into procurement contracts with Sperry Canada for an additional year.

[14] This figure was mentioned in interviews government representatives had with Sperry Canada's Employment Manager. Employment Forecast Survey Interview Report, 7 May 1956, DDP, Accession 70/349, box 558, file 200-13-395.

[15] The high precision nature of the work led Sperry Canada to hire fifty watchmakers. "The work here," observed one Sperry Plant Superintendent, "is very meticulous involving production and assembly of fine gears, wheels and pinions and a lot of detailed wiring. For instance, the motor that powers the standard gyroscope is about two inches in diameter and turns over 2400 revs a minute." Employment Forecast Survey Interview Report, May 7, 1956, DDP, Accession 70/349, box 558, file 200-13-395. Surprisingly, few women were hired to do the fine assembly work.

[16] For more technical discussion of the design and manufacture of these instruments see Crawford, "Instruments to keep pace with today's aircraft."

[17] King, "Instruments and Controls: Key Items in Air Power."

Government procurement had successfully encouraged the diffusion of production engineering to Canada, but it had yet to provoke any transfer of design engineering or the creation of any significant research and development program. The parent firm designed all the aeronautical instrumentation manufactured at Sperry Canada.[18] Where Sperry Canada had an ostensible R&D mandate, which was in rocket and automatic fire control, progress was non-existent. One reason was the lack of any direct parent firm investment to support such a program.[19] The other was the absence of government contracts in this domain. During the Korean War, the Canadian military viewed Sperry Canada simply as a local manufacturer of American instrument technology. As the Government's resolve to finance the technological and industrial burden of "military self-reliance" waned in the years immediately following the rearmament boom, Sperry Canada abandoned all hope of developing its mandate in rocket and fire control systems. Instead, as the next sections discusses, the company set about to create a new product mandate for itself within the Sperry empire; a mandate that would break the Canadian subsidiary's total dependence on military contracts.

After the Defence Procurement Binge: The Imperative to Define a New Technological and Business Strategy

The momentum of the Korean War government procurement at Sperry Canada continued through 1955 after which it dropped by over 50 percent in 1956 and 1957.[20] The contraction of Canadian military equipment spending in the mid-1950s underscored the vulnerability of Sperry Canada's total dependence on defence business. From a peak labour force of 1,100 at the height of the Korean War, Sperry Canada had by 1956 slashed its workforce to 400. With the

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[18] The machometers were manufactured under license from the Kollsmann Co.

[19] The reader will recall that the second mission statement in Sperry Canada's founding charter was "to design, manufacture, purchase, sell, lease, import, export and deal in any gunfire, bomb, torpedo and rocket control equipment appliances and devices, for use on or under the sea, on land, or in the air."

[20] The total contracts awarded for 1953, 1954, 1955, 1956, and 1957 were $1.3, $1.6, $1.2, $0.6, and $0.8 million respectively. These figures were pieced together from monthly announcements, in *Canadian Machinery and Manufacturing News*, of Department of Defence Production contracts issued to Canadian companies. The data was limited because the contracts listed were at least $10,000 and did not include any secret military projects. The first limitation means that the totals for Sperry Canada were slightly underestimated. There is no evidence known to this author to suggest that Sperry Canada had obtained any substantial secret weapons contracts. The 1953 and 1955 values may be significantly undervalued because data for three months were unavailable.

unpredictability in the timing and size of military contracts, it became very difficult for the company to maintain a stable labour force. The other problem, of course, was the under utilized productive capacity of the 90,000 square foot plant during the lulls in military procurement. The unreliability of defence procurement made year-round plant utilization impossible to maintain.

After having built an important Canadian manufacturing facility from the ground up, Wence King and his Canadian executives were not about to let their company die because the military well was running dry. Their minds turned to finding civilian applications to which Sperry Canada's technical expertise could be turned. Around 1956, the company set out a long-term strategy to redirect 50 percent of its engineering, manufacturing, and sales efforts to the civilian market.[21] To make this transition, Sperry Canada had to face some hard questions. What should the new product be? How would the development of this product be financed? And how could Sperry Canada's efforts to define a technological and commercial future articulate itself within the parent firm's long-term business strategy? The imperative to diversify into the civilian sector also forced Sperry Canada to confront its non-existent research and development capacity.

Dramatic changes within the American parent firm created both an opportunity and an additional compelling reason for Sperry Canada to redefine its business activities. Sperry Corporation, a large, multi-divisional corporation whose business activities spanned all manner of sophisticated weapons systems, aircraft and marine instrumentation, electronic component manufacture, hydraulic servo-controls, and farm machinery, merged on 30 June 1955 with the Remington Rand Corporation. Remington Rand had its origins in gun production: E. Remington & Sons, created in 1856, had become famous for the rifle bearing their name. Over the next hundred years, the Remington organization branched out, through numerous acquisitions and mergers into the office equipment market.[22] Like its office equipment competitor, IBM, Remington Rand had moved into electronic data processing technology; in 1951, it had created the Univac Division through the acquisition of the Eckert-Mauchly Computer Corporation[23] and Engineering Research Associates of St. Paul and Minneapolis.

By the time of its 1955 merger with the Sperry Corporation, Remington Rand had grown

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[21] The 50 percent figure was explicitly mentioned in Sperry Gyroscope Co. of Canada Employment Forecast Survey Interview Report, 7 May 1956, DDP, Accession 70/349, box 558, file 200-13-395.

[22] See brief historical overview of the Remington Rand Corporation in M. N. Rand, Report To Operations Committee of Sperry Rand Corporation, 24 February, 1958, Sperry Rand, Sperry Gyroscope, Minute Books, box 30, file Operations Committee.

[23] Eckert and Mauchly had formed this company to commercialize their pioneering work on the ENIAC computer.

into a business with net sales of over $250 million.[24] It employed 13,000 people in thirty manufacturing facilities scattered across twenty cities. It produced all manner of office equipment and supplies, civilian and military electronic computer systems, photographic supplies, and electric razors.[25] For its office equipment business, Remington Rand also maintained a 6,100 person sales-and-service network in 230 locations, and a network of 10,000 authorized dealers.

Rather than any drastic reorganization and rationalization, the merger of Sperry and Remington Rand created two parallel lines of management authority. The co-ordination of these two powerful interests took place at the highest level, at the Executive Committee.[26] The Sperry portion of the new company consisted of four fairly independent units, which reflected different markets and technologies: the Sperry Gyroscope Inc. ("Gyro Group"), Vickers Inc., the Ford Instruments Inc. and the New Holland Machinery Inc.[27] Sperry Canada was one of eleven geographically dispersed divisions that comprised the Gyro Group.[28]

"Divisionalization and decentralization" became the prime directive soon after merger.[29] Fundamental to this strategy was the principle that each division define its own product mandate. In effect, Sperry Rand became a "federation" of co-operating profit centres, each with its own distinctive, self-funded research and development programs, and product lines. An essential feature of the co-operation was that the profit centres avoid competition among themselves. In the case of the Gyro Group, these ideas were enshrined, in 1958, as corporate commandments. "EACH UNIT OF THE GYRO GROUP SHALL: 1) Develop, design, manufacture and sell the product lines prescribed by its charter; 2) Refrain from entering new product areas, or areas

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[24] Taken from balance sheet data found in Rand, Report to the Operations Committee of Sperry Rand Corporation, 24 February 1958

[25] Remington Rand manufactured its first electric razors in 1937. This business had a separate sales and service network of 1,800 wholesalers and 75,000 retailers.

[26] This Committee was made up of Sperry Rand's president, executive vice-president, general counsel, treasurer, and secretary, and two additional executive vice-president from each of the two parallel lines of authority. Harry Vickers (President of Sperry Rand), Memorandum on Corporate Reorganization, 8 January 1958, Sperry Rand, box 30, file Operations Committee Meeting January 8, 1958.

[27] The Remington Rand Group also consisted of divisions: Remington Rand Division, Electric Shaver Division, Univac Division, and International Division. See Chart 2 - Sperry Rand Organization in Countermeasures Division (Sperry Gyroscope Company), Presentation To The Operations Committee: Sperry Rand Corporation, 20 October 1958, Sperry Rand, box 30, file Operations Committee Meeting 20 October 1958.

[28] The other nine divisions were Aero Equipment, Air Armament, Tubes, Marine, Microwave, Surface Armament, Wright, Semiconductor, and Engineering and Manufacturing Services. Carl Frische (President of Sperry Gyroscope), The Gyro Group: A Progress Report, 7 February 1958, Sperry Rand, box 30, file Operations Committee Meeting 7 November 1958.

[29] Carl Frische, The Gyro Group: A Progress Report, 7 November 1958

assigned to other divisions, without prior approval, or specific approval, by the Chairman of the Products Committee; and 3) Purchase its requirements from other units of the Gyro Group or of the Corporation to the greatest possible extent."[30] The last commandment attempted to reinforce complementarity, as well as to minimize cash outflows, by requiring each profit centre to favour internal over external sourcing.

Divisionalization and decentralization not only offered Sperry Canada the opportunity to define its own product mandate area, but they also made it essential. The product-oriented rationale that defined the corporate and geographic organization of Sperry Rand under divisionalization also compartmentalized R&D.[31] The absence of a central corporate source of R&D thus opened the door for an independent Canadian design program -- provided that this program did not impinge on some other division's territory. For Sperry Canada, being a profit centre became a two-edged sword. With R&D autonomy came the burden of self-financing. In seeking to develop a new product area for itself, Sperry Canada had to juggle market opportunities, avoid territorial conflicts with other divisions, make the best use of a manufacturing facility originally designed for the production of fighter aircraft instruments, and test its ability to finance the development and commercialization of all prototypes.

In 1955 Sperry Canada sent engineers to various industries to assess technological opportunities. Control technologies were the focal point of the company's industrial inquiries. Why control technologies? This particular technological inclination was a legacy of the only, and as yet unrealized, R&D mandate Sperry Canada had in its founding charter. Unable to design, manufacture, and export rocket and fire control systems, Sperry Canada switched to civilian applications that entailed similar principles of negative feedback and servo-control. Inquiries to the pulp and paper industry to discover potential applications for control technology proved a dead-end. Atomic Energy of Canada Limited, on the other hand, asked Sperry Canada to design power controls for its reactor technology. Despite the initial success, Sperry Canada eventually dropped this business in the early 1960s because it yielded only one-off sales, as Atomic Energy

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[30] See figure 12, *Ibid.*, 27,

[31] At one point, the downward trend in profits provoked the president of the Gyro Group to rethink the way Sperry Rand organized its R&D. Frische observed that "it might be difficult to maintain continuous long-term research programs within the framework of product-oriented operating Divisions and some consideration is being given to the feasibility of establishing an R&D organization and facility for the common benefit of the Gyro Group." Frische, The Gyro Group: A Progress Report, 7 November 1958.

of Canada Limited took Sperry Canada's designs and manufactured them in cheaper shops.[32] In 1955, the Canadian subsidiary also started to consider the still embryonic field of numerical control (NC), which represented the revolutionary application of digital electronics to the operation of machine tools.

Canada's First Designer and Manufacturer of Numerical Control Technology

Numerical control (NC) was pioneered under the patronage of American military enterprise. The development of supersonic aircraft, which started during the late 1940s, created new manufacturing demands on the aviation industry. As the weight of on-board weapon systems climbed, it became imperative to minimize the weight of the aircraft's frame while at the same time maximizing its strength. Machining large sections of an aircraft from solid pieces of metal produced frame structures with a higher strength-to-weight ratio than the conventional practice of rivetting aircraft together from a large number of parts. To machine down the walls of the aircraft structure to a minimum thickness, without compromising structural integrity, required cutting metal in an extremely precise manner, along very complex paths. This high-precision machining was an extremely time-consuming process. Furthermore, if, after hours of work one mistake was made, the entire piece had to be scrapped and the work started again. As fighter-aircraft designers pushed the limits of performance, the precision and complexity of aircraft-machining demanded ever higher levels of precision and complexity of operation. Machining time grew linearly with the top speed of the fighter aircraft.[33] Similar machining demands were present in the construction of rocket, missile, and satellite systems.

Work at the Massachusetts Institute of Technology, under the patronage of the American Air Force, demonstrated that the use of electronic, digital, servo-control techniques could accelerate the production of these complex, machined parts. The machining operations were encoded in a digital format: punched holes on a tape. The NC tape resembled the continuous loop of punched cards used by Jacquard in 1805 to automate certain aspects of weaving. In Jacquard's

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[32] This anecdotal story comes from the founder of Sperry Canada, B.W. King. *Burton Wensley King*, interview with this author, 18 February 1985, Computer Oral History Project, National Museum of Science and Technology, Ottawa, Canada.

[33] J. J. Childs, *Numerical Control: Part Programming* (New York: Industrial Press, 1973), 5.

system, digital information of a particular weave pattern was conveyed from the cards to the loom through mechanical rods. In the NC system, the tape's control information was passed on electronically to the machine tool's actuators. The key to NC technology lay in the closed feedback loop that automatically, quickly, and accurately, ensured that the cutting tool was doing precisely what it should be doing at precisely the right spot on the workpiece.

In 1955, when Sperry Canada decided to experiment with NC, the technology was still esoteric and only a handful of American companies were trying to commercialize it. No one in Canada had any real technical knowledge of the NC. Sperry Canada's experimentation with NC technology had to start from zero. The company's first task was to find a development engineer with a good grasp of both mechanical and electronic design. Late that year, Sperry Canada hired Peter Herzl. Born in Vienna, Herzl had immigrated to Canada in 1939, where he later received his Bachelors of Mechanical Engineering degree from McGill University. After his first job at Northern Electric, Herzl had gone to RCA Victor, Montreal, where he had becme involved in designing new ways to automate various manufacturing processes in the company's plant. Though this automation had not been NC-based, in Sperry Canada's eyes, Herzl's experience in both mechanical engineering and electronics made him a excellent candidate to head up the NC experiment. This choice turned out to be a wise one. Herzl's considerable inventive talents became the cornerstone of Sperry Canada's successful entry into the NC business.

From the moment Herzl's first prototype proved successful in 1957, Sperry Canada set out to claim NC as one of its product mandates within the Sperry Rand Corporation. The Canadian subsidiary's NC ambitions, however, had to confront an immediate challenge posed by the head office of the Sperry Gyroscope Group (Gyro Group) at Great Neck, New York. The need for high precision, small batch machining of complex parts was an essential feature of the weapon systems development work done by the all the American divisions of the Sperry Gyroscope Group. Some time around 1956, work started at the Great Neck headquarters of the Gyro Group to develop in-house numerical control technology to meet its own manufacturing needs. The American company also hoped to spin-off a commercial business from the in-house NC developments at its Great Neck facility. The focus of the parent firm's NC development program was on very large, sophisticated, and expensive prototypes.[34]

With limited development funds of its own, Sperry Canada's NC design philosophy

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[34] *Peter Herzl*, interview with this author, 7 February 1995.

focussed on simpler and less expensive solutions to handle less complex machine operations. The imperative to diversify required putting a new product on the Canadian market quickly. Modest design ambitions thus ensured a shorter innovation cycle. For similar reasons, Sperry Canada confined itself to point-to-point machine tool operations rather than complex, contour-cutting operations. Herzl's patents demonstrated that within these design constraints there was room for considerable product innovation.

Within the logic of divisionalization and the harsh realities of declining profits, it made no sense for the Gyro Group to have two divisions with NC product mandates. Although the group at Great Neck had succeeded in building several sophisticated NC systems for its own machine shops, no commercial sales had ever resulted. Meanwhile, Sperry Canada started to find customers for its simpler NC technology. By early 1958, the head office decided to relinquish any commercial interest in NC and the president of the Gyro Group recognized Sperry Canada's claim to a global NC mandate. Out of the eleven divisions comprising the Gyro Group, Sperry Canada was the only one listed with a program to develop numerical control. If there were doubts about this decision within head office, they were silenced after the Great Neck manufacturing facility put Sperry Canada's technology on several of its own machine tools.[35]

Through a series of inventions, Herzl singlehandedly addressed all the key technical components needed to build an NC system. The exactitude of the digital machining data contained on punched tape would be of little utility if it could not be properly translated by the machine tool's positioning system, which was analogue by its very nature. The electric or hydraulic actuators that moved the machine tool's table and cutting instruments also were analogue devices, as were the systems used to measure position. Depending on the machine tool, the table on which the work piece sits could weigh several tons. Getting this table to move very quickly and precisely to digital NC instructions demanded very responsive and accurate analogue actuators. Herzl's work produced positional and actuating systems of considerable accuracy and responsiveness.[36] Though NC heralded the ascendency of the digital paradigm into the forces of

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[35] Herzl recalls that several Sperry Canada NC systems were installed at Great Neck. He suggests that the successful operation of the Canadian numerical control systems played an important role in increasing the Gyro Group head office's confidence in the technical merits of the Canadian system.

[36] These innovations were formalized in a series of patents. In order to get the most protection of a commercial development, Sperry Canada tended to delay filing patents until the product was ready for commercial sale. This meant that the filing dates on Herzl's patents came at least a year after the idea was designed, tested and implemented. Peter Herzl, *Fluid Valve Apparatus*, Canadian Patent no. 646,723, filed 16 July 1959, issued 14 August

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production, the thrust of Herzl's innovations revealed that the real engineering challenge in building a successful NC product lay in developing better analogue technology.

Gyro Group's management had given NC to Sperry Canada, but another group within the Sperry Rand empire retained ambitions in the same area. Harry F. Vickers had founded the Vickers Company in 1920 to produce specialized hydraulic machinery.[37] The Sperry Corporation acquired Vickers in 1937. By the time of the merger, Vickers produced all manner of hydraulic equipment for industrial, mobile, marine, ordnance, and aircraft. Unlike the Gyro Group, the Vickers Group had strong interests in the civilian market. The Vickers Group had "devot[ed] a large share of its program to the development of [hydraulic] servo-controlled machines."[38] Since hydraulic servo-controls were a key component in an important class of numerically controlled machine tools, the Vickers Group's desire to commercialize this technology thus became a natural extension of its long history in the hydraulics business.

In a 1959 examination of all the product development being undertaken by the Gyro, Vickers, and Ford Instrument Groups, the Committee on Fields of Endeavour noted the Sperry Canada and Vickers overlap in machine tool controls. But the Committee made no recommendations about whether to encourage or discourage this overlap in product jurisdictions. The Vickers Group had greater financial resources and corporate clout than Sperry Canada. But any Vickers Group ambitions to lay claim to NC had to deal with Sperry Canada's clear technical lead. While the Vickers Group was still struggling to develop an appropriate electro-hydraulic valve, Sperry Canada had already designed and built the entire NC system. For example, in 1959, Sperry Canada demonstrated a commercial NC system which impressed observers by its ability to move an 8,000 pound machine tool bed quickly while still maintaining a repeat accuracy of

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1962. Peter Herzl, *Positional Control System and Pick off Therefor*, Canadian Patent no. 668,938, filed 21 January 1960, issued 20 August 1963. Peter Herzl, *Digital-to-Analog Converter*, Canadian Patent no. 625,838, filed 4 February 1960, issued 15 August 1961. Peter Herzl, *Reliability Check for Programmed Multi-Channel Position Control*, Canadian Patent no. 624,649, filed 4 February 1960, issued 25 July 1961. Peter Herzl, *Coarse-Fine Positioning System*, Canadian Patent no. 714,200, filed 12 January 1962, issued 30 July 1965.

[37] Among the company's first innovations were a balanced vane type hydraulic pump for powering hydraulic control systems and a hydraulic power-steering device for automobiles. See "Sperry Rand Corporation Chronology," *Inventory for Accession 1910*. Hagley Museum and Library.

[38] Sperry, Ford and Vickers Committee on Fields of Endeavour, Participation of the Sperry Group in FIELDS OF ENDVEAVOR, March 1959, 27, Sperry Rand, Harry Vickers Papers, box 13, Stockholder Relations, file 1959.

.00005 inches.[39] To what extent the Vickers Group continued to spend money on its own NC ambitions is not own, but a decade later, its interest in the NC business resurfaced and it became embroiled with the Canadian government in a struggle to ship technology developed by Sperry Canada back to its plant in Detroit.

Having won the right to develop NC, Sperry Canada now faced the daunting task of finding the money to do it. The absence of parent-firm funds to directly support Sperry Canada's development of NC was symptomatic of a corporate culture shaped by the deep pockets of American military. In 1959, for example, the United States Pentagon, paid for 99 percent of all the R&D undertaken by American Sperry Corporation.[40] Military R&D entailed few financial risks. With the military as the dominant source of R&D revenues, gambling its own money to create new civilian markets did not appear to be part of the American Sperry corporate ethos. But this was exactly what Sperry Canada hoped to do with NC.

Even if the other divisions had been open to underwriting some portion of Sperry Canada's NC program, Sperry Rand's deteriorating profits during the late 1950s made this possibility even more remote. Sperry Rand's percent of return on capital investment fell from 9 percent for the 1955-56 fiscal year to 3.5 percent for the 1958-59 fiscal year.[41] The Remington Rand portion of the new company saw its profitability tumble from a 7.32 percent return on investment to in 1955 to 0.53 percent in 1958. The Sperry half of Sperry Rand exhibited similar declines. Sperry Gyroscope's Treasurer, E. M. Brown, called his group's long-term decline in profits "alarming." From a value of 21.91 percent in 1954, the Gyro Group's return on capital invested steadily declined to a value of 6.9 percent in 1959.[42]

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[39] The total cumulative error, over any number of operations, remained less than .00025 inches. "Positioning control holds .00025 limits; rugged enough for use but in the shop'," *Canadian Machinery and Manufacturing News* 70 (June 1959): 98-100.

