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EFFECT OF FLOW OBSTRUCTION ON PRESSURE LOSS

by

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ABSTRACT

Single-phase and two-phase flow experiments have been performed on (i) six obstruction shapes each with two blockage area ratios, and (ii) two sets of 4-rod bundles, which include the simulated form of the regular bundle that currently is being used in the CANDU reactor and the modified regular bundle to which streamlining is applied. The effects of blockage area, location, and shape of the obstruction on pressure loss were being investigated. The static pressures at various locations were measured with the Meriam well-type manometers. The pressure loss is separated into frictional and local components. The value of each component is obtained from the pressure distribution graph.

In single-phase flow, the blockage area, the location and the shape of the obstruction have a strong influence on the pressure loss. More pressure is lost for a large obstruction, a blunt type (plate type) obstruction, or an obstruction which blocks the high velocity region of the flow. In two-phase flow, a large obstruction or a blunt type obstruction causes more pressure loss. The effect of obstruction location on pressure loss depends on the flow distribution. More pressure is lost as the obstruction blocks more of the liquid phase.

Modification of the obstruction shape in the simulated regular bundle has improved the pressure recovery in both the junction and the spacer planes. It also reduces the dependency of the pressure loss upon the misalignment of the bundles.

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NOMENCLATURE

Symbol	Meaning	Unit	Eqn. Refer.
A	Area	m^2	3.1,E.4,E.5,E.6
D	Pipe Diameter	m	3.2,3.5,3.7,3.9,E.4,E.5
D_e	Hydraulic Diameter	m	3.1,3.3,3.11,3.13,3.16, 8.1,8.6
f	Friction Factor		3.3,3.4,3.5,3.6,3.8,3.9, 3.11,3.13,3.16,8.1,8.6
G	Mass Flux	$kg/m^2 s$	4.5,4.6,E.6
g	Acceleration due to Gravity	m/s^2	4.7
K	Loss Coefficient		3.10,3.11,3.12,3.13,3.14, 3.15,3.16,8.2,8.5,8.7,8.8, 8.9
L	Characteristic Length	m	3.3,3.11,3.16,8.1,8.6
n	Index		4.3,4.4
P	Perimeter	m	3.1
ΔP	Pressure Loss	kPa	3.3,3.10,3.12,3.13,3.14, 3.15,3.16,4.1,4.2,4.3,4.5, 4.6,4.7,4.8,4.9,8.1,8.2, 8.3,8.4,8.5,8.6,8.7,8.8, 8.9,8.11,8.12,8.13,8.14, 8.15
p	Local Pressure	kPa	E.8
Re	Reynolds Number		3.2,3.4,3.6,3.8,3.9
S	Specific Gravity		E.8
t	Obstruction Thickness	m	3.13

v	Velocity	m/s	3.2,3.3,3.7,3.10,3.12, 3.13,3.14,3.15,3.16,8.1, 8.2,8.5,8.6,8.7,8.8,8.9
W	Mass Flow Rate	kg/s	E.1,E.2,E.3,E.6,E.7
x	Quality		4.3,4.4,4.5,4.6,8.10,E.7
y	Distance from the Wall	m	3.7

<u>Greek</u>

α	Void Fraction		4.6,4.7,8.10
γ	Specific Weight	N/m^3	E.8
ϵ	Absolute Roughness	m	3.5,3.9
ν	Kinematic Viscosity	m^2/s	3.2
ρ	Density	kg/m^3	3.3,3.10,3.12,3.13,3.14, 3.15,3.16,4.5,4.6,4.7,8.1, 8.2,8.5,8.6,8.7,8.8,8.9, 8.10,E.1
ϕ^2	Two-phase Multiplier		4.1,4.2,4.4,4.8,8.3,8.4, 8.11,8.12,8.14,8.15

Subscripts

A	Acceleration
F	Friction
G	Gravitation
g	Gas Phase
J	Junction
L	Single-phase Pressure Loss Assumming Liquid Only Flow
LO	Single-phase Pressure Loss Assumming Total Flow as Liquid
LOC	Local
l	Liquid Phase
max	Maximum
Ob	Obstruction
Reg.	Regular Bundle
ref.	Reference
S	Spacer
Str.	Streamlined Bundle
TP	Two-phase Flow

Chapter I

INTRODUCTION

Pressure loss caused by flow obstructions has been a significant problem in the primary circuit of a pressurized heavy-water nuclear reactor. Because of the losses, the energy consumption by the pump is increased, while the cooling efficiency is reduced in the steady operating stage and in the transient stages such as the Loss Of Coolant Accident (LOCA). Substantial reduction of the losses does not only improve the performance of the reactor, but also decreases the hazard level during the transient periods.

The present work is performed to investigate the effect of size, location, and shape of flow obstruction on pressure loss. Single-phase flow experimental data are presented as loss coefficients. Two-phase flow pressure loss values are presented as ratios of two-phase to single-phase pressure loss, and the ratios are compared with some existing correlations.

Chapter II

BACKGROUND

Flow obstructions can be encountered in many industrial applications such as heat exchangers, or valves in oil and gas pipelines. This study is related to obstructions located in the nuclear fuel bundle of the CANDU reactor.

The CANDU reactor (the abbreviation is derived from CANada Deuterium Uranium, which indicates that the moderator is deuterium and the fuel is natural uranium), has a horizontal core configuration. When the reactor operates, the coolant (also heavy water) which is circulated through the pressure tubes by the primary pumps, extracts heat from the activated bundles. The high-temperature coolant is then led into the steam generator where heat is released to the light water for steam production. The steam produced is then used to power the turbine which is linked with a generator for generating electricity. A simplified flow diagram of the CANDU reactor is shown in Figure 2.1 [1]. The pressure tube, as partly shown in Figure 2.2, contains a string of bundles (the number of bundles varies with reactors). Each bundle spends an average of 17 months in the reactor and releases enough energy to generate approximately one million kWh of electricity [2].

The bundle shown in Figure 2.3 consists of fuel rods, end-plates, spacers and bearing-pads. Each fuel rod is filled with natural uranium oxide pellets in a Zircaloy-4 cylindrical sheath. A thin layer of graphite is applied on the inside surface of the sheath to reduce interaction between the pellets and the sheath. Both ends of the fuel rod are covered with end-plugs:

1. to seal the content of the elements;
2. to provide effective element termination for attachment to end-plates; and
3. to provide the interface with the fuel-handling system.

Thirty-seven fuel rods are then welded to two end-plates. Subchannels are left between fuel rods through which the coolant can flow. Spacers (located in the mid-plane of the bundle) are used to maintain the subchannel area and prevent vibration of the rods. Bearing pads are brazed near the ends and at the middle of the outer ring of the rods to avoid the bundle from contacting the wall of the pressure tube.

The end-plates, spacers, and bearing pads in the bundle improve the cooling efficiency; however, they also decrease the pressure head of the flow. In the reactor core, a substantial amount of pressure energy is being lost when the coolant flows through the bundles. The pressure loss per channel varies from 565 kPa (the CANDU installation at

Pickering) to 758 kPa (Gentilly-2 CANDU installation) [2]. This loss, at the expense of the pump energy, affects the performance of the reactor in both steady and transient states. Although most of the loss is caused by the skin friction between the flow and the walls of both the channel and the fuel rods, the local pressure losses caused by the attachments are also significant.

Besides the hydrodynamic effect, the obstructions in the bundle also influence the critical heat flux behavior [3]. The blockages induce a better mixing effect so that heat transfer to the coolant intensifies. Often, a burnout point occurs behind the blockage because the flow cannot cool that area efficiently enough in the presence of the blockage [4]. With a well-designed blockage, which minimizes the pressure loss, critical heat flux behaviour can be improved.

Chapter III

SINGLE-PHASE FLOW

In most reactor operations, the coolant frequently flows in a liquid state with a negligible amount of vapour. The pressure loss can be estimated with single-phase equations, since the flow quality is low. For a string of bundles, the pressure loss can be separated into two major catagories:

1. the pressure loss due to friction; and
2. the pressure loss due to such local obstructions as
   a) junction;
   b) spacer; or
   c) bearing pad.

3.1 SKIN FRICTION PRESSURE LOSS

The skin friction pressure loss is caused by the friction between the fluid and the wall of the pressure tube and the fuel cladding. It is affected by the flow velocity, the flow viscosity, the characteristic length of the channel (i.e., the hydraulic diameter of the channel and the distance covered by the flow), and the roughness of the pipe. The hydraulic diameter of the channel is defined as

$$D_e = 4A/P \tag{3.1}$$

where A is the cross-sectional area, and P is the wetted perimeter of the channel. For a circular channel, it is equal to the pipe diameter D.

Factors such as flow velocity, fluid viscosity, and the hydraulic diameter of the channel affect the transition of laminar to turbulent flow. Osborne Reynolds introduced a dimensionless parameter to combine the influences of these factors. The parameter is called the Reynolds number and is defined as

$$Re = v_1 D/\nu \tag{3.2}$$

where v_1 is the velocity of the flow, D is the diameter of the channel, and ν is the kinematic viscosity of the flow. Turbulent flow, which is frequently encountered in reactors, is generally assumed when the Reynolds number exceeds 2000.

For steady and incompressible flow, the friction pressure loss is estimated with the Darcy-Weisbach equation, which is written as

$$\Delta P_F = (fL/D_e)(\rho_1 v_1^2/2) \tag{3.3}$$

where f is the friction factor of the channel wall, L is the length of channel that the fluid flows over, D_e is the hydraulic diameter of the channel, and ρ_1 is the density of the fluid. In the case of turbulent flow, the friction factor depends not only on the Reynolds number but also on the relative roughness of the contact surface. For laminar flow, it only depends on the Reynolds number and is defined as

$$f = 64/Re \tag{3.4}$$

For turbulent flow, Nikuradse performed experiments on some artificially roughened pipes and derived a friction factor equation for rough pipes as

$$f^{-0.5} = 1.14 - 2\log(\epsilon/D) \tag{3.5}$$

where ϵ is the absolute roughness of the channel. For smooth pipes, Blasius provided a friction factor expression, which is written as

$$f = 0.316/Re^{0.25} \tag{3.6}$$

for Reynolds numbers up to 100,000, by assuming a velocity profile of the form

$$v/v_{max} = (y/(D/2))^{1/7} \tag{3.7}$$

where V_{max} is the maximum velocity, and y is the distance from the wall of the channel. However, Nikuradse found from his experimental data that the power factor should be varied from 1/6 to 1/10 according to the Reynolds number. He then stated that the expression in the form

$$f^{-0.5} = 2\log(Re\, f^{0.5}) - 0.8 \qquad (3.8)$$

is more reliable for smooth pipes with Reynolds numbers up to 3,400,000.

In 1939, Colebrook presented a general equation for both rough and smooth pipes. The equation is written as

$$f^{-0.5} = -2\log((\epsilon/D)/3.7 + 2.51 f^{-0.5}/Re) \qquad (3.9)$$

On the basis of this equation and the consideration of the roughness of several kinds of new pipe materials, Moody published a chart for the friction factor as a function of Reynolds number (Re) and relative roughness (ϵ/D). Because of the difficulty in getting data for the actual pipe-roughness, the experimental data do not always agree with the values obtained from both the Colebrook equation and the Moody chart [5].

Tong [6], among many authors, suggested that the frictional pressure loss for the bundle geometry channel could also be obtained from equation 3.3 with the friction factor evaluated with the equivalent hydraulic diameter.

However, Courtaud et al. [7] and Le Tourneau et al. [8] have demonstrated that the friction factor is affected by the geometry of the channel as well as the velocity and viscosity of the flow. Rehme [9] and Malak et al. [10] studied the effect of bundle geometry and proposed relations which have been proven valid for turbulent flow (with Re > 2000).

The skin friction pressure loss can also be written in terms of the head loss coefficient K_F as

$$\Delta P_F = K_F (\rho_1 v_1^2/2) \tag{3.10}$$

Comparing the equations 3.3 and 3.10, the coefficient K_F can be written as

$$K_F = fL/D_e \tag{3.11}$$

3.2 LOCAL PRESSURE LOSS

The local pressure loss can be caused by either

1. a change of flow direction, e.g., bend;
2. a change of flow area, e.g., sudden expansion, or contraction; or
3. a flow obstruction, e.g., valve or orifice.

It is generally expressed as a function of the head loss coefficient K_{LOC}

$$\Delta P_{LOC} = K_{LOC} (\rho_1 v_1^2 / 2) \tag{3.12}$$

The pressure loss in a bend is mainly caused by the secondary flow set up by the centrifugal forces. The loss coefficient for the bend decreases with the ratio of the bend radius to the pipe diameter (Figure 3.1) [11]. Loss coefficients for certain bends and elbows were reported by Pigott [5] and Kittredge & Rowley [12].

The pressure loss in a sudden expansion is caused by the dissipation of kinetic energy as eddies in the surrounding fluid at the exit region. The pressure loss in a sudden contraction is caused by the flow separation which generates turbulence. The loss coefficients for the expansion and the contraction depend on the upstream and downstream area ratio of the fixture (e.g., Figure 3.2) [11]. These pressure losses can be significantly reduced by changing the area gradually or by rounding the corner of the entrance or exit.

When fluid flows across an obstruction, separation may occur and a turbulent wake is formed behind the obstacle. Some of the pressure energy is converted to kinetic energy and is only partially recovered after the blockage. The unrecovered energy is dissipated as heat. This pressure loss depends upon the size, location, and shape of the blockage.

The pressure loss due to obstruction is expressed as

$$\Delta P_{Ob} = (f_{Ob} t/(D_e)_{Ob})(\rho_1 v_1^2/2) - (ft/D_e)(\rho_1 v_1^2/2)$$

$$+ K_{Ob}(\rho_1 v_1^2/2) \qquad (3.13)$$

where f_{Ob} is the friction factor, t is the thickness, and $(D_e)_{Ob}$ is the hydraulic diameter of the obstruction; f is the friction factor, and D_e is the hydraulic diameter of the channel. For a thin obstruction, the first two terms can be neglected since t is small. Hence, the general expression has the same form as equation 3.12.

The size of the blockage influences the level of turbulence formation which, in turn, affects the pressure recovery. Figure 3.3 shows the percentage of differential head lost as a function of orifice opening ratio [13]; smaller opening ratios are accompanied by larger losses.

The shape of the blockage affects the point of separation. Figure 3.4 shows the flow patterns of a two-dimensional flow around various objects [14]. For the flat plate, the separation point occurs at the edge. A large amount of turbulence, which affects the pressure loss, is formed behind the blockage. The best shape for pressure recovery is the streamlined one (the lower part in Figure 3.4 (c)), for which the separation point occurs so far downstream that the pressure deficit is greatly reduced. A blockage of circular shape causes less pressure loss than the flat plate, but more than the streamlined obstruction. Idel'chik [15] compared the loss coefficients for cylindrical rods of various shapes, and indicated that the streamlined rod had the smallest value. More pressure energy is recovered by rounding the blunt leading edge of the rod (Figure 3.5).

In a string of reactor fuel bundles, the local pressure loss includes the following:

1. the junction pressure loss;
2. the spacer pressure loss; and
3. the bearing pad pressure loss.

Since the total obstructed area by the bearing pads is small as compared to the flow area in a 37-element bundle (less than 2%), the bearing pad pressure loss is assumed to be part of the skin friction pressure loss.

3.2.1 Junction Pressure Loss

Junction pressure loss appears only in a few types of reactor core configurations. In other types, such as in a pressurized water reactor or in a boiling water reactor, each fuel rod occupies the full length of the activated zone in the reactor core. For the pressurized heavy-water reactor (CANDU reactor), the reactor core consists of numerous strings of bundles. Pressure is lost as the coolant flows through the junction of two bundles.

The junction pressure loss is composed of three types of losses:

1. the loss due to the end-plate;
2. the loss due to the discontinuity of fuel elements; and
3. the loss due to the blockage from the exposed rod in a string of misaligned bundles.

It can be written as

$$\Delta P_J = K_J (\rho_1 v_1^2/2) \qquad (3.14)$$

where K_J is the junction loss coefficient.

The local loss at the end-plate region is mainly due to the obstructional effect. The end-plate currently used in the CANDU reactor is the flat plate type which induces a high degree of turbulence.

The pressure loss caused by the discontinuity of the rod is the effect of flow expansion and contraction. The discontinuity effect on pressure loss had been shown experimentally in bundles [8] and plates [16]. Turbulence is generated as soon as the fluid leaves the bundle located upstream of the junction and flows into a larger area (the gap). When the fluid enters the next bundle, separations occur at the edges, and a large amount of pressure energy is lost. The loss can be minimized with a gradual variation of exit and entrance areas.

The loss caused by bundle rotation appears only in misaligned bundle settings. The term 'misaligned bundle' means that the centre line of the fuel rods is not along the same line as that of the adjacent bundle. In such case, the end of the fuel rod for the downstream bundle is exposed to the subchannel flow (Figure 3.6). The pressure loss due to the additional obstruction of the exposed rods in a string of misaligned bundles depends mainly on the shape of the end-plug. The pressure loss can be reduced by using a round or streamlined shape, which does not promote eddy formation.

3.2.2 Spacer Pressure Loss

The spacer used to maintain the subchannel space and prevent rod vibration, tends to induce a high pressure loss by blocking the flow.

The type of spacer used in the reactor depends upon the core configuration. Spacers are produced in various types: wire type, plate type, grid type, and wart type. Some examples of spacing devices are shown in Figure 3.7. The pressure loss due to the wire-type spacer is distributed evenly throughout the length of the rod. It is usually assumed to be part of the skin friction pressure loss. The pressure loss for the other type of spacing devices occurs in the local region. A significant drop of static pressure is always observed in the vicinity of the spacer. Rehme [17] stated that the pressure loss due to the grid-type spacer is directly proportional to the ratio of projected grid cross-sectional area to the unobstructed flow area. From his experimental data, he obtained identical loss coefficients for the grid-type spacer in both triangular and square arrangements of fuel rods. However, his prediction has been found not to be valid for the other type of spacer [18].

Spacer pressure loss is also an obstructional type of local loss. It is affected by such factors as the shape of the leading edge [19] and the trailing edge [20], the roughness of the rod [21], and the length of the spacers [18]. It can be expressed as

$$\Delta P_S = K_S (\rho_1 v_1^2/2) \qquad (3.15)$$

where K_S is the spacer loss coefficient. The spacer loss coefficient is often obtained from experimental investigations. However, an analytical method introduced by

Barroyer [22] has shown a good agreement with the experimental data of other researchers.

3.3 TOTAL PRESSURE LOSS

The total pressure loss in a string of bundles is the summation of the skin friction pressure loss and all the local pressure losses. It is written as

$$\Delta P_T = \Delta P_F + \Delta P_J + \Delta P_S \tag{3.16a}$$

$$= (fL/D_e + K_J + K_S)(\rho_1 v_1^2/2) \tag{3.16b}$$

$$= K_T(\rho_1 v_1^2/2) \tag{3.16c}$$

where K_T is the total loss coefficient.

Chapter IV

TWO-PHASE FLOW

When the coolant flows through the activated bundles in some reactors, it is partially evaporated after extracting heat from these high-temperature bundles. In the recent reactor operation, the exit flow quality has been increased to about 3.5% at higher power levels. The vaporized coolant travelling down the pressure tube together with the liquid constitutes a two-phase flow.

Two-phase flow consists of a simultaneous flow of two different states of matter (i.e. vapour and liquid, liquid and solid, or vapour and solid). It can be encountered in industrial applications, for example, in boilers, heat exchangers, pressure tubes of a reactor core, etc. A similar condition for two different substances flowing along the same passage is called the two-component flow. Even though two-phase flow and two-component flow are different in nature, the common name 'two-phase flow' has been adopted by researchers for both types of flow. Two-component flow has been widely used in research to simulate the two-phase flow conditions, since the gas and liquid flow loop is easier to control and operate. Furthermore, the operating loop with steam and water is more expensive than that with gas and water. If the differences in density and viscosity for both types of flows are compensated, the experimental data from the two-component flow may be extended to provide information for the two-phase flow [23]. However, the similitude criteria are not well established and caution should be exercised for extrapolating results.