[40] See Chart A1, "Group Activities Showing Customer and Company Funds," in Sperry, Ford and Vickers Committee on Fields of Endeavour, Participation of the Sperry Group in FIELDS OF ENDVEAVOR, March 1959. The major sources of military funding was for the development of missile systems and subsystems, radar systems and bombing-navigation systems. Of the massive missile program launched by President Eisenhower in 1957, Sperry had a role, either as a prime contractor or subcontractor, in 35 missile projects including ICBM Atlas and Titan, the IRBM Navy Polaris, the Redstone, the Bomarc, the Jupiter, the Nike, and Sparrow missiles. See the table entitled, The Breadth and Depth of Sperry Rand Participation In The Nation's Major Missile Programs, Sperry Rand, Gyroscope Co., box 31, file Operations Committee Meeting 26 January 1959.

[41] Return on Total Assets, Sperry Rand, Sperry Gyroscope Co., Minute Books, box 31, file Operations Committee Meeting, 26 January 1959.

[42] The definition of the return on capital invested used here is the ratio of net-income to total assets, and not to capital employed. The 1959 value was a forecasted figure. E. M. Brown, Presentation on Cost Plus Fixed Fee

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An uncertain Canadian defence market did not help matters. Sperry Canada's capacity to finance NC development depended entirely on the its ability to siphon money off any surpluses generated by its defence contracts. Sperry Canada's Industrial Relations Manager lamented the "horribly" competitive military equipment market in Canada in which there were "too many companies competing for the very few Defence contracts available."[43] The uncertainty of military procurement manifested itself in the company's financial planning. In 1958, the Sperry Canada Board of Directors rescinded a total of $683,000 of previously approved capital appropriations. In 1961, another $109,000 was rescinded. In these circumstances Sperry Canada's ability to find "approximately $460,000 in the development of numerically controlled equipment and techniques" by the end of 1961 attests to the company's determination to gamble on its technological vision and market ambitions.[44]

Though the Sperry Rand corporate federation did not contribute directly to R&D on NC in Canada, it did play an important role in offsetting some of the instability in the Canadian defence market that Sperry Canada faced. Throughout the late 1950s and early 1960s, the various divisions in the Gyro Group subcontracted work to their Canadian partner. Sperry Rand used the United States - Canada Defence Production Sharing Agreement, whose objective was to give Canadian companies access to American military procurement, to bring more American military spending into the overall corporate coffers. In 1961, 75 percent of Sperry Canada's $7 million

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Contracts, 1 April 1959, Sperry Rand, Gyroscope, Minute Books, box 31, file Operations Committee Meeting, 25 August 1958. In an attempt to underscore that this decline was not due to excessive profits in the earlier years, Brown predicted that the Gyro Group's 1959 after-tax return on invested capital would be nearly, nas a percentage, half the average of the 100 largest U.S. manufacturers. Brown's argumentation on this point is weak. He uses data from "The One Hundred largest Manufacturing Corporations in 1956," *The National Industrial Conference Board's Business Record*, XV (February 1958): 68-9, to substantiate his comparison. Despite the 1958 publication data, this data is for 1956. If one looks at the Gyro Group's after tax percent return on invested capital during the 1956-57 fiscal years, the company comes close to the average. However, its performance still falls far below that of the top fifty companies. In actual fact Sperry Gyroscope's percent return on investment had declined steadily since 1940. Sperry Gyroscope's most profitable years, in terms of percent of return on investment, were from 1935-39. Surprisingly, the very sharp increase in sales during both World War II and the Korean War did little to alter this trend. Profits as a percent of sales, however, did show considerable movement. Graphs depicting changes in profits, profits as percent of sales and return on investment, as well as total sales were compiled by the President of the Sperry Gyroscope Co. in a report to the Sperry Rand Board of Directors. Frische, The Gyro Group: A Progress Report, 7 November 1958.

[43] Employment Forecast Survey Interview Report, DDP, Accession , box 555, file 200-13-395.

[44] D. A. Golden (Deputy Minister of Defence Production), Letter to the Secretary of the Treasury Board, 19 December 1961, IC, box 1784, file P8270-270/S18-10, pt. 1.

sales were from exports, an unusually high percentage for the Canadian manufacturing sector.[45] Most of these sales had originated from intra-firm purchases by the other divisions of Sperry Rand.[46] The subcontracting work entailed nothing more than routine parts manufacturing and assembly. Nevertheless, it was an important source of revenue for the Canadian subsidiary that generated the internal funding for NC development.[47]

Despite the early success of Sperry Canada's first experimental prototype in 1957 and its first commercial system in 1958, it took several years before Sperry Canada's investment in NC bore fruit. In 1961, Sperry Canada saw total NC sales climb to sixty systems.[48] For the 1960-61 fiscal year, the value of Sperry Canada's NC systems added up to $1 million, or about one-eighth of the company's total revenues. For the 1961-62 fiscal year, sales climbed to $2 million.

After several years of work and $460,000[49] of investment from its limited surpluses, the acceleration of sales engendered great enthusiasm and optimism. One Sperry Canada official concluded that the 1962-63 sales would double again to $4 million. To enhance its competitive position, Sperry Canada maintained a constant rhythm of NC development engineering. Three years after the appearance of the Mark I, Sperry Canada had improved its technology three times, with the Mark II, Mark III and Mark IV. With most of Sperry Canada's NC sales in the United States, Germany and Switzerland, the company's President boasted that his company was proving that made-in-Canada technology could succeed in global markets.[50] In the spring of 1963, to penetrate the European market, Sperry Canada signed a licensing agreement with an Italian firm, Nuova San Giorgio, S.P.A. of Genoa-Sestri to manufacture the Canadian NC technology in Europe.[51] As one trade journal noted, the alliance with the Italian company was, "to sidestep the rising scale of duties and competitive manufacture in European [Common Market] which could

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[45] *Ibid.*

[46] In late 1961, Sperry Canada received an order of $2 million from Sperry Rand. Within a few months, Sperry Canada was to receive an additional order, or a comparable amount, from the parent firm. Taken together $4 million dollars of purchases from the parent firm represented a large proportion of Sperry Canada's $7-8 million sales. *Ibid.*

[47] There have been no historical studies, to this author's knowledge, that examine how American multinationals, with branch plants in Canada, used the Defence Sharing Agreement.

[48] The figure of 60 was reported in *Metal Working News*, 28 August 28 1961.

[49] This amount was stated in Golden, Letter to the Secretary of the Treasury Board, 19 December 1961

[50] *Canada Month*, 1 (July 1961):12.

[51] *Industrial Canada* 62 (April 1963): 17.

eventually shut out the Canadian built equipment."[52] There was even talk of Sperry Canada licensing its technology to a Japanese firm.[53]

Two contracts, one from Swiss machine tool maker Societe Genvoise d'Instrument de Physique (SIP) and the other from American aerospace company, Rocketdyne, symbolized Sperry Canada's worldwide competitiveness in NC technology. SIP, an internationally renowned machine tool maker, was synonymous with ultra-high-precision engineering. Sperry Canada had initially used SIP's small jig borer to prepare the first accurate measuring scales for its NC systems. SIP played an active role in helping Sperry Canada adapt its machine tool to manufacture these scales. In the process, Herzl built up a close working relationship with SIP's chief engineer. SIP already had an NC technology for its very large and expensive jig borers. In 1961, Herzl convinced the Swiss machine tool maker's technical people that Sperry Canada could produce a simpler and cheaper NC system to accompany SIP's smaller line of jig borers.[54] The machining tasks of the jig borer fit perfectly into Sperry Canada's market expertise of point-to-point NC technology.[55]

Both the President of the Gyro Group in the United States and Wence King, the President of Sperry Canada, considered the SIP deal as *the* prestige contract and the pivotal opportunity needed to gain industry-wide recognition. After all, if SIP decided to attach Sperry Canada digital controllers to its machine tools, then how could lesser lights refuse to follow suit? But if Sperry Canada failed to meet SIP's high-precision standards, the marketing consequences would be disastrous. Bob Cox, the Manager of Engineering Development at Sperry Canada, later recalled how everyone felt that the SIP contract could make or break Sperry Canada's NC diversification strategy.[56] When it was completed, the Sperry Canada NC system guaranteed a remarkable overall accuracy of eighty millionths of an inch in the positioning of the jig-borer's table and spindle-head. Sperry Canada controls became a standard feature on SIP's smaller 3KCN

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[52] *Canadian Controls & Instrumentation* 2 (April 1963): 7.

[53] Irwin Wolfe, *Canadian Machinery and Metalworking* 73 (April 1962): 36-38.

[54] Sperry Canada was awarded the SIP contract in the spring of 1961. Brief announcement in *Metalworking News* (New York), 8 May 1961.

[55] The key innovation here was to develop digital-to-analog and analog-to-digital interfaces to SIP's rather unique measuring system. SIP designed and manufactured its own lead screw measuring systems. For each lead screw, SIP would custom make a cam that would correctly compensate for any small errors in the lead screw's production. SIP prided itself on the accuracy of this solution. Sperry Canada had to adapt its NC technology to SIP's unusual approach.

[56] *Bob Cox Interview*, 25 January 25, 1995.

and 5ECN jig borers.[57] The first such system sold by SIP went to Aviation Electric, a subsidiary of the Bendix Corporation, itself a prominent manufacturers of NC.[58]

Developing digitally-controlled inspection systems offered another outlet for Sperry Canada's point-to-point NC technology. In 1961, the Rocketdyne Company[59] in Los Angeles received $400,000 from the United States Air Force to build two prototype, numerically controlled inspection machines.[60] In the aerospace industry, inspection was a critical step in the production process. Discussions of NC usually focus on the speed and precision needed to machine very complex one-piece metal structures. An equally important aspect of the early development of NC was the development of digitally-controlled, automatic, inspection machines. Depending on the complexity of the machining, the task of ensuring that the final metal part corresponded, within very precise tolerances, to the specifications given in the engineering diagram could be far more labour-intensive and time-consuming than the actual production of the piece. Rocketdyne restricted bidding on the prototype of the numerically controlled inspection systems to four companies, Sperry Canada being one of them. One can assume that Rocketdyne's selection reflected its satisfaction with an NC system that it had already bought from the Canadian company.

To win the Rocketdyne contract, Sperry Canada turned for the first time to the Canadian government for financial subsidy. Sperry asked the Department of Defence Production (DDP) to cover any losses arising from a below-cost bid. Of the $400,000, it was estimated that only $160,000 to $200,000 would be available for the sub-contract to design and build the digital controller for the inspection unit.[61] Sperry Canada argued that if it forewent any profit, the design and construction of the two prototypes would cost about $236,000. To come in at a bid of $160,000, Sperry Canada asked the DDP to cover the difference of $76,000. After assuring

[57] SIP's single order for fifteen NC systems from Sperry Canada prompted one trade journal to call the sale "probably the largest single order for numerical units ever placed by a European company." *Canada's Machine Production*, January 1963. After this initial order, the Italian firm San Georgio signed a licensing agreement to produce and sell Canadian NC systems in Europe. For many years after, San Georgio continued to sell a transistorized version of the original Sperry Canada NC system to SIP.

[58] H. G. Hauck (Manager of Industrial Marketing, Sperry Canada), Numerical Control Newsletter #6, 13 February 1963, Accession 1910, Sperry Rand Records, Harry Vickers Papers, box 13, file - Sperry Gyroscope Company Group, 1962-64, the Hagley Museum and Library

[59] Rocketdyne was a division of California-based North American Aviation.

[60] Golden, Letter to the Secretary of the Treasury Board, 19 December 1961.

[61] The rest of the $400,000 would go to the machine tool builder who would build the machine-bed for the inspection unit.

himself that $400,000 was all the American Air Force was going to pay Rocketdyne, the Deputy Minister of DDP, D. A. Golden, sent a long letter to the Treasury Board in support of Sperry Canada's request. Having already financed much of its NC program entirely from company funds, Sperry Canada, argued Golden, was an exemplary Canadian corporate citizen that deserved assistance. But even more important, noted Golden, the development of these two prototype NC inspection machines could, in the short- to mid-term, be the basis for $1 million of additional export sales. DDP provided the subsidy. Without DDP support, Sperry Canada would never have won the Rocketdyne contract.

The Rocketdyne inspection machine contract reveals that Sperry Canada's efforts to diversify into the "civilian" sector nevertheless depended greatly on the American military-industrial complex. In the area of digitally-based controls for machine tools, the defence-oriented companies were the single largest consumer group of numerical control technology in the United States. By the end of 1962, the American Air Force had single-handedly supported the purchase of $60 million of NC technology. In 1963, the aerospace industry alone accounted for 36 percent of all numerical control installations in the United States. One survey estimated that by the end of 1964, this figure would climb to $100 million.[62].

During the early 1960s, a sizeable portion of Sperry Canada's NC business arose directly, or indirectly from the American defence program. After Sperry Canada completed the two prototype NC inspection machines for Rocketdyne, the United States Air Force paid the Canadian company for two more such systems; one to be delivered to the Boeing Aircraft Company in Seattle, and the other to the McDonnell Aircraft Company in St Louis. Pleased with Sperry Canada's abilities in NC technology, the U.S. Air Force also granted the Canadian company a $400,000 industrial R&D contract.[63] Rarely before had the American Air Force granted an NC development contract to a company outside the United States. In addition to systems paid for by the Air Force, Sperry Canada also shipped NC technology for the machining needs of American Navy and Army, and the American Atomic Energy Commission related programs.

Despite the preponderantly American defence-based demand for NC systems, Sperry

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[62] This information was a contained in one of Sperry Canada's proposal submissions to Canada's Department of Industry. Sperry Gyroscope Company of Canada, Limited, Proposal to the Department of Industry Concerning the Development of Numerical Control Systems, IC, vol. 1784, file P8270-270/S18-10, pt. 1.

[63] The purpose of this R&D contract was to develop a highly precise machine and digital adaptive control system for the production of small bore holes to extremely tight tolerances in aerospace materials. *Ibid.*

Canada had believed from the outset that the domestic market could serve as an important source of revenue. The company's desperate effort to market its technology as a "natural" for Canada tried to play off the findings of the 1957 *Royal Commission on Canada's Economic Prospects.* The Commission pointed to the dilemmas of a small domestic market as one of the principal obstacles blocking the growth of a competitive manufacturing sector.[64] Ninety-four percent of Canada's total secondary manufacturing output was for the domestic market. This reliance on an internal market, which had been first nurtured by the National Policy, constrained economic opportunities. If Canada had a massive domestic market, then this reliance would have been more an asset than a liability. After all, the United States' successful economic development stemmed from its massive domestic market. The large internal American market formed a supportive environment for the development of the American System of manufacture, which later grew into the mass-production paradigm. Alfred Chandler's work shows how the expanding American domestic market also supported the rise of the multi-divisional firm and the rise of the American system of management.[65] Dependence on a small market, according to this report for the Commission "prevented [Canadian secondary manufacturers] from obtaining the maximum economies from mass production and specialized operations."[66]

Another structural weakness of Canadian secondary manufacturing, which the report also tied to the dilemma of a small market, was the proliferation of shorter and more varied production runs. "In comparing manufacturing plants in Canada and the United States," observed Fullerton and Hampson, "one is struck not so much by the relatively greater size of the United States production units -- although United States plants are usually somewhat larger -- but by the fact that the Canadian plant in practically all cases produces a much greater variety of products for its size."[67] To illustrate the problem, Fullerton and Hampson referred to the testimony of one manufacturer:

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[64] D. H. Fullerton and H. A. Hampson, "Canadian Secondary Manufacturing Industry," for the *Royal Commission on Canada's Economic Prospects*, May 1957.

[65] Alfred Chandler, *The Visible Hand: The Management Revolution in American Business* (Cambridge, Mass.: Belknap Press of Harvard University Press, 1977)

[66] Fullerton and Hampson, "Canadian Secondary Manufacturing Industry," 63.

[67] *Ibid.*, 72.

There is potentially as great a variety of tastes and quantity requirements in a market of 15 million as there is in a market of ten times that size; but only in the larger market will the minority requirements be large enough to warrant economical production in specialized plants. Where an American plant manufactures a single type of brick, we have to produce five, six or more different colours, grades and finishes.[68]

Sperry Canada's Marketing Manager, Hugh Hauck, understood that the dominance of Fordism, with its specialized tools and high set-up costs amortized over large production runs of one product, had turned Canadian small batch production into a competitive handicap. "Our market is too small to support mass production with specially designed automated machine tools, and our labor costs are too high to make us competitive with our high-labour content methods of manufacturing," wrote Hauck in 1962.[69] In mass production, the costs of retooling are relatively small because they can be amortized over very large production runs. But for small production runs, of the order of 20 to 100 units, which characterized most Canadian machine shops, the costs of retooling comprised a large portion of the total costs. Hauck preached NC as the ideal answer to the competitive challenges facing Canadian machine shops. Numerical control technology, he argued, "allows standard machine tools to be automated for economical short or medium-run production runs. By simply changing a tape you change your product."[70] In 1957, the Fullerton and Hampson study had underscored the inability of Canadian manufacturers to justify specialization on economic grounds as an important impediment to competitiveness. Hauck argued that the flexibility of numerical control would at last level the playing field for Canadian manufacturers.

When Sperry Canada first set about developing its technology and business strategy in the 1950s, the company was convinced that Canada would be a major market for NC. To Sperry

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[68] *Ibid.* Diversification was itself a Canadian manufacturing strategy "to reduce the handicap for short runs in a relatively small and fragmented market." While an American tire manufacturer produced for a large orders of only a few types of tires, its Canadian counterpart manufactured 600 different types of tires in much smaller batches. Some Canadian wire and cable plants produced over 1,000 kinds of wires.

[69] Hugh G. Hauck, "Are We Snubbing a Profit Maker," *Canadian Machinery and Metalworking* 73 (January 1962): 48.

[70] *Ibid.* Sperry Canada's espousal of the advantages of NC for the Canadian context was picked up by other observers. "A possible answer to the problem of applying automation to short-run production is numerical control of machine tools", wrote the journal *Plant Management*. "Available for some time, it is surprising that more companies have not taken advantage of it. There are probably no more than half-dozen installations in Canada." "Numerical Control Equipment," *Plant Management* 7 (February 1962): 33.

Canada's surprise, Canadian machine shops did not beat a path to this new digital technology that promised more flexibility. From 1954 to the end of 1962, only nine NC systems found their way onto Canadian shop floors. To make matters worse for the company, only two of the nine NC systems were made by Sperry Canada. In the United States the total number of NC systems by then had surpassed 2,300.[71] By any measure of comparison, NC technology was extremely under-represented in Canada's industrial infrastructure. Though the relative distribution of machine tools between the United States and Canada closely matched the ratio of their GDPs due to manufacturing, the relative distribution of NC systems was about 230 to 1.[72]

Sperry Canada's efforts to market its NC products domestically were frustrated by the Canadian metalworking industry's perception that NC was only a mass-production tool, hence inappropriate for Canadian machine shops. Why Canadian industry had this perception is not known; but it lingered on beyond the 1960s.[73] Sperry Canada's Manager of Engineering

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[71] The figure of nine NC systems in Canada was extracted from a special issue of *Canadian Machinery and Metalworking*, 77 (April 1966). From the table, on pages 130-7, of all NC installations, one can select out those installed on, or before, 1962. The U.S. data comes from "Machine Tools with Numerical and Prerecorded Motion Program Controls," *Current Industrial Reports Series BDSAF-630(63)-1* (Washington D.C.: U.S. Bureau of the Census: 28 August 1964).

[72] The proportion of the U.S. GDP arising from manufacturing was eighteen times larger than Canada's. Bernard Mueller, *A Statistical Handbook of the North Atlantic Area* (New York: The Twentieth Century Fund, 1965). As an internal report within Canada's Department of Industry noted, in 1965, the U.S. was investing about $1.5 billion per year on machine tools and $250 million in NC technology. In Canada, the annual investment in machine tools was $75 million and $5 million in NC technology. "This means," the brief underscored, "that our demand was one-twentieth of the USA and the numerical content one-fiftieth." Advanced Machine Tool Development, 6 May 1965, IC,vol. 1784, file P8270-270/S18-10, pt. 1. In 1962, with only nine NC systems in Canada, this disproportion was probably even more exaggerated.

[73] "The acceptance of [NC] is still agonizingly slow," observed one writer for Canadian Machinery and Metalworking. He then added: "the view that it is best suited to a large volume still lingers - along with other misconceptions." T. W. Weissmann, "Can You Really Afford to Be Without Tape Control?" *Canadian Machinery and Metalworking* 75 (April 1964): 110. According to a 1966 survey on the state of NC in Canada, the increase to 120 NC systems in Canadian machine shops demonstrated that the misconception of NC as a mass-production strategy was less widespread than in the early 1960s. The fact that the number of NC installations was not higher indicated that this misconception was nevertheless still present. Richard M. Dyke, "Numerical Control In Canada," *Canadian Machinery and Metalworking* 77 (April 1966): 75-127.