4.1 FLOW PATTERN

Two-phase pressure loss is affected by the flow distribution as well as by the basic parameters that determine the single-phase pressure loss [24,25]. Depending on the conditions of the flow (e.g. velocities of the phases), the two phases are distributed differently in the channel. These phase distributions are called flow patterns or flow regimes. Though different names have been used in describing the flow patterns by various authors, only five of them in vertical flow and six of them in horizontal flow have been widely adopted [26]. The main difference between the vertical and horizontal flow patterns arises from the gravitation effect on the horizontal flow. The gravitational force tends to bring the liquid flow towards the bottom of the channel. The flow patterns defined in the horizontal flow, which are shown in Figure 4.1 [27], are described as follows:

1. Bubbly flow : A dispersion of bubbles flows continuously within the liquid. Owing to the gravity, the liquid occupies mainly the bottom portion of the channel. This kind of flow normally occurs in high liquid and low gas superficial velocity flows.

2. Plug flow : As the gas velocity increases, the size of the bubbles grows and bullet-shaped bubbles are generated. These bubbles move closer to the top of the channel due to the gravitational effect that brings the liquid flow to the bottom.

3. Stratified flow : Under the influence of gravity, the liquid is moving smoothly under the gas.

4. Wavy flow : This is a rough stratified flow. The two phases are still moving in separate layers, but waves are formed at the interface because of the increase in gas velocity.

5. Slug flow : If the gas velocity increases, some waves become so pronounced that they touch the top surface of the channel.

6. Annular flow : At very high gas velocity, the gas phase rushes through the core of the channel with the liquid phase flowing around it. Usually, there is liquid entrainment in the gas core and the bottom liquid film is thicker than the top one due to the gravitational effect.

The flow patterns are presented in map form with the properties of the phases as the coordinates. After Baker [28] introduced the earliest flow pattern map, numerous studies have been performed and flow pattern maps were produced in various coordinate systems. Mandhane et al. [29] gathered a substantial amount of flow pattern data and presented a generalized map in the coordinate system of liquid and gas superficial velocities. Dukler [30] analytically developed a model to predict the flow transition boundary. The result shown in Figure 4.2, indicates that the boundaries are slightly shifted when compared with those provided by Mandhane et al. [29]. Besides the maps, equations have also been proposed to locate the flow transition line [31].

The flow pattern transition is greatly affected by the velocities of the two phases. In addition, other factors such as the fluid properties, the geometry of the channel [32], the inclination of channel to the horizontal plane [33,34], and the local disturbance [35] also have significant influences on the flow pattern transition.

4.2 TWO-PHASE PRESSURE LOSS

The pressure loss for the two-phase flow is often much larger than that for the single-phase flow due to the presence of an inter-phase shear force. For analysis, assumptions are usually introduced to simplify the complexity of two-phase flow. Two models have been used to investigate the two-phase pressure drop. The first one, which assumes the same velocity for the two phases, is the homogeneous flow model. This model is applicable for the bubbly flow pattern. It has been widely adopted for pressure loss calculations in petroleum and refrigeration industries. The second model, based on the assumption of two different phase velocities, is the separate flow model. It considers the phases travelling separately in two streams with a distinct inter-phase boundary separating them. The separate flow model is valid for both the stratified flow and the annular flow patterns.

In general, the total pressure loss is composed of the following :

1. frictional pressure loss;
2. accelerational pressure loss;
3. gravitational pressure loss; and
4. local pressure loss, such as change of direction, area, etc.

4.2.1 Two-phase Frictional Pressure Loss

The frictional pressure loss is produced by the shear stress not only between the phases and the wall of the channel, but also between the two phases themselves. Lockhart and Martinelli [36] introduced a parameter defined as the ratio of the two-phase pressure loss to the single-phase pressure loss. The single-phase pressure loss is obtained when only the liquid phase is flowing in the channel. The parameter is called the two-phase multiplier and is written as

$$\phi_L^2 = \Delta P_{TP} / \Delta P_L \qquad (4.1)$$

where ΔP_{TP} is the two-phase pressure loss, and ΔP_L is the single-phase pressure loss. Equation 4.1 can be applied to the two-phase flow with no phase change (e.g. air-water flow). In such case, the flow quality is constant along the channel. For two-phase flow with phase change (e.g. steam-water flow), the flow quality varies along the channel and is difficult to measure or estimate. The two-phase multiplier in the form of a ratio of the two-phase pressure loss to the pressure loss when the total flow is flowing with single-phase physical properties, was presented by Martinelli and Nelson [37]. It is defined as

$$\phi^2_{LO} = \Delta P_{TP} / \Delta P_{LO} \tag{4.2}$$

and is the most accepted relation for two-phase flow associated with phase change.

The ratio between ΔP_L (the pressure loss obtained by assuming liquid only flow) and ΔP_{LO} (the pressure loss obtained by assuming the total flow to be liquid) is expressed as [38]

$$\Delta P_L = \Delta P_{LO} (1-x)^n \tag{4.3}$$

where x is the quality. The relation between equations 4.1 and 4.2 can then be written as

$$\phi^2_{LO} = \phi^2_L (1-x)^n \tag{4.4}$$

The index 'n' has been evaluated by many authors [38,39,40]. Even though its value varies among different authors, the pressure loss ratio will not be significantly affected by 'n' for low quality flows.

From a series of two-phase mixture experiments, Lockhart and Martinelli first proposed a systematic correlation of the two-phase multiplier for the gas-liquid flow. The correlation expresses the two-phase multiplier for friction (two-phase frictional multiplier) as a function of the density and viscosity ratio of the two phases. Similar results were also derived from the theoretical approach by Chisholm [41]. Although the Lockhart and Martinelli correlation has been shown to be more reliable than the other correlations [42,43], the predicted values are sometimes different from the experimental data. The difference seems to be partly caused by the exclusion of the flow pattern effect [44,45].

Another empirical correlation that takes into consideration the influence of mass velocities in addition to the densities and the viscosities of the two phases, was proposed by Baroczy [39]. The correlation closely estimates the experimental data for the two-phase flow both with and without phase change. In a theoretical development, Chisholm [38,46] derived an equation that provides values close to those obtained from the Baroczy correlation.

Analytically, Dukler et al. proposed a frictional pressure loss correlation based on similarity analysis [47]. Correlations for both homogeneous and slip flow were presented. They were proven to be reasonably reliable for the prediction of pressure loss [43].

A different approach was used by Levy who introduced a pressure loss correlation based on the mixing length theory model [48]. Good agreement was obtained between the experimental results and the predicted values for both laminar and turbulent flows. With the same theory, Beattie extended the two-phase pressure loss study for various flow conditions [49,50]. A complete summary of the equations for the two-phase friction factor and for the ~~two~~-phase Reynolds number in different types of flow is presented by the same author [51]. A simpler method has also been introduced to calculate the frictional pressure loss [52], however, it is not recommended for flow with local disturbances such as spacers in the rod bundle.

On comparing published correlations for the steam-water flow, the ones by Baroczy [38], Thom [53], and the homogeneous theory have been shown to perform best [54].

For bundle geometry, the equivalent diameter concept is accepted by most researchers. Lahey summarized the available correlations for various flows in the Boiling Water Nuclear Reactor [40]. Beattie has shown that the mixing length theory is also applicable for cluster geometry [55].

4.2.2 Two-phase Accelerational Pressure Loss

The two-phase accelerational pressure loss is a measure of the difference between the in and out momentum flux. For the homogeneous flow model, the accelerational pressure loss is expressed as

$$\Delta P_A = G^2 \Delta(x/\rho_g + (1-x)/\rho_l) \tag{4.5}$$

where G is the mass flux of the mixture, x is the quality, ρ_g is the density of the gaseous phase, and ρ_l is the density of the liquid phase. For the separate flow model, it is written as

$$\Delta P_A = G^2 \Delta(x^2/(\rho_g \alpha) + (1-x)^2/(\rho_l (1-\alpha))) \tag{4.6}$$

where α is the void fraction.

The separate flow model is widely used by researchers because the assumption is more adapted to the real flow situation. However, the homogeneous flow model has been shown to predict the experimental results closely for many practical situations [56]. The two-phase acceleration pressure loss is a significant factor in two-phase flows with phase change [37,53], but it can be neglected in channel flows when the phase change does not occur [57] and the density gradients are small. Martinelli and Nelson [37] separated this term from the total pressure loss and defined it as a function of a multiplier which was adopted by other researchers in steam-water flow [53,56].

4.2.3 Two-phase Gravitational Pressure Loss

The two-phase pressure loss due to gravity is a measure of change in hydrostatic head. It is written as

$$\Delta P_G = g \sin\theta (\rho_g \alpha + \rho_l (1-\alpha)) \tag{4.7}$$

where g is the acceleration due to gravity, and θ is the angle between the flow direction and the horizontal plane. For horizontal flows, the two-phase pressure loss due to gravity is not present since the angle θ is 0°.

4.2.4 Two-phase Local Pressure Loss

The pressure loss due to local disturbances can be caused, as in single-phase flow, by either

1. a change in direction, e.g., bend;
2. a change in area, e.g., sudden expansion or contraction; or
3. a flow obstruction, e.g., valve or orifice.

The pressure loss is produced by the flow separation, the turbulent wake formation and the acceleration effect. The pressure loss is expressed as the two-phase multiplier which is defined as

$$(\phi^2_{LO})_{LOC} = (\Delta P_{TP}/\Delta P_{LO})_{LOC} \tag{4.8}$$

Since bends are common fixtures in pipe systems, the pressure losses produced by bends have been extensively investigated. Chisholm and Sutherland [38] proposed a two-phase multiplier for bends using the Lockhart and Martinelli parameter. Chisholm [58] further presented a simpler equation with which the obtained values agreed with the experimental data of Fitzsimmom [59]. An improved correlation was provided by introducing the single phase loss coefficient [60].

Pressure losses in both sudden expansion and sudden contraction are caused by the separation and the acceleration of the phases, and the change of interphase shear stress due to variation of phase velocities. From a series of experimental results, correlations for these pressure losses in both single-phase and two-phase flows have been presented by Richardson [61]. Lottes [62] compared four different correlations (including the Richardson correlation) and recommended the Romie correlation for sudden expansion. In the study of the sudden contraction, Geiger and Rohrer [63] found that the pressure drop was influenced by the flow regime in the reexpansion. They suggested the use of the homogeneous two-phase multiplier for the prediction. Chisholm [38,57] presented a similar equation for both sudden contraction and sudden expansion, but with different coefficients for each case. For the sudden contraction, the equation is identical to the homogeneous two-phase multiplier relation.

Flow blockages such as orifices, venturis and nozzles have been investigated for two-phase flow rate measurements [64]. Janssen [65] observed a homogeneous mixture after the orifice. This was an indication that the homogeneous two-phase multiplier which was also mentioned by Chisholm [57], was applicable. Correlations for orifices have been proposed by various authors [66,67,68]; however, some of them are subjected to specific assumptions or conditions. For other blockages such as valves or plates, Chisholm provided a general equation with different coefficient values to adapt for various cases [38,57].

The two-phase local pressure loss in a string of bundles* include :

1. the two-phase junction pressure loss; and
2. the two-phase spacers pressure loss.

These losses are mainly due to the effect of obstruction. Though investigations have been performed on the subject, access to the information is difficult because of the

*The two-phase pressure loss due to the bearing pads has been assumed as part of the skin friction pressure loss.

commercial confidentiality.

Sher et al [69] performed low-pressure tests on the 81-pin square array bundles and high-pressure tests on the 16-pin square array bundles. They proposed a spacer pressure loss prediction method that agreed reasonably well with their low-pressure test data. For the high-pressure investigation, they recommended Lottes' model for estimating the local losses.

Beattie extended the mixing length theory for estimating the two-phase multipliers for orifices and spacers [51]. The proposed equations agreed with his experimental results.

4.2.5 Two-phase Total Pressure Loss

The two-phase total pressure loss for the investigated geometry is the summation of all pressure loss components:

$$(\Delta P_{TP})_T = (\Delta P_{TP})_F + (\Delta P_{TP})_J + (\Delta P_{TP})_S + (\Delta P_{TP})_A \qquad (4.9)$$

where $(\Delta P_{TP})_F$, $(\Delta P_{TP})_J$, $(\Delta P_{TP})_S$, and $(\Delta P_{TP})_A$ is the pressure loss due to friction, junction, spacer, and acceleration, respectively.

Chapter V
OBJECTIVE

The present experimental work was carried out in single-phase (water) and two-phase (air-water) horizontal flows. It consisted of two sections:

The first section (Experiment A) of the work investigates the effects of both the size and location of an obstruction on the pressure loss in horizontal channel flow. The tests were performed on six different shapes of obstruction, each one with two different flow blockage ratios (25% and 40%).

The second section (Experiment B) of the work investigates the influence of the shape of the obstruction upon the pressure loss in the bundle geometry. The tests were performed on two sets of bundles : the simulated regular bundle used currently in the CANDU reactor, and the streamlined bundle which was modified according to the streamlining concept. The total pressure loss in a string of bundles is separated into various components which are compared between the two types of bundles.

Chapter VI

EXPERIMENTAL SET-UP

In the present work, two experimental loops were used. The effects of obstruction size and location on pressure loss are being investigated with the loop set-up (Figure 6.1) at the University of Ottawa (hereafter will be called Experiment A). The effect of obstruction shape on pressure loss and the pressure loss comparison between the simulated regular bundle and the streamlined bundle are being investigated with the loop set-up (Figure 6.2) at the Chalk River Nuclear Laboratory (hereafter will be identified as Experiment B).

6.1 THE LOOP

The construction of the flow loop was similar for both Experiment A and Experiment B. Water and air were the working fluids. Air was supplied by the compressor of the central system. Both streams were adjusted manually with gate valves. The flow rates of water and air were measured with rotameters of different ranges. A Bourdon gage was installed at the common outlet of the air rotameters. The gauge pressure reading was used for pressure correction of the rotameter reading. A gate valve was installed at the exit of the test-section to control the pressure of the system.

In the two-phase flow test, the fluids were mixed with a mixer. The mixture was stabilized in a calming section before entering the section in which the measurements were carried out.

The differences between the two experimental loops are the circulation of water, and the type of mixer used to mix the fluids.

6.1.1 Experiment A

Water, which was circulated in an open loop, was supplied from the building water supply line at 1.03 MPa (150 psia) with maximum discharge rate of 0.002 m^3/s (4.24 scfm). It was led to the drainage after passing through the test-section. The mixer used was a honey-comb type.

6.1.2 Experiment B

The water was recirculated by a centrifugal pump with a maximum flow rate of 1.84 kg/s (30 USGPM). The water and air were mixed with an air sprayer with air injected into the water stream in various directions. After passing through the test-section, the mixture was led to a reservoir where the phases were separated. The water was recirculated in the system, and the air was exhausted to the atmosphere.

6.2 TEST-SECTION

6.2.1 Experiment A

The test section as shown in Figure 6.3 consisted of two 0.0254-m ID, 2-m long Lucite tubes. A flange was used to hold the obstruction plate and to connect both sections. A total of 17 pressure taps were installed along the test-section for pressure measurement.

6.2.2 Experiment B

The test section as shown in Figure 6.4 consisted of a 0.0381-m ID, 1.83-m long Lucite tube. It was connected to the loop with flanges for easy removal so that the bundles could be adjusted or replaced. Twenty-three pressure taps were installed along three 0.5-m long bundles for pressure measurement.

6.3 PRESSURE MEASUREMENT

The static pressure variation along the test-section was measured with Meriam 33KB35 well-type multitube manometers. Through a 0.00635-m ID plastic tube filled with water, the static pressure in the test-section was applied to the manometric fluid which was water for the single-phase test. For the two-phase test, the manometric fluid was Meriam No. 3 fluid (Acetylene Tetra-bromide, S.G. 2.95) in Experiment A, and mercury (S.G. 13.6) in Experiment B. The other end of each manometer was connected to a tank which provided the same reference pressure head. Toggle valves were installed between the pressure taps and the manometers. They could be closed simultaneously to hold the pressure readings for recording.

6.4 BY-PASS SYSTEM

Air bubbles which affected the accuracy of the readings, were often trapped in the plastic tubes especially during the two-phase flow test. A by-pass line was connected to each plastic tube between the pressure tap and the toggle valve. The by-pass lines, which were controlled by another set of toggle valves, were used to drain the air bubbles from the plastic tubes.

6.5 OBSTRUCTIONS

6.5.1 Experiment A

Six different shapes of obstruction plates are shown in Figure 6.5, with two blockage area ratios (25% and 40%). The obstructions are :

1. the central obstruction - a circular blockage which is supported by three steel rods*. It obstructs the center part of the flow area.

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*The blockage area includes the obstructed area by the steel rods.

2. the peripheral obstruction - a blockage which obstructs the circumference of the flow area.
3. the horizontal obstruction - a horizontal strip obstructing the center part of the flow area.
4. the vertical obstruction - the same blockage as in (3) but placed vertically.
5. the bottom obstruction - a circular segment located at the bottom of the flow area.
6. the top obstruction - the same obstruction as in (5) but placed at the top of the flow area.

6.5.2 Experiment B

Two sets of 4-rod bundles were constructed. One of them simulated the regular bundle, whereas the other simulated the modified bundle.

6.5.2.1 The Simulated Regular Bundle

The bundle was composed of four stainless steel tubes with two end-plugs (one at each end), one central rod, two end-plates, sixteen spacers, and twelve bearing pads (Figure 6.6). The rods, end-plugs, spacers, and bearing pads had the same dimensions as those in the 37-element bundle. The central rod, which was used to provide the bundle with the same hydraulic diameter as a 37-element bundle, had the same length as the rods. The shape of the end-plate was circular with a rectangular cross-sectional area, which gave a flat surface facing the flow direction.

6.5.2.2 The Modified Bundle

The components of the modified bundle were the same as those in the simulated regular bundle (Figure 6.7). The end-plug was hemispherical in shape with the same diameter as the rod. To keep the overall length uniform, the rods were shortened by about 1 cm to adjust for the increased size of the end-plugs. These changes were also applied to the central rod. The end-plate which had the same mean-diameter as the one in the regular bundle, is shown in Figure 6.8. It had a circular cross-sectional shape which provided a smooth entrance and exit to the flow. The spacer and bearing pad of the modified bundle had the same size as those in the simulated regular bundle. However, the edges of the spacer and bearing pad had been smoothened and rounded (Figure 6.9).

Chapter VII

EXPERIMENTAL PROCEDURE

7.1 OBSTRUCTION SETTING

7.1.1 Experiment A

An obstruction plate was inserted between two flanges which were tightened with three screws.

7.1.2 Experiment B

The simulated regular bundles were aligned in the test-section. A small pin was inserted into two small holes on the adjacent end-plates to keep a fixed relative position between bundles.

7.2 SINGLE-PHASE FLOW TEST

Water was circulated at the maximum rate. The toggle valves were opened. After a steady manometric fluid level had been reached, the valves were closed simultaneously. If air bubbles were found trapped in the plastic tubes, they would be removed through the by-pass lines, and the test would be repeated until no more bubbles were detected. The heights of the manometric fluid in each manometer were recorded.

7.2.1 Experiment A

The procedure was performed on each of the twelve obstruction plates at a constant water flow rate of 0.3 kg/s.

7.2.2 Experiment B

The procedure was performed on the simulated regular bundles (0°, 22.5° and 45.0° misalignments), and the streamlined bundles (0°, 22.5° and 45.0° misalignments) at various water flow rates as presented in Table 7.1.

7.3 TWO-PHASE FLOW TEST

Before performing the two-phase flow test, the manometric fluid was replaced, and the reference tank was filled with water. The air in the pressure measuring system was drained.

Air was introduced to the system before the water to prevent the water from flowing into the air system. The water flow rate was adjusted to the desired value and the air flow rate was adjusted to the maximum pre-set value. The toggle valves were opened. When the steady level of the manometric fluid was reached, the valves were closed simultaneously. After trapped air bubbles in the plastic tubes had been removed, the procedure was repeated. The heights of manometric fluid were recorded. The test was also performed for several lower air flow rates.

7.3.1 Experiment A

The procedure was performed on various obstruction plates with the water and air flow rates as presented in Table 7.2.

7.3.2 Experiment B

The same test was performed on the simulated regular bundles (0°, 22.5° and 45.0° misalignments) and the streamlined bundles (0°, 22.5° and 45.0° misalignments) at the ranges of water and air flow rates as shown in Table 7.3.

Chapter VIII

RESULTS AND DISCUSSION

8.1 EXPERIMENT A

The effects of size and location of the obstruction are being investigated in Experiment A. Local pressures in 17 axial positions along the test-section are calculated based on the heights of manometric fluid. Pressure distribution curves are drawn with the local pressure readings as a function of the axial distance. Frictional pressure losses and local pressure losses are evaluated from the pressure distribution curve.

8.1.1 Single-phase Flow

The frictional pressure loss is expressed in terms of the friction factor, while the local pressure loss is expressed in terms of the loss coefficient.

8.1.1.1 Pressure Distribution

The pressure variation along the test-section can be divided into five separate regions. This is illustrated in Figure 8.1 for the 40% peripheral obstruction plates. The flow in Region I and V is the undisturbed channel flow which is only affected by the friction between the flow and the channel wall. An increase of the static pressure, which is caused by the stagnation effect of the flow obstruction, is shown in Region II. The conversion of pressure energy to the mean kinetic energy of the flow and the turbulent kinetic energy due to the obstruction, occurs in Region III. A significant pressure drop occurs in this region. Part of the energy is recovered after the obstruction as the velocity decreases. The remaining energy is dissipated as heat (Region IV). The length of regeneration, which is the required distance for flow recovery, takes about five pipe diameters in the single-phase flow.

8.1.1.2 Friction Pressure Loss

The friction pressure loss results in a gradual decrease of static pressure in the non-obstructed channel. It is expressed as a function of the friction factor

$$f = (\Delta P_F D_e / L)/(\rho_l v_l^2 /2) \tag{8.1}$$

in Table 8.1. The friction factor is affected by experimental errors and channel parameter variation (channel diameter, velocity, etc.). The average of the upstream and downstream friction factors is calculated. The standard deviation for the friction factor as shown in Table 8.1 is 0.0006.

Several estimated values for channels assumed to behave as smooth pipes are also presented for comparison. The experimental results are larger than the predicted values. This indicates that the channel cannot be considered as a smooth one. By using the Colebrook equation, the relative roughness of the channel is found to be 0.00128.

8.1.1.3 Local Pressure Loss

The local pressure loss caused by the obstruction, as indicated in Figure 8.1, is the net energy loss through the blockage. It is expressed as the loss coefficient which is written as

$$K_{Ob} = \Delta P_{Ob} / (\rho_1 v_1^2 / 2) \qquad (8.2)$$

and is shown in Table 8.2. The blockage size has a strong influence on pressure loss. More pressure energy is lost for a larger blockage when comparing the same obstruction of different sizes. The central type obstructions (both the central and the central segment obstructions) cause the largest amount of loss, while the peripheral obstruction generates the least. This is probably due to the blocking of the high velocity flow by the central obstruction while the low velocity flow is blocked by the peripheral obstruction. For the central obstruction, the blockage area is calculated including the flow obstructed area of the support rods. The horizontal and vertical segments, respectively the top and bottom segments should give the same pressure loss. The difference is due to experimental inaccuracy. An average value is taken for the respective obstructions.

8.1.2 <u>Two-phase Flow</u>

The two-phase pressure losses caused by various obstruction plates are obtained for the range of air flow rates as shown in Table 7.2. The pressure losses are expressed as two-phase multipliers and plotted against the flow quality.

8.1.2.1 Pressure Distribution

The pressure variation along the axial distance in two-phase flow is similar to the one in single-phase flow. As indicated in Figure 8.2, the static pressure in the test-section is much larger. The five regions are also identified in the distribution curve for two-phase flow. The pressure loss in Region I and V is frictional loss. The stagnation effect from the obstruction is observed in Region II. A much larger local loss occurs in Region III and the flow takes a longer distance to recover than in the single-phase flow (Region IV).

8.1.2.2 Two-phase Frictional Pressure loss

The frictional pressure loss in two-phase flow is larger than the one in single-phase flow. It is expressed in terms of the two-phase multiplier

$$(\phi^2_{LO})_F = (\Delta P_{TP} / \Delta P_{LO})_F \qquad (8.3)$$

which is shown in Figure 8.3 through Figure 8.6 for the flows upstream and downstream of the obstruction. The two-phase multipliers increase with the quality. The upstream two-phase multipliers are identical for various obstruction plates. The downstream two-phase multipliers are larger than the upstream ones and different for various obstruction plates. The difference is caused by the density and void distribution variation due to the obstruction.

Some two-phase frictional multiplier correlations are also presented in Figure 8.3 to Figure 8.6. The homogeneous two-phase theory (with the viscosity term) and the Beattie correlation have shown good agreement with the experimental results in the low quality flow. However, they tend to underestimate the results as the quality rises. The Lockhart & Martinelli prediction is valid for low quality flow but it gives larger values than the obtained results for high quality flow. The Chisholm correlation gives a reasonable estimation in high quality, but predicts larger values than the experimental results at low quality. When comparing the two-phase homogeneous multipliers (with and without the viscosity term), the viscosity difference of the phases has a significant influence on the prediction.

8.1.2.3 Two-phase Local Pressure Loss

The two-phase local pressure loss is affected not only by the size and location of the obstruction, but also by the distribution of the phases. The pressure losses for various obstructions are shown in Figure 8.7 and Figure 8.8. They increase with increasing quality. The pressure loss is much higher for the 40% blockage than for the 25% one. On comparing the pressure losses caused by the obstruction in different locations, the bottom segment obstruction causes the largest pressure loss, while the top segment obstruction causes the least. Since the bottom segment obstruction interferes mainly with the liquid phase (which moves in the bottom part of the channel due to the flow stratification effect), and the top segment obstruction interferes mainly with the gas phase, one might conclude that less pressure is lost for the blockage that obstructs the gaseous phase. This effect can also be observed from the pressure loss difference between the vertical segment and the horizontal segment obstructions. More pressure is lost for the vertical segment obstruction because it blocks the liquid phase more than the horizontal segment obstruction. Despite the fact that the peripheral obstruction causes the least pressure loss in the single-phase flow, it causes a significant pressure loss in two-phase flow. This is on account of the effect of flow distribution. Within the experimental range, it appears that the flow pattern is annular according to the Dukler flow transition map (Figure 4.2). The liquid phase which travels along the circumference of the channel is blocked by the peripheral obstruction; thus, more energy is lost. The central obstruction that causes the largest pressure loss in the single-phase flow does not produce a large loss in the two-phase flow because it interferes mainly with the high-velocity gaseous phase.

The two-phase multiplier for the obstruction is affected by both the single-phase and two-phase pressure losses. It is defined as

$$(\phi^2_{LO})_{Ob} = (\Delta P_{TP} / \Delta P_{LO})_{Ob} \qquad (8.4)$$

and is shown in Figure 8.9 and Figure 8.10. The bottom segment obstruction and the peripheral obstruction have larger two-phase multipliers because of the larger two-phase pressure loss for the former obstruction and the least single-phase pressure loss for the latter one. The top segment obstruction causes the least two-phase pressure loss among all and has the smallest two-phase multiplier.

The two-phase multiplier from the experimental results are compared with values provided by some correlations. The comparisons are shown in the Figure 8.9 and Figure 8.10. In general, the two-phase multiplier values from the homogeneous theory (with the viscosity term) and from the Chisholm correlation for the thin plate have better agreement with the experimental results than the other presented correlations. However, in view of the large variation of the two-phase multipliers with the size and the location of the obstruction, the correlations do not predict the two-phase multiplier values correctly for various obstructions.

8.2 EXPERIMENT B

The effect of the obstruction shape on pressure loss is investigated in Experiment B. The local pressure readings along two sets of bundles are obtained. They are plotted against the axial distance to provide the pressure distribution curve from which the pressure losses are evaluated.

8.2.1 Single-phase Flow

The single-phase flow tests are performed with a range of water flow rates as shown in Table 7.1. The frictional pressure loss is expressed as both the loss coefficient and the friction factor. The local pressure losses are expressed in terms of loss coefficients.

8.2.1.1 Pressure Variation

When the flow travels along the bundle, the static pressure decreases gradually because of friction, and sharply in the vicinity of local disturbance. An example of the pressure distribution for the aligned regular bundles is illustrated in Figure 8.11. The locations of various planes are indicated with dotted lines. The frictional pressure loss appears to be uniform, since the roughness is the same throughout the bundle section. Local pressure loss exists because of the flow interference with the obstruction. The junction pressure loss is much larger than the spacer pressure loss. This is caused by the larger blockage area and the discontinuity of the rods in the junction plane. Along the string of bundles, the respective losses for junctions and spacers at various locations are close.

The trend of pressure variation for various bundle settings of the regular bundle and the streamlined bundle corresponds closely (Figure 8.11). However, the magnitude of the local loss varies for different arrangements. The differences in losses are shown in terms of head loss coefficients as a function of Reynolds numbers in Figure 8.12 to Figure 8.15.

8.2.1.2 Skin Friction Pressure Loss

The frictional pressure loss is identical for both types of bundles in various misalignments because the rods in each bundle have about the same roughness. The frictional pressure loss is expressed as the friction loss coefficient which is defined as

$$K_F = \Delta P_F/(\rho_1 v_1^2/2) \qquad (8.5)$$

and is shown in Figure 8.12. The loss coefficient decreases with increasing Reynolds numbers for the lower range, but becomes constant at large Reynolds numbers.

The frictional pressure loss is also expressed as the friction factor

$$f = (\Delta P_F D_e/L)/(\rho_1 v_1^2/2) \qquad (8.6)$$

which is presented in Figure 8.13 along with some correlations. Within the experimental range, the friction factors obtained from Blasius equation for smooth tubes, and those obtained from the Colebrook equation (with ϵ/D =0.0002) are very close. However, these equations tend to underestimate the present experimental results. Predictions proposed by Malak et al. and Rehme for the bundle geometry have shown a closer agreement with the present results. This indicates that the channel geometry does have a significant influence on the friction factor. By using the Colebrook equation, the relative roughness is found to be 0.00076.

8.2.1.3 Junction Pressure Loss

The junction pressure loss is presented by the junction loss coefficient for various bundle arrangements. The junction loss coefficient is written as

$$K_J = \Delta P_J / (\rho_1 v_1^2 / 2) \quad (8.7)$$

and is shown in Figure 8.14. For the regular bundle, the junction loss coefficients are not affected by the Reynolds number. The misalignment of bundles has a strong influence on the pressure loss. The junction loss coefficient rises with an increase in misalignment angle. This is caused by the additional blockage from the exposed rods that increases the turbulence level in the subchannel flow. However, the rate of increment is slower when going from 22.5° to 45.0° of misalignment than from 0° to 22.5°.

The junction loss coefficients for the streamlined bundle vary with Reynolds numbers, but are not significantly affected by the change in bundle rotation. The reason is that the direction of flow changes so gradually that turbulence is substantially reduced.

As the flow passes through the obstruction, pressure and friction drags usually occur. The pressure drag is the force resulting from the pressure difference and tends to move the body with the flow. The friction drag is the surface resistance between the fluid and the body. These drags can occur either separately or combined on the body. The dependency of these drags on the Reynolds number can be easily observed as the fluid flows across a thin flat plate in various directions. When the plate is held perpendicular to the flow, the pressure drag can be significant, while the friction drag is negligibly small. The drag coefficient, which is generally adopted to express the drag force, does not depend considerably on the Reynolds number for large Reynolds number turbulent flow. On the other hand, the friction drag has stronger influence as the fluid flows parallel to the thin plate. The friction drag coefficient, unlike the pressure drag, has a strong dependence on the Reynolds number. This seems to explain the dependence of the junction head loss coefficient on the Reynolds number for the streamlined bundle as opposed to the regular bundle, which exhibits a constant junction loss coefficient for the investigated range.

8.2.1.4 Spacer Pressure Loss

The spacer pressure loss is presented by the spacer loss coefficient for both types of bundles. The spacer loss coefficient is defined as

$$K_S = \Delta P_S/(\rho_1 v_1^2/2) \qquad (8.8)$$

and is shown in Figure 8.15. It is slightly affected by the Reynolds number. The small loss coefficient corresponds to the high Reynolds number. The loss coefficient for the regular bundle is larger than that for the streamlined bundle. This indicates that the pressure recovery can be improved with a minor modification to the shape of the blockage. From the obtained results, the loss coefficients for both types of bundles are slightly affected by the bundle rotation. One possible explanation would be that the spacers are located within the eddy zone created by the junction of the misaligned bundles.

8.2.1.5 Total Pressure Loss

The total pressure loss is expressed in terms of the loss coefficient which is defined as

$$K_T = \Delta P_T/(\rho_1 v_1^2/2) \qquad (8.9)$$

and is shown in Figure 8.16. The loss coefficient decreases as the flow rate increases. A large part of the total pressure loss is contributed by the frictional component which is approximately 50% of the total pressure loss for the 45.0° misaligned regular bundle and 75% for the streamlined bundle. The second dominant factor is the junction pressure loss which induces the dependence of the total pressure loss upon the misalignment of the bundles. The modified shapes in the junction plane have improved the pressure recovery up to about 33% (on comparing the streamlined bundle and the 45.0° misaligned regular bundle) at larger Reynolds numbers. Though improvement has been shown for the spacer pressure loss of the streamlined shape, it did not significantly affect the total pressure loss. This is because the spacer pressure loss is only about 5% of the overall pressure loss.

8.2.2 Two-Phase Flow

Two-phase flow tests are performed on each set of bundles at the ranges of water and air flow rates as shown in Table 7.3. The two-phase pressure losses are obtained from the pressure distribution curve. Two-phase multipliers for the experimental results are presented with some existing correlations.

8.2.2.1 Pressure Distribution

The trend of pressure distribution in two-phase flow is similar to that in single-phase flow, but the magnitude of the individual loss is much larger in two-phase flow. An example of the two-phase pressure distribution for the aligned regular bundle is shown in Figure 8.17. The pressure is lost gradually because of friction; however, the rates of dissipation are not identical in various sections. This is probably caused by the acceleration effect and the change of the flow distribution due to the presence of the flow obstruction. The acceleration pressure loss effect is eliminated by using the separated flow model with the estimated void fraction from the Armand-Messina correlation* [70]. The resulting friction pressure loss is illustrated in Figure 8.18. Since there is no phase change occurring in the channel, the acceleration pressure loss does not significantly affect the total pressure loss. The comparison shows that it is less than 3% of the total pressure loss. Thus, the increase of the pressure loss gradient is mainly caused by the change of the flow distribution due to the obstruction effect in the junction region. The mean frictional pressure loss for the last two bundles is calculated.

The local losses due to the junction and spacer are also indicated in the figure. As in the single-phase flow, the junction pressure loss is larger than the spacer loss. Along the string of bundles, the respective losses in the junction

*The Armand-Messina correlation is defined as

$$\alpha = (0.833+0.167x)/(1+(1-x)\rho_g/(x\rho_l)) \quad (8.10)$$

and spacer planes are slightly different, probably because of changing density and void distribution. The spacer pressure loss in the first bundle is not considered because it is located in the entrance region.

The two-phase pressure variation for the aligned streamlined bundle is shown in Figure 8.19. The comparison made with the regular bundle indicates that the two-phase frictional pressure loss is identical for both types of bundles, but less pressure loss occurs in the spacer and junction areas.

8.2.2.2 Two-Phase Frictional Pressure Loss

The frictional pressure loss increases with increasing quality and water flow rate, and it is not affected by the bundle misalignment. The average two-phase frictional pressure loss of the last two bundles is calculated and is illustrated in Figures 8.20, 8.21, and 8.22 for various water flow rates.

The frictional pressure loss is expressed in terms of the two-phase multiplier

$$(\phi^2_{LO})_F = (\Delta P_{TP}/\Delta P_{LO})_F \qquad (8.11)$$

The two-phase multiplier is shown in Figures 8.23 to 8.25 as a function of flow quality. It depends on the flow quality, but it is not affected by misalignment. One could conclude that the misalignment does not considerably affect the interfacial shear stress.

A few two-phase frictional multiplier correlations are also shown in the same figures for comparison. For various water flow rates, the correlations proposed by Beattie and Chisholm & Sutherland show good agreement with the experimental results. Other correlations presented tend to underestimate the two-phase multiplier especially in the high quality flow.

8.2.2.3 Two-Phase Junction Pressure Loss

The two-phase pressure loss in the first junction plane for a constant water flow rate of 1.25-kg/s is shown in Figure 8.26. It increases with increasing air flow rate. Similar to the single-phase junction pressure loss, the bundle misalignment affects the pressure loss for the regular bundle more than the one for the streamlined bundle. The regular bundle with 45.0° misalignment causes the largest pressure loss. The streamlined bundle produces the lowest pressure loss, and its junction pressure loss is not affected by the bundle rotation. The pressure loss in the second junction plane for the same water flow rate is shown in Figure 8.27. The pressure losses in both junction planes are reasonably close. The small deviation of pressure loss is probably caused by the change in the void distribution and the experimental inaccuracy. For different water flow rates, the average values are calculated and shown in Figures 8.28 to 8.30. The junction pressure loss increases with increasing water flow rate. The 45.0° misaligned regular bundle produces the largest pressure loss. The streamlined bundle has a better pressure recovery than the regular bundle.

The junction pressure loss is also expressed as a two-phase multipler, which is the ratio of the two-phase junction pressure loss to the single-phase junction pressure loss. It is written as

$$(\varnothing^2_{LO})_J = (\Delta P_{TP} / \Delta P_{LO})_J \qquad (8.12)$$

and is shown in Figures 8.31 to 8.33 for various water flow rates. The misaligned regular bundle has the lowest two-phase multiplier. This is explained by the large pressure drop which takes place in the single-phase flow. The streamlined bundle is not significantly affected by the bundle rotation. It has the largest two-phase multiplier because the ratio of the two-phase pressure losses for various bundle arrangements is smaller than that of the single-phase; i.e.,

$$(\Delta P_{TP})_{Reg.} / (\Delta P_{TP})_{Str.} < (\Delta P_{LO})_{Reg.} / (\Delta P_{LO})_{Str.} \qquad (8.13)$$

The junction two-phase multiplier obtained from the experiment is compared with some correlations in the same figures. Since it varies for different bundle arrangements and streamlining, none of the correlations is capable of predicting reasonable values for the various multipliers. On the whole, the orifice correlation proposed by Beattie is the best for estimating the multiplier for the aligned regular bundle and has the least error for predicting the other bundle settings. The homogeneous two-phase multiplier, on the other hand, is acceptable for predicting the results for the streamlined bundle.

8.2.2.4 Two-Phase Spacer Pressure Loss

The two-phase pressure loss in the second spacer plane* is shown in Figure 8.34. Though the results are quite scattered, the streamlined bundle still shows a better pressure recovery than the regular bundle. This indicates that less pressure is lost by simply rounding and smoothening the edges. The bundle misalignment does not affect the pressure loss through the spacers for any of the bundle arrangements. The two-phase pressure loss in the third spacer plane is shown in Figure 8.35. The results are similar to those in the second spacer plane. The mean values for the spacer pressure losses in a string of bundles

*As mentioned before, the spacer pressure loss in the first bundle is not being considered because of the influence from the entrance flow.

are shown in Figures 8.36 to 8.38 for various water flow rates. Like the junction pressure loss, the spacer pressure loss is affected by both the water and air mass flows. Throughout the investigated range, the streamlined shape promotes a greater recovery of pressure energy.

The two-phase spacer pressure loss is expressed as the two-phase spacer multiplier which is defined as

$$(\phi^2_{LO})_S = (\Delta P_{TP}/\Delta P_{LO})_S \qquad (8.14)$$

The two-phase spacer multiplier is presented in Figures 8.39 to 8.41. It increases with increasing flow quality and appears to be independent of the misalignment. The two-phase multipliers are very close for both streamlined and regular bundles. The scattered results between flow qualities of 0.5% and 1.0% may be caused by the flow transition.

The same correlations used with the junction two-phase multipliers are also shown for comparison. For various water flow rates, the values from the homogeneous flow correlation (with the viscosity term) are close to the experimental results. The Beattie spacer correlation generally over-estimates the results, but it gives close predictions in the transition region. However, this may be merely a coincidence. The Beattie orifice correlation tends to under-estimate the results.

8.2.2.5 Two-Phase Total Pressure Loss

The two-phase total pressure loss is the summation of all the losses. It is illustrated in Figures 8.42 to 8.44 for various water flow rates. The pressure loss increases with increasing quality. For the regular bundle, the pressure loss is larger than that for the streamlined bundle. It is affected by the bundle rotation. The 45.0° misaligned regular bundle has the largest loss among the investigated bundle arrangements. The pressure loss for the streamlined bundle is not affected by the misalignment, and it is slightly lower than the loss for the aligned regular bundle. Variation of the water flow rate also affects the pressure loss. For the same flow quality, more pressure loss results for a higher water flow rate.