Even as late as 1982, about twenty five years after the appearance of the first NC system in Canada, this digital production technology was still not widely diffused. One survey, carried out by the Canadian Manufacturer's Association and the CAD/CAM Technology Advancement Council, found that only 38 percent of the metal fabricating industry used NC. "Information Needs of Canadian Companies on Computer Aided Design and Computer Aided Manufacture," February 1982, *Results of Questionnaire Prepared by and Distributed by the Canadian Manufacturer's Association in Cooperation with the CAD/CAM Technology Advancement Council.*

Another speculative explanation over Canadian industry's perception of NC as a mass production technology may have been management's belief that automation was only a strategy for lowering labour costs. As late as the 1980s, Canada's CAD/CAM Council lamented how Canadian management had failed to see that other nations were using electronic, digitally- based, machine-tool automation to increase market share. "Canadian industry tends to

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Development, Bob Cox, encountered this misconception when he went to work for RCA in 1965. Cox, who brought the first NC systems into RCA Montreal, recalls that "when [he] tried to sell NC to Jack Sutherland, who was then VP and General Manager of RCA's Government and Commercial Systems Division, Sutherland would say we were not in mass production."[74]

The high initial equipment cost of NC also reinforced the wait-and-see attitude of traditionally conservative machine shops. In the United States the start-up costs associated with NC had been systematically defrayed by defence contracts.[75] With no such equipment support programs in Canada, the machining industry may have sensed a flaw in the economics underlying the advantages of NC for small production runs. One study found that the average machine tool in the United States worked only 25 percent of the time.[76] But an NC machine, according to the same study, had to operate at least 75 percent to 80 percent of the time before it could pay for itself. In the context of small production runs, loading a machine tool to 80 percent capacity would require producing a steady stream of different, high-precision, machined products. Was this kind of machining widespread in the Canadian metalworking industry? Probably not. But at the present stage of research one can neither substantiate nor disprove this speculation.

Sperry Canada's NC-based diversification strategy failed to create the fifty/fifty split between military procurement and civilian markets for which it had hoped. In 1963, nine years after the company made the decision to gamble on the then nascent technology called numerical control, the civilian market accounted for only 20 percent of company sales.[77] Sperry Canada's overly optimistic forecasts of rapidly expanding sales became the victims of what Schumpeter had called the "swarming" effect; a rapid proliferation of imitators who follow the pioneering innovator/entrepreneurs. Swarming reduces the high profit margins enjoyed by the early

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view the new manufacturing technologies in a more tactical sense, mainly as a way to shed direct labour even though labour costs in manufacturing typically accounts for only 10 per cent of total costs." The Canadian CAD/CAM Council, *Management in Crisis: Implementing Computer Integrated Manufacturing in Canada*, 1982, 2.

[74] *Bob Cox Interview*, 25 January 25, 1995.

[75] Barker Industrial Equipment reasoned that Canada's import tariff rates, which taxed machines tools at 7.5 percent and numerical control equipment at 22.5 percent, would privilege made-in-Canada NC technology. The company imported American machine tools and then fitted them with Sperry Canada numerical control units. This strategy was only of marginal benefit to Sperry Canada. Weissmann, "Can You Really Afford to Be Without Tape Control?"

[76] Herbert E. Klein, "Numerical Control: From Class to Mass Market," *Dunn's Review and Modern Industry* (August 1965): 34-5, 63-66.

[77] Employment Forecast Survey Interview Report, 2 May 1963, DDP, vol. 555, file 200-13-395.

innovators due to their monopoly over the technology.

When Sperry Canada first got into the NC business in the mid-1950s there were only a handful of companies designing and building systems. By the early 1960s, there were well over 100 companies in North America competing for NC business. The effect of this competition was felt most in the lower end of the NC market in which Sperry had concentrated its innovation strategy. Sperry Canada was a Schumpeterian firm whose once exclusive North American technological/market niche was overrun by imitators, mostly American. Faced with this competition, Sperry Canada decided once again to be a Schumpeterian firm and define a new exclusive niche for itself through radical innovation. This time it would take aim at the up-scale market.

In a bold move, Sperry Canada decided, sometime in late 1962, to bring the programmable electronic digital computer directly into the hands of the machinist on the shop floor. Computer Numerical Control (CNC) was born. None of the component technologies of CNC were new. Computer technology was well established. Sperry Canada already had the digital measuring and actuating technology. However, the integration of all the elements into one small system that could work directly on the shop floor was a radical innovation, for computer hardware designed to run in clean, air-conditioned rooms had to be adapted to the harsh environment of the machine shop. Considerable innovation was thus needed to make the integration work.

The design of Sperry Canada's new generation of CNC had to walk the fine line between the pursuit of sheer technical performance and market realities. Performance sought at any cost, though acceptable for strategic military projects, would not work in the civilian market. Sperry Canada's strategy that hardware compromises could be overcome through software proved problematic. In the end, as discussed in the next section, the hardware engineer's lack of appreciation of the complexity of real-time programming, and management's inability to subject software development to the same discipline found in hardware development, led Sperry Canada into a technical and financial minefield from which the company did not ever emerge fully intact.

UMAC-5: Performance and Market Flexibility Through Software

Despite the claims of great flexibility, there was no universal numerical control (NC) system that could be simply plugged into any given machine tool. Considerable re-engineering was required to adapt a basic NC system to each new machine tool. "As the need for more sophisticated control systems is recognized by users, and as more machine tools are adapted to N/C," one prominent American trade journal summarized, "many control systems need extensive modification after initial assembly. Hardware must be adapted to suit specific drive and operational characteristics. Valuable shop and engineering time is consumed in these modifications."[78] The high costs of these hardware modifications increased the prices of NC systems. Custom-engineering NC to match the various new generation of multi-axis machine tools and the new "machining centre" became problematic.[79] The more complex the machine tool was, the greater the modification costs.

Sperry Canada took the solution of the adaptability problem as the basis for its future NC business strategy. In late 1961, the company decided to develop a new generation of NC systems that could be married easily, with a minimum of re-engineering, to any two, three, four, and even five axes machine tools. Such a radical innovation, the company reasoned, would lower its production costs significantly, speed up delivery times considerably, and expand the flexibility of its NC systems -- in short, increase the compnay's competitiveness. To want adaptability was one thing, to achieve it quite another. Sperry Canada's management and engineers were unsure of the technical framework for the innovation of this new generation of NC systems.

Yet determined to create this market niche, the company started hiring more Canadian development engineers. One of these men was Paul Caden, a graduate of the University of Toronto's Engineering Physics program. Caden's first job was on DRB's Velvet Glove project for the De Havilland Aircraft Company during the Korean War period.[80] Borrowed from De

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[78] William Stocker, "Building Adaptability into N/C," *American Machinist/Metalworking Manufacturing* 107 (24 June 1963): 64-5.

[79] "Machining centres," which started to appear in the early 1960s in the most advanced machine environments, were capable of a multiplicity of operations in one setup. Unlike the traditional special purpose machine tool characteristic of mass-production, a single machining centre could face-mill, end-mill, profile, contour, drill, ream, tap, bore, and counter-bore in five or more axes.

[80] The Velvet Glove project to design a short range guided missile arose from Canada's post-World War II determination to be an active contributor to the military technology pool of the North Atlantic Triangle alliance. See

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Havilland for a year, he went to the Canadian Armaments Research and Development Establishment (CARDE), in ValCartier, Quebec, to study the technical feasibility of certain aspects of the proposed AVRO Arrow project. When he returned to De Havilland, the Canadian Velvet Glove project had been abandoned in favour of the American Sparrow missile project. Caden then went to work on the Sparrow, again at De Havilland. Canada's share in the development of the Sparrow never materialized. Work on the Sparrow having been cancelled, Caden moved on to A.V. Roe to work on the Arrow fighter plane. There he did tactical simulation studies. With the demise of the Arrow, he moved on to CAE in Montreal, where he designed flight simulators for the Argus aircraft.

In late 1961, Bob Cox, now the Head of Sperry Canada's Engineering Development, called Caden to enquire if he wanted to work on a new generation of numerical control systems. The idea of getting involved in sophisticated, digital, machine tool control systems struck a chord in Caden, and he accepted Cox's offer. Sperry Canada's management had not even considered the use of a general purpose-computer when it hired Caden. Instead the company felt that the answer to greater adaptability somehow lay in more sophisticated and clever hardwired designs. Caden was hired because of the electronics experience he could bring to bear on the problem. But from his work at CAE, Caden had become increasingly fascinated by the possible industrial control applications of electronic digital technology. [81]

After considerable study, Caden concluded that the NC adaptability sought by Sperry Canada could best be implemented by embedding a programmable computer into the heart of the NC system. In this way, Caden reasoned, an NC system could be adapted to any machine tool configuration, however complex, by simply reprogramming it. It was perhaps inevitable that, after acquiring a taste for designing computers, Caden would try to push Sperry Canada in this direction.

Sperry Canada's management greeted Caden's idea with caution. Skeptics objected that general-purpose computers tended to be too large, too expensive, or too fragile to be placed next to a machine tool on the shop floor. With no experience in the design, testing and production of

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Chapters 2-4.

[81] Work on the Argus simulator had introduced Caden to the design of electronic digital systems. While still at CAE, he also designed a small relatively simple, solid-state, special-purpose, digital computer to process hydrographic data.

computer systems, senior management worried whether the company could undertake building a computer specifically for the machine tool environment. Sperry Canada's military systems group had already built and installed a hybrid digital/analogue tactical simulator on the HMCS Stadacona for the Royal Canadian Navy (RCN) sometime in 1961.[82] But the digital computer in this simulator was an off-the-shelf Packard Bell PB-250. The software development for the RCN tactical simulator had not been complex, but it still served as a reminder that programming was not to be taken lightly. Caden's proposal entailed far more than tinkering with off-the-shelf technology. As one government expert noted:

> *While the incorporation of a small digital computer into a multi-axis numerical control may appear at first hand to be a straightforward task, in fact, it becomes a special purpose digital system development. Not only is the equipment itself special, but the type of computer programming and the approach that must be taken thereto in order that it can be widely used also necessitates special development. Specifically, programming suitable for this special computer must be written to marry the control to every different machine tool.*[83]

Despite the very difficult software challenge, Bob Cox supported Caden's proposal. In late 1962, after many studies and presentations, management finally accepted the programmable computer approach. No sooner had Sperry Canada embarked on the project when the company naively boasted, in the summer of 1963, that it would soon have a commercial system ready to go. The company's Manager of Industrial Contracts, Hugh Hauck, told one *Montreal Gazette* reporter that Sperry Canada had developed a new generation of NC that represented "a major breakthrough in the industry."[84] Though no system had yet been delivered, the Senior Editor of *American Machinist/Metalworking Manufacturing*, announced that, with UMAC-5's general-purpose computer, Sperry Canada had solved the versatility problem that had hitherto plagued NC systems.[85] With its CNC system, UMAC-5, Sperry Canada sought to develop one NC system that could be universally interfaced to any complex machine tool without having to always redo the circuit design. UMAC-5's hardware was standardized and fairly independent of the machine

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[82] *Bob Cox Interview*, 25 January 25, 1995.

[83] W. S. Kendall (Chairman, Electronics Advisory Committee, Department of Defence Production), Memorandum to the Inter-departmental Committee, 26 May 1965, IC, vol. 1784, file P8270-270/S18-10, pt. 1.

[84] "Canadian Firm Develops New Control System," *Montreal Gazette*, 4 July 1963, 10.

[85] Stocker, "Building Versatility Into NC," 24 June 1963.

tool it was to control. When a customer ordered a UMAC-5, all the detailed information about the configuration and operation of the customer's machine tool would be loaded as a program into the computer before being shipped from the Sperry Canada plant. If for any reason the customer wished to change the configuration of this machine tool, UMAC-5 had only to be reprogrammed.

By November, as orders for UMAC-5 came in, the company found itself having to push back the first delivery into the new year.[86] Hauck's marketing was so effective that by October 1964, the company had received thirty-two orders for UMAC-5.[87] The pressure to deliver the first complete working system mounted. UMAC-5's development became mired in software problems. Once Sperry Canada locked on to the idea of flexibility through programming, there was a tendency to want to design UMAC-5 to be all things to all people. The company wanted to prepackage more complex multi-step machining operations into subroutines which would simplify the job of the parts programmer.[88] In its aggressive marketing promises, the company had grossly underestimated the time and money that would be needed to develop all this software. When Sperry Canada embarked on UMAC-5 it mistakenly thought that after designing and building the hardware, everything else would be relatively straightforward: Simply a Matter Of Programming (SMOP), as the over-confident UMAC-5 engineers called it. After two years, in which the software overruns had exhausted the company's financial resources, SMOLOM (Simply a Matter Of a Lot Of Money) would have been a better acronym.

The difficulties in UMAC-5's software development arose from the inexperience of the design team, the craft-like nature of programming, and the cost-driven compromises made in the computer's hardware. The programmers had little understanding of metal-working or knowledge of the intricacies of gear boxes, servo-mechanisms, and other aspects of machine tool construction and operation. Gila Bauer, who headed up the group, was trained as a

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[86] "Sperry Has Order Backlog Before First Delivery Made," *Montreal Gazette* 15 November 1963, 31.

[87] For a list of the orders see B. W. King (President, Sperry Gyroscope Co. of Canada Ltd.), Letter to Department of Industry, 6 November 1964, IC, vol. 1784, file P8270-270/S18-10, pt. 1.

[88] "Parts programming" should not be confused with the UMAC-5 software development. "Part programming" entailed preparing the tape with the machining instructions for each job. Part programming was carried out by the machine shop. UMAC-5's software then translated the very general instructions into all the detailed measuring and control functions needed to carry out the work. UMAC-5's software can be likened to the operating system that oversees a computer's operation. Part programming was an application that ran within the operating system.

mathematician.[89] It is symptomatic that the development of software, which was the essence of the new Sperry Canada NC approach, had been given to inexperienced computer programmers. If anything, this choice reflected Sperry Canada's naïve belief that programming would be a relatively simple and routine matter. In time, the programmers gained the requisite experience, but it was a long and costly process. The consequences of CNC programming mistakes could be far more dramatic than a simple error message. "It was all too easy for someone who was a pure programmer," Cox later observed, "to say 'well I'll just engage this clutch and that clutch' and have the spindle gear box going forward and reverse at the same time. The end result was broken gears all over the floor."[90] On one occasion, a programmer did not realize that the control software for a large horizontal boring machine needed to include a limit switch. During a demonstration of UMAC-5, a software bug caused the table to keep moving in one direction. Not stopped by a limit switch, the six ton table went off the lead screw and through a brick wall.[91] After trying to get programmers to learn about machine tools, Sperry Canada discovered rather belatedly that faster results could be had by teaching machine tool technicians how to be programmers.

The very nature of the art of programming amplified the early problems of inexperience. "Despite 50 years of progress," observed W. Gibbs in a recent article in *Scientific American*, "the software industry remains years - perhaps decades -- short of the mature engineering discipline needed to meet the demands of an information-age society."[92] The thrust of the Gibbs's argument is that software development has for a very long time been "craft"-based and has escaped the systematic, disciplined and quantifiable ethos that characterized the emergence of modern engineering in the twentieth century. To this day, software is still handcrafted by artisans using techniques they neither can measure nor are able to repeat consistently. One computer scientist likens current software development to the craft production that preceded the rise of interchangeable parts manufacturing.[93] During the 1960s, when UMAC-5 was being developed,

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[89] Paul Caden remembers two other women, but is unable to recall their full names.

[90] *Bob Cox Interview*, 25 January 25, 1995.

[91] All those to whom this author spoke made reference to this incident. In Paul Caden's version, the machine tool's table fell one storey and landed on a parked car!

[92] W. Wayt Gibbs, "Software's Chronic Crisis," *Scientific American* (September 1994): 87.

[93] "It's like musket making. Before the industrial revolution, there was a no specialized approach to manufacturing goods that involved very little interchangeability and maximum of craftsmanship. If we are going to lick the software

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the craft-like nature of software development was even more pronounced.

With little experience in software development, Sperry Canada's management found it even more difficult to subject the craft of programming to strict engineering control. "The software people tended to be a bunch of mavericks and gurus," Cox later recalled. "They did not follow any discipline in documenting or modularizing their programs. They made changes in an uncontrolled fashion. There was no configuration management on software. People would make changes in the middle of the night and not tell the next guy."[94] One Sperry Canada document reported how "it was virtually impossible to keep accurate records of what individual machine programmes consisted of."[95] Sperry Canada's usual design estimation and control procedures, which had proved reliable in hardware engineering, failed to get a handle on software development.

The marketing idea behind UMAC-5 was the cost and time savings to be had by replacing hardwire re-engineering with "soft-wired" reprogramming. The fact that it took eleven weeks to load and debug a program for the prototype did not bode well for profitable sales.[96] In addition to the factors cited above, the absence of a high level programming language lengthened the software development cycle. All programming was done in a very unintuitive and cumbersome machine language. "As we had no means of automatically assembling master programmes," noted one company progress report, "each of the prototype machines had to be programmed, optimized and loaded command by command. This in turn caused further problems. It took a great deal of time and money to programme the controls. A great number of errors were made, some of which were of such an insidious nature that we still have not removed them from the Avey turret drill we own."[97] For Sperry Canada's programmable computer strategy to succeed, the company had to develop techniques that could generate and document the software in a quick, predictable and routine manner. To do this, a high-level language had to be

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crisis, we're going to have to stop this hand-to-mouth, every-programmer-builds-everything-from-the-ground-up, pre-industrial approach." *Ibid.*

[94] Bob Cox, Private Communication.

[95] Sperry Gyroscope Company of Canada Limited, UMAC 5 Development, 1 November 1965, 2, IC, vol. 1784, file P8270-270/S18-10 pt. 1.

[96] Problems with software also made the installation far more time consuming and costly than was necessary. The first UMAC-5 controller took ninety days to install. *Ibid.*, 8.

[97] *Ibid.*, 2.

developed for UMAC-5; the conventional compilers found on mainframes were unsuitable.[98] The absence of any efficient, program-debugging tools also limited the productivity of UMAC-5's programmers.

Sperry Canada's design strategy created a conflicting set of design objectives whose final resolution compounded the difficulties of software development. The computer had to be fast enough to monitor and control machining processes that demanded split second response. At the same time, the computer had to be small and resilient enough to be placed next to the machine tool in a harsh, shop floor environment. The production costs for the computer had to be low enough to allow the company to market it as an economic alternative to existing hardwired NC technology. Finally, the design had to be simple enough to ensure that the company could finance development and get a product on the market in a reasonable time.

Although Sperry Canada's CNC approach was technologically driven, the computer's design was pragmatic and cost-driven. After some analysis, Sperry Canada decided that a ceiling of $5,000 had to be placed on the cost of the computer's hardware inputs if UMAC-5 were to be competitive in price.[99] To keep costs down and simplify hardware design, a serial, rather than parallel architecture was chosen. This compromise in performance did not pose any serious problems. However, the decision to go with an all-drum memory was a different matter. Magnetic cores offered superior performance, but with this memory running about $0.25 per bit this option would push costs far beyond the $5,000 limit. The choice of a drum for CNC created as many problems as it solved. Drum memory complicated the task of software development because of the need for a very efficient programming code to overcome the relatively slow access time arising from the drum's non-random access memory. The technical issue was one of how information was stored on, and read off, the drum.

The memory on the drum was divided into read-only and read/write tracks. The machine tool operator's program went on the read/write track. The "firmware," which took up most of the drum's memory, was put on the read-only track at the Sperry Canada plant. This firmware

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[98] "General purpose compilers, such as used with conventional data processing facilities," explained one company document, "are not suitable for our purpose due to the fact that the internal organization of the UMAC-5 computer is specifically directed at machine control functions rather than general purpose data processing." Sperry Gyroscope Co. of Canada Ltd., Proposal to the Department of Industry Concerning the Development of Numerical Control System, 7 April 1965, 13-4, IC, vol. 1784, file P8270-270/S18-10, pt. 1.

[99] Both Bob Cox and Paul Caden mentioned this figure in oral history interviews. Unfortunately, neither can remember the details of how the $5,000 figure was arrived at.

contained all the information and sub-routines needed to compile the part program and then operate the various parts of the machine tool precisely and in the proper sequence. In a revolving drum system, any given piece of data appears under the read head once every revolution, which in this case took seventeen milliseconds.[100] For some machine tool operations a maximum seventeen millisecond access time was acceptable while in others it was not. Servo-commands were very time-sensitive while the control of such activities as spindle speeds, and turning the coolant on and off, were not.

The UMAC-5 prototypes turned out to be too slow "due to the inefficient distribution of data on the drum and the absence of 'fast tracks'." When UMAC-5 prototypes were demonstrated at Sperry Canada, representatives of the machine tool industry were quick to spot the smallest hesitation in the computer's control of the movement of the cutting tool or work piece. Caden's efforts to time-optimize the software in order to overcome the limitations of drum memory met with partial success. The pursuit of better real-time performance from a drum memory also underscored the need to reduce the size and complexity of all the programs that had been developed, and to optimize their integration.

As software problems mounted, Sperry Canada turned to UNIVAC, another Sperry Rand division, for assistance. A leading manufacturer of computer technology, UNIVAC hitherto had shown little interest in applying its expertise to the machine tool market. It had other more pressing concerns: losing a great deal money, UNIVAC was in a desperate fight against IBM for survival in the mainframe computer business. Nevertheless, as a division of Sperry Rand, UNIVAC was quite open to intra-firm transfer of its know-how. It provided Sperry Canada with the printed circuit boards for UMAC-5's construction. In return, Sperry Canada provided the NC technology for UNIVAC's machine shops[101] and for the high-speed automated wiring of UNIVAC's mainframe computers.[102] Late in 1963, or early 1964, a software team from UNIVAC

[100] Sperry Canada used Bryant drum which was an aluminium cylinder ten inches in diameter and five inches long. Memory was distributed along 96 of the drum's 100 tracks. The other tracks were for timing purposes. Each track could hold a maximum of 4096 bits of information. The drum rotated at sixty revolutions per second.