The total two-phase pressure loss is presented using the two-phase total multiplier which is defined as

$$(\phi^2_{LO\,T}) = (\Delta P_{TP} / \Delta P_{LO\,T}) \qquad (8.15)$$

The total two-phase multipliers are illustrated in Figures 8.45 to 8.47. The larger values of the two-phase multipliers for streamlined bundles are due to the larger ratio of regular bundle losses to streamlined losses in single-phase flow. No comparison has been made with any correlations since there is not any published information regarding the total pressure loss in nuclear fuel bundles.

Chapter IX

SUMMARY OF RESULTS

9.1 EXPERIMENT A

The pressure loss through various obstruction sizes, locations, and shapes were investigated for horizontal single-phase and two-phase flows. The results are summarized as follows:

9.1.1 Single-phase Flow

The friction factor obtained for the channel was 0.0319 with a standard deviation of 0.0006. The relative roughness of the channel was found to be 0.00128 by using the Colebrook equation.

The local pressure loss depends strongly on the size and the location of the obstruction. More pressure energy was lost for the 40% blockage than that for the 25%. Among various obstructions, the highest pressure losses were observed for the central type obstructions probably due to their obstruction of the highest velocity fluid. On the other hand, the peripheral obstruction, which interfered only with the slow moving flow along the wall, showed a lower pressure loss.

9.1.2 Two-phase Flow

The frictional pressure loss increased with increasing qualities. For various obstructions, the upstream frictional pressure losses are slightly different from the downstream ones. The variation was probably caused by the change in the void distribution in the downstream region due to the blockage.

The local pressure loss was also affected by the air flow rate. In addition, the flow distribution also played an important role. The pressure loss, as in single-phase flow, was higher for a larger blockage. The bottom segment obstruction had the largest loss because it blocked the liquid phase which travelled along the bottom portion of the channel due to the stratification effect. Similarly, the peripheral obstruction produced a larger loss probably because it interfered with the liquid phase along the circumference of the channel as a result of the flow distribution.

9.2 EXPERIMENT B

The pressure losses for the simulated regular bundle and the modified regular bundle (streamlined bundle) have been investigated. The total loss was separated into the frictional loss, the junction loss, and the spacer loss. Among the losses, the frictional loss was the major contributing factor whereas the spacer loss was the minor one. The results are summarized as follows:

9.2.1 Single-Phase Flow

For both types of bundles, the frictional pressure losses were identical and not affected by the change of the bundle arrangement. The relative roughness was obtained to be 0.00076 by using the Colebrook equation. The junction pressure loss and the spacer pressure loss were larger for the regular bundles. The change of the bundle setting influenced the junction pressure loss (more pressure was lost as the misalignment increases) for the regular bundle only. The spacer pressure loss was slightly affected by the bundle misalignment. The total pressure loss was the summation of all these losses. A large part of it was contributed by the frictional component. The streamlined bundles produced less pressure loss than the regular bundles.

9.2.2 Two-Phase Flow

Similar to the single-phase flow, the streamlined bundle generally caused less pressure loss than the regular bundle. For various bundle arrangements, the two-phase frictional pressure losses were identical. The two-phase junction pressure loss was larger for the misaligned regular bundle.

Despite the fact that the streamlined bundle produced a smaller pressure loss, it had a larger two-phase junction multiplier. This was caused by the difference between the single-phase and two-phase pressure loss ratios. The two-phase spacer pressure loss was smaller for the streamlined bundle. The bundle misalignment had no significant effect on the spacer loss in any of the bundle settings. The two-phase total pressure loss, which was the summation of the losses, was affected by the bundle misalignment because of the effect of the junction pressure loss.

The results have been compared with some existing correlations. In general, the homogeneous flow equation and the correlations suggested by Beattie agreed reasonably well with the present experimental data.

Chapter X

CONCLUSION

According to the present investigation, it is concluded that the local pressure loss depends strongly on the size, the location and the shape of the obstruction. In addition to these, the effect of the void distribution has to be considered in the two-phase flow. Obstructions intercepting the heavy phase are associated with larger losses than those intercepting the light phase. The modified bundle has shown a better performance than the regular one as pressure losses are reduced in both junction and spacer areas; these losses are independent of bundle misalignment.

REFERENCES

1. Foster, A.R. and Wright, R.L.Jr., Basic Nuclear Engineering, Third Edition, Allyn and Bacon, Inc., Boston, 1977.

2. CANDU Nuclear Power System, Atomic Energy of Canada Limited Publication, TDSI-105, 1981.

3. Groeneveld, D.C. and Yousef, W.W., Spacing Devices for Nuclear Fuel Bundles: A Survey of Their Effect on CHF, Post-CHF Heat Transfer and Pressure Drop, paper summitted to The ANS/ASME Topical Meeting on Nuclear Reactor Thermalhydraulics, Saratoga, New York, October 6, 1980.

4. Ginoux, J.J., Two-phase Flow and Heat Transfer with Application to Nuclear Reactor Design Problems, McGraw-Hill Book Company, 1978.

5. Pigott, R.J.S., Losses in Pipe and Fittings, Trans. ASME, pp. 1767-1783, November, 1957.

6. Tong, L.S., Pressure Drop Performance of a Rod Bundle, in Single-Phase Coolant Heat Transfer in Rod Bundles, ed. V.E. Schrock, pp. 57-69, ASME, New York, 1968.

7. Courtaud, M., Ricque, R. and Martinet, B., Etude des Pertes de Charge dans des Conduites Circulaires Contenant un Faisceau de Barreaux, Chemical Engineering Science, Vol. 21, pp. 881-893, 1966.

8. Le Tourneau, B.W., Grimble, R.E. and Zerbe, J.E., Pressure Drop for Parallel Flow Through Rod Bundles, Trans. ASME, pp.1751-1758, November, 1957.

9. Rehme, K., Simple Method of Predicting Friction Factors of Turbulent Flow in Non-Circular Channels, Int. J. Heat Mass Transfer, Vol. 16, pp. 933-950, 1973.

10. Malak, J., Hejna, J. and Schmid, J., Pressure Losses and Heat Transfer in Non-Circular Channels with Hydraulically Smooth Walls, Int. J. Heat Mass Transfer, Vol. 18, pp. 139-149, 1975.

11. Prasuhn, A.L., Fundamentals of Fluid Mechanics, First Edition, Prentice Hall, Inc., New Jersey, 1980

12. Kittredge, C.P. and Rowley, D.S., Resistance Coefficients for Laminar and Turbulent Flow Through One-half-inch Valves and Fittings, Trans. ASME, pp. 1759-1766, 1957.

13. Daugherty, R.L. and Franzini, J.B., Fluid Mechanics with Engineering Applications, Sixth Edition, McGraw-Hill Book Company, 1965.

14. Binder, R.C., Fluid Mechanics, Third Edition, Prentice-Hall, Inc., New york, 1955.

15. Idelchik, I.E., Handbook of Hydraulic Resistance, AEC-tr-6630, 1966.

16. Cur, N. and Sparrow, E.M., Experiments on Heat Transfer and Pressure Drop for a Pair of Colinear, Interrupted Plates Aligned with the Flow, Int. J. Heat Mass Transfer, Vol. 21, pp. 1069-1080, 1978.

17. Rehme, K., Pressure Drop Correlations for Fuel Element Spacers, Nuclear Technology, Vol. 17, pp. 15-23, 1973.

18. Grover, R.B. and Venkat Raj, V., Pressure Drop along Longitudinally-finned Seven-Rod Cluster Nuclear Fuel Elements, Nuclear Engineering and Design, Vol. 58, pp. 79-83, 1980.

19. Rehme, K., The Pressure Drop of Spacer Grids in Rod Bundles of 12 Rods with Smooth and Roughened Surfaces, KFK-2697.

20. De Stordeur, A.N. Drag Coefficient for Fuel Element Spacers, Nucleonics; Vol. 19, No. 6, pp. 74-79, 1961.

21. Rehme, K., Pressure Drop of Spacer Grids in Smooth and Roughened Rod Bundles, Nuclear Technology, Vol. 33, pp. 314-317, 1977.

22. Barroyer, P., Analytical Model For the Prediction of Spacer Pressure Drop Coefficients, EIR-Bericht No. 350.

23. Pletcher, R.H. and McManus, H.N.Jr., Heat Transfer and Pressure Drop in Horizontal Annular Two-phase, Two-component Flow, Int. J. Heat Mass Transfer, Vol. 11, pp. 1087-1104, 1968.

24. Hewitt, G.F. and Boure, J.A., Some Recent Results and Development in Gas-Liquid Flow: A Review, Int. J. Multiphase Flow, Vol. 1, pp. 139-171, 1973.

25. Simpson, H.C., Rooney, D.H., Grattan, E. and Al-Samarrae, F.A.A., Two-phase Flow Studies in Large Diameter Horizontal Tubes, NEL Report No. 677, 1981.

26. Butterworth, D., A Comparison of Some Void Fraction Relations for Co-current Gas-liquid Flow, Int. J. Multiphase Flow, Vol. 1, pp. 845-850, 1975.

27. Collier, J.G., Convective Boiling and Condensation, McGraw-Hill Book Company, 1972.

28. Baker, O., Multiphase Flow in Pipelines, Oil and Gas J., pp. 156-167, 1958.

29. Mandhane, J.M., Gregory, G.A. and Aziz, K., A Flow Pattern Map for Gas-Liquid Flow in Horizontal Pipes, Int. J. Multiphase Flow, Vol. 1, pp. 537-553, 1974.

30. Dukler, A.E., Modelling Two-Phase Flow and Heat Transfer, Keynote paper KS-11. Presented at Sixth International Heat Transfer Conference, Toronto, Canada, August, 1978.

31. Spedding, P.L. and Chen, J.J.J., A Simplified Method of Determining Flow Pattern Transition of Two-phase Flow in a Horizontal Pipe, Int. J. Multiphase Flow, Vol. 7, pp. 729-731, 1981.

32. Weisman, J., Duncan, D., Gibson, J. and Crawford, T., Effects of Fluid Properties and Pipe Diameter on Two-phase Flow Patterns in Horizontal Lines, Int. J. Multiphase Flow, Vol. 5, pp. 437-462, 1979.

33. Weisman, J. and Kang, S.Y., Flow Patterns Transitions in Vertical and Upwardly Inclined Lines, Int. J. Multiphase Flow, Vol. 7, pp. 271-291, 1981.

34. Barnea, D., Shoham, O., Taitel, Y. and Dukler, A.E., Flow Pattern Transition for Gas-liquid Flow in Horizontal and Inclined Pipes, Int. J. Multiphase Flow, Vol. 6, pp. 217-225, 1980.

35. Salcudean, M., Chun, J.H. and Groeneveld, D.C., Effect of Flow Obstructions on the Flow Pattern Transitions in Horizontal Two-Phase Flow, to be published in the Int. J. Multiphase Flow.

36. Lockhart, R.W. and Martinelli, R.C., Proposed Correlation of Data for Isothermal Two-Phase, Two-Component Flow in Pipes, Chemical Engineering Progress, Vol. 45, No. 1, pp.39-48, 1949.

37. Martinelli, R.C. and Nelson, D.B., Prediction of Pressure Drop During Forced-Circulation Boiling of Water, Trans. ASME, Vol. 79, pp. 695-702, 1948.

38. Chisholm, D. and Sutherland, L.A., Prediction of Pressure Gradients in Pipeline Systems During Two-Phase Flow, Inst. Mech. Eng. Symp. Two-Phase Flow Systems, Leeds, paper No. 4, 1969.

39. Baroczy, C.J., A Systematic Correlation for Two-Phase Pressure Drop, AIChE reprint No. 37, 8th Nat. Heat Transfer Conf., Los Angeles, 1965.

40. Lahey, R.T. Jr., Two-Phase Flow in Boiling-Water Nuclear Reactor, NEDO-13388, pp. 59-70, 1974.

41. Chisholm, D., A Theoretical Basis for the Lockhart-Martinelli Correlation for Two-Phase Flow, Int. J. Heat Mass Transfer, Vol. 10, pp. 1767-1778, 1967.

42. Dukler, A.E., Wicks, M. and Cleveland, R.G., Frictional Pressure Drop in Two-phase Flow: A. A Comparison of Existing Correlation for Pressure Loss and Holdup, AIChE J., Vol. 10, pp. 38-43, 1964a.

43. DeGance, A.E. and Atherton, R.W., Horizontal-Flow Correlations, Chemical Engineering, Vol. 77, pp. 93-103, 1970a.

44. Chen, J.J.J. and Spedding, P.L., An extension of the Lockhart-Martinelli Theory of Two-Phase Pressure Drop and Holdup, Int. J. Multiphase flow, Vol. 7, No. 6, pp. 659-675, 1981.

45. Chenoweth, J.M. and Martin, M.W., Turbulent Two-Phase Flow, Petroleum Refiner, Vol. 34, No. 10, pp. 151-155, 1955.

46. Chisholm, D., Pressure Gradients due to Friction During the Flow of Evaporating Two-phase Mixtures in Smooth Tubes and Channels, Int. J. Heat Mass Transfer, Vol. 16, pp. 347-358, 1973.

47. Dukler, A.E., Wicks, M. and Cleveland, R.G., Frictional Pressure Drop in Two-phase Flow: B. An Approach through Similarity Analaysis, AIChE J., Vol. 10, pp. 44-51, 1964b.

48. Levy, S., Prediction of Two-phase Pressure Drop And Density Distribution from Mixing Length Theory, J. Heat Transfer, Vol. 85, pp. 137-152, 1963.

49. Beattie, D.R.H., Two-Phase Flow structure and Mixing Length Theory, Nuclear Engineering and Design, Vol. 21, pp 46-64, 1972.

50. Beattie, D.R.H., Two-Phase Pressure Loss and Void Fraction Characteristics in Rod Bundle Geometries, Paper in 18th Cong. Int. Assoc. Hydraulic Research, Cagliari, Italy, 1979.

51. Beattie, D.R.H., A Note on the Calculation of Two-Phase Pressure Losses, Nuclear Engineering and Design, Vol. 25, pp. 395-402, 1973.

52. Beattie, D.R.H. and Whalley, P.B., A Simple Two-Phase Frictional Pressure Drop Calculation Method, Int. J. Multiphase Flow, Vol. 8, No. 1, pp. 83-87, 1982.

53. Thom, J.R.S., Prediction of Pressure Drop During Forced Circulation Boiling of Water, Int. J. Heat Mass Transfer, Vol. 7, pp. 709-724, 1964.

54. Idsinga, W., Todreas, N. and Bowring, R., An Assessment of Tw-Phase Pressure Drop Correlations for Steam-Water Systems, Int. J. Multiphase Flow, Vol. 3, pp. 401-413, 1977.

55. Beattie, D.R.H. and Lawther, K.R., Two-Phase Hydrodynamic Experiments with Axial Flow Through Seven-Rod Clusters, Int. J. Multiphase Flow, Vol. 7, pp. 423-437, 1981.

56. Andeen, G.B. and Griffith, P., Momentum Flux in Two-phase Flow, J. of Heat Transfer, Trans. ASME, Vol. 90, pp. 211-222, 1968.

57. Delhaye, J.M., Giot, M. and Riethmuller, M.L., Thermohydraulics of Two-phase Systems for Industrial Design and Nuclear Engineering, First Edition, McGraw-Hill Book Company, 1981.

58. Chisholm, D., Prediction of Pressure Drop at Pipe Fittings During Two-Phase Flow, Proc. 13th International Inst. of Refrig. Congress, Washington, D.C., Aug. 29-Sept. 3, 2, pp. 781-789, 1971.

59. Fitzsimmons, D.E., Two-phase Pressure Drop in Piping Components, HW-80970 rev.1, 1964.

60. Chisholm, D., Two-phase Flow in Bends, Int. J. Multiphase Flow, Vol. 6, pp. 363-367, 1980.

61. Richardson, B.L., Some Problems in Horizontal Two-phase, Two-component Flow, ANL-5949, 1958.

62. Lottes, P.A., Expansion Losses in Two-phase Flow, Nuclear Science Engineering, Vol. 9, pp. 26-31, 1961.

63. Geiger, G.E. and Rohrer, W.M., Sudden Contraction Losses in Two-phase Flow, J. Heat Transfer, Trans. ASME, pp. 1-9, 1966.

64. Chisholm, D., Metering of Two-phase Mixtures: Report of a Meeting at NEL, 6th January, 1965, NEL Report NO. 217, 1966.

65. Janssen, E., Two-Phase Pressure Loss Across Abrupt Contraction and Expansion, Steam-Water at 600 to 1400 psia, Proc. of the 3rd International Heat Transfer Conference, Chicago, pp. 13-23, 1966.

66. Murdock, J.W., Two-Phase Measurement with Orifices, Trans. ASME, pp. 419-433, 1962.

67. Chisholm, D., Pressure Gradients During the Flow of Incompressible Two-Phase Mixtures Through Pipes, Venturies and Orifice Plates, British Chemical Engineering, Vol. 12, No. 9, pp. 1368-1371, 1967.

68. Chisholm, D. and Watson, G.G., The Flow of Steam/Water Mixtures Through Sharp-edged Orifices, NEL Report No. 213, 1966.

69. Sher, N.C., Kangas, G.J. and Neusen, K.F., On the Phenomenon of Boiling Flow in A Parallel Rod Array, Chemical Engineering Progress Symposium Series, Vol. 61, pp. 127-156, 1965.

70. Messina W.A., Steam-Water Pressure Drop and Critical Discharge Flow-Digital Computer Program, HW-65706, June, 1960.

TABLE 7.1

Water Flow Rates Tested in Experiment B

Water Flow Rate (kg/s)	Water Flow Rate (USGPM)
0.46	7.5
0.61	10.0
0.77	12.5
0.92	15.0
1.07	17.5
1.23	20.0
1.38	22.5
1.53	25.0
1.69	27.5
1.84	30.0

TABLE 7.2

Water and Air Flow Rates Tested in Experiment A

Flow Rate (kg/s) Water	Air
0.3	0.014
0.3	0.022
0.3	0.032
0.3	0.042
0.3	0.053
0.3	0.064

TABLE 7.3

Water And Air Flow Rates Tested in Experiment B

Flow Rate (kg/s) Water	Air
0.92	0.0085
0.92	0.0108
0.92	0.0131
0.92	0.0159
0.92	0.0182
0.92	0.0211
1.23	0.0018
1.23	0.0031
1.23	0.0051
1.23	0.0068
1.23	0.0091
1.23	0.0120
1.23	0.0142
1.23	0.0171
1.53	0.0003
1.53	0.0005
1.53	0.0026
1.53	0.0040
1.53	0.0057
1.53	0.0074

TABLE 8.1

Friction Factor Comparison Between the Unobstructed Channel and the Smooth Tube Equations

Mean Experimental Friction Factor	Smooth Pipe Blasius	Nikuradse	Moody
0.0319	0.0305	0.0304	0.0255

TABLE 8.2

Loss Coefficients for Various Obstructions

Obstruction	Loss Coefficient 25%	40%
Central	0.81	2.40
Peripheral	0.27	1.37
Horizontal	0.86	2.59
Vertical	0.87	2.61
Bottom	0.59	1.98
Top	0.58	1.97

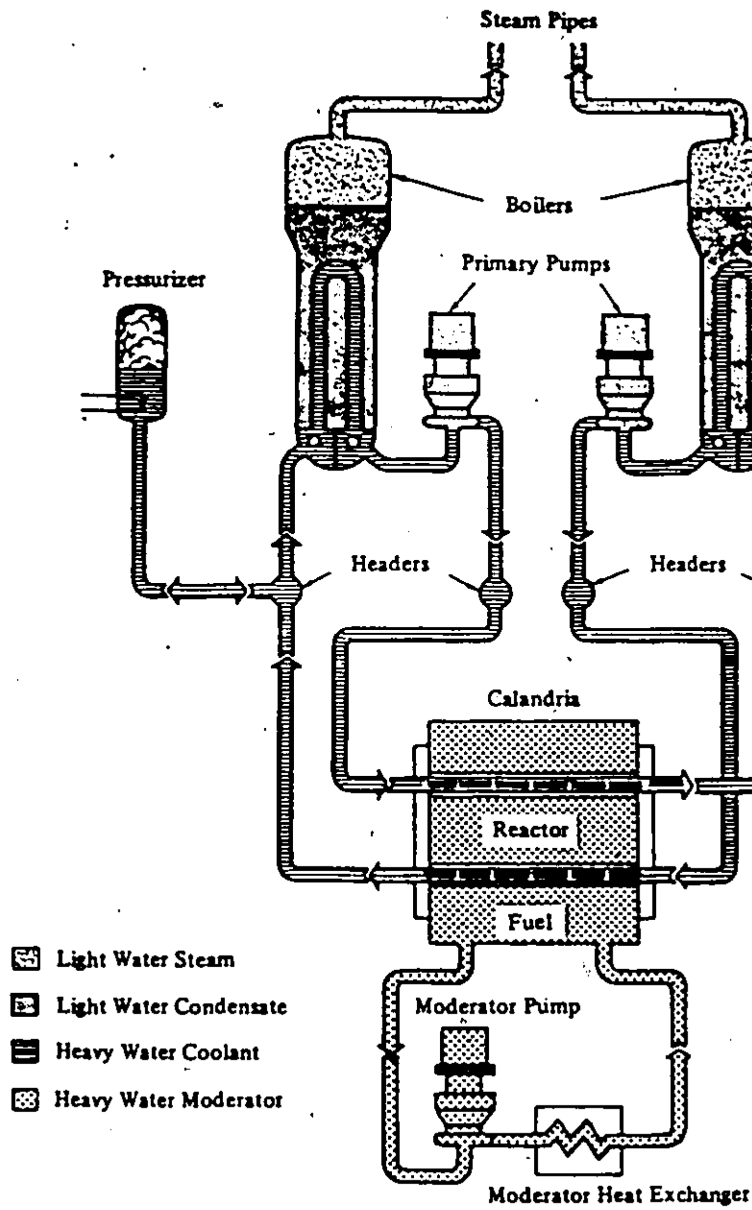


Figure 2.1: Schematic Diagram of the Flow Loop in the CANDU reactor [2].