[101] "Canadian NC system prunes tooling costs in U.S. plant," *Canadian Machinery and Metalworking* 74 (April 1963): 170.

[102] "An automatic wire-wrap machine fitted with numerical control designed and produced by Sperry Gyroscope Co. of Canada, Ltd., Montreal, is handling 2,000-wire panels at less than 7 percent of the cost of hand wiring." "Automatic Wire Wrap Proves Out," *Canadian Controls & Instrumentation* 2 (February 1963): 36.

came to Montreal to help accelerate the pace of software development.[103] Whatever its contribution, the UNIVAC team did not, however, cure the UMAC-5 project of its software ills.

In 1965, after two years of work and $475,000 of investment, UMAC-5 development's was still incomplete.[104] Sperry Canada's two prototype installations still exhibited "several important design deficiencies in hardware and software."[105] To make matters worse, the Liberal government's cancellation of the defence contract for frigates underscored how Sperry Canada's financial capacity to underwrite the completion of UMAC-5's development still rested precariously on military procurement. This cancellation reflected the changed perspective since Canada came into its own in the North Atlantic Triangle alliance as result of its important role in the Battle of the North Atlantic. After World War II ended, Canada's military was determined never to be caught unprepared again. The RCN, which saw its future strategic role as continuation of its wartime escort role, made plans to build a sophisticated escort fleet. Ferranti-Canada's DATAR technology was part of this strategy. Another aspect was the construction of modern frigates. These ships were to be the modern descendants of the Canadian Corvettes that had defeated the German submarines in the Battle of the North Atlantic. However, it was not until 1962 that the Conservative government finally approved the construction of eight frigates, all to be equipped with the latest weapons systems.

A year later, the Liberals, elected in the interim, had second thoughts about the high costs of such a naval construction program. In addition, the RCN was now wondering about the operational limitations of the frigate in modern anti-submarine warfare. Nuclear submarines could circumnavigate the globe without ever coming up for air; they could disappear easily under the Arctic ice, they were faster than frigates, and they could launch missiles from the ocean's depths. Frigates were at risk of obsolescence. There was even talk that the RCN wanted to replace the frigates with three submarines or even hydrofoils. On 24 October 1963, the Minister of Defence, Paul Hellyer, stood up in the House of Commons and announced the cancellation of the $452 million defence contract, one of the largest single defence contracts since the Korean

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[103] *Paul Caden Interview*, 9 December 1994.

[104] *Ibid.*

[105] Sperry Gyroscope Company of Canada Limited, UMAC 5 Development, 1 November 1965, IC, vol. 1784, file P8270-270/S18-10 pt. 1. p. 2

War.[106] Conservative opposition members howled their indignation; Gordon Churchill called Hellyer's actions a "crippling setback."[107] Behind the political controversy stood the economic impact of the cancellation on Quebec's shipyards and Canada's weapon systems industries.

Sperry Canada had a substantial stake in the frigate program. The manufacture of the ships' navigation systems was projected to provide the company with 25 to 35 percent of its total 1964 and 1965 revenues. The cancellation was a crushing blow to Sperry Canada and its CNC ambitions. The funds to support the company's diversification into NC and then CNC had been drawn from its defence contract revenues. The cancellation of the frigate program left Sperry Canada with no money to complete UMAC-5. To compound the company's cash flow difficulties, its parent firm was no longer in a position to make up the shortfall through intra-firm subcontracting.[108]

In its efforts to survive in the civilian market, Sperry Canada for the second time turned to the state for help. On 6 November 1964, the President of Sperry Canada, Wence King, asked the Liberal government to share the cost of $125,000 needed to complete UMAC-5's development. He argued that this support was critical if Sperry Canada were ever going to gain a firm foothold in a $30 million export market for high performance point-to-point CNC.[109] Once again, King used the export argument to win government support. Management was convinced that, with its computer strategy, Sperry Canada could win as much as 17 percent of this global market by 1968.[110]

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[106] Canada, House of Commons, *Debates*, First Session, Twenty Sixth parliament, Volume 1, 24 October 1963, 3937.

[107] *Ibid.*, 3998. There was a certain irony in this political debate, which was being fought under the shadow of the cancelled Avro Arrow program. In Opposition, Hellyer had condemned the Diefenbaker government's destruction of Canada's defence industry. Now it was the Conservative party's turn to decry the Liberal party's dismantling of the Canadian defence industry.

[108] Sperry Rand's various American divisions, explained one company official to a Canadian government official, "were now experiencing a period of greatly reduced volume and [were] unable to provide subcontract work" to the Canadian division. R. H. Littlefield, Letter to C. R. Nixon, 11 January 1965, IC, box 1784, file P8270-270/S18-10, pt. 1.

[109] See Chart #3 in B. W. King, Letter to Department of Industry, IC, box 1784, file P8270-270/S18-10, pt. 1.

[110] Bendix, Hughes, TRW, and GE had the largest share of the high performance NC business. Sperry Canada concluded that these four companies would maintain approximately 63 percent of this market over the foreseeable future. But the Canadian company hoped that it would eat into the market share of the other smaller competitors. According to Sperry Canada's scenario, its share would grow from 6 percent in 1964, to 8 percent in 1965, 14 percent in 1966 and then taper off to 17 percent over 1967 and 1968. With firm orders adding to $1.2 million before even delivering its first system, the company believed that by 1968 its UMAC-5 sales could total as much as $4.5 million. *Ibid.*, Chart #4.

In seeking funds from the State, Sperry Canada's strategy to win a share of the high-performance NC market consisted of more than point-to-point applications. In point-to-point machining, the cutting tool moves only in straight lines relative to the workpiece. Contour machining entails machining along arbitrary and often complex curves. Sperry Canada's management believed that a programmable computer approach also had distinct commercial opportunities in the contour machining market.[111] However, considerable investment was needed to perfect this line of innovation. In addition to servomechanical innovations, new hardware and software would have to be designed to meet the faster and more intense computational demands of contour machine-control. Unable to spend any money in a new round of CNC development, Sperry Canada tried to get the Government to underwrite this technological ambition. It confidently forecast that a new UMAC-5 for contour applications would capture 10 percent of an estimated $18 million total global market.[112] In terms of its total CNC sales, Sperry Canada predicted that by 1968, 40 percent would come from contour applications.

About $600,000, according to company estimates, would be required to develop and commercialize a contour version of UMAC-5. Most of this money was to cover the costs of designing, developing, testing, and commercializing new computer hardware and software. Preliminary design plans for the new UMAC-5 computer called for the latest micro-circuit technology, parallel architecture with core memory, a new assembler and Fortran compilers, and an all important library of real-time, software sub-routines to handle the complex task of machining over arbitrary curves. Drawing from military systems development, Sperry Canada also proposed the creation of software to test the system in simulation. Sperry Canada estimated that it would need twenty months to design the prototype computer systems. An additional sixteen months would be needed marry the computer and new servo-control technology to a sophisticated "machining centre" and then to test the entire system.[113]

Sperry Canada's fifty/fifty cost sharing proposal was a poorly disguised attempt to get the federal government to carry all the costs of developing the advanced version of UMAC-5 for contour applications. The costs to complete the point-to-point version of UMAC-5 and build a

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[111] Among the advantages cited were an internal computing ability to shorten program tapes; easy set-up features; high adaptability; a capacity to combine point-to-point and contour capabilities without loss of accuracy; a high order of interpolation in contour-cutting; easy installation; and the ability to re-enter a cut without retraversing; *Ibid.*, 4.

[112] *Ibid.*, Chart #3.

[113] See chart entitled "Continuous Path Numerical Control System Schedule," and graph entitled "Proposed Rate of Expenditure for Continuous path N/C System," in Littlefield, Letter to C. R. Nixon, 11 January 1965.

new contour version were $725,000. The company, however, proposed a fifty/fifty split of $1.2 million. Rather than asking for 50 percent of future costs, Sperry Canada wanted the Government to share the costs of UMAC-5 retroactively to the very beginning of the program in 1962-63. In effect, Sperry Canada was offering to pay only $125,000 for the completion of the current UMAC-5 version. The Government's $600,000 share conveniently matched the total estimated costs to develop and commercialize a new continuous path, UMAC-5 CNC system.

When the Department of Industry (DOI) balked at this funding ploy, Sperry Canada revised its cost sharing proposal to a sixty/forty split.[114] When the Government questioned why the company's wealthy parent firm, Sperry Rand, did not contribute to UMAC-5's development, Sperry Canada underscored the divisional and decentralized corporate structure of Sperry Rand: "Each division of the corporation, including Sperry Canada," explained R. H. Little, Director of Marketing, "is treated as a discrete cost entity. Each division must provide its own funding for its own operation."[115] The other divisions had absolutely no reason to divert their own precious R&D funds to Canada.

Within the Sperry Rand empire, Sperry Canada had won the world product mandate for "numerical and industrial controls." But without government aid, there was little likelihood that Sperry Canada could turn its ambitions of global technological leadership into profits. DOI, while receptive to Sperry Canada's export market argument, also had reservations. In the end, it was concern over the fate of Canada's metal-working industries that shaped the government's response to Sperry Canada's call for development cost-sharing. As early as 1958, a warning was sounded over the impending obsolescence of Canada's manufacturing infrastructure. "The machine building industries - machinery, machine shop, machine tools, iron casting, office and household machinery, electrical apparatus - might be expected to act as bellwethers of modern production practice," observed *Canadian Machinery and Manufacturing News*. The journal went on to add: "there are more machine tools from eleven to twenty years old than there are under eleven years. Despite the tremendous expansion since the war almost 60 percent of today's machine tools in these industries date back to war's end or earlier."[116]

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[114] *Ibid.*

[115] *Ibid.*

[116] "CN machine tool census sounded industry warning," *Canadian Machinery and Manufacturing* 69 (December 1958): 190. In the same issue see also, "Canada has 262,000 machine tools in the metalworking industry," 126-7; and (continued...)

These results, which appeared shortly after the report of the Royal Commission on Canada' s Economic Prospects, added another dimension to the Government's concern over the future competitiveness of the Canadian manufacturing sector. Six years after this report, the Economic Council of Canada, in its first report, again raised the issue of increasing the productivity of the nation's industrial infrastructure:

> *The productivity of a country's economy...is at the heart of its economic welfare and prosperity of its people. Productivity gains are also the essence of economic growth and are the real source of improvements in average living standards. Moreover, without adequate productivity growth, a nations's competitive position...may be subjected to disturbing pressures and strains.*[117]

The Council suggested that in order to reverse the decline in the nation's productivity, registered from 1956 to 1963, new emphasis had to be placed on increasing the technological preparedness of Canada's industries.

With the Economic Council Report barely a few months old, Sperry Canada's UMAC-5 funding proposal resonated strongly within the Department of Industry (DOI). The remarkably slow diffusion of NC technology into Canada's forces of production was one symptom of the productivity problem.[118] One trade journal warned that if the diffusion of NC installations did not accelerate dramatically, Canada's metalworking industry would "crumble."[119] In 1965, in an effort to interest Canadian industry in NC, DOI actively participated in seminars on productivity sponsored by the Economic Council of Canada at which NC was the specific theme.[120] DOI saw the capacity to produce this technology indigenously as crucial to furthering the spread of NC in

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"How the Census was prepared and what it tell, and how," 130-50.

[117] Economic Council of Canada, *First Annual Review: Economic Goals for Canada to 1970*, December 1964.

[118] In 1962, there were only nine NC-equipped machine tools in Canada. By the end of 1964, only fifty-one machine tools with NC existed in Canada. Internal Report: Advanced Machine Tool Development, 6 May 1965, IC, vol. 1784, file P8270-270/S18-10, pt. 1. Over a year later, the number had climbed to 121, eleven of which had been made by Sperry Canada. Though considerable in absolute terms, in relative terms, Canada still lagged far behind its biggest competitor, the U.S. While the ratio of machine tools between the U.S.A. and Canada were 17 to 1, the ratio for NC systems deployed was 62 to 1. Simon Reisman (Deputy Minister of the Department of Industry), Draft of Memorandum to C. M. Drury (Minister of the Department of Industry), 21 April 1966, IC, vol. 1784, file P8270-270-/S18-10 pt. 2.

[119] "Canada must catch up or crumble," *Canadian Metalworking/Machine Production* (February 1965): 31-2.

[120] Reisman, Draft of Memorandum to Drury, 21 April 1966.

Canada. When the Government asked what DOI was doing to "promote the use of numerical control in Canada," the Deputy Minister replied: "action by the department has taken two forms: first, the support of the development of numerical control in Canada where applicable, and the second, the encouragement of the acquisition of numerical controls by industry."[121]

Fearful that the nation's aging stock of machine tools seriously impaired the ability of the civilian sector to respond to military procurement needs, the Government created the Defence Industry Modernization (DIM) program. Under the DIM program, continued Deputy Minister, Simon Reisman,

> *Companies [were] encouraged to enter the defence export market which demands that their products be competitive in quality, delivery and price with the best American...For relatively short run production this [meant] usually numerically controlled machines..DIM [was] used with discrimination to favor such modernisation of facilities rather than simply to expand Canadian production facilities to meet particular American requirements.*[122]

Sperry Canada's ambitions to perfect CNC offered the only opportunity for DOI to promote a domestic capacity to design and sell this technology. But was Sperry Canada's computer numerical control design agenda the optimal answer to the inadequate spread of NC technology in Canada? The poor experience to date with NC made it doubtful that many Canadian machine tool shops would be interested in the even more expensive CNC.

The premise of Sperry Canada's entry into computer design had been to escape from the swarm of competitors producing cheaper and less sophisticated NC systems. "It is the opinion of our company," Sperry Canada had explained in the first and second proposals, "that the low performance point-to-point market, due to the extremely active competition and relatively unsophisticated nature of the equipment involved, makes it an unsuitable product for a company of our technological background."[123] The company's desire to create a new CNC product for contour machining applications was a further indication of the company's strategy to use computer technology to pursue the high performance market.

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[121] *Ibid.*

[122] *Ibid.*

[123] King, Letter to the Department of Industry, 6 November 1964.

Sperry Canada's CNC approach made sense only for that portion of the market that used large and complex machine tool set ups, of which machining centres were a perfect example. Spending $30,000 to $70,000 for a UMAC-5 CNC system could be justified only if it were joined to $100,000 to $500,000 machine tools. The contour-machining version of UMAC-5 promised to be even more expensive. Not only were "machining centres" rare in Canada, but the bulk of Canadian purchases of metal-working machinery were for less complex equipment.[124] The first detailed analysis of machine tools imports carried out by the Department of Industry suggests that smaller, lower priced, machine tools dominated Canada's secondary manufacturing sector.[125] Another internal DOI memorandum noted that the Canadian market for metal-working machinery was about $75 million but that proportion of the demand for more sophisticated numerically controlled machines was forecast to be only of the order of some $10 million in two year's time.[126]

Although Sperry Canada expected to sell some UMAC-5s in Canada, the marketing thrust of its CNC strategy was global. DOI, however, felt that there was a greater need for cheaper, high-performance NC technology for the vast majority of smaller machine tools that populated Canada's metalworking industry. To spend $125,000 for the completion of the point-to-point CNC system seemed a reasonable expenditure of DIM funds. After all, the company had already spent a considerable amount of its own money on UMAC-5. DOI also recognized that UMAC-5 was of great potential value to those Canadian metal-working companies that produced very short runs of sophisticated parts on complex machine tools. On the other hand, DOI was reluctant to spend an additional $600,000 on the development of an even more advanced CNC system, when the vast majority of domestic machine shops needed a less costly alternative.

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124 The first order for an American Kearney & Trecker machining centre had been placed in Canada in 1965. The purchase was funded by the Defence Modernization Vote. See Internal Report: Advanced Machine Tool Development, 6 May 1965.

125 Very little data are available showing both the number and value of machine tools purchased by Canadian industry. From the study referred to here, it was impossible to find any category of machine tool for which the average price was more than $20,000. "Metalworking machinery imports: first full-detailed analysis," *Canadian Machinery and Metalworking* 75 (August 1964): 67-9. By contrast, the average cost of a machine tool found in the U.S. was considerably higher: $73,000 for a boring machine, $94,000 for milling machine, $40,000 for a lathe, and up to $140,000 for other more exotic types of machine tools. See U.S., Department of Commerce, *Current Industrial Reports: Machine Tools With Numerical and Prerecorded Motion Program Controls - 1963*, 28 August 1964, Series BDSAF-630-(63)-1, Table 1. In these average prices are for the machine tool alone. The cost of the NC unit has been subtracted.

126 F. Dugal (Machinery Branch, Department of Industry), Memorandum to W. H. Huck (Chairman, Capital Assistance Committee, Department of Industry), 23 April 1965, IC, vol. 1784, file P8270-270/S18-10, pt. 1.

Two months after asking DOI to share the $600,000 costs for a new CNC development, Sperry Canada did an almost complete turn around in its technological and marketing strategy. In a revised cost-sharing proposal, dated 7 April 1965, Sperry Canada reaffirmed its desire to complete the software development for the point-to-point UMAC-5 system. But the company completely dropped its plan to design a contour version of UMAC-5. Instead, embracing a new technological strategy to reflect the priorities of the State, Sperry Canada proposed that, with DOI funding, it would develop a new family of low cost NC systems.[127] "The smaller manufacturer," explained Sperry Canada in its revised proposal, "who cannot afford the substantial investments represented by the major numerically controlled machines, nevertheless, is beginning to recognize the advantages to be gained from flexible short run automation, and is investing in the machines within his financial reach. These more economical machine tools demand two and three axis numerical control systems in the $10,000 to $16,000 price range."[128] The fifty/fifty cost sharing arrangement was approved on 30 June 1965 -- eight months after Sperry Canada first asked for support to complete software developments on UMAC-5.[129] During that period, Sperry Canada, confident that it would get some form of government assistance, had continued work on the UMAC-5 computer.[130] By the time Treasury Board actually approved the development contract, Sperry Canada had completed much of the software work.[131]

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[127] Instead of a sixty/forty split of $1.2 million, Sperry Canada now asked for a fifty/fifty split of $557,000. The amount of money needed to complete UMAC-5 was increased from $125,000 to $277,000. The total cost to develop the new NC system was $280,000. R. H. Littlefield, Letter to C. R. Nixon, 7 April 1965, DOI, vol. 1784, file P8270-270/S18-10 pt. 1.

[128] Sperry Gyroscope Company of Canada Ltd., Proposal to the Department of Industry Concerning the Development of Numerical Control Systems, 7 April 1965, pp. 11-2. DOI's official request for approval from the Treasury Board reaffirms the Government's view that a cheaper NC technology was not only needed to promote Canadian defence production requirements, but that it was also an important step in meeting the Economic Council of Canada's call for ways to improve national productivity. Asssistant Deputy Minister (Department of Industry), Details of Request to the Honourable the Treasury Board, 18 June 1965, IC, vol. 1784, file P8270-270/S18-10 pt. 1.

[129] Assistant Secretary (Treasury Board), Letter to S. S. Reisman (Deputy Minister of the Department of Industry), 5 July 1965, IC, vol. 1784, file P8270-270/S18-10 pt. 1.

[130] The cost sharing agreement was dated retroactively to November 1964, when Sperry had made its first proposal.

[131] This entailed the computer's assembler language, all the needed subroutines, and the programming aids for debugging. The structure of the memory drum was also improved with the inclusion of "fast tracks," which helped to optimize the software. The assembler had one fundamental flaw. It was written in a non-standard language that ran on the commercial Bendix G20 computer. This choice was purely utilitarian. Located at the federal government's Meteorological Department at Dorval Airport, the computer was accessible and only ten minutes from the plant. However, over the course of writing the assembler, it became apparent that Fortran had become the language of choice in software development. With a Fortran compiler, UMAC-5 software development could be carried out on

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When the UMAC-5 was finally available, Sperry Canada found that its CNC innovation had priced itself out of the market. As the President of Sperry Canada, Wence King, recalled some twenty years later, "UMAC-5 was just not saleable." Only the most demanding point-to-point applications needing very complex machine tools could justify the high cost of UMAC-5.[132] This market turned out to be far smaller than Sperry Canada's over-optimistic estimates. About fifty UMAC-5s were sold in the United States, Europe, and Canada. In the United States, UMAC-5 was sold mainly to defence contractors, such as Boeing, Lucas, Rocketdyne and McDonnell Douglas. The precision demands for automated inspection machines, often requiring control in ten axes, offered another market for the expensive UMAC-5, particularly when the deep pockets of the United States Air Force underwrote the purchase of the costly equipment. In Canada, only a handful of machine shops bought UMAC-5, and these were the very large operations such as Rolls Royce, Orenda, and Westinghouse.

The company's strategy to design a computer-based NC system that would be "adaptable to any machine...any machine requirement" was an important technological achievement. But as a commercial product, CNC failed to give Sperry Canada the volume of civilian revenues it needed to diversify its business. The failure to anticipate fully the enormity of the software development required for UMAC-5, the initial inexperience of Sperry Canada's software team, and the mismatch between conflicting design goals and limitations in the available enabling technologies all contributed to this failure. By 1967, the burden of initial technical trade-offs in UMAC-5's design became onerous in the face of advances to basic computer hardware. Soon thereafter, Sperry Canada ceased selling UMAC-5s.

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any mainframe. After a competitive bid, Sperry Canada chose the Service Bureau Corporation, in Boston, over two Canadian firms to rewrite UMAC-5's assembler in Fortran IV.

[132] For example, Sperry Canada sold a number of UMAC-5s to Europe in which they were used to make side press frames for printing presses. This point-to-point application required that a lot of precise holes be bored in a very precise relationship to each other. The Burghardt boring machine used for this was fitted with over 160 different tools. *Burton Wencely King*, interview with this author, 18 February, Computer Oral History Project, National Museum of Science and Technology, Ottawa, Canada. The ability to program all the tool offsets into a computer made Sperry Canada's CNC approach quite advantageous.

A Retreat From CNC Back to NC: The Final Chapter of Sperry Canada

The Department of Industry's desire to fit technological change to what it perceived to be the needs of Canada secondary manufacturing helped push Sperry Canada out of computer numerical control (CNC) and back into numerical control (NC). The new NC system was called UMAC-6. From the viewpoint of computer history, UMAC-6 was a regression from a programmable solution back to a hardwired one. But from a business perspective, UMAC-6 seemed to have more market promise. Once again, Sperry Canada's capacity to carry out its engineering development and commercialization plans balanced precariously on the fate of the company's defence contracts.

Work on the design of UMAC-6 started in March 1966. The prototype was ready in two years.[133] Designed to work with a Brown & Sharpe machine tool, UMAC-6 was publicly demonstrated in May 1968 at a machine tool trade show in the United States. The new low cost, high performance, point-to-point UMAC-6, the latest integrated circuit technology, elicited considerable interest from machine tool manufacturers. Soon after the prototype was completed, Sperry Canada successfully negotiated with four prominent machine tool manufacturers to build pre-production versions for extensive testing.[134] If the trials proved successful, these machine tool manufacturers agreed to buy at least forty UMAC-6s by the end of 1968.[135] Optimism once again ran high: "The future of this program looks most promising," wrote Sperry Canada's Director of planning.[136] He added that, "with an unquestionably successful product technically, and in price, we are anticipating export sales approaching $10 million annually by Fiscal 1973." But serious financial difficulties lay just below the surface of this optimism.

Market forecasts had proven overly optimistic and the Canadian defence market was as unreliable a source of revenue as ever. Over the years, the company had exhausted all its surplus revenues; first in the pursuit of NC, then in its costly pioneering CNC, and finally in the development of UMAC-6. In 1968, the company's military equipment business had sunk so low

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[133] G. J. House, Notes on Sperry, 7 August 1968, IC, Accession 85-86/666, box 96, file P.8001-270/S.18 pt. 2.

[134] R. H. Littlefield (Director of Planing, Sperry Canada), Letter to J. R. Killick (Chief, Avionics & Electronic Data Processing, Department of Defence Production), 8 April 1968, IC, Accession 85-86/666, box 96, file P.8001-270/S.18 pt. 2.

[135] House, Notes on Sperry, 7 August 1968.

[136] Littlefield, Letter to Killick, 8 April 1968.

that the plant was running at less than 35 percent capacity.[137] Once again, Sperry Canada was plagued with the same cruel irony. To break away from its vulnerability to the uncertain Canadian military equipment market, Sperry Canada needed stable revenues from this very same market. With no profits, the company was unable to finance the development and construction of the four pre-production models it promised to make available to machine tool manufacturers for testing. Furthermore, even if the testing proved successful, as expected, the company did not have the resources to sustain the critical initial marketing and support of UMAC-6.

Desperate for military subsistence, Sperry Canada officials were "shocked" when the Government failed to consider it for the contract to build the Primary Display Units in the ASW/DS Systems, which were to be used as part of the Canadian Navy's SQS-5-5 Sonar System.[138] Having spent considerable money to develop this unit, Sperry Canada was angry that it was then denied the production contract. The revenues from the manufacture of the Primary Display Units were crucial to the future commercialization of the UMAC-6. Playing on DOI's financial involvement in UMAC-6 and the Department's commitment to accelerate the diffusion of NC in Canada, Sperry Canada threatened to drop out of UMAC-6 unless it was given the Primary Display Unit contract or offered other military production work to replace it.[139] But Sperry Canada got neither.

By the summer of 1968, Sperry Canada's financial situation was desperate. Plant loading was down to 25 percent.[140] Vainly searching for ways to use the plant's capacity, Sperry Canada's president, Wence King, tried to convince Univac's management to transfer some computer production to Canada. No doubt King argued that UMAC-5 had demonstrated that Sperry Canada could handle this production responsibility. DOI advised King that it "would be very willing to assist him in whatever way feasible to gain more manufacturing and R&D

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[137] D. B. Mundy, Draft of Memorandum to J. S. Glassford, 29 May, 1968, IC, Accession 85-86/666, box 96, file P.8001-270/S.18, pt. 2.

[138] Littlefield, Letter to Killick, 8 April 1968.

[139] To the Department of Defence Production, Sperry Canada wrote that the cancellation of the Primary Display Unit carried "grave implications as to the future of the Company....Despite our best efforts in search of business, we know of no other program to take its place. Without it or some alternative source of volume we would be operating below our breakeven point for factory operations. To add to this loss, the substantial investment required to insure success on the UMAC-6 program is cause for great concern. It is questionable whether as responsible management, we should proceed with UMAC-6 investment under these circumstances." Littlefield, Letter to Killick, April 8, 1968. p. 3

[140] House, Notes on Sperry, 7 August 1968.

responsibility from Univac in the United States."[141] How far King got in his discussions with Univac management is not known. In the end, however, nothing came of it. Given Sperry Rand's divisional corporate ethos and a Canadian tariff structure that made it cheaper for American firms to export entire computer systems to Canada than to build them there, King was grasping at straws.[142]

The extant records show quite clearly that, in its bid to raise development capital, Sperry Canada never sought help from Canada's banks. The fact that Ferranti-Canada also never approached banks strongly underscores the remarkable absence of Canada's banking institutions in meeting the capital needs of leading-edge industrial innovation throughout the 1945 to 1970 period. With no defence contracts forthcoming from the Canadian government and Canadian commercial banks not an option, King turned to the parent firm in desperation. He negotiated a loan to finance the four pre-production versions of UMAC-6. In such uncertain economic circumstances, borrowing money from the parent firm was a big gamble because Sperry Canada's autonomy was at risk if it defaulted on the loan.

In agreeing to the loan, did Sperry Rand executives have a hidden agenda in their dealings with their Canadian subsidiary? Only a few months after the loan was approved, Sperry Rand announced that it was closing down all its Canadian manufacturing operations and transferring UMAC-6 to its Vickers Division in Troy, Michigan.[143] Wence King was angered by the news. He had spent eighteen years of his life trying to build Sperry Canada into a truly Canadian operation. He resigned. P. Caden was sent in to shut down the operation and oversee the transfer of UMAC-6 to Vickers.[144]

Sperry Rand stated that $3 million would be needed to turn UMAC-6 into a profitable product. The parent firm argued that the Canadian operation did not have the cash flow to carry

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[141] R. A. Gordon, Memorandum To File: A Visit to Sperry, Montreal - May 8, 1968, 10 May 1968, IC, Accession 85-86/666, box 96, file P.8001-270/S.18 pt. 2.

[142] On the question of the impact of the tariff on the Canadian manufacture of computers see preceding chapter on Ferranti-Canada.

[143] E. A. McIntyre (Deputy Director of Electrical and Electronics Branch, Department of Industry), Memorandum to D.B. Mundy on Meeting with Sperry Officials, 8 August 1968, IC, Accession 85-86/666, box 96, file P.8001-270/S.18 pt. 2.

[144] The circumstances of King's resignation are still unclear. In his eighties, King currently lives in Montreal. Still bitter, he adamantly refuses to discuss these events. His only comment was that the leadership of Sperry Rand had changed for the worse during those years. This P. Caden, who came from the head office in New York, should not be confused with the Paul Caden, the engineer who designed the computer in UMAC-5. The primary sources do not reveal what the initial "P" in P. Caden stands for.

this out. Furthermore, the small Canadian market could not support UMAC-6's development. Sperry Rand also contended that locating UMAC-6 operations closer to the market was essential for a successful sales effort. Since the United States was the world's largest market, the Vickers Division was the natural choice.[145] There was one hitch: the terms of government funding, under which UMAC-5 and UMAC-6 were developed, forbade the transfer of design rights to foreign firms without governmental consent. Sperry Rand pressured the Canadian government to assign the design rights of UMAC-6 to Vickers quickly. If the company delayed too long in getting the UMAC-6 test versions to the machine tool builders, a commercial window of opportunity would close.

DOI officials were incensed that Sperry Rand wanted to move technology developed in Canada and paid for by public funds to the United States. DOI's support of Sperry Canada's CNC and NC development program had been one cornerstone of Canada's efforts to modernize its industrial infrastructure. At issue was not the loss of the public funds spent on Sperry Canada. Rather it was the disappearance of an indigenous technological capacity that had taken over ten years build up. If UMAC-6 were allowed to go to Vickers, the entire eighteen person team at Sperry Canada would be transferred to Troy, Michigan. The government was faced with two choices: to continue to subsidize the UMAC-6 project to keep it in Canada, or to find another Canadian company to take over UMAC-6.[146] As DOI tried to explore each option, it ran into a very unco-operative Sperry Rand. The American firm was determined to force an action in its favour. Sperry Rand had originally told DOI officials that it had seriously considered how to keep the UMAC-6 in Canada, but there was no realistic way to do it. However, after pressing the parent firm for details, DOI officials discovered that Sperry Rand had prevaricated. One senior DOI official concluded that Sperry Rand barely gave the option any thought.[147] The American parent firm was determined to shut down Sperry Canada without losing the UMAC-6 technological jewel.

In an effort to keep the technology in Canada, DOI proposed that Sperry Rand sell UMAC-6 to Honeywell Canada, who had expressed an interest in the UMAC-6 technology. The

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[145] J. Marshall, Letter to E. McIntyre (Deputy Director Electrical and Electronics Branch, Department of Industry), 7 October 1968, IC, Accession 85-86/666 box 96, file P.8001-270/S.18 pt. 2.

[146] E. A. McIntyre, Memorandum to D. B. Mundy (Assistant Deputy Minister, The Department of Industry), 4 September 1968, IC, Accession 85-86/666, Box, 96, file P.8001-270/S.18 pt. 2.

[147] *Ibid.*

Apparatus Controls Division of Honeywell, in Minneapolis, had been negotiating for over a year with the Nippon Electric Company (NEC) for the right to market the Japanese company's NC technology in the United States. But from Honeywell's perspective, NEC was demanding too much. As a fallback position, Honeywell contemplated developing its own NC expertise and product. Despite the superiority of the Japanese NC system, Honeywell felt that, if NEC refused to lower its price, then the Sperry Canada team and UMAC-6 technology could serve as the basis of its own product. Honeywell was willing to leave the NC development and production operation in Canada and access the American market through its Apparatus Controls Division in Minneapolis. However, before making any decisions, Honeywell wanted to study the engineering data for UMAC-6.[148]

When DOI tried to broker an arrangement between Sperry Rand and Honeywell, the former went to great lengths to discourage the arrangement. A meeting was held on 3 September 1968 between DOI, Sperry Rand, and Honeywell representatives. While Honeywell was serious in its desire to explore the possibilities of negotiating a co-operative take-over from Sperry Canada, P. Caden, from Sperry Rand, "threw up obstacles at every turn."[149] The meeting convinced DOI officials that Sperry Rand would have to be forced to keep UMAC-6 in Canada.

In a long letter to Sperry Rand, DOI argued that Sperry Rand's case to move UMAC-6 to the United States was flawed and based more on "corporate convenience than on economic necessity."[150] Under the terms of the cost sharing arrangement for the development of UMAC-5 and UMAC-6, design rights could not be transferred outside of Canada without the Government's approval. DOI served notice that there was no way it would release these rights. The choice given to Sperry Rand was clear: either negotiate in good faith to sell UMAC-6 technology to another company or stay in Canada. If it stayed in Canada, there were various financial assistance programs, suggested DOI, to support further work on NC product development.[151]

The rights over UMAC-6 were DOI's ace in the hole. Sperry Rand gave in to DOI's

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[148] R. A. Gordon, Memorandum to File: UMAC-6, 27 August 1968, IC, Accession 85-86/666, box 96, file P.8001-270/S.18 pt. 2.

[149] R. A. Gordon, Memorandum to File: Meeting with Sperry and Honeywell on September 3, 1968, 5 September 1968. E. A. McIntyre, Memorandum to D.B. Bundy: UMAC-6, 6 September 1968, IC, Accession 85-86/666, box 96, file P.8001-270/S.18 pt. 2.

[150] E. A. McIntyre, Letter to J. Marshall, 23 October 1968, IC, Accession 85-86/666, box 96, file P.8001-270/S.18 pt. 2.

[151] The programs cited were the Program for Advancement of Industrial Technology (PAIT), the Industrial Research and Development Incentives Act (IRDIA) and Industry Modernization for Defence Exports (IMDE).

pressure and agreed to keep UMAC-6 in Canada. As part of the arrangement, the Sperry Gyroscope Co. of Canada (Sperry Canada), after eighteen years of operation, was closed down. All the UMAC technology was transferred to a new Vickers UMAC Division that was to be set up in Pointe Claire, Quebec. Vickers planned to develop NC marketing, sales, and service facilities in existing offices in Cleveland, Detroit, Cincinnati, New York, Philadelphia, Milwaukee, Chicago, Seattle, and in its offices in Europe and Canada. The manufacture of the first production units of UMAC-6 began on 1 December 1968.[152] In the end, Sperry Rand decided that location of manufacturing could be profitably separated from the market. Based on the extant sources open to public scrutiny, one cannot assess the commercial success of UMAC-6 under Vickers tutelage. Even more important, without more extensive research, one cannot determine whether the Canadian operation maintained an active R&D program in digital electronic automation of machine tools, or whether such a program was transferred to one of the Vickers Division's American operations. While extremely important, such research takes the reader into the 1970s and 1980s and beyond the scope of this thesis.

Epilogue

In a special 1982 commemorative issue to mark the Golden Anniversary of the American Society of Manufacturing Engineers (ASME), *Manufacturing Engineering* celebrated how the United States had "built an industrial juggernaught such as the world had never seen."[153] This issue portrayed the United States as the stage upon which all the important postwar technological dramas in manufacturing were played out.[154] No doubt most Canadians concurred with this Americans self-assessment. However, when *Manufacturing Engineering* proclaimed that computer numerical control (CNC) was born in 1967, in the United States, J. E. Crozier felt it was time to pull out his Canadian flag.[155]

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[152] "Sperry Assigns NC to Vickers," *Financial Post*, 7 December 1968, 14.

[153] Daniel B. Dallas, "Industry At War," *Manufacturing Engineering* 88 (January 1982): 79-119, 79.

[154] See the articles Gary Vasilash and Glenn Hartwig, "The Boom Begins: 1946-1950," *Ibid.*, 119-140; and Gary Vasilash, "The Advent of Numerical Control," *Ibid.*, 143-172.

[155] The Strippit Division of Houdaille Industries Inc., of Akron New York, explained Hartwig, "started out just trying to bring the flexibility of digital computing to machine controls." But in the end, Hartwig added, the company

(continued...)

Crozier, then Vice-President and General Manager of the Canadian Institute of Metalworking, informed the journal that CNC's parentage was Canadian and not American. Sperry Canada, Crozier wrote, had designed and commercialized this pivotal technology in the early 1960s. Daniel Dallas, the Editor-in-Chief, was sceptical.[156] Dallas conceded that Sperry Canada was in 1963 among the first to conceptualize CNC. "But," he added, "it is also my understanding that their system did not work, and that modern CNC came into being via a different evolutionary route."[157]

Crozier's response was unequivocal: "The development work took place between 1961 and 1963 and resulted in the Sperry UMAC-5 computer numerical control system. I know this to be a fact," emphasized Crozier, "because I spent three long years in the project as a field engineer and initially on the computer design interface team."[158] Crozier's assertion that fifty UMAC-5 systems had been sold by 1968 stood as a blatant contradiction to Hartwig's contention that CNC first "began to move from the [Strippit] laboratory to the production floor" in 1968.[159] After some further study, Dallas apologized "that the Golden Anniversary issue did not correctly identify the originators of this technology."[160] Dallas tempered this retraction, by adding that his research was unable "to find any documentation better than [Crozier's] letter concerning CNC's true origin."[161]

(...continued)
"wound up creating an entire new field, computer numerical control, or CNC." Glenn Hartwig, "Electronic Control Moves Into Ascendancy," *Manufacturing Engineering* 88 (January 1982): 181-202.

[156] Ted Crozier, Memorandum to Dan Dallas, 13 October 1982. Copies of this memorandum and other letters between Crozier and Dallas were made available to me by Jack Scrimgeour, who was a Senior Advisor for Advanced Manufacturing Technologies and Industrial Automation, at the National Research Council. Crozier had sent Scrimgeour a copies of all the correspondence. At the time, Scrimgeour was responsible for a small newsletter called *CAD/CAM and Canada*. Henceforth, this source will be called Scrimgeour.

[157] Daniel Dallas, Letter to J. E. Crozier, 21 October 1982, Scrimgeour.

[158] J. E. Crozier, Letter to Daniel Dallas, 29 October 1982, Scrimgeour.

[159] Hartwig, "Electronic Control Moves Into Ascendancy, 1960-69," 199.

[160] Daniel Dallas, Letter to J. E. Crozier, 5 November 1982, Scrimgeour.

[161] *Ibid.* A retraction was never printed in *Manufacturing Engineering*. Given all the coverage that UMAC-5 received in the trade literature, Dallas's inability to find evidence of Sperry Canada's achievements in the historical record is quite surprising. Another erroneous version of events assigns the development of UMAC-5 to the Univac division of Sperry Rand. Recounting the historical roots of machine tool control, two professors from Carnegie Mellon University wrote: "The first general-purpose apparatus to record the signals magnetically and play them back to control the motions of a mechanical device seems to have been invented by George Devol in 1946 (U.S. patent 2,590,091, issued in 1952). This patent was first licensed by Remington Rand for use in connection with the Univac computer but was found to be too slow for the purpose, and rights were returned to Devol. Later, Remington-Rand did develop and market the UMAC general-purpose process controller in 1964. UMAC was not itself a great success, but general purpose controllers later became widespread in industry." Robert Ayres and Steven Miller, *Robotics:*
(continued...)

Though important in fostering national pride, the historical importance of the UMAC-5 story does not lie in who really developed CNC first. Rather, the Sperry Canada narrative offers yet another much needed case study of how Canada tried to jump onto the postwar digital electronic and computer innovation wave.

Sperry Canada's autonomy first arose from Canada's flirtation with military self-reliance. Canada's efforts to promote local sourcing of military equipment led to Sperry Canada's manufacturing mandate. Any thought, on the part of Canadian management, to the necessity of an in-house R&D program lay dormant under the large volume of Korean War defence procurement of parent firm technology. Sperry Canada's pursuit of a design mandate was provoked by the need to diversify after the collapse of Canadian military self-reliance. Building a business on NC and CNC represented an opportunity to overcome its vulnerability to an unpredictable defence market. However, the Canadian subsidiary could only succeed in this quest because of the policy of corporate decentralization and divisionalization engendered by the merger of the Sperry Corporation with Remington Rand. Product-based divisionalization was supported by decentralized research and development. Sperry Canada's autonomy lay in staking out a product line not already claimed by one of the other divisions. The ensuing autonomy offered an outlet for the corporate and technological ambitions for Sperry Canada's management and engineers.

By the 1960s, Sperry Canada had jumped from the stereotypical branch plant manufacturer to being a centre of innovation of global stature. In the process, the Canadian subsidiary created its own R&D agenda and aggressively tried to shape its own global product mandate. In asserting its own technological and corporate raison d'être within the empire of its American parent firm, Sperry Rand, the Sperry Canada Limited ventured into the unchartered waters of computer numerical control technology. The result was the Universal Multi-Axis Control Mark 5 (UMAC-5), described by Sperry Canada as "the most powerful production tool ever developed for point-to-point automation." Sperry Canada's efforts to embed a real-time programmable computer in machine tools was a harbinger of the profound transformation that the computer would have on the industrialized world's forces of production.

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Applications & Social Implications (Cambridge, Massachusetts: Ballinger Publishing Company, 1983), 20.

Chapter 8

Conclusion: The Importance of Keeping Busy

In the decades immediately following World War II, a new constellation of technologies and industries emerged as powerful engines of global economic development. A century and a half after the Industrial Revolution, digital electronic innovations were about to herald in the Post-Industrial, or Information Revolution. "Just as in the previous era," write Peter Hall and Paschal Preston, "automobiles and electrical machinery had determined the course of high technology economic growth and the relative fortunes of the major economic powers, so now the laurel would pass to the nation that proved the most effective in bringing electronic information systems to the market place."[1] In 1950, it was not clear which nation, if any, would come to dominate the future technical development and commercialization of the still nascent digital electronic paradigm. The United States, Great Britain, and even war-torn Germany all had the pre-requisite scientific and technical skills to push ahead in digital electronic-based information technologies. But by the 1970s, the United States had become the pre-eminent technical and industrial leader in all things digital electronic. A large internal market, driven first by heavy defence spending and then reinforced by a prosperous civilian sector, contributed considerably to the United States' ability to win global dominance in digital electronic technology from 1945 to 1970.[2] While Europe's major industrialized nations struggled, in the wake of the American technological and economic juggernaught, to create some semblance of a domestic digital electronic industry, Japan loomed unexpectedly on the horizon as the principal rival to American technological and industrial hegemony. Though Japan did not have a military-industrial complex to kick-start its computer industry, protectionist policies allowed its large internal market to reinforce the domestic, state-sponsored appropriation of technology transfer.