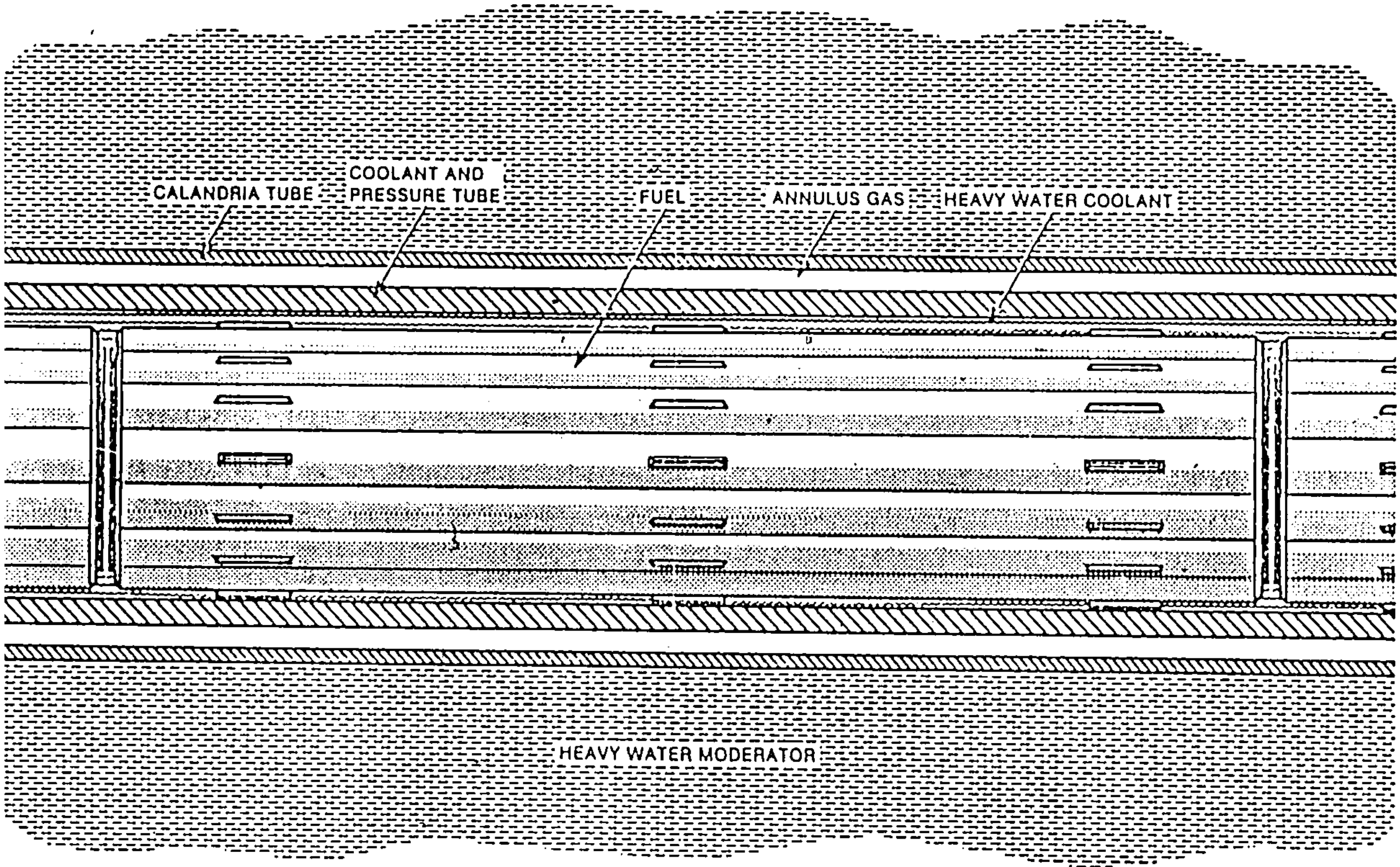


Figure 2.2: Pressure Tube Description [2].

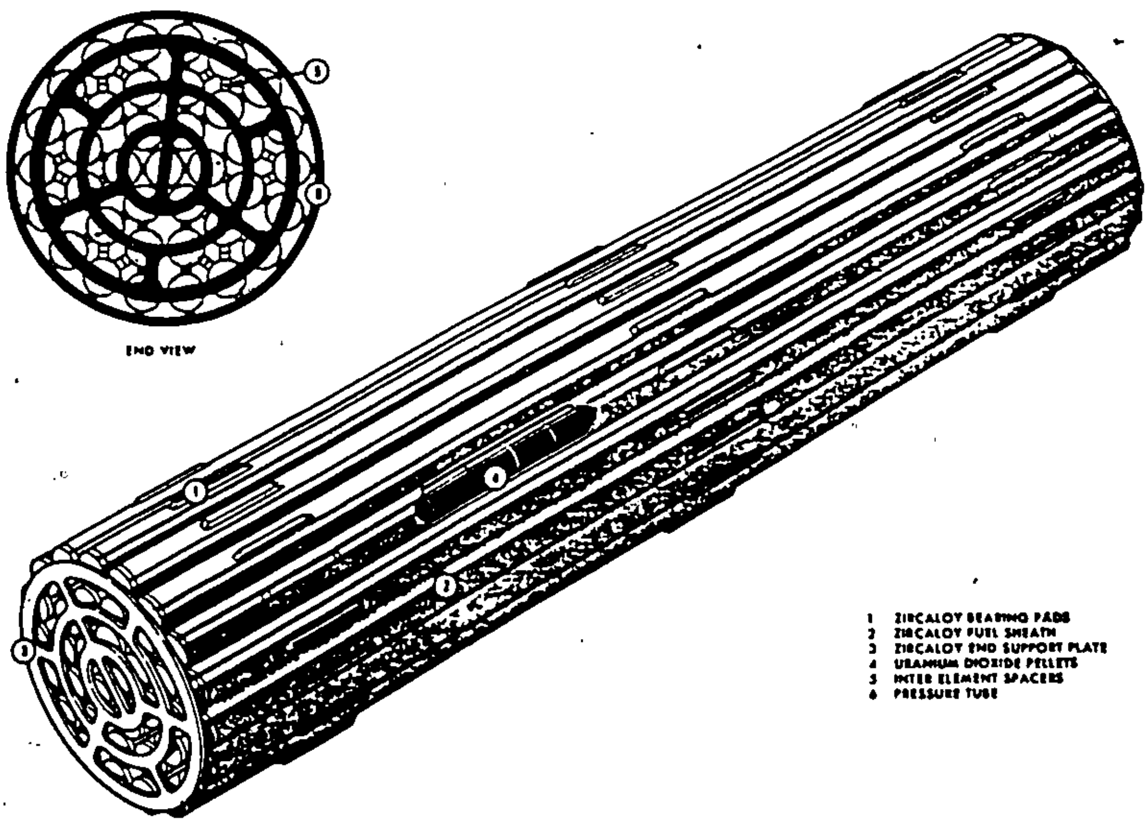


Figure 2.3: The 37-element Regular Bundle of the CANDU reactor [2].

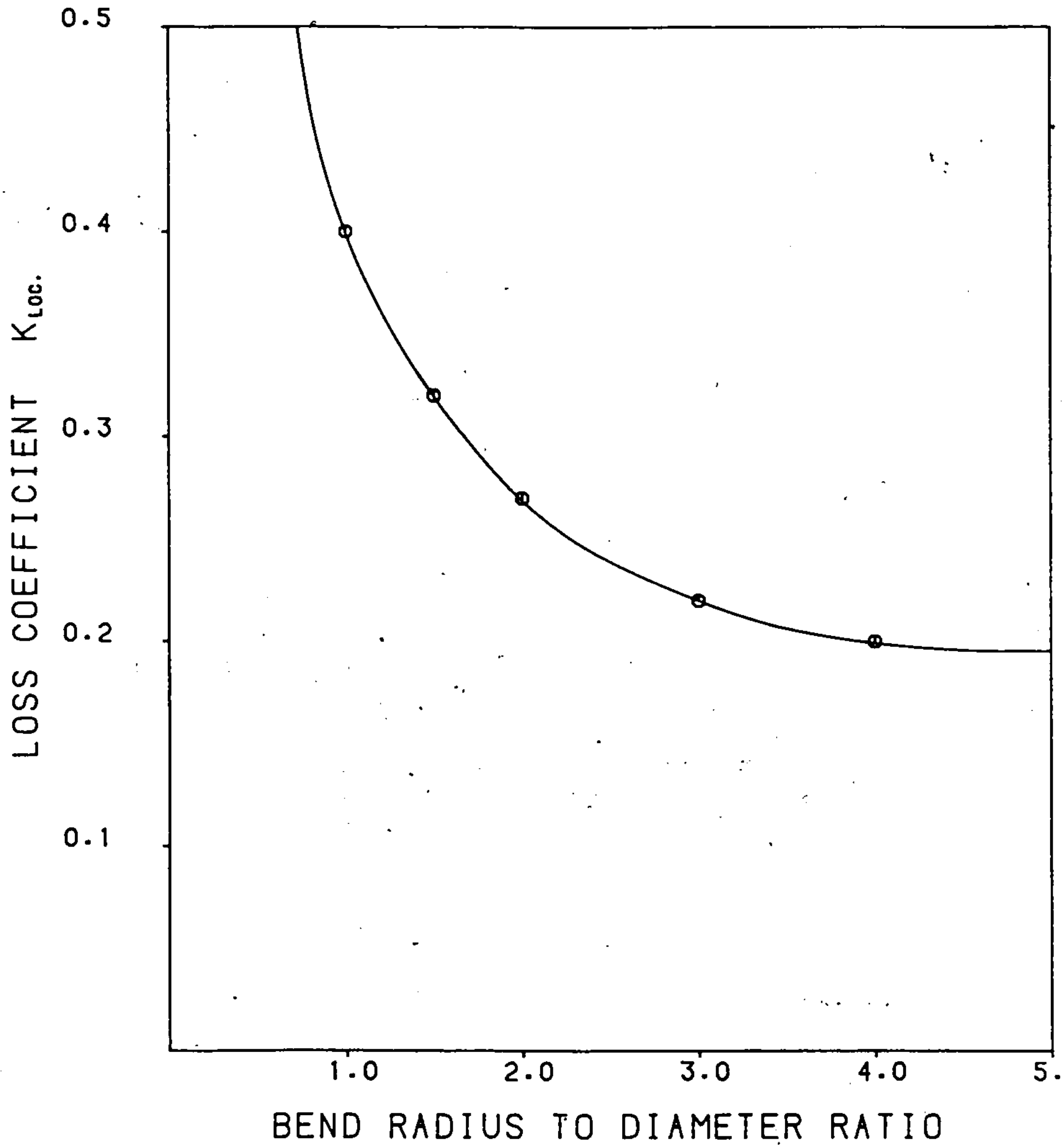


Figure 3.1: Relation Between Bend Loss Coefficient and the Bend Radius to Diameter Ratio [11].

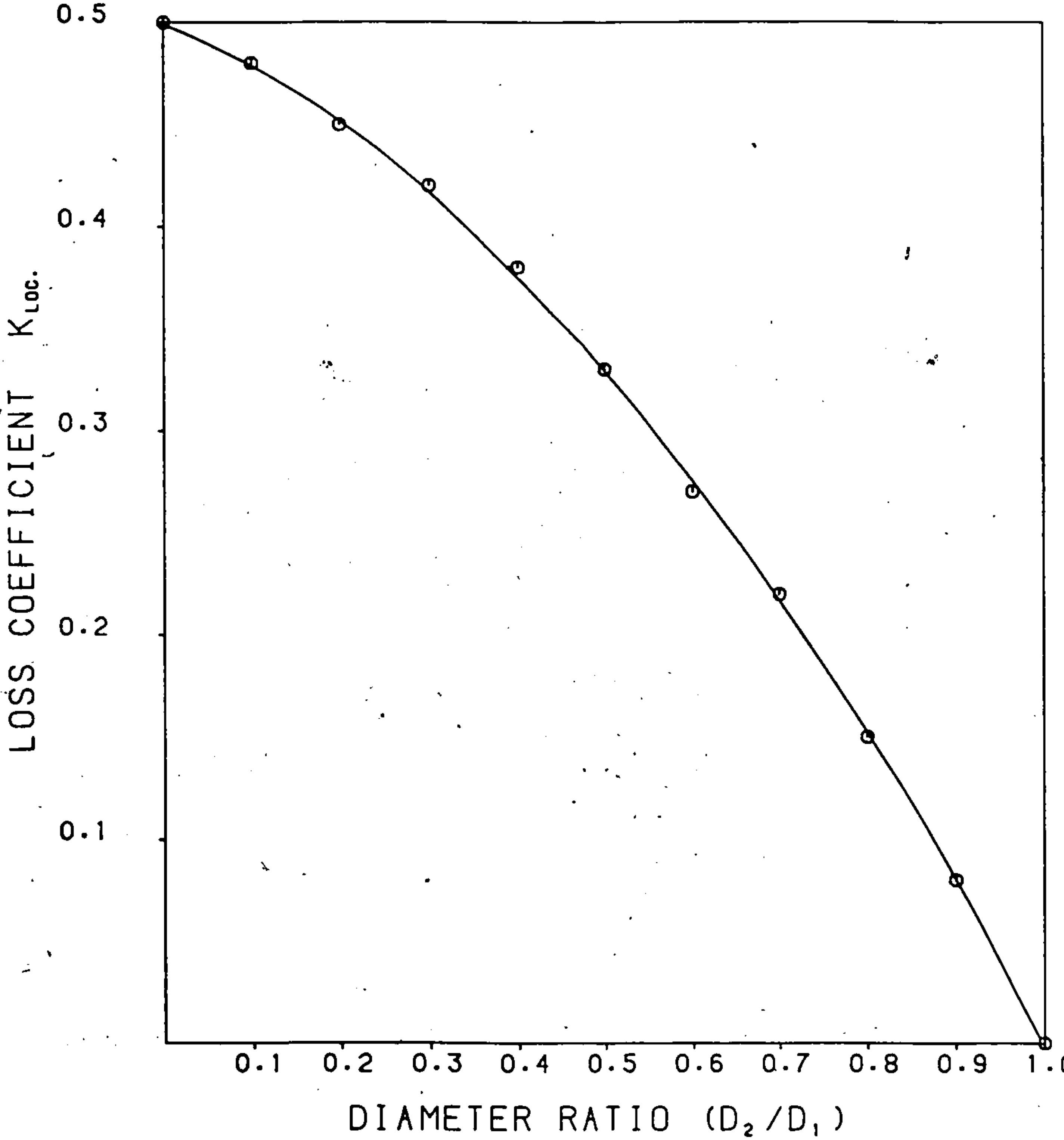


Figure 3.2: Loss Coefficient for Sudden Contraction as a Function of the Diameter Ratio [11].

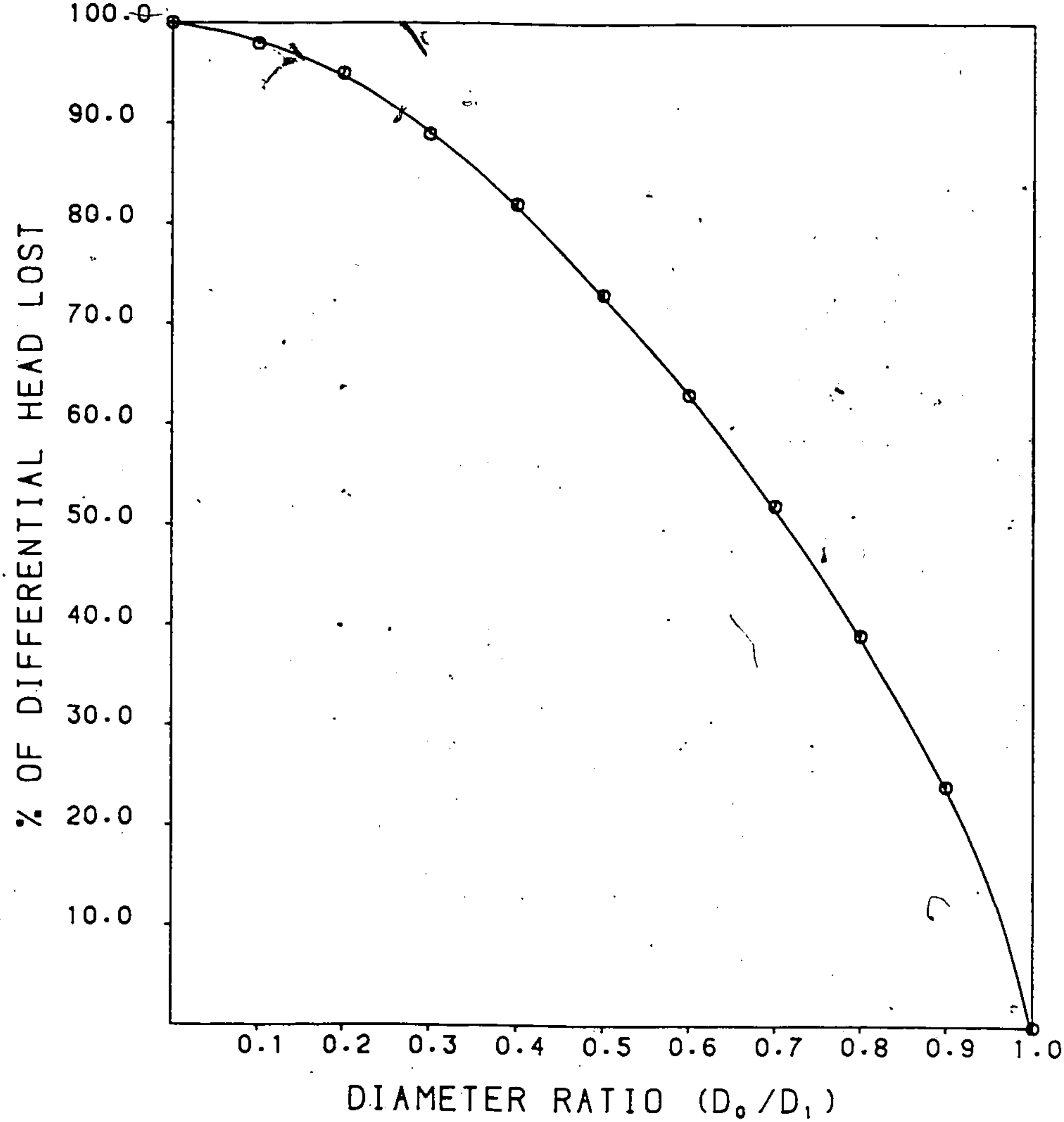


Figure 3.3: Percentage of Differential Head Lost for Various Orifice Diameter to Pipe Diameter Ratio [13].