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[1] Peter Hall and Paschal Preston, *The Carrier Wave: New Information Technology and the Geography of Innovation, 1846-2003* (London: Unwin Hyman, 1988), 166.

[2] After military enterprise, the U.S. civilian space program also played an important role in sustaining the growth of that country's digital electronic industry.

In the midst of this international scramble to jump on this rising global innovation wave, where was Canada? From a macro-economic perspective, Canada was poised at the end of World War II to get a jump start in the race to profit from the nascent digital electronic paradigm. After all, while most of the industrialized economies lay in ruins, Canada's economy and infrastructure, along with the United States', remained unscathed. In fact, Canada came out of the war with a larger and more vigorous industrial economy than it had before the war. This initial advantage, however, was offset by the absence of any industrial tradition of scientific research and experimental development, a weakness that was particularly acute in the areas needed for digital electronic innovation. The six case studies presented in this thesis offer the first fine-grained view of Canada's participation in the fourth innovation wave. The salient features of Canada's ascent of the digital electronic learning curve were the unprecedented role of the military enterprise in the creation of a peacetime pool of scientific and technical skills in industry and government defence laboratories; the smaller, sometimes erratic, but nevertheless important role of civilian public enterprise in nurturing industrial learning after the military's retreat; and the surprising contribution of branch plants to fostering indigenous technical knowledge accumulation and skill acquisition at the very frontiers of technical change. In many instances this newly created pool of technical expertise, in its design decisions, refracted the global innovation wave through the Canadian context. Each of these features will now be elaborated upon in the concluding sections of this narrative.

Military Enterprise Accelerates Canada's Jump to the Fourth Wave

Without a doubt, military enterprise was the primary force behind Canada's early participation in the digital electronic revolution. "Military enterprise," according to Merrit Roe Smith, "refers to a broad range of activities through which armed forces have promoted, co-ordinated, and directed technological change and have thereby, sometimes directly and sometimes indirectly, affected the course of modern industry."[3] While American historiography is replete with studies of the role of the military from the earliest days of the Republic in the process of peacetime technological and industrial development, Canadian historians have devoted

[3] Merritt Roe Smith, "Introduction," in Smith, *Military Enterprise and Technological Change*, 1.

little, if any, attention to this line of enquiry. Is this lacuna Canada's national historiography simply an indication of the absence of anything of importance to write about? Has there ever been a Canadian peacetime "military enterprise" that matches Smith's sense of the term? This narrative has shown that military enterprise did indeed play a crucial and sizable role in shaping the direction and rhythm of technological change in Canada from 1945 to about 1958.

This thesis adds more substance to Keith Krauss's assertion that from 1945 to 1958 Canada "flirted" with military "self-reliance." In fact, one could say that it was an historically unprecedented "flirtation." The problem with Krauss's assertion, however, was the dearth of evidence to support it. Except for studies of the AVRO Arrow, and to a lesser degree of the Mid-Canada and Dew Lines, the Canadian historical literature contains few details about the impact of the military's quest for self-reliance on the content and rhythm of Canadian peacetime technological development. This narrative has provided a richer portrait of this process. By linking national defence with national welfare and sovereignty, Canadian military enterprise greatly accelerated Canada's movement up the digital electronic learning curve. Through its collaboration with academia, direct support of industrial, experimental development, and the creation of in-house research and development facilities, military enterprise fostered creation of a national capacity to design and manufacture products within the fourth innovation wave many years earlier than otherwise would have been the case.

The systematic exploitation of science for modern warfare, which started in World War II and grew in intensity after the war's end, called for an ever increasing capacity to carry out high-speed, large-scale computations. By 1948, it had become clear to the more technically-oriented elements of Canada's military that the absence of advanced computational facilities doomed any national effort to carve out some semblance of a self-reliant, weapons development program within the overall North Atlantic Triangle alliance. First with UTEC and then with the purchase of FERUT, the military's desire to secure a domestic access to computational power was the driving force behind the creation of Canada's first computer science research facility and high-speed computation centre at the University of Toronto.[4] Although the purchase of FERUT precipitated the collapse of electronic computer design at the University, it nevertheless gave Canada a valuable head start in the growth of a national competence in high-speed computation

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[4] The national strategic importance of automated computation was bolstered by Canada's ambitions to be a postwar pioneer in the development of nuclear energy.

techniques and, even more important, it gave Canada an earlier start up the software design learning curve.[5] For nearly five years, FERUT served as a public training ground for academics, students, and people from industry and the military. The military's sponsorship of academic computation centres did not end with the University of Toronto. The need to meet the computational needs of its geographically dispersed laboratories also led Canadian military enterprise during the 1950s to subsidize the creation of computation centres in other universities such as the University of British Columbia.

Through its early support of computation centres at the universities, the military again fostered the dissemination of digital electronic technology. During the 1950s, in its educational program, research, and interaction with industry, the University of Toronto helped forge a whole generation of expertise in computer science. In the case of the University of British Columbia (U.B.C.), military assistance allowed this institution to develop into an oasis of software know-how in a region far removed from the eastern centre of Canada's digital electronic activity. In the years that followed, U.B.C.'s computer department nourished the growth of a high-tech sector in the Vancouver. During the late 1970s and early 1980s, U.B.C.'s programming talent nourished the growth of software-based companies such as MacDonald Dettwiler and Associates, the Sydney Development Corporation, and the Basic Software Group.[6]

Despite its cancellation, the UTEC project contributed to moving Canada up the learning curve by fostering the early formation of technical expertise that became the first nodes in an ever widening network of know-how. The hardware design team of Ratz, Kates, Casciato, and Johnston subsequently formed part of the nucleus of Canada's first generation of computer engineers. While the latter three failed in their initial attempt to establish a computer manufacturing business, they nevertheless became an important source of know-how to the private and public sectors looking to jump to the fourth innovation wave. Kates, Casciato and Johnston, for example, advised Trans-Canada Air Lines on the engineering feasibility of a computerized reservation system. They interacted with manufacturing companies such as Ferranti-Canada and users such as the federal government. Kates and Casciato later went on to form a well known computer engineering firm called KCS Limited, which designed and implemented the world's first computerized road traffic control system in Toronto.

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[5] Even if the design and construction of a full-scale version of UTEC had proceeded, it is unlikely that an operational computer would have been ready in under two years.

[6] Thomas, *Knights of the New Technology*.

The purchase of FERUT signalled the end of the military's interest in designing computers for scientific computations, but it did not diminish the strategic importance of designing modern weapon systems around the nascent digital electronic paradigm. The Royal Canadian Navy's (RCN) pursuit of DATAR reflected a new vision of an automated "battlefield" dependent on high-speed information processing and communications. The RCN's very costly Naval Battle Simulator (mentioned in this thesis but not examined) was further evidence of the importance the RCN placed on the digital electronic paradigm. Not only could digital electronics be used to wage war, but it could also be used to train Canadians for war.[7]

The dream of military self-reliance, through the mediation of technology, led the RCN to invest heavily in forging a core of Canadian research, development, prototyping and production engineering capacity. In seeking to elevate its role within the North Atlantic Triangle, the RCN sponsored Canada's first industrial competence in digital electronic design and manufacture: Ferranti-Canada and Computing Devices of Canada. While the former built DATAR, the latter worked on the Simulator. While Ferranti-Canada tried to move its DATAR experience into the civilian sector, Computing Devices kept its focus on the military sector.[8] As a result, while both companies started out as being good candidates to create an indigenous computer industry, by the end of the 1950s, Ferranti-Canada represented Canada's only hope in this realm.

Success in the design of sophisticated computational systems also depended on the transistor. Without the capacity to miniaturize, the growing weight of electronic circuit complexity would have crushed any attempt at self-reliance in the design of advanced weapons systems. As a result, the ability to manufacture, and design with, high-performance transistors became crucial issues for all members of the North Atlantic Triangle in the mid-1950s. In the case of Canada, the constraints of a small and open economy set limits to the self-reliance the military could pursue in the area of miniaturization. Canadian military enterprise flirted with the idea of promoting an indigenous source of transistors, but it could never ensure a sufficiently high level of procurement to stimulate any domestic R&D or production, branch plant or not.

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[7] The most intense work in real-time computer simulators was for combat aircraft. In fact, the term man/machine interface first arose in the context of the U.S. Navy's research into flight simulators. While Computer Devices failed to go further with computer simulation, the Canadian Aviation Electronics Co. (CAE) turned its early work in this area, which was also supported by the Canadian military enterprise, into a thriving international business in flight simulators for both civilian and military applications.

[8] An American firm, Control Data Corporation, one of the world's leading manufacturers of mainframe computers, later bought Computing Devices of Canada.

However, while the creation of a domestic expertise in transistor manufacture proved impossible, Canadian military enterprise did consciously invest in expanding the nation's capacity to do innovative circuit design work within the semiconductor medium. The Defence Research Telecommunications Establishment's (DRTE) digital transistor work not only served as pole of innovation diffusion to the defence industry, it also contributed to the increased scientific and engineering capacity of the State to be a direct agent of ground-breaking technological change, such as Canada's space program.

In the early 1950s Canada became, after the United States and the former Soviet Union, the third nation in the world to design, build, and deploy an artificial satellite in space. Behind the guise of civilian government scientific research, the impetus to embark on a space program was Canadian military enterprise.[9] Concern over secure and reliable communications across Canada's northern flank led to DRTE intensive study of the behaviour of the ionospheric in high latitudes.[10] The Alouette I satellite provided invaluable scientific data. While the Alouette project involved the entire DRTE, it was the silicon, transistor-circuit research program that helped create the in-house, miniaturization know-how needed to build the satellite. Canada's subsequent satellite design program, from Alouette II, ISIS I and II, through the Hermes program, Radarsat, and MSAT, all drew on the human expertise first nurtured by military enterprise at DRTE in the 1950s. On the industrial front, the influence of DRTE extended up through the 1980s. According to a study carried out by Denzil Doyle, the existence of DRTE influenced the creation of over thirty-two high-tech electronics firms in Canada.[11]

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[9] Dr. John Chapman, who had been with DRTE since its inception and later became the first Assistant Deputy Minister of Space Programs, was quite clear on the military dimension of the Alouette I project. "The Alouette program was begun, "Chapman later recounted in 1966, "in an attempt to generate a Canadian program which would give some experience in space technology to DRB [Defence Research Board], in anticipation of the ultimate military importance of satellites. At the time," Chapman went on to explain, "there was little immediate hope of developing a direct Canadian requirement for a satellite system which would justify a military project. It was therefore necessary to seek a scientific objective that was consistent with DRTE skills and experience. A study of the high ionosphere had obvious applications both to communications and to the ICBM [Intercontinental Ballistic Missiles]." John Chapman, The Alouette - ISIS Program, Chapman Papers, vol. 12, file 13.

[10] Long-distance radio communications, beyond line of sight, used the ionosphere as a reflective medium. Solar storms, which consist of highly energetic charged particles, wreak havoc with the ionosphere. The disturbances are most pronounced in the far North because the charged particles funnelled in by the Earth's magnetic field. Another concern was the effect of nuclear detonations on the radio communication properties of the ionosphere.

[11] When the American firm Digital Equipment Corporation (DEC, also known as Digital), which had pioneered the minicomputer concept, set up operations in Canada it named Denzil Doyle as the first President. This study was carried out after he had retired from the company. Denzil Doyle, *The Communications Research Centre: its contribution to the Canadian economy during the past twenty-five years, and some recommendations for the future*

(continued...)

The importance of military enterprise to the history of Canadian technology during the 1945-58 period does not reside in the success or failure of particular projects such as UTEC, DATAR, and the DRTE computer. Rather it lies in the military's role in channelling investment into high-risk R&D that otherwise would have had little chance of finding support within an economy dominated by the export of natural resources. The military accelerated the creation of a vitally important pool of skilled scientists and engineers who kept Canada within reach of rapidly advancing technological frontiers. Throughout the early stages of the digital electronic revolution, it was the "visible hand" of Canadian military enterprise that incited and boosted companies such as Ferranti-Canada, Computing Devices of Canada, Canadian Aviation Electronics (CAE), RCA Victor, and Canadian Marconi up the digital electronic learning curve.

To underscore the Canadian military's important role in the production and dissemination of digital electronic know-how, it is useful to consider the contrasting case of Australia. The initial political will to support the design and construction of Australia's first electronic, digital computer came from the preoccupations of a staple economy, and not from the computational imperatives of advanced weapons development.[12] Like Canada, Australia is a vast, but sparsely populated land with a small domestic market where the export of primary natural resources has dominated economic development. Since half of the Australian land mass is a hot desert and much of the other half is arid savanna, the availability of water has been of utmost importance to Australia's agriculturally-dominated export economy. In 1947, scientists within Australia's Council of Scientific and Industrial Research (CSIR) toyed with the idea of developing methods to induce and control rainfall. Radar, developed during the war, provided the powerful new tool with which to probe the physics of cloud and rain formation. But, in order to carry out this line of investigation effectively, considerable computational power was needed to model and analyse the microwave propagation data.

By the end of 1947, Trevor Pearcy, who had considerable experience on large scale

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(...continued)
(Ottawa: Doyletech Corp., November 1987). Doyle, who founded DEC Canada, has been an important voice in high-tech policy issues. This report was based on surveys he carried out across much of the electronics industry. As soon as the Department of Communications was created in 1969, it set about trying to transfer as much of DRTE's military electronics and communications expertise to the civilian sector. To carry this out, the Department of Communications created the Communications Research Centre (CRC). CRC staff were all drawn from DRTE. See also Doyle's most recent schematic of the genealogy of Ottawa's high-tech sector, sometimes referred to as "Silicon Valley North," which appeared in a full page spread in the newspaper *The Ottawa Citizen*, Wednesday, 1 May 1, 1996, A11.

[12] See Trevor Pearcy, "Australia Enters the Computer Age," in *Computing in Australia: The Development of a Profession*, ed. J. M. Bennett et al. (Sydney, Australian Computer Society, 1994), 15-30.

computational issues while working on the wartime development of radar in the United Kingdom, convinced CSIR to fund the engineering development of an electronic digital computer of his own design.[13] By the end of 1949, Pearcy and his team of engineers at CSIR's Radiophysics Division had built the Mark I, Australia's first computer, and performed crude programming tests on it. A year later, the Mark I was finally working more or less reliably. Not animated by any military fascination with performance, as was the case with the University of Toronto UTEC project, the MARK I was of humbler design. The machine was serial rather than parallel; simpler delay lines were used instead of electrostatic memory; and there were no attempts to pioneer vacuum-tube miniaturization. Instead, the Mark I was a practical, cost-effective solution to an immediate computational need.

After its initial funding of the Mark I's development, CSIR's enthusiasm for computer engineering quickly waned, and in 1954, it pulled the plug on all further computer design work. For an institution whose R&D ethos revolved around the needs of the nation's natural resource industries, the still nascent field of digital electronics held little interest.[14] The computer development at CSIR's Division of Radiophysics thus became an isolated occurrence within the Australian technological landscape. There is no evidence to suggest that Australia's military ever seriously pursued a policy of national technological self-reliance during the 1950s.[15] As a result,

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[13] Pearcy obtained his B.Sc. from Imperial College, London, in 1940. He stopped his graduate studies to go off and work on the radar project where he concerned himself with the program's large-scale computational demands. After the war's end, he immigrated to Australia to join the CSIR. In 1980 he was elected as a Fellow of the Australian Academy of Technological Science and, in 1985, he retired as Dean of Engineering at Caufield Institute of Technology.

[14] "CSIR's management," wrote Pearcy in 1994, "discounted the valuable expertise so early in the development from the Mark I project. Clearly, the executive's belief that Australia's main interests lay with her primary industries was a deciding factor in the eventual termination of computing at [CSIR in 1954]." Pearcy, "Australia Enters the Computer Age," 30.

[15] The one area where Australian military tried to establish a technological expertise was in the development of instrumentation for gathering data in long-range missile testing. Because of its vast, relatively flat, and unpopulated desert areas, Australia became an important testing ground for British long-range missile technology after World War II. Because of the need to process the large amounts data generated during a missile test, the Australian military proposed, in 1950, the development of its own "Long Range Weapons Digital Automatic Computer." The proposal never got to the development stage because the British members on the Joint Project Board, the group that oversaw the British-Australian testing programming, argued that there were British firms that could provide "off-the-shelf" equipment to do the job. Seven years later, in 1957, the British made Elliot Bros. computer was installed at Australia's Weapons Research Establishment. "The Weapons Research Establishment Digital Automatic Computer (WREDAC), as the [British made machine] was known, never reached the reliability hoped for, despite all the engineers could do for it...It was replaced in 1960 by an IBM 7090 transistor machine." George Barlow, "Electronic Digital Computers in Australian Defence," in Bennet et. al., *Computing in Australian*, 123. Like the Weapons Research Establishment (WRE), DRTE also decided to buy IBM to handle the growing amount of data it was processing. But unlike WRE, DRTE had not only aggressively sought to advance Canada's ability to design digital

(continued...)

there were no deep pockets in Australia to counter the investment logic of a staples export economy, and to divert resources to creating of a national capacity to manufacture, adapt, and design along the fourth innovation wave.[16]

Clearly, Canadian military enterprise pushed Canada earlier and faster up the digital electronic learning curve than was the case in Australia. While the University of Toronto had, with FERUT, become a important pole of technology diffusion in 1952, a computer did not appear in an Australian university until 1956. During the 1950s, Australia did not have military-sponsored industrial and governmental facilities, such as those at Ferranti-Canada, Computing Devices of Canada, Canadian Marconi, RCA Victor, CAE, Sperry Canada, and DRTE pursuing sophisticated research, experimental development, prototyping, testing, and production engineering in a broad range of digital electronic technologies. Did Canada's earlier and faster move up the digital innovation wave give decided long-term benefits over Australia? An initial, cursory look at the evidence suggests that it did.[17] However, a far more detailed comparative study is needed to test this conclusion.

The evidence in this thesis thus adds considerable weight to sociologist Gordon Laxer's speculation that Canada was slow to develop a diversified industrial economy before 1945 because it lacked a strong peacetime military. The case studies presented in this thesis suggest that military enterprise, within the limitations of Canada's small economy and close proximity to

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(...continued)
electronic circuitry around silicon transistors, it also designed the sophisticated satellites whose top-sounding data the IBM machine processed. WRE's purpose remained a place to test British technology.

[16] E. T. Robinson, who has had forty years of experience in the Australian computer scene and is currently advisor on information technologies to the Australia's Minister of Industry, Technology, and Commerce, is emphatic about the absence of any government support, during the 1950s, to move Australia up the digital electronic leaning curve. E. T. Robinson, "Government's Participation in the Australian Computer Industry," in Bennet et. al., *Computing in Australian*, 59-65.

[17] Any lasting benefits from the pool of skilled scientists and engineers spawned by military enterprise during the 1950s, would take at several decades to take root. Throughout the 1960s, 1970s, and 1980s, and into the 1990s, the economic activity surrounding digital electronic activity was far greater in Canada than in Australia, even if one factors in differences in population. For example, from 1989 to 1993, Canada imported nearly 250 percent more Automatic Data Processing Equipment than Australia. This attests to the much higher diffusion of digital electronic technology into the Canadian economy. At the same time, Canada exported 750 percent more Automatic Data Processing Equipment than did Australia. Of course, to calculate the total economic activity one needs statistics on the domestic production of each country. Without any easy access to Australian data, this author cannot make any comparisons. Nevertheless, one can confidently conjecture that Canada's domestic production will also be much higher. For import/export data see *Annual International Trade Statistics, Vol II*, (Paris: United Nations) under Commodity SITC Number 752, for the years in question. Similar disparities in economic activity associated with Telecommunications Equipment (SITC 764) reinforces the conclusion of Canada's greater appropriation of digital electronic technology.

the American empire, systematically tried to promote a national industrial competence in the constellation of technologies that would contribute mightily to post-1945 economic success. The flirtation with military self-reliance, according to Krauss, ended in the closing years of the 1950s.[18] Yet despite the collapse, Canada retained a core of sophisticated, technology-driven engineering firms.

As the Canadian military enterprise's financial resources for experimental engineering development decreased, the Canadian firms highlighted in this thesis showed remarkable ingenuity in trying to sustain the knowledge, experience, and skills acquired under military patronage. They aggressively shifted the focus of their product development to the civilian sector. However, the civilian departments of government failed to use their full power of procurement to reinforce the commercial viability of industrial R&D in digital electronics. Even so, on those occasions when public enterprise investment actually became available it made an important contribution to the knowledge accumulation of the engineering firms. Meanwhile, the corporate commitment effort to nurture a strong in-house technical expertise in leading-edge experimental engineering belies the usual stereotype of Canadian branch plants as the passive or parasitic entities that nationalist, political economists devised in the 1970s and the 1980s. The branch plant profile that emerges from studying the postwar, digital electronic industry in Canada is, as the final pages will argue, one of fierce local pride, independent initiative, daring product innovation ambitions, and high managerial risk-taking.

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[18] For Krauss, the signing of the Defence Production Sharing Agreement with the U.S. was a defining moment in Canada's retreat from self-reliance. This view is reinforced by Ernie Regehr, *Arms Canada: The Deadly Business of Military Exports* (Toronto: James Lorimer & Company, 1987). From a different perspective, Granatstein also underscored the accelerated continentalization of Canadian defence during the post 1958 era, which he labelled the "Defence Debacle." Granatstein, *Canada 1957-1967: The Years of Uncertainty and Innovation.*

The Branch Plant as a Schumpeterian Player

The development of electronic data processing (EDP) equipment at Ferranti-Canada and of digital electronic machine tool automation at Sperry Canada suggests a Schumpeterian vitality to the behaviour of foreign-owned branch plants that nationalist historians have greatly underestimated. Both subsidiaries showed a fiercely independent ambition to carve out a business niche in the fourth wave based on indigenously cultivated expertise. After the collapse of the Korean War boom in defence spending, Ferranti-Canada set out to convert its DATAR experience into a commercial line of products. Sperry Canada, on the other hand, had no experience in digital electronics when it entered the field of machine tool automation. The pursuit of a self-reliant, sophisticated R&D program characterized both these subsidiaries' business approach to the opportunities offered by the fourth wave. While one wanted to be Canada's leading computer manufacturer, the other wanted to be a global player in digital electronic, automated machine tools. Neither Ferranti-Canada nor Sperry Canada were composed of the "terrified little men that nationalist J. J. Brown claimed populated Canadian industrial culture during the entire century surveyed by his 1967 history of Canadian technology.[19] Neither did the existence of foreign-owned branch plants in Canada preclude Schumpeterian corporate, behaviour, despite Kari Levitt's claims to the contrary in her oft-cited 1970 book.

Ferranti-Canada's and Sperry Canada's experiences reveal that the relationship between the nationality of capital investment and Canada's industrial capacity to design and manufacture within a global innovation wave was far more nuanced than the black-and-white "de-industrialization" thesis raised by the nationalist discourse, in which foreign owned branch plants have been identified as the agents of technological dependency. To be sure, one could argue that Ferranti-Canada was an isolated case and that, as a British-owned firm operating under what Alfred Chandler called a personal capitalism regime, this company does not directly contradict the nationalist argument that the domination of the Canadian economy by American-owned subsidiaries "arrested" Canadian development. But the story of Sperry Canada is more difficult to explain, for it showed that an American-owned branch plant, running according to managerial capitalist principles, could and did act as an agent of radical product innovation with its own

[19] Brown, *Ideas in Exile*, 340.

ambitious business agenda.

At the time, both these subsidiaries represented Canada's best hopes to produce an indigenous capacity to design and manufacture EDP equipment and machine-tool automation technology. Their foreign parent firms did not exercise any iron grip over the capacity of these two subsidiaries to define and pursue their own R&D programs. Rather than a tale of passive dependency, the history of these firms underscores the determined efforts of Canadian management and engineers to assert their own technological vision and product agenda.[20] In both cases, the subsidiary's autonomy to define, create, and sustain its own advanced digital electronic product development program resulted from a technology-driven corporate culture and a rather decentralized organizational structure that tended to be defined along geographic and product lines. Like their parent firms, both subsidiaries looked to radical technical innovation as the key to commercial success. Sperry Rand was a kind of federation of technology and product mandates; the Ferranti organization behaved like a collection of trading houses, each with its technological niche. As long as Sperry Canada and Ferranti-Canada did not lose much money, their parent organizations left them alone. To understand Sperry Canada's failure to turn its computer numerical control (CNC) innovation into a long-term business and Ferranti-Canada's inability to create a profitable business out of designing and building general-purpose computers, one must look to the inherent uncertainties in leading-edge experimental development, the realities of the market, the dilemma of capital formation, and the reluctance of civilian government to move quickly and aggressively to support an indigenous commercial niche in digital electronics. In the case of Sperry Rand, one might add David Noble's findings that victory in automated machine tools went to firms with the best backing from "American" military enterprise.

Both subsidiaries had difficulties finding the financial resources to sustain their Schumpeterian ambitions. Sperry Canada had entered the nascent machine-tool automation business as a way to reduce its dependence on military contracts. However, its entire numerical control (NC) and CNC development program was constantly compromised by under funding. Paradoxically, the very vulnerability to shrinking defence contracts from which Sperry Canada wanted to escape continually crippled its ability to diversify into the civilian sector. Ferranti-

[20] Graham Taylor's study of Canadian Industries Limited (CIL) reveals similar findings. Graham Taylor, "Management Relations in a Multinational Enterprise: The Case of Canadian Industries Ltd., 1928-48," *Business History Review* LV (no. 3 1981): 337-58.

Canada, on the other hand, until 1964, was able to sustain much of its digital electronic R&D through its opportunistic exploitation of public enterprise initiatives. Each of the one-off digital electronic systems developed for the Canadian Post Office, Trans-Canada Air Lines, and the Federal Reserve Bank of New York allowed Ferranti-Canada to build incrementally on its DATAR experience and thus develop the needed design and manufacturing expertise required to move into the general purpose computer field. While designing the FP6000 marked an important accomplishment for the company, marketing the computer posed an even greater and far costlier challenge. Competing in a business dominated by IBM required far more money than Ferranti-Canada could raise.

For both Ferranti-Canada and Sperry Canada, along with the freedom to formulate and pursue aggressive R&D program came the crushing burden of self-financing. Though the Canadian government recognized that these two companies were its only hope to establish an indigenous hardware industry in electronic data-processing equipment and machine-tool automation technology, its financial support was timid and tardy. The federal government never really appreciated the fact that Sperry Canada and Ferranti-Canada, though subsidiaries of large foreign firms, essentially functioned as small Canadian companies with their own R&D programs and business strategies, with a consequent, desperate need for investment support from it. Certainly, Canadian banks offered no alternative support. After several years of exhaustive exploration through all the primary resource material available, this author was struck by the conspicuous absence of any reference to banks playing any role whatsoever in financing these companies' R&D, product development, or commercialization plans. The absence in the historical evidence of even the slightest hint that these two companies ever approached the banks or even contemplated approaching them seems to reinforce the nationalist argument that banks have been an obstacle to the emergence of a diversified and sophisticated industrial sector.[21]

Sperry Canada's failure to turn UMAC-5 into a successful CNC business had less to do with its existence as a subsidiary and more to do with the uncertainties associated with any high-risk technological gamble and the Canadian government's reluctance to act aggressively in support of the company's ambitions. Though there was some inter-divisional rivalry within Sperry Rand over the right to develop and commercialize NC, the parent firm was supportive of its Canadian

[21] For a nationalist critique of the role of banks in Canadian industrial development see Tom Naylor, *The History of Canadian Business, 1867-1914*, 2 vols. (Toronto: James Lorimer & Company, 1975).

subsidiary's overall product-development strategy.[22] In adopting the novel strategy of using a programmable computer to breath new flexibility into digitally-based, machine-tool automation, Sperry Canada never imagined that the development of software for the real-time control would lead them into a technical minefield. While applauding Sperry Canada's pioneering work, the Department of Industry declined to help the company stay in the vanguard of CNC. Its refusal, which had little to do with any assessment of Sperry Canada's capability to resolve future technological uncertainties, stemmed from the Government's desire to use the company's unique Canadian expertise as a vehicle to promote the modernization of Canada's metal-working industry. But even when Sperry Canada turned back to develop the simpler and less costly UMAC-6 system for the Canadian metal-working industry, the Government was unwilling to move aggressively to ensure its successful commercialization. The Department's unwillingness to put up any more money reflected its misunderstanding of intra-corporate realities that underlay Sperry Canada's world product mandate. The Department of Industry expected the parent-firm to make up the shortfall. But as a profit centre, Sperry Canada was responsible for paying its own way. In the end, the Department of Industry never quite grasped the fact that Sperry Canada was on its own.

In the case of Ferranti-Canada, public enterprise had played an important role in nurturing the company's journey up the digital electronic learning curve. The Canadian Post Office Department's pioneering electronic mail sorter gave Ferranti-Canada the opportunity to master the use of transistors in high-speed digital circuit design, as well as the opportunity to perfect its drum memory technology. The Trans-Canada Air Lines project to computerize airline reservations enabled Ferranti-Canada to design and build its first general-purpose computer. Though not Canadian, the American Federal Reserve Bank of New York contract to build a digital electronic cheque sorting machine allowed Ferranti-Canada to spawn the idea of endowing mid-size computers with multiprogrammable operating systems. One should not, however, confuse the Post Office and TCA contracts with any coherent government policy to nurture the growth of a Canadian computer industry -- there was none.

Except for a brief flirtation with military self-reliance, throughout the first twenty-five

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[22] Although the mechanism of centrally dispensed R&D funds did not exist within Sperry Rand, the parent corporation indirectly supported Sperry Canada through the vehicle of intra-firm sales. Sperry Canada financed its entire R&D program in machine-tool automation from defence contracts. As Sperry Canada's domestic military sales fell, the parent corporation channelled American contracts to its subsidiary through the vehicle of the U.S.-Canada Defence Production Sharing agreement.

years of the fourth innovation wave the Canadian government never formulated any substantial policy to support the growth of a domestic computer hardware industry. While there was considerable interest within the Government in improving the scope and efficiency of its own operations through a greater use of electronic data processing (EDP) technology, there appears never to have been any discussion as to whether the State's purchasing power should be channelled to foster local equipment manufacture. Without an explicit "Buy Canadian" policy, backed up by some form of financial inducement, no government department could turn its gaze away from the aura of the big names such as IBM and Univac to consider Ferranti-Canada. Equal in importance to government procurement in fostering the growth of a domestic computer industry was the need to provide capital. Ferranti-Canada lacked the financial resources to establish the kind of marketing and service infrastructure needed to compete with the established players. Ferranti-Canada's inability to raise money -- either internally or externally - made the Canadian government its sole possible source of capital.

Lacking a clear industrial and technological policy related to the Fourth Wave, the Department of Industry could not act quickly and aggressively to come to Ferranti-Canada's aid. The important role FP6000 played in International Computer Limited's product development and commercialization strategy attests to the technical worthiness of the Canadian-designed computer. Digital Electronics Corporation's subsequent development of the minicomputer market suggests that Ferranti-Canada's attempts to commercialize a mid-sized machine was the only way before 1970 to penetrate IBM's market invincibility. Technical attractiveness, however, does not in itself guarantee market acceptance. Without a large infusion of capital, Ferranti-Canada's innovative computer had little chance of securing even a tiny toe-hold in the market. In the end, the FP6000's poor commercial showing in Canada made it that much easier for Ferranti U.K. to pull the FP6000 design rights out from under Ferranti-Canada and to sell them to International Computers and Tabulators (later to become International Computers Limited, ICL). One could argue that even if the State had poured money into making the FP6000 the first flagship of Canada's computer industry, there were few guarantees that the product would have stolen a profitable niche away from the onslaught of IBM's 360 strategy. But without a vigorous and co-ordinated support program, Ferranti-Canada's failure was assured.

The case studies in this thesis do not nullify the nationalist argument. Instead, they suggest very strongly that the discourse of dependency and de-industrialization needs more balance. Neither in Sperry Canada, which at the time was Canada's leading industrial development centre for digital electronic machine tool technology, nor in Ferranti-Canada, which was Canada's best chance for a domestic computer hardware, does one find any evidence of any "dependency" that crippled their capacity to do research and development. In fact the opposite proved to be the case. In the context of the digital electronic revolution, both companies exhibited aggressive product-development programs, the capacity for radical innovation, and daring market ambitions. Of course this is not to say that dependency was not a weakness of Canadian industry. But the issue is whether this dependency was as prevalent in the industries associated with producing the products of the global fourth innovation wave as it was in other segments of the economy.

Were the Sperry Canada and Ferranti-Canada experiences anomalies of the Canadian political economy, or were there other technology-driven Schumpeterian subsidiaries in Canada during the 1945-1970 period? Or have there been any since? In Arthur Cordell's typology of how foreign-owned subsidiaries carry out R&D in Canada, using conclusions from a study he conducted for the Science Council of Canada, he argues that these two companies appear to be the exception.[23] They were neither an "international interdependent laboratory" nor a "support laboratory," the only two types of multinational R&D activities he claimed were then taking place in Canada.[24] But Cordell's characterization of Canadian branch-plant R&D was not based on case studies of actual corporate practice over time. Except for a brief account of Northern Electric, his work does not draw on any extensive historical data that would allow one to understand the *process* by which the global, digital electronic, innovation wave was articulated in Canadian branch plants. Instead, he attempts to use an industrial snapshot from around 1970 to

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[23] Arthur Cordell, *The Multinational Firm, Foreign Direct Investment, and Canadian Science Policy*, Background Study for the Science Council of Canada No. 22, (Ottawa: Information Canada, December 1971). Inspired by the rising nationalist political economic discourse of the 1970s, Cordell's work for the Science Council of Canada provided important ammunition to the theoreticians of Canada's deindustrialization and truncated development.

[24] Cordell defined the "international interdependent laboratory" which conducts research (with little development) and which is closely connected to the international research program....Research programs of an international interdependent type may have little to do with the capacity for new product innovation in Canada. Specialized research of this type is often confined to a specific stage of the R&D process...While innovation capability (both product and process types) is increased for the firm as whole, there is little obvious benefit which accrues to the Canadian economy...An enclave operation of this type may be a form of brain drain." *Ibid.*, 42, 44. The "support laboratory" on the other hand "acts as a technical service centre, i.e. to examine why a product may fail to operate in the Canadian market or to help with the adaptation of the product to the Canadian market, and/or acts a translator of foreign manufacturing technology, i.e., to implement the process of 'technology transfer'...However, one must distinguish the benefits which accrue when the R&D is undertaken in the process of transferring technology from those that accrue when R&D is undertaken in an indigenous firm....The potential benefit to the Canadian economy arising from exploitation of either product or process is great in indigenous firms and almost non-existent in subsidiary operations." *Ibid.*, 43.

abstract a "universal" typology of branch plant R&D behaviour in Canada.

Historian Graham Taylor, in contrast, tried to extrapolate a typology of the technology relationships between foreign parent firms from in-depth historical analyses. His assertion that the "parent firm's willingness to transfer resources, particularly advanced technology was closely linked to the degree of control they exercised over the affiliated companies" may prove to have wide validity, but its relevance to Sperry Canada and Ferranti-Canada is questionable.[25] The creation of Sperry Canada and the creation of Ferranti-Canada's digital electronic program both entailed some initial technology transfer in the hope of winning Canadian defence contracts. But because of the decentralized management structure that defined the parent-subsidiary relationship of both firms, the direction and rhythm of the technical innovation process in the two subsidiaries was shaped more by the local managers' and engineers' ambitions and talents than by the parents' needs. As separate profit centres, both Sperry Canada and Ferranti-Canada were left to their own devices to formulate and implement their product development strategies. Paradoxically, the fate of those two strategies does partially affirm Taylor's main point about the linkage between technology transfer and parental control. In both cases, the parent firm eventually exercised its authority to appropriate the Canadian-devised technology, and to transfer it back to the home country. However, neither Ferranti nor Sperry Rand would have interfered with the autonomous operations of their Canadian subsidiary had the latter found local funding -- from the government or from the banks -- necessary to bring its R&D to commercial fruition.

Neither the case studies presented here, nor those by Taylor, capture the entire story. More case studies are needed before one can develop a deeper understanding of how the process of innovation did, or did not, unfold in branch plants. Was there more autonomy in the design stage than in the commercialization stage, as the Ferranti and Sperry Rand stories suggest? A definitive answer will require historians to study the performance of domestically-owned companies in the technologically-advanced industries such as digital electronics in the 1945-1970 era. Only through comparative research will it be possible to know whether 'home-grown' companies better served the national interest than their foreign-owned counterparts, as the nationalist discourse assumes.

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[25] Graham Taylor, "Negotiating Technology Transfers within Multinational Enterprises; Perspectives form Canadian History," *Business History* 36 (January 1994): 153.

Canadian Context and the Direction of Design

One of the challenges facing the historian of technology is to create a narrative that explains why and how technical change proceeded as it did. In writing such a story, historians must seek not only to portray design choices and the factors that shaped them, but they must also elucidate the forces that set the design process in motion and explain how the process was maintained. The content and conceptual structure of the tale that "technology's story-tellers" weave will, however, depend on the factors they view as the key determinants of change. The "internalist" narrative mistakenly treats dynamics of technology as essentially exogenous to society. In the internalist's tale of change, technology unfolds as some inexorable internal techno-scientific logic that transcends human will. The "externalist" narrative of technological change, however, falls into the trap of spinning a socio-economic and political tale devoid of technical contingency. While the internalist narrative offers a technological deterministic view of history, the externalist offers the equally mistaken view that only economic, social, and political categories are needed to account for the face of technological change. A more fruitful approach to understanding the process of technological change is to see it as the simultaneous interplay between the technical logic of design and a host of economic, political, and cultural forces that comprise the society within which science and engineering is practised. As a result of this interplay, the myriad of imaginable technical possibilities is reduced to what the German historian J. Hillige calls the "techno-scientific problem-solving horizon."[26] This horizon demarcates the socially, economically, politically, and/or culturally determined directions to which the knowledge and experience of given technological branch can extend.[27]

Despite considerable scholarship in other countries on how the interplay of technical and

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[26] The horizon is consensus that represents the problem solving behaviour of the individual disciplines and schools represented in the engineering community. Discussed in Felix Rauner and Klaus Ruth, "Industrial Cultural Determinants of Technological Determinants: Skill Transfer or Power Transfer?" *AI & Society* 3 (April-June 1989): 88-102. Also see, H. D. Hillige, "Die gesellschaftlichen und historischen Grundlagen der Technikgestaltung als Gegenstand der Ingenieurausbildung," in Troitzsch and König (eds.), *Lernen aus der Technikgeschichte*, (Düsseldorf: VDI-Verlag, 1984)).

[27] Since the social, economic, cultural, and political factors, as well as basic technical knowledge change over time, the "extent" and "shape" of the "horizon" are also historical properties.

non-technical forces in shapes design choices, this area of research remains relatively unexplored in Canadian historiography. This thesis has presented considerable evidence to demonstrate that the Canadian context did shape the "techno-scientific problem-solving horizon." For example, the Canadian Post Office Department and Trans-Canada Air Lines' patronage of digital electronic innovation illustrate that design in Canada resulted from the historically specific interplay of the practitioners and the State. In both cases, monopoly public enterprise guided the direction of industrial innovation as a means of furthering political goals. Thus the Post Office turned to the digital revolution to deflect growing political criticism of its efficiency. Whereas American Airlines pursued SABRE under a free enterprise system, Trans-Canada Air Lines turned to technological efficiency and computerization as a tool to preserve its monopoly status. But the most striking evidence that artifacts are the material images of technical logic refracted through a political economy can be found in the Royal Canadian Navy's development of DATAR and Sperry Canada's Schumpeterian entry into numerical control (NC) and computer numerical control (CNC).

The circumstances of World War II had thrust Canada into a position of geopolitical prominence that otherwise would have been inaccessible to it. Unlike the end of World War I, when the Canadian military returned to its former oblivion, the Armed Services were determined to retain much of their wartime status and play an important role in the post-World War II era. At the outbreak of World War II, the Royal Canadian Navy's (RCN) senior officers had dreamed of leading conventional naval task force into battle. Unable to win political approval for the program to build aircraft carriers, battleships, and destroyers, the RCN instead found itself thrust into the less glorious role of escorting shipping convoys. At the war's end, the RCN senior staff again aspired to command a conventional task force of the sort launched by world naval powers, albeit on a smaller scale. When Mackenzie King's anti-militarism and the budgetary constraints of returning to a peacetime economy scuttled the RCN's postwar fleet aspirations, the navy returned to its prior anti-submarine/escort role as the fulcrum about which it would try to pry out a new role of importance within the North Atlantic Triangle alliance. But its wartime experience in this area had taught the RCN that the absence of an indigenous R&D capacity in this area would surely compromise its postwar aspirations of self-reliance and sovereignty.[28] Accordingly,

[28] Throughout the war, Canada's dependence on its Allies for the sophisticated electronic technology had seriously compromised RCN's military effectiveness. "The consequences of that technological gap for this junior partner [that is (continued...)

while the British and American navies devoted their R&D energies to the future battle requirements of large naval tasks forces, the RCN sponsored the creation of a strong national R&D capability to assert its pre-eminence in anti-submarine warfare.

This quest to transform Canada's limited naval resources into a respected military presence within the North Atlantic Triangle alliance determined the contents of the RCN's entire R&D program, of which the most daring element was DATAR. On a technical level, DATAR represented perhaps the earliest comprehensive fusion of communications, computation, and control into one unified digital paradigm. DATAR's, digital, decentralized and modular design for information processing and exchange was specifically developed for the needs of Canada's small fleet of frigates engaged in submarine hunting rather than for the large naval task forces of its more powerful allies. From 1948 through much of 1954, the RCN, through its DATAR project, had become the leading exponent of the digital electronic navy. In its search for a sovereign voice within the post-World War II military order, the RCN pushed the internal logic of the nascent digital technology into a new design paradigm for automated naval warfare.

Sperry Canada's pursuit of NC and subsequent "invention" of CNC also adds compelling evidence of the importance of national contexts in delimiting the "techno-scientific problem-solving horizon." The UMAC-5 story in particular suggests that the dominant interpretation in the American literature of the social construction of machine tool automation needs to become more nuanced if it is to explain developments north of the forty-ninth parallel, and perhaps south of it as well. David Noble's landmark study on the origins of the American NC program argued that the eventual triumph of the NC design approach to machine tool automation was based more on the exercise of power than on the merits of technical and economic rationalization.[29] Support for NC over the alternative "record and playback" (RP) technology, argued Noble, arose because the former eliminated the machinist's monopoly over skill. He concluded that NC's very design embodied an alliance between the United States Air Force, industrial management, and academia whose purpose was to strip machinists of their power of the labour process by deskilling them. While both methods produced a tape of instructions which could then be used to automate

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[28](...continued)
Canada] were grave" writes Marc Milner. He goes on to argue that as a result, "Canadian escort services suffered perhaps the highest loss rates of the war." Marc Milner, "The Implications of Technological Backwardness: The Canadian Navy 1939-1945," *Canadian Defence Quarterly* 19 (Winter 1989): 46-52.