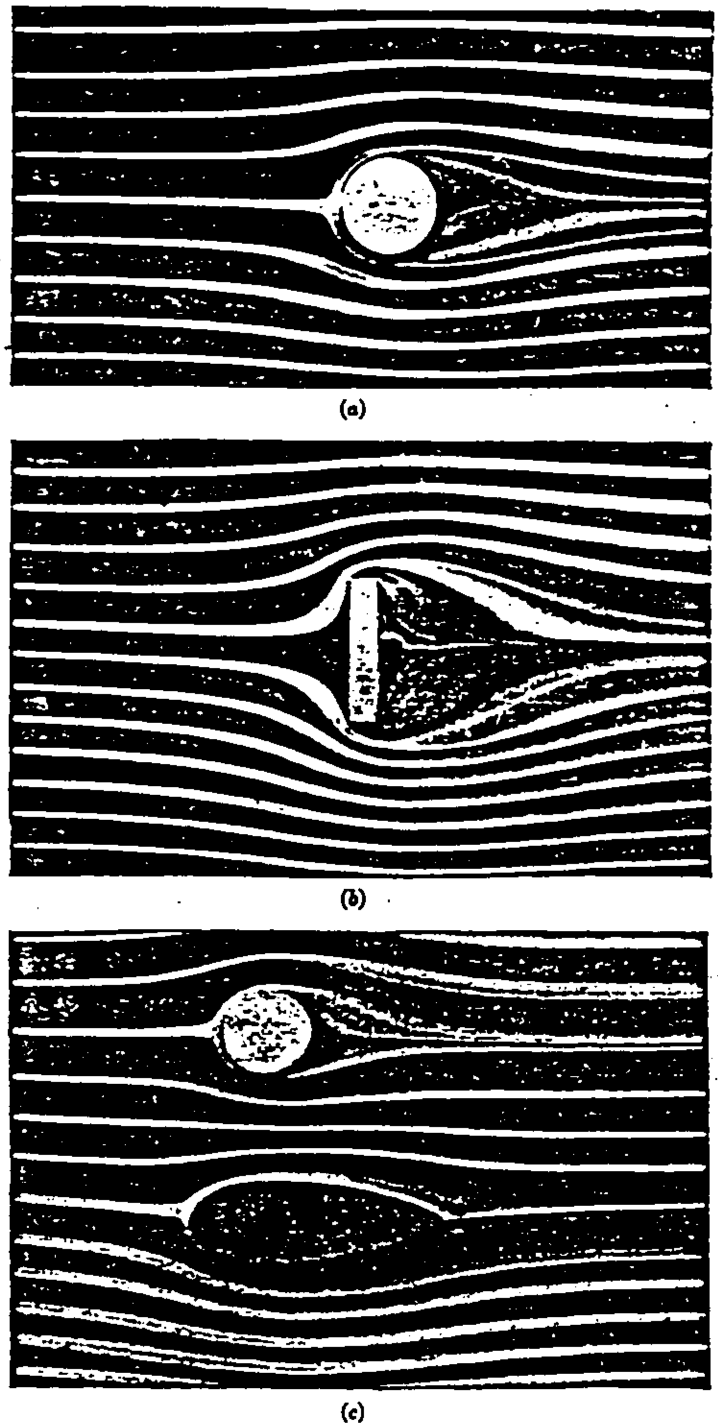


Figure 3.4: Two-dimensional Flow Around Various Objects [14].

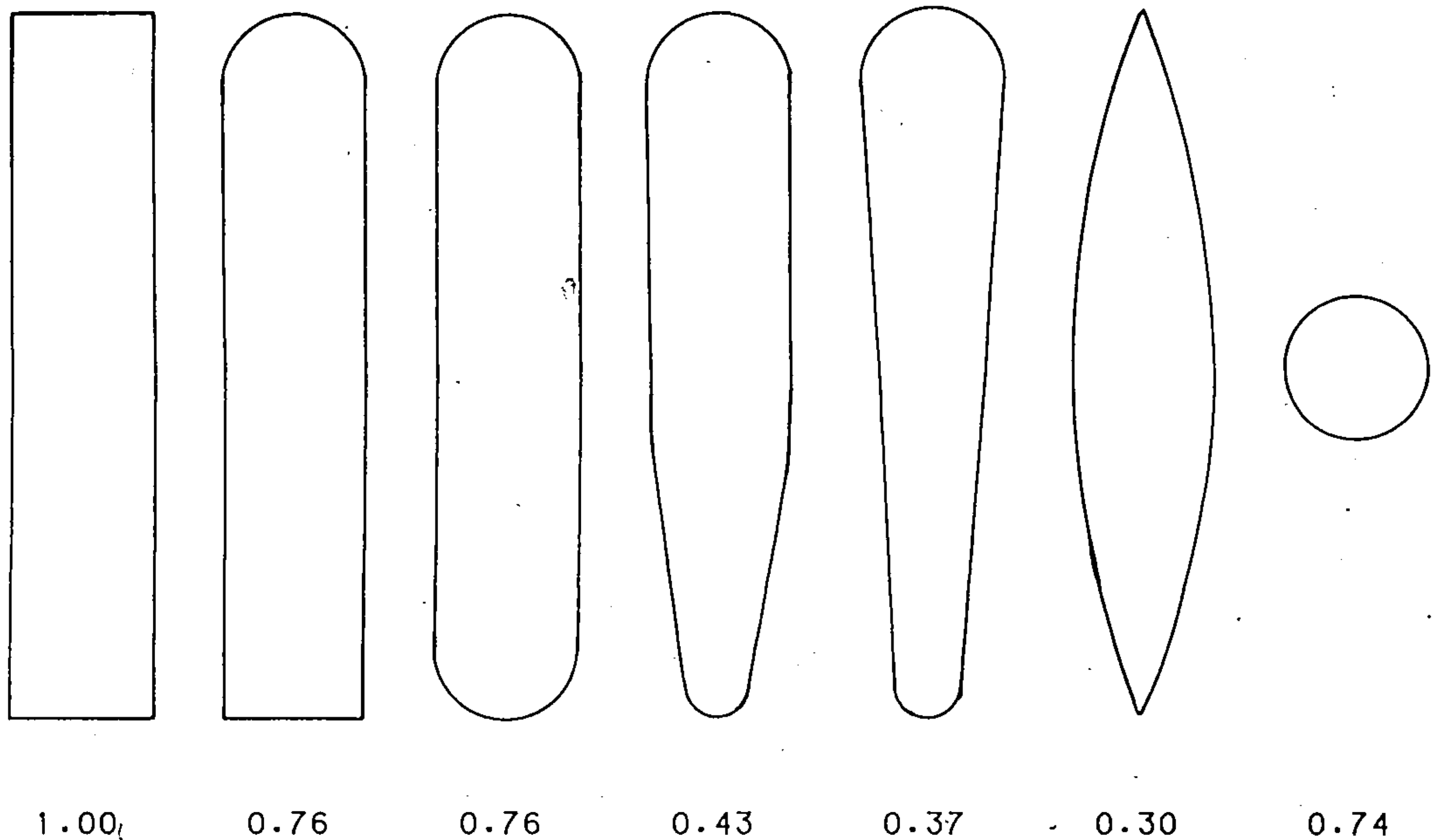


Figure 3.5: Shape Coefficient for Various Cylindrical Rods [15].

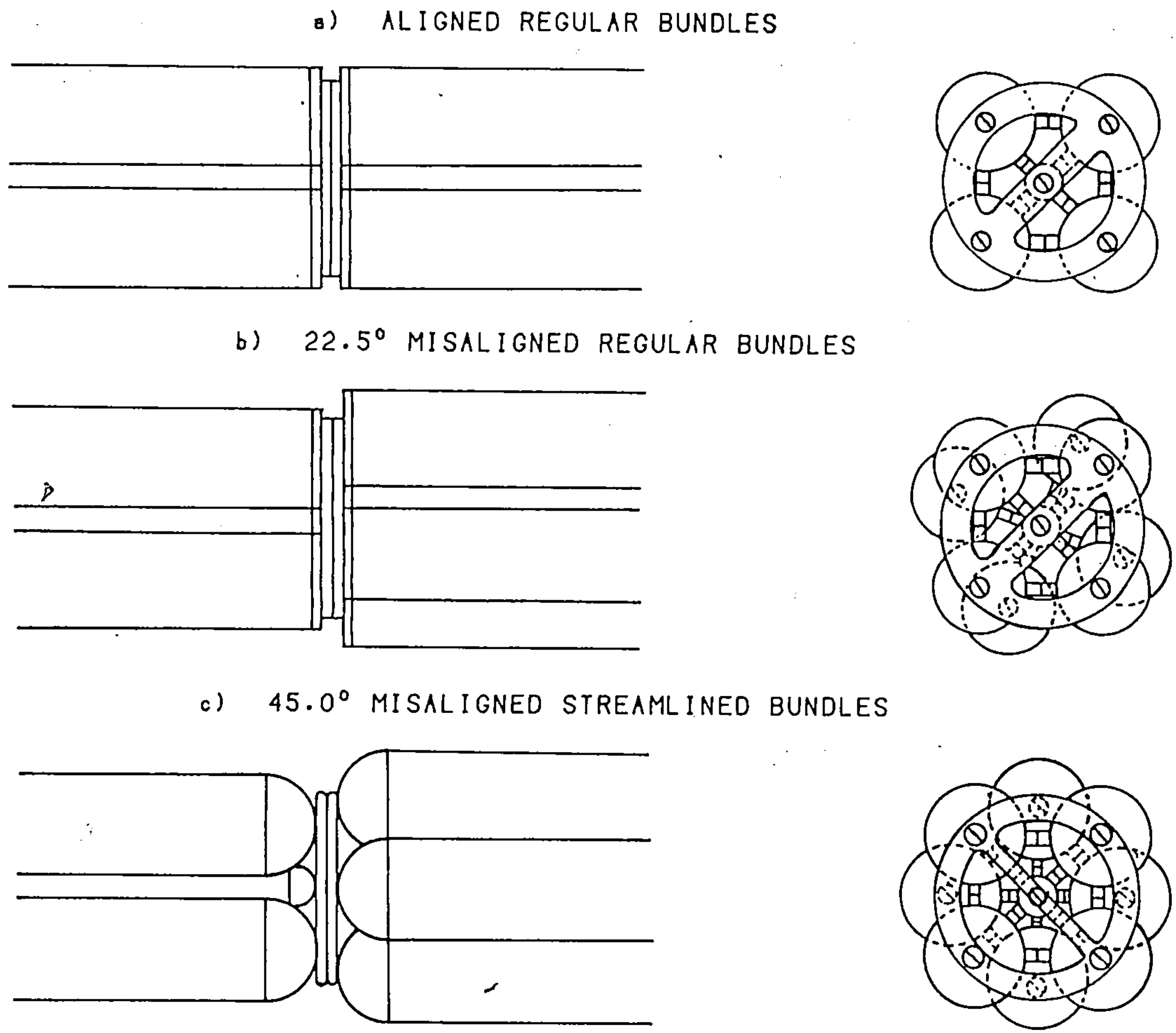


Figure 3.6: Change of Flow Blockage Area in Junction Plane due to Bundle Rotation.

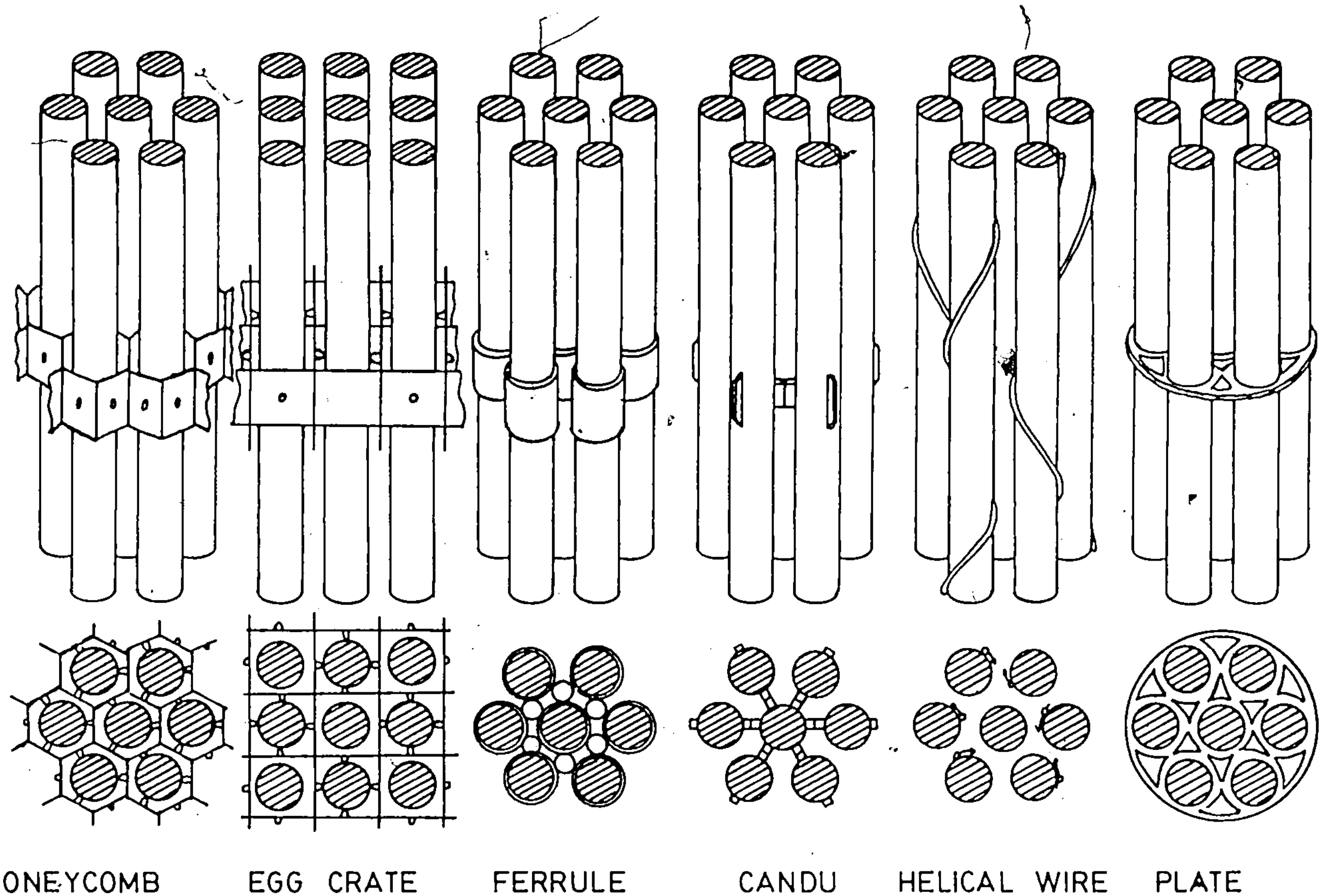


Figure 3.7: Types of Spacers Used in Nuclear Bundles [3].

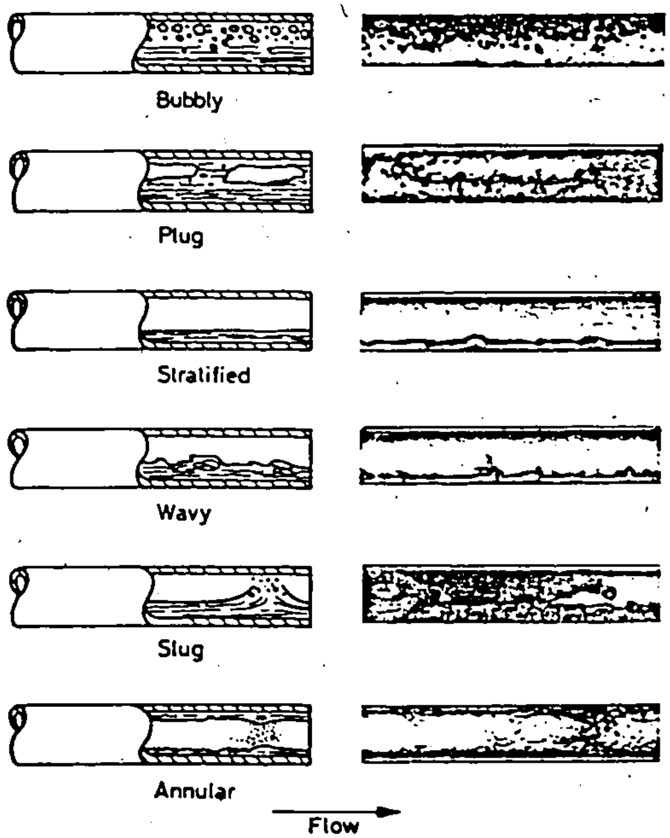


Figure 4.1: Horizontal Flow Patterns [27].

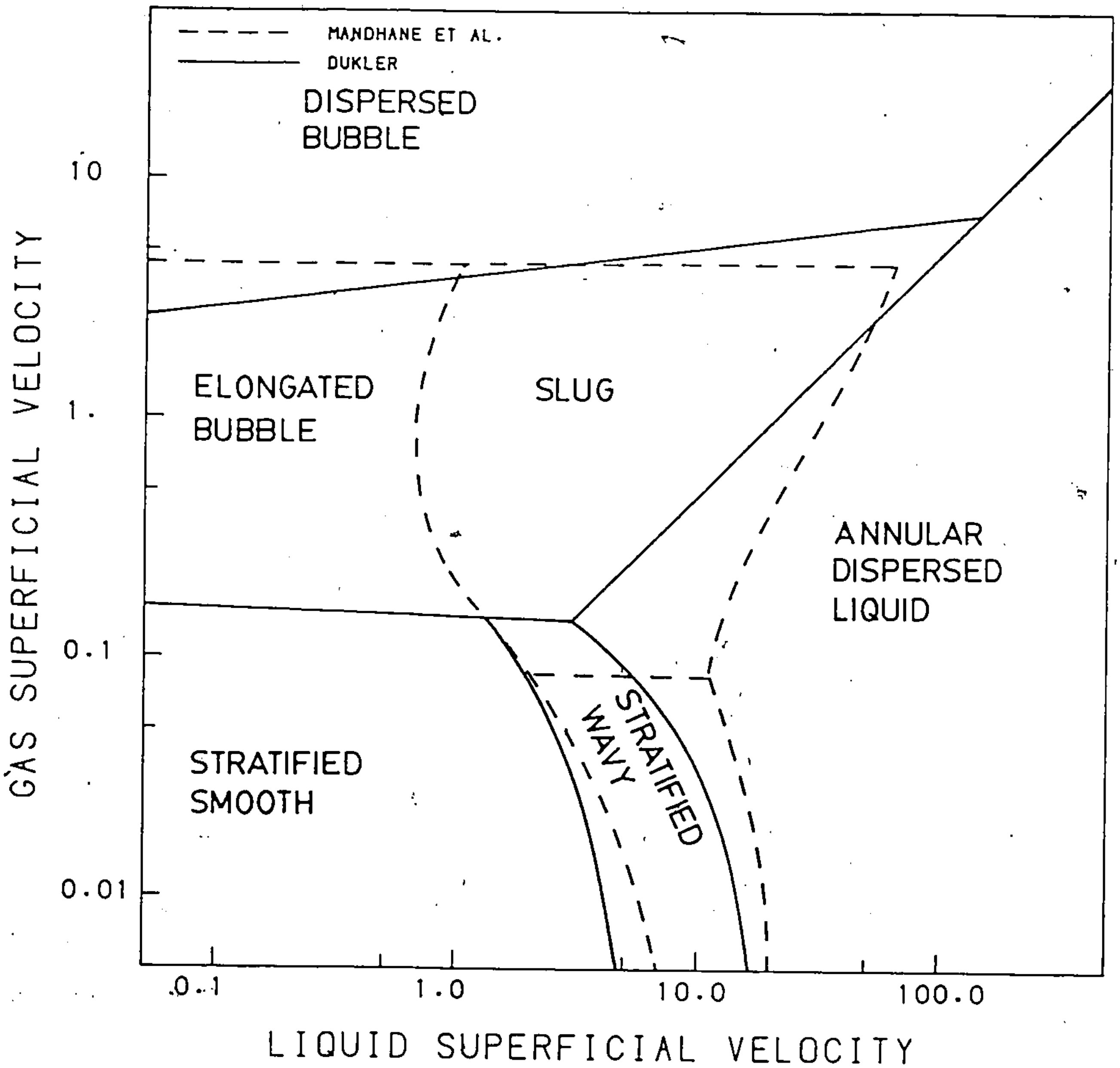
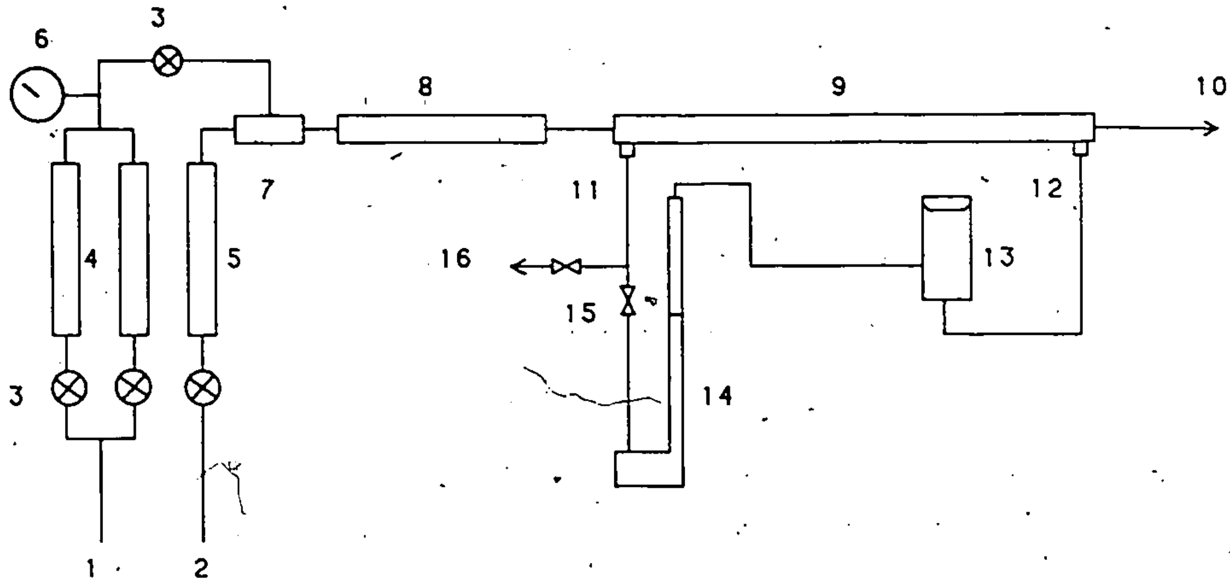
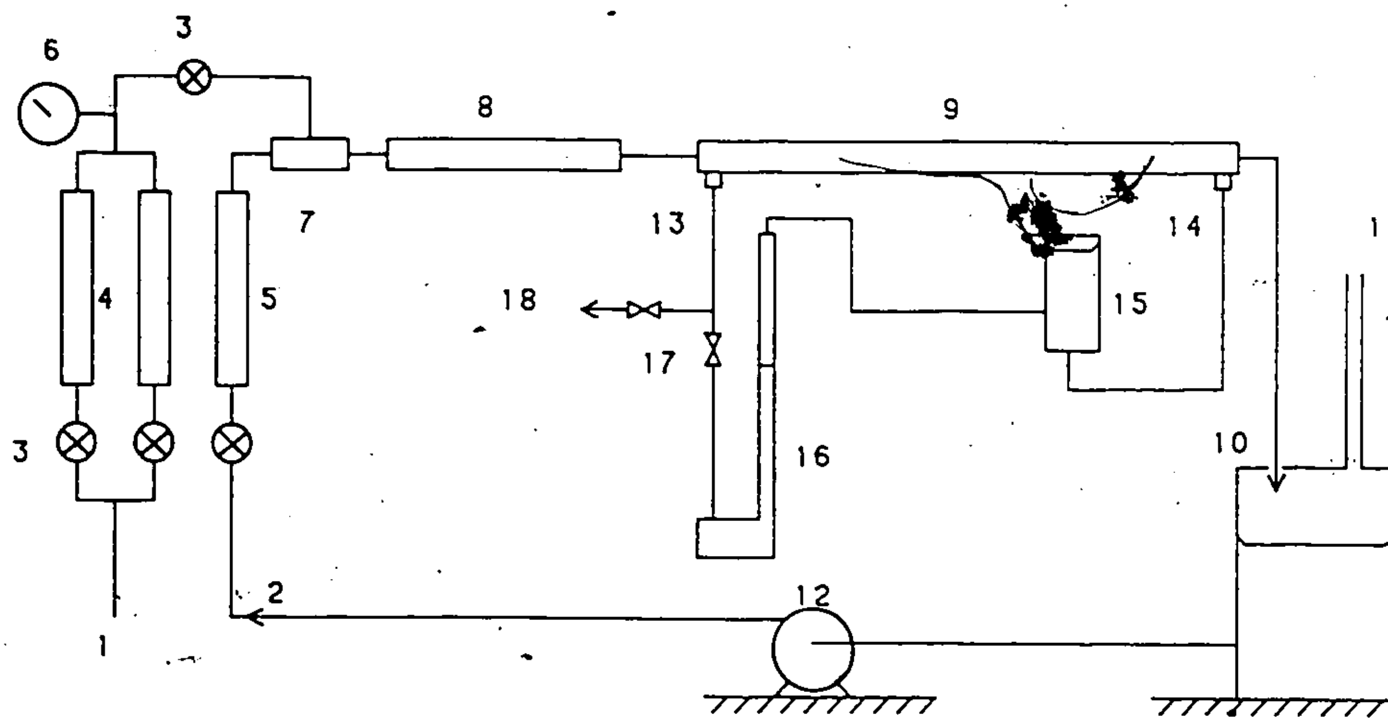


Figure 4.2: Comparison Between Flow Pattern Maps Obtained by Mandhane et al. and Dukler [30].



1 AIR INLET
2 WATER INLET
3 GATE VALVE
4 AIR ROTAMETER
5 WATER ROTAMETER
6 BOURDON GAGE
7 AIR-WATER MIXER
8 CALMING SECTION
9 TEST-SECTION
10 MIXTURE OUTLET
11 PRESSURE TAP
12 REFERENCE TAP
13 REFERENCE TANK
14 MANOMETER
15 TOGGLE VALVE
16 TO DRAIN

Figure 6.1: Schematic Diagram of the Loop in Experiment A.



1 AIR INLET

2 WATER INLET

3 GATE VALVE

4 AIR ROTAMETER

5 WATER ROTAMETER

6 BOURDON GAGE

7 AIR-WATER MIXER

8 CALMING SECTION

9 TEST-SECTION

10 MIXTURE OUTLET

11 RESERVOIR

12 CENTRIFUGAL PUMP

13 PRESSURE TAP

14 REFERENCE TAP

15 REFERENCE TANK

16 MANOMETER

17 TOGGLE VALVE

18 TO DRAIN

19 AIR OUTLET

Figure 6.2: Schematic Diagram of the Loop in Experiment B.

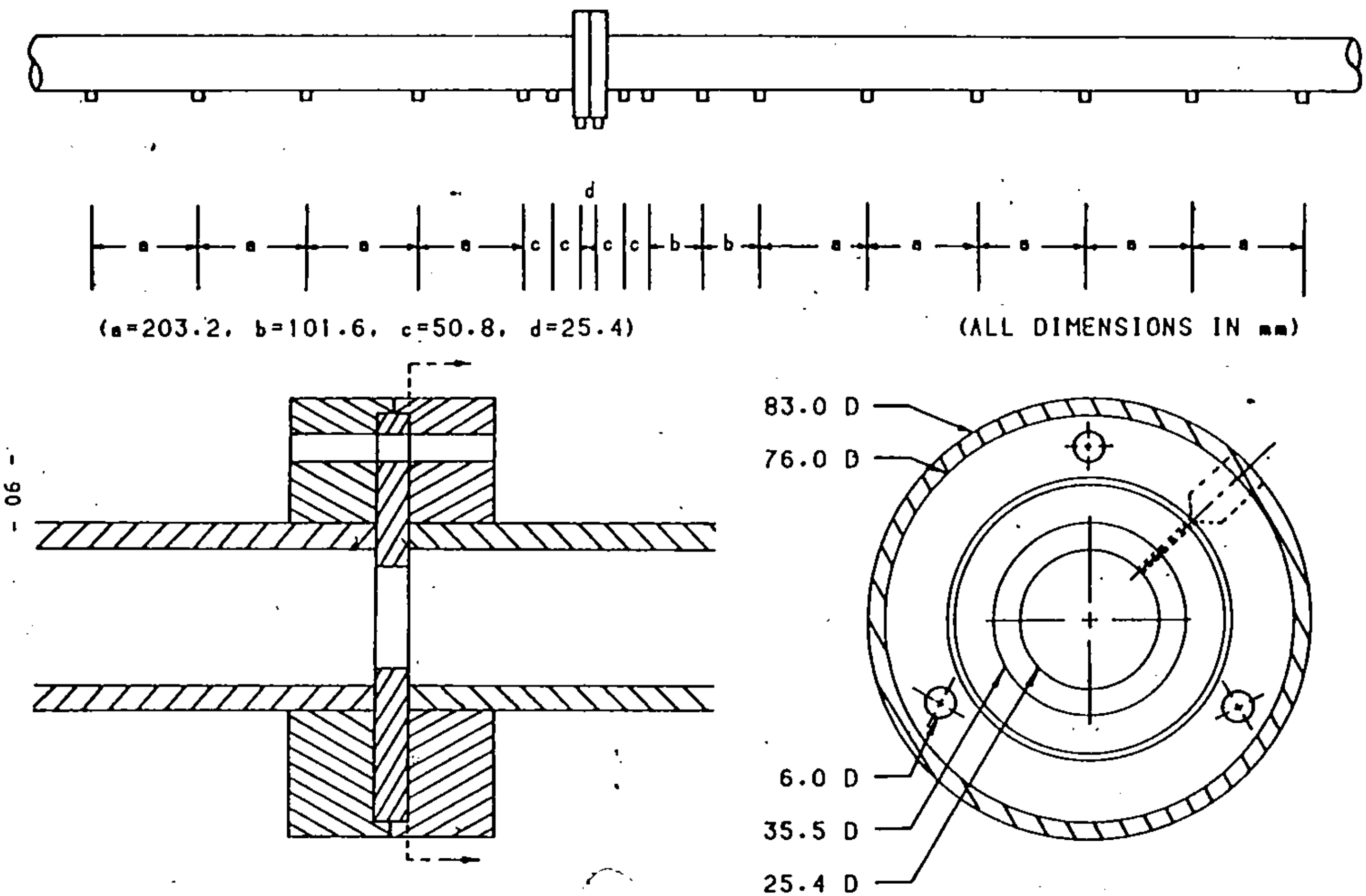


Figure 6.3: Test-section and Flange Assembly in Experiment A.

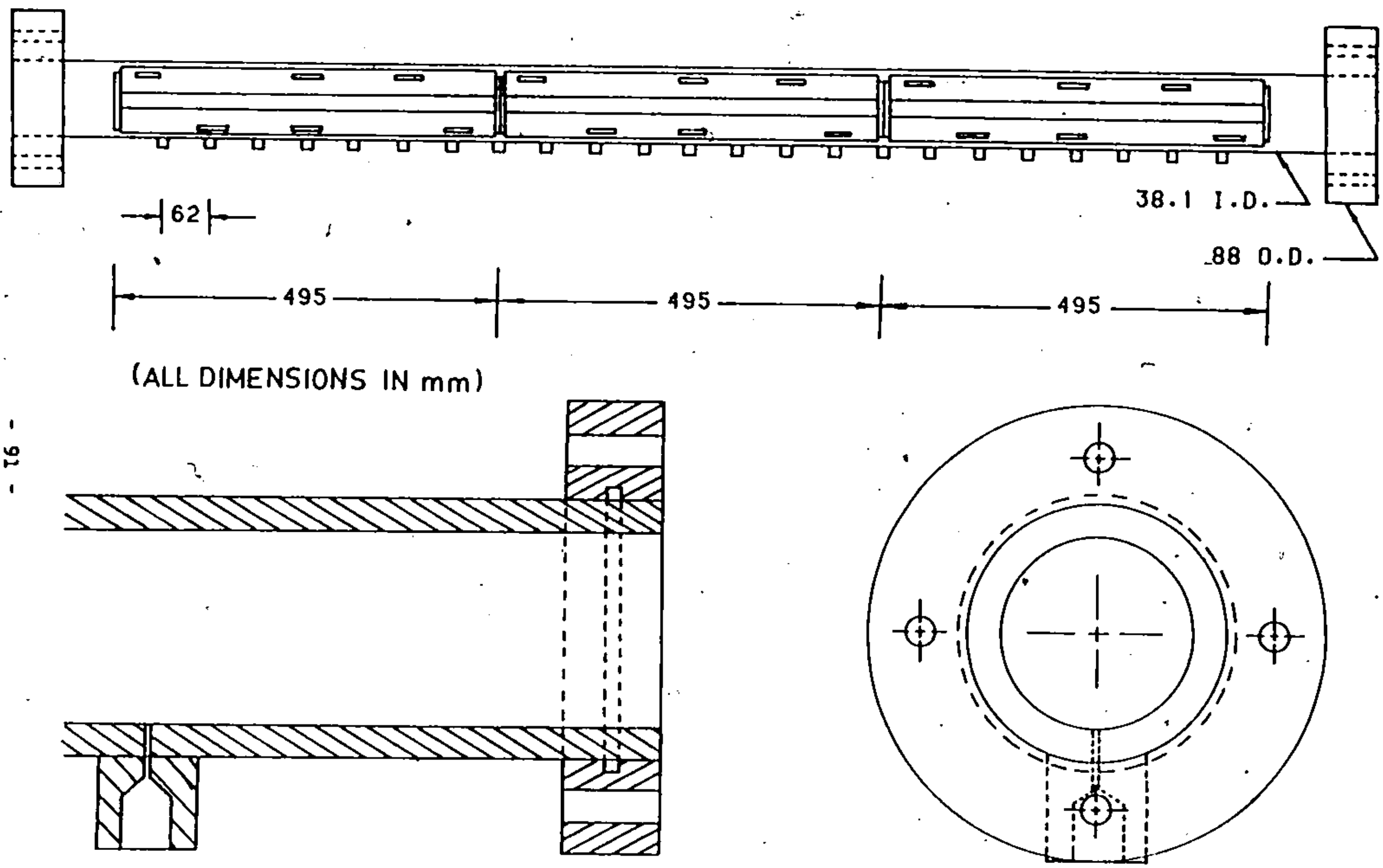


Figure 6.4: Test-section Arrangement in Experiment B.

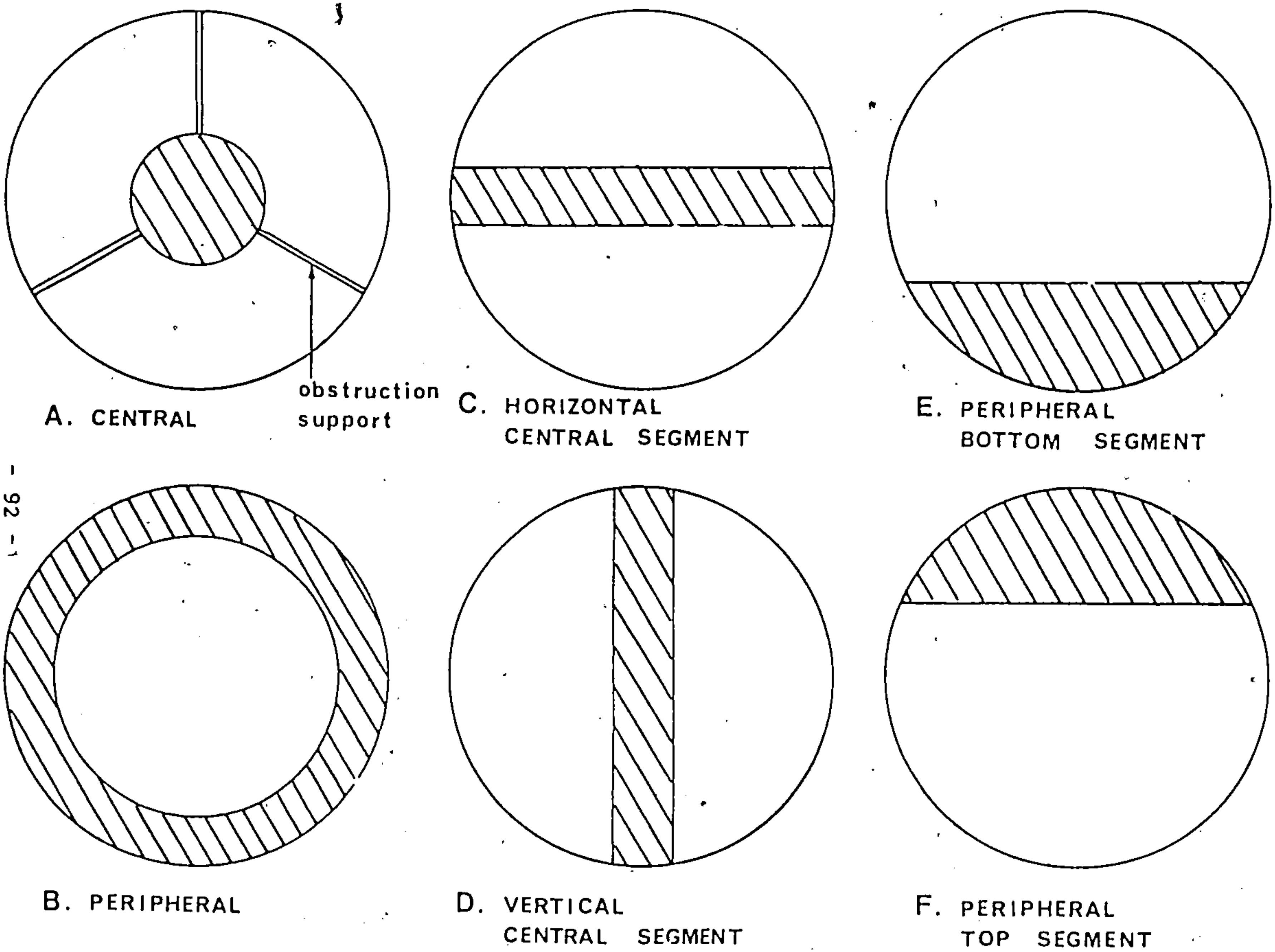


Figure 6.5: Types of Obstruction Tested in Experiment A.

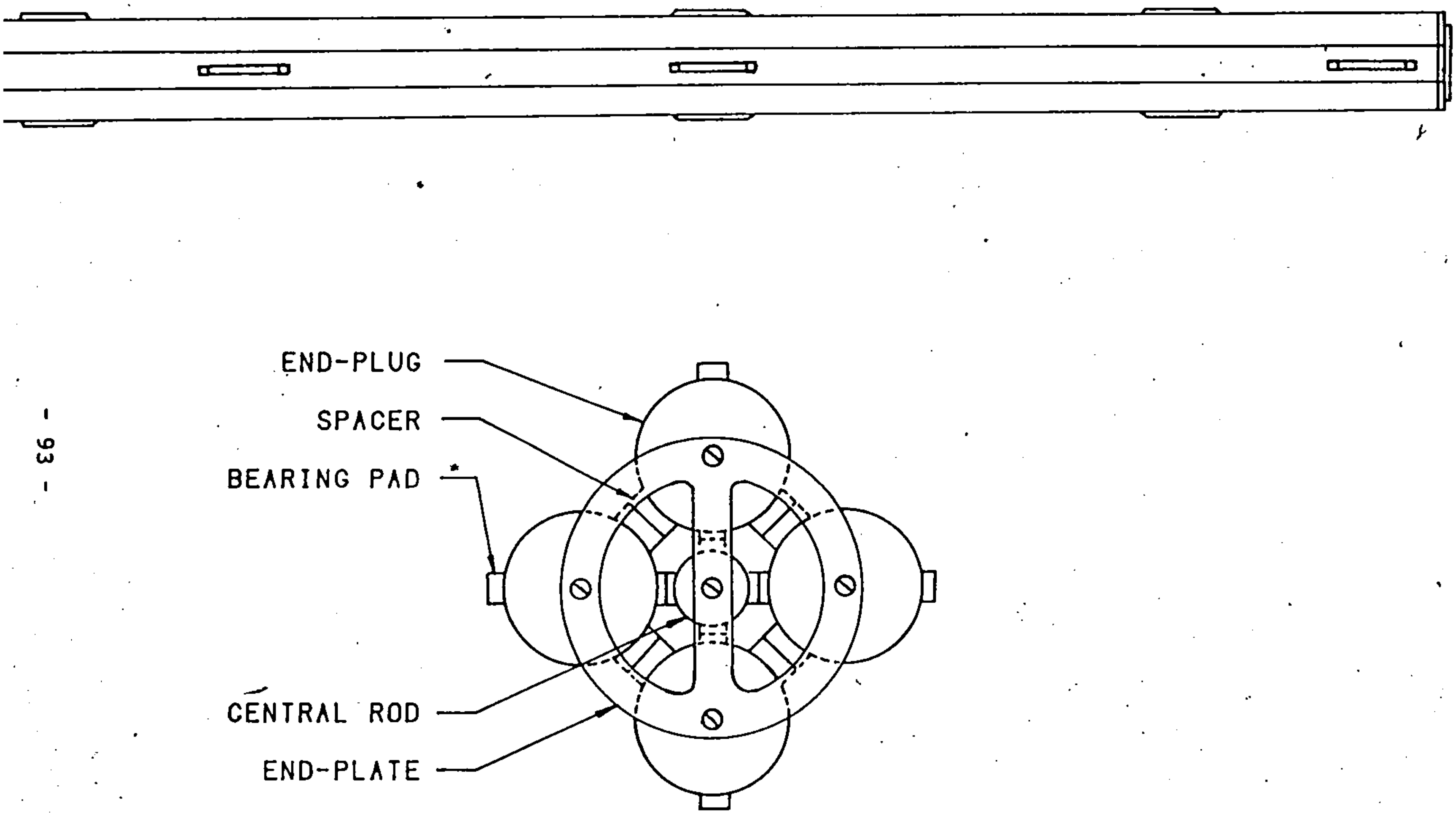


Figure 6.6: The Simulated Regular Bundle.