[29] David Noble, *Forces of Production: A Social History of Industrial Automation* (New York: Oxford University Press, 1986).

production in RP, the tape was produced by recording the skilled worker's motions during the actual machining process, while in NC, the tape was produced by a programmer removed from the shop floor.[30] Management's superior control of machinists, not technical efficiency or economics, stresses Noble, had determined the success of the NC over RP. Showing that design choices in machine tool automation were not purely technical and neutral, Noble's work provided the first comprehensive validation of Langdon Winner's provocative assertion that "Artifacts have politics."[31]

Forty years have passed since the introduction of NC. And yet, the evidence of any widespread deskilling remains inconclusive.[32] But the power and controversy of Noble's discourse stem less from the eventual ramifications of design per se, and more from the ideological intent that shapes design decisions. Even if NC did not deskill workers, was the early engineering development motivated by a Machiavellian desire to deskill the machinist? Put differently, was the imperative to wrest control of production from the machinist the dominant factor that shaped "techno-scientific problem-solving horizon" within which NC developed? Noble answers with an unequivocal yes. The comprehensiveness, cogency, and passion of Noble's study of NC's development at Massachusetts Institute of Technology should not, however, blind us to the possibility that the social construction of NC proceeded differently in other nations.

In 1955, with the global state-of-the-art of NC technology still its infancy and still an unknown concept in Canada, Sperry Canada decided to develop its own product line in this area. The corporate rationale for such a move was clear -- diversify or perish. Sharing the technology-driven ethos of its parent firm, Sperry Canada naturally chose "radical product innovation." But much of its analysis as to why NC was an attractive product to develop was animated by a belief that NC was the ideal technology for the small-batch and highly fragmented nature of Canada's

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[30] On this distinction Noble writes: "Both N/C and R/P were aimed at reducing the amount of skilled labor required to produce finished metal parts, but they viewed that skill differently. With N/C, machinists skills were devalued and viewed as little more than a series of straight forward operations...N/C viewed machining is a process fully amenable to an abstract, formal mode of programming which eliminated the need for machinist skills altogether. The purpose of N/C was to move directly, without any manual or shop floor intervention, from the mathematical description of a part to the automatic machining of it." *Ibid.*, 149.

[31] Noble's historical study of NC offers one of the most comprehensive replies to Winner's question about the politics of artifacts. Winner, "Do Artifacts Have Politics?" *Daedelus* 109 (Winter 1980): 121-36.

[32] Jeffrey Keefe, "Numerically Controlled Machine Tools and Worker Skills," *Industrial and Labour Relations Review* 44 (April 1991): 503-519. This paper provides the most up-to-date review of the deskilling debate as it relates to numerical control.

metalworking industry. The dominance of Fordism, with its specialized tools and high set-up costs amortized over large production runs of one product, had turned Canadian small batch manufacturing into a competitive handicap. Sperry Canada consistently asserted that the flexibility of NC would level the playing field. All the evidence clearly suggests that promoting labour displacement and deskilling were never a consideration in Sperry Canada's design, testing, or marketing decisions. Sperry Canada's view that digital electronic technology would empower rather than deskill machinists becomes more apparent in the way it went about designing the world's first stand-alone computerized NC system for machine tools.

Though Noble assigned malevolent intentions to the design of NC, he has been ambivalent about CNC. He even suggested that CNC could potentially enhance the worker's skill. Yet his ideological convictions led him to conclude that management would never bow to such worker-centred approach to automation. Harley Shaiken in the United States and Barry Wilkinson in Great Britain also argued that the process of CNC's implementation is still motivated by management's desire to enhance its control over the production process.[33] In all the discussions of CNC, scholars from the Left are silent as to how CNC was socially constructed. What is clear, at least in the Canadian case, is that the deskilling, to which Harry Braverman[34] attributed a leading role to technological change in the capitalist systems, did not provoke the CNC radical innovation at Sperry Canada, a subsidiary of the very sort of corporation that should have been bent on deskilling workers, according to the Braverman-Noble school.

Sperry Canada's invention of CNC was sparked, first and foremost, by the need to escape from the swarm of NC imitators and to create a new Schumpeterian niche. Technological imperatives rather than any deskilling agenda were paramount in the company's decision to embed computational power directly into the machine tool. The central issue for Sperry Canada was how to overcome the costly hardwire inflexibility associated with trying to match one NC system to different machine tool configurations. Solving this problem was the key to creating a more exclusive market niche. However, once the programmable computer approach was adopted, Sperry Canada management and engineers consciously sought to design UMAC-5 so that it

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[33] Harley Shaiken, *Work Transformed: Automation and Labor in the Computer Age* (New York: Holt, Rinehart and Winston, 1984); Barry Wilkinson, *The Shopfloor Politics of New Technology* (London: Heinemann Educational Books Ltd., 1983).

[34] Harry Braverman, *Labor and Monopoly Capitalism: The Degradation of Work in the 20th Century* (New York, Monthly Review, 1974).

would expand the machinist's skills.

Sperry Canada's design team put a great deal of effort into making the use of UMAC-5 transparent to the machinist. UMAC-5 could run an NC tape prepared elsewhere, or the machinist could directly program UMAC-5. Through a menu-driven, push-button panel, the machinist could program UMAC-5 to perform any complex set of point-to-point machining operations. The design logic of the interface was to make the programming task easy for the machinist.[35] Furthermore, UMAC-5 also allowed the machinist to prepare the tape by actually performing each machining operation rather than through formally programming. UMAC-5's ability to store the machinist's operations was the digital version of the earlier analogue record/playback method.[36]

Created to manufacture sophisticated aircraft instrumentation and inertial navigational systems, Sperry Canada had its roots in high-precision complex machining. From the outset, Sperry Canada envisaged CNC as a technology to enhance the capabilities of skilled machinists. Despite the most persistent detective work, this author has been unable to find any machinist who actually used UMAC-5. It still remains to be seen if UMAC-5 was used the way it had been designed. Whether the customer shared Sperry Canada's philosophy on UMAC-5's use is impossible to tell. Certainly in Canada, Sperry Canada's inability to sell its technology reflected the entrenched attitude of Canadian metalworking industries that NC and CNC were cost-cutting strategies to be applied to labour inputs. In their eyes, the high price of the technology made it an uneconomical approach to cutting costs. Domestic manufacturers, in other words, may have acted more like the archetypal capitalist firm, as depicted by radical political economists such as David Noble and Harry Braverman, than did Sperry Canada, an American branch plant.

The case studies add new meaning to Bruce Sinclair, Norman Ball, and James Paterson's observation that "nothing more characterizes the Canadian situation than the continual selection

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[35] When the latter pushed a button to program a particular operation, the computer would ask him what he wanted to do next. The questions were presented as a series of menu options. For each decision, UMAC-5 presented the machinist with the array of possible options. Each option was represented by a lit button. The push-buttons for inappropriate programming options were unlit. They could not be activated by mistake. In this way, the machinist did not have to be a parts-programming specialist. For details the reader is referred to the UMAC-5 user's manual. Sperry Gyroscope Company of Canada, Ltd., *UMAC-5 Numerical Control System: Operator's Manual*, (1965). Copies exist at the National Museum of Science and Technology, in Ottawa, Canada, and with this author. For those wanting to examine the actual interface, the only existing UMAC-5 can be found in the National Museum of Science and Technology's collection.

[36] Interestingly enough, Sperry Canada had included this record/playback option in its earlier more advanced NC systems.

of techniques from other societies....The ability to adapt is just as critical as the ability to originate."[37] Most, if not all, the key inventions -- such as ENIAC, Colossus, the transistor, pulse coded modulation and even radar -- that set the digital electronic revolution in motion originated from just two vertices of the North Atlantic Triangle: Great Britain and the United States. Nevertheless, quite creative adaptation that very often merged seamlessly into invention, marked Canada's early participation in this fourth global innovation wave. The Royal Canadian Navy's digitally-mediated self-reliance, the Post Office's quest for digital automation, Trans-Canada Airlines' use of the digital paradigm to consolidate its monopoly status, the Defence Telecommunications Research Establishment's exploration of transistor design to cope with the crippling problems of circuit complexity, Ferranti-Canada's ingenious search for a product niche in a market dominated by giants, and Sperry Canada's technology-driven strategy of diversification collectively demonstrate that the process of design in Canada did indeed refract the international state-of-the-art through an historically specific national context.

The Importance of Learning by Doing and Canada's First Community of Digital Practitioners

In the end, the reader may chose to interpret this story of public enterprise's flirtation with technological self-reliance, the Schumpeterian vitality of foreign-owned branch plants, and of the daring and creative technological adaptation in Canada as a litany of failure. After all UTEC was cancelled. DATAR failed to go beyond the prototype stage, as did the Canadian Post Office mail sorter. Though the Trans-Canada Air Lines ReserVec system proved an operational success, this technology was never sold anywhere else in the world. The FP6000 never became the basis of an indigenous computer hardware industry. Sperry Canada was unable to turn UMAC-5 into a profitable business in computer numerical control. Despite considerable government funding, the company Consolidated Computer and the Department of Communications' (DOC) Telidon project, which were briefly discussed in Chapter Six, yielded few if any commercial successes.

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[37] Sinclair et. al., *Let Us Be Honest and Modest*, 2.

To focus on failure, however, would miss the crucial underlying process in Canada's articulation of the fourth innovation wave: moving people up the learning curve. Although measures of technical and market success are very important, they can obscure a fundamental historical issue: the timely formation of the requisite national core of scientific and engineering expertise needed to keep a small and open political economy, such as Canada's, responsive to the longer-term opportunities arising from profound global shifts in technology. Throughout this thesis the narrative's emphasis of "R&D as process" over "R&D as product" has underscored the creation of expertise.[38] While "R&D as product" measures the success of R&D efforts strictly through a cost-benefit perspective, "R&D as process" focuses one's attention on the important opportunities for skill formation and networking. R&D as result is tied to information production. R&D as process, on the other hand, is about knowledge creation. French economists Patrick Cohendet, Jean-Alain Héraud, and Ehud Zuscovitch argue that the received view of innovation as basically an informational phenomenon fails to recognize that "the development of new technologies is fundamentally a localized and path dependent learning process to which access is quite limited even when the general characteristics are publicly known."[39] While information may be freely available and "off-the-shelf," technical knowledge is not. Chris Freeman argues that unless there is the industrial capacity first to assimilate and then to improve upon this publicly available know-how, it is unlikely that it will be used efficiently.[40] This capacity is acquired from "learning by doing."[41] Michael Porter's work also reinforces the importance of "learning by doing" in forging a nation's technological capacity. Underlying a nation's competitive advantage among nations is its ability to foster the formation of industrial

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[38] See Dominique Foray's introductory essay in Dominique Foray and Chris Freeman (eds.), *Technology and the Wealth of Nations: the Dynamics of Constructed Advantage*, (London: Frances Pinter, 1993), 1-22. Foray raises the distinction of result and process to illuminate a debate over how to assess the economic value of R&D. But this distinction equally serves to illuminate how one assigns historical meaning to events.

[39] Patrick Cohendet, Jean-Alain Héraud and Ehud Zuscovitch, "Technological learning, economic networks and innovation appropriability," in Foray and Freeman, *Technology and the Wealth of Nations*, 66-76, 67.

[40] See section 3 "Technical learning from external source" and the references in Chris Freeman's critical survey article,, "The Economics of Technical Change," *Cambridge Journal of Economics* 18 (no. 5 1994): 463-514.

[41] Keith Pavitt, "Patterns of Technical Change: Towards a Taxonomy and Theory," *Research Policy* 13, no. 6: 343-73; Keith Pavitt, "What do firms learn from basic research?" in Foray and Freeman, *Technology and the Wealth of Nations*; and Bruno Amable, "National Effects of Learning, International Specialization and Growth Paths," in Foray and Freeman, *Technology and the Wealth of Nations.*

engineering/management skill and the accumulation of technical knowledge.[42] Similarly, in his work on the origins of the "turbojet revolution," Edward Constant suggests that a nation's "technological knowledge comprises traditions of practice which are properties of communities of technological practitioners."[43] In other words, a nation's accumulated technical knowledge resides not in the material artifacts but in an existing community of technical practitioners. From the perspective of this thesis, "learning by doing" is essential to sustain the emergence of a community of technological practitioners.

Animated by the interrelated themes of R&D as "process," this thesis has presented the first fine-grained of how the interplay of public and private enterprise nourished the growth of Canada's earliest community of digital electronic technologists and their associated traditions of practice. Despite the nationalist assessment during the 1970s of Canada's inadequate appropriation of the benefits of the post-industrial revolution, Canada had by 1967, the highest per capita diffusion of computer systems in the world, next the United States. It was twice that of Europe and over three times that of Japan.[44] One obviously cannot prove a rigorous necessary and sufficient relationship between the existence of the community of practitioners portrayed in this thesis and the diffusion of digital electronic technology. Nevertheless, the widespread dissemination in Canada of a sophisticated digital technology such as the computer could never have occurred without the co-existence of a sizable group of technologists with shared technical knowledge and experiences. Furthermore, the legacy from this first core of expertise and the mass of technical knowledge it had accumulated in the 1950s and 1960s served Canada well in the decades that followed.

Once we understand that modern prosperity depends on the creation and sustenance of this community of technologists, rather than on the fate of individual products, then we can understand the true tragedy engendered by the cancellation of Canada's most expensive R&D project in the 1945 to 1960 era, the AVRO Arrow jet interceptor. The tragedy lay not in the cancellation, for Canada could not afford the Arrow, but in the subsequent departure of an entire

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[42] Porter, *The Competitive Advantage of Nations*. High productivity here refers to more than just a higher value of the ratio of output to inputs. It also refers to the ability to bring new products into the market. Thus high productivity embraces both "product" and "process" innovations.

[43] Edward W. Constant, *The Origins of the Turbojet Revolution*, Johns Hopkins Studies in the History of Technology, vol. 5, (Baltimore: John Hopkins University Press, 1980), 10.

[44] Canada had 214 computer systems per million workers. Japan, France, Germany, the United Kingdom, and Sweden had 68, 126, 125, 92, and 122 respectively. See data on page 7 of OECD, *Gaps In Technology Between Member Countries*, October 1967.

community of technologists (centred this time on military aeronautics) from the country. In the case of the digital revolution, thanks to all the actors who have appeared in this story, young Canadian talent, instead of going down the road to the United States, found an indigenous community of technologists and a tradition of technical practice they could join.

The genealogical lineage of Canada's "high-tech" industry makes us aware of how much knowledge, and of how many careers, were fostered by the "failed" technologies described by this thesis. Consider Denzil Doyle, the acknowledged "dean" of Canada's "Silicon Valley North" which emerged in the Ottawa-Carleton region in the 1970s and 1980s.[45] Upon graduation from Queen's University, as a winner of the Governor General's Medal for academic excellence, Doyle first found employment in Computer Devices of Canada, then at the Defence Research Telecommunications Establishment. Doyle was later responsible for the creation of Digital Equipment Canada, a branch plant of the American firm Digital Equipment Corporation, and became its first Chief Executive Officer. Today Digital Canada has the corporation's world product mandate for personal computers and workstations. CAE, a Montreal company known for its sophisticated flight simulators, offered another Canadian, Stephen Dorsey, the opportunity to return home after his graduation from the prestigious Massachusetts Institute of Technology in 1958. Dorsey became a leader in the design and commercialization of the first generation of stand-alone wordprocessors. The two companies he created in Montreal, AES Data Ltd. and Micom, which sold wordprocessing systems around the world, then became new nodes from which the network of Canadian technologists could grow. I. P. Sharp & Associates, which spun-off from the FP6000 software team, developed into one of the largest international, time-sharing networks. Not only did this company provide new opportunities for young Canadian hardware and software engineers, but it also attracted the renowned Harvard mathematician and computer

[45] During the 1970s and early 1980s, Saskatoon looked as if it would earn the title of "Silicon Flats." Manufacturers of digital electronic equipment, like SED Systems and Develcon Electronics, with important development programs of their own, sprouted up in Saskatoon during the early 1980s. The University of Saskatchewan had provided an important educational and research environment to attract and nourish the city's community of technologists. The nucleus of this university's digital electronic know-how was forged in the late 1960s and early 1970s when people such as Arthur Porter, the man who first headed the DATAR project for Ferranti-Canada, went there to be Dean of Engineering, and Norman Moody and Richard Cobbold, who led DRTE's experimentation with digital transistor circuits, went there to head up new research programs. Moody later returned to the University of Toronto to start up the Institute of Bio-Medical Engineering, where digital electronics research became an important part of the Institute's innovations in bio-medical instrumentation Cobbold later succeeded Moody as Director of the Institute.

scientist Kenneth Iverson back to Canada.[46] From the Consolidated Computer failure flowed the Dynalogic Corporation and its aggressive campaign to win the American personal computer market in the early 1980s.[47]

Mitel, Newbridge, and Corel, Canada's high-tech stars of the 1990s, also owe much of their existence to the community of technologists forged with the help of public enterprise that product-oriented analysis might dismiss as yet another "failure," this time involving Northern Electric (Nortel). In the early 1950s, Northern Electric had little R&D capacity to speak of. But the search for a national capacity to resolve the potentially crippling problems of complexity and reliability associated with large-scale circuits led the military to enter into close co-operation with Northern Electric to explore transistor circuit applications and manufacture. This collaboration contributed to the growth of the Advanced Devices Centre at Northern Electric and the creation of the nation's first industrial training ground for the manufacture of microchips. In 1969, with the help of a $37 million government subsidy, the Advanced Devices Centre spun-off into Microsystems International, the precursor of Mitel, an internationally successful telecommunications firm (subsequently acquired by British Telecom) and the training ground for Michael Copeland and Terrence Mathews. After they left Mitel, Copeland created the company Corel, while Mathews formed Newbridge, which continues to spin-off new high-tech companies.

Thus far from being a tragic tale of lost opportunities, the case studies in this thesis underscore the invaluable skill formation that took place from 1945 to 1970. In this period, Canadians pooled the resources of the military, universities, business, and the federal government to finance the ascent of an entire generation of technologists up the learning curve. In the process, Canadians learned that they could make a living without having to pillage their natural resources or compete ruthlessly on price with the world's poorest peoples in the global commodity markets. Instead Canadian could enrich themselves and the world by continuing to pass on the technical

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[46] Kenneth Iverson was born and raised in Camrose, Alberta. After World War II he went to university and completed his education with a doctorate at Harvard. There he worked with Howard Aitken, one of the early pioneers of digital computers. Iverson later created the programming language called APL.

[47] Murray Bell, another winner of the Governor General's Medal for academic excellence, upon graduation from Queen's University went to work for the Consolidated Computer Co. When the company went into receivership, Bell eventually formed Dynalogic. After spending $1 million to develop a new personal computer called the Hyperion and $300,000 to advertize it, Bell introduced the computer at the 1982 COMDEX show in Atlantic City. The response was enthusiastic. The U.S. Magazine *Electronics* described the unveiling of the Hyperion as a "20 pound bombshell." See Thomas, *Knights of the New Technology*, 175. David Thomas's book offers a journalistic staccato-like who's-who account of Canada's computer industry in the late 1970s and early 1980s. Though weak in its analysis, the book nevertheless offers a fascinating picture of the web of business ties that bound the nation's computer industry in this period.

knowledge they first acquired from busying themselves by learning about the functioning of the postwar digital innovation wave. If, sometimes, they wondered whether they had made the best use of the opportunities that fate handed them in 1945, it was only perhaps because they realized that only a few dollars more of government support might, have at times, transformed what was already largely a success story into a truly epic tale of accomplishment.

Abbreviations of Archival Sources Found in Foonotes

Chapman	Papers of John H. Chapman, (MG 31, J 43), National Archives of Canada.
CPDL	Records of Canadian Patents and Development Limited, (RG121), National Archives of Canada.
DND	Records of the Department of National Defence, (RG24), National Archives of Canada
DDP	Records of the Department of Defence Production, (RG49), National Archives of Canada.
Ferranti	Records of Ferranti Limited, Manchester, U.K.
FP	Ferranti-Packard Collection, Archives of the Province of Ontario, Toronto.
FRBNY	Records of the Federal Reserve Bank of New York, New York City.
Gotlieb	Calvin Carl Gotlieb Papers, (B88-0069), University of Toronto Archives.
IC	Records of Industry Canada (RG20), National Archives of Canada. Formerly the Department of Industry, Trade, and Commerce.
Levy	Papers of Dr. Maurice Levy, in author's possession.
Mackenzie	Chalmers Jack Mackenzie Papers, (MG30 B122), National Archives of Canada.
NRC	Records of the National Research Council of Canada, (RG77), National Archives of Canada.
OPC	Records of the Office of the Privy Council of Canada, (RG2), National Archives of Canada.
PO	Records of Canada Post, (RG3), National Archives of Canada.
Smith	Papers of the President of Toronto University of Toronto, Sidney Smith, (A68-0007), University of Toronto Archives.
Sperry	Sperry-Univac Company Records, Accession 1825, Hagley Museum and Library, Wilmington, Delaware.
TB	Records of the Treasury Board, (RG55), National Archives of Canada.
TCA	Records of Air Canada, (RG70), National Archives of Canada. Formerly Trans-Canada Air Lines.

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