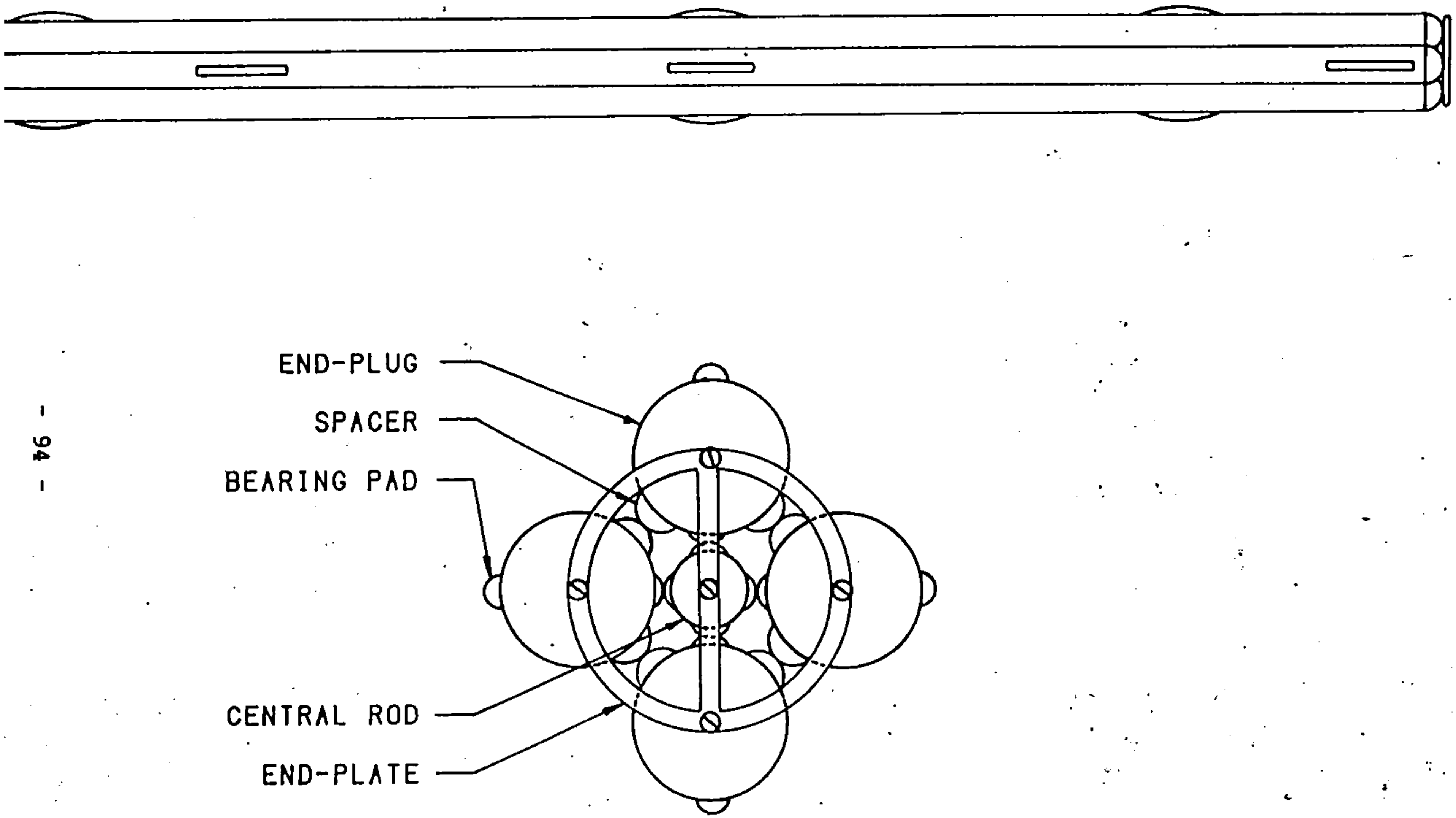


Figure 6.7: The Modified Regular Bundle (Streamlined Bundle).

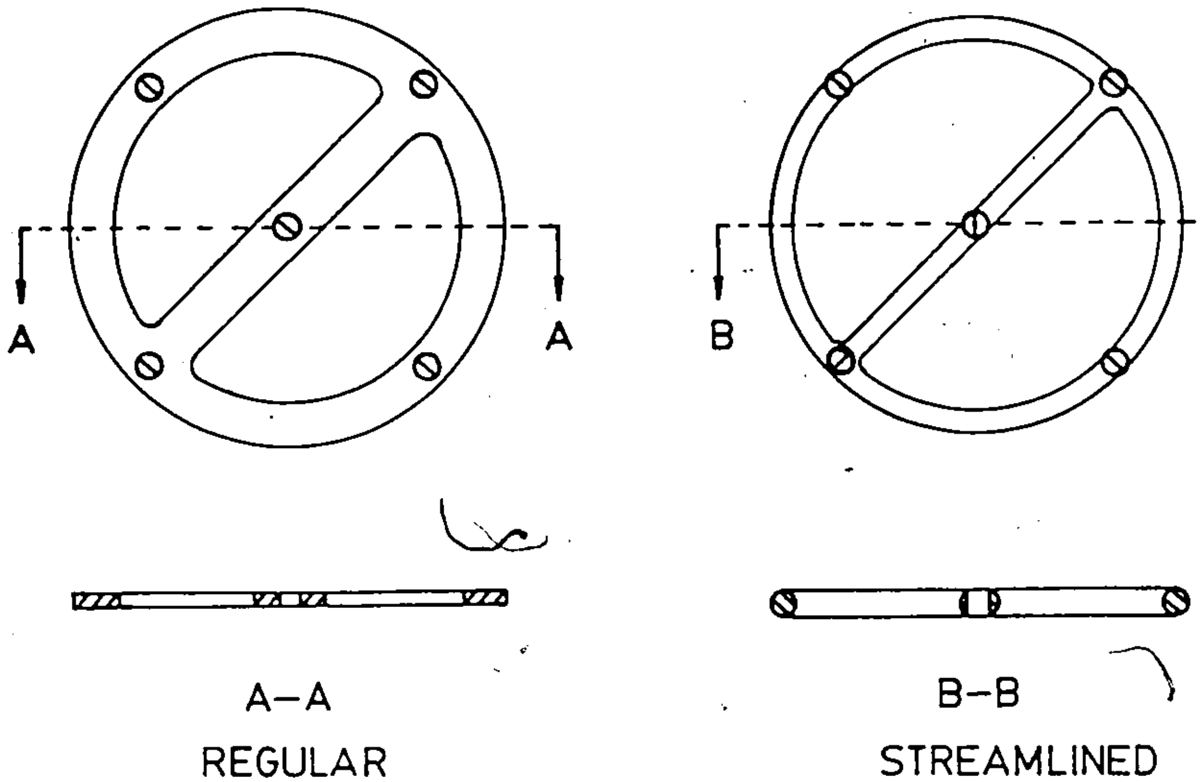


Figure 6.8: End-plate Comparison.

Figure 6.9: Modification of Spacer Design.

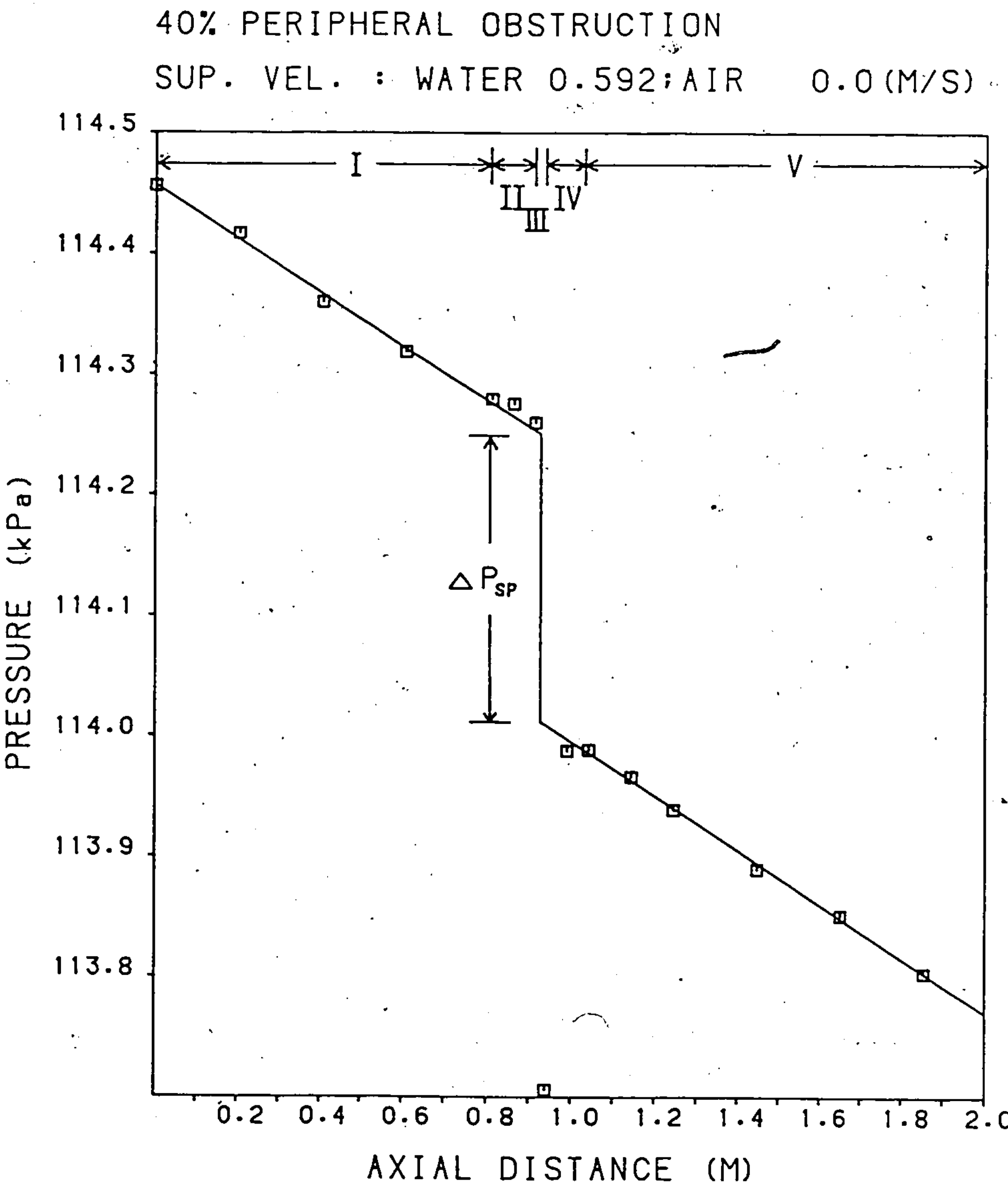


Figure 8.1: Single-phase Pressure Variation for the 40% Peripheral Obstruction.

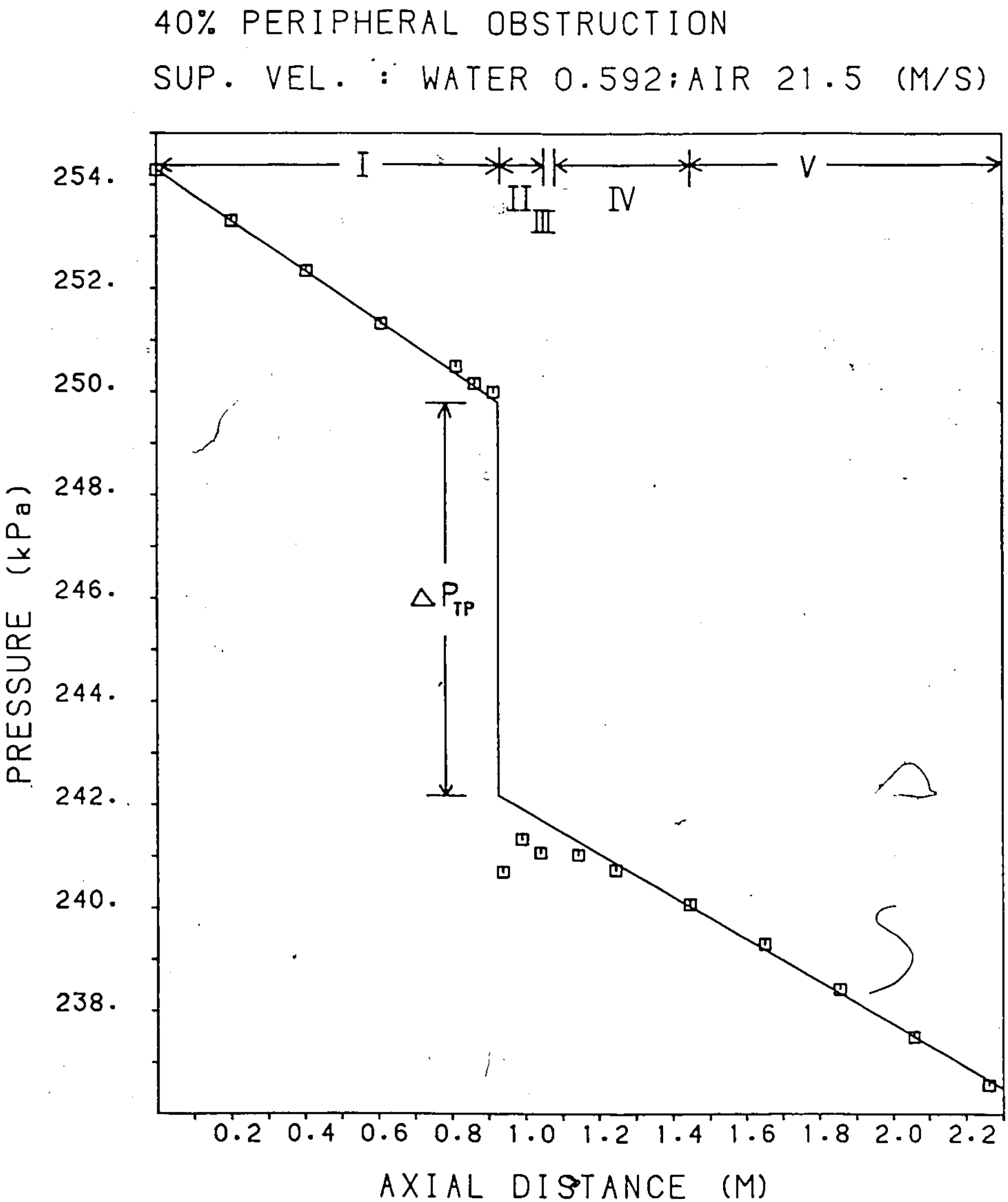


Figure 8.2: Two-phase Pressure Variation for the 40% Peripheral Obstruction.

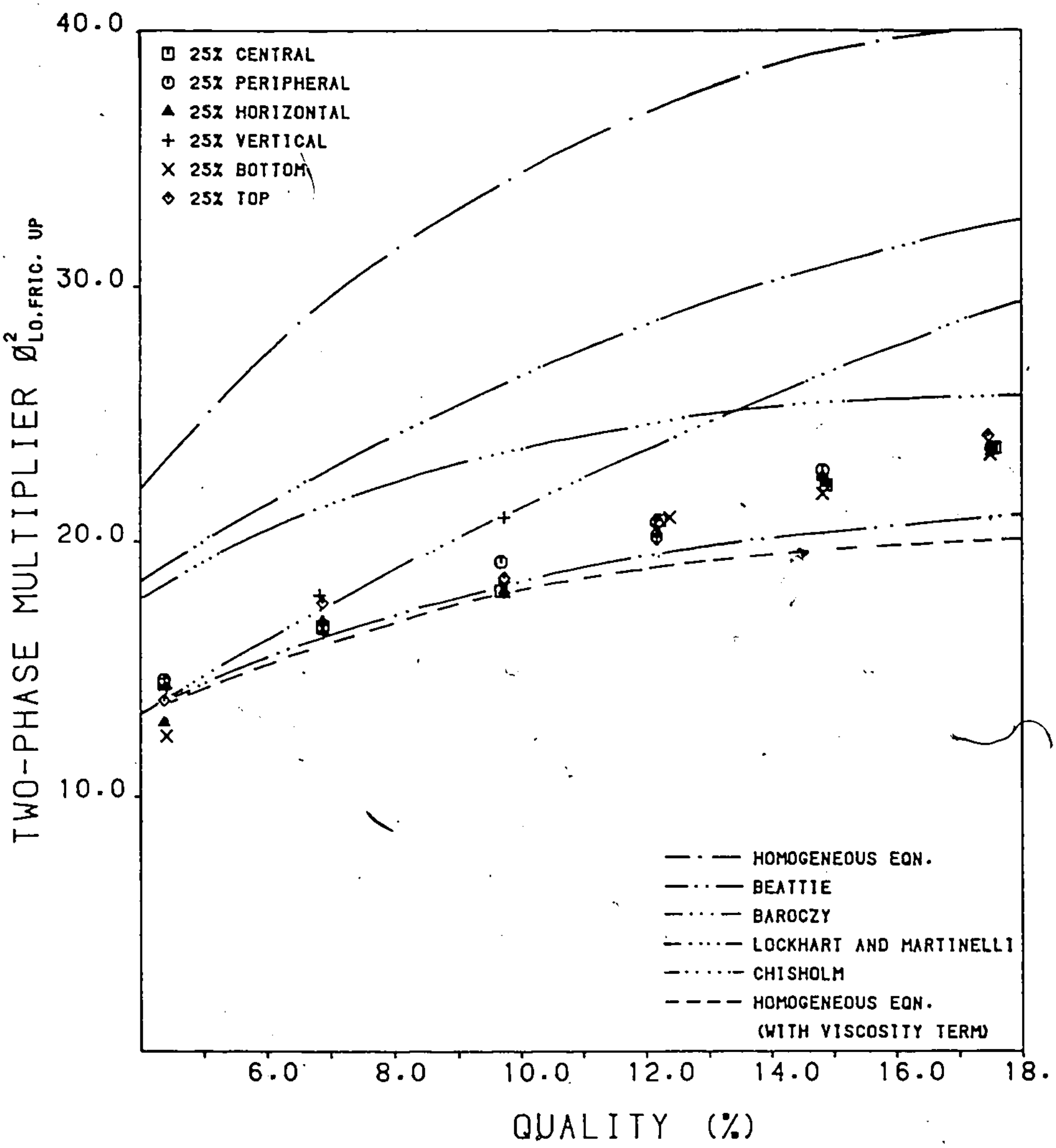


Figure 8.3: Two-phase Upstream Frictional Multipliers for the 25% Obstructions.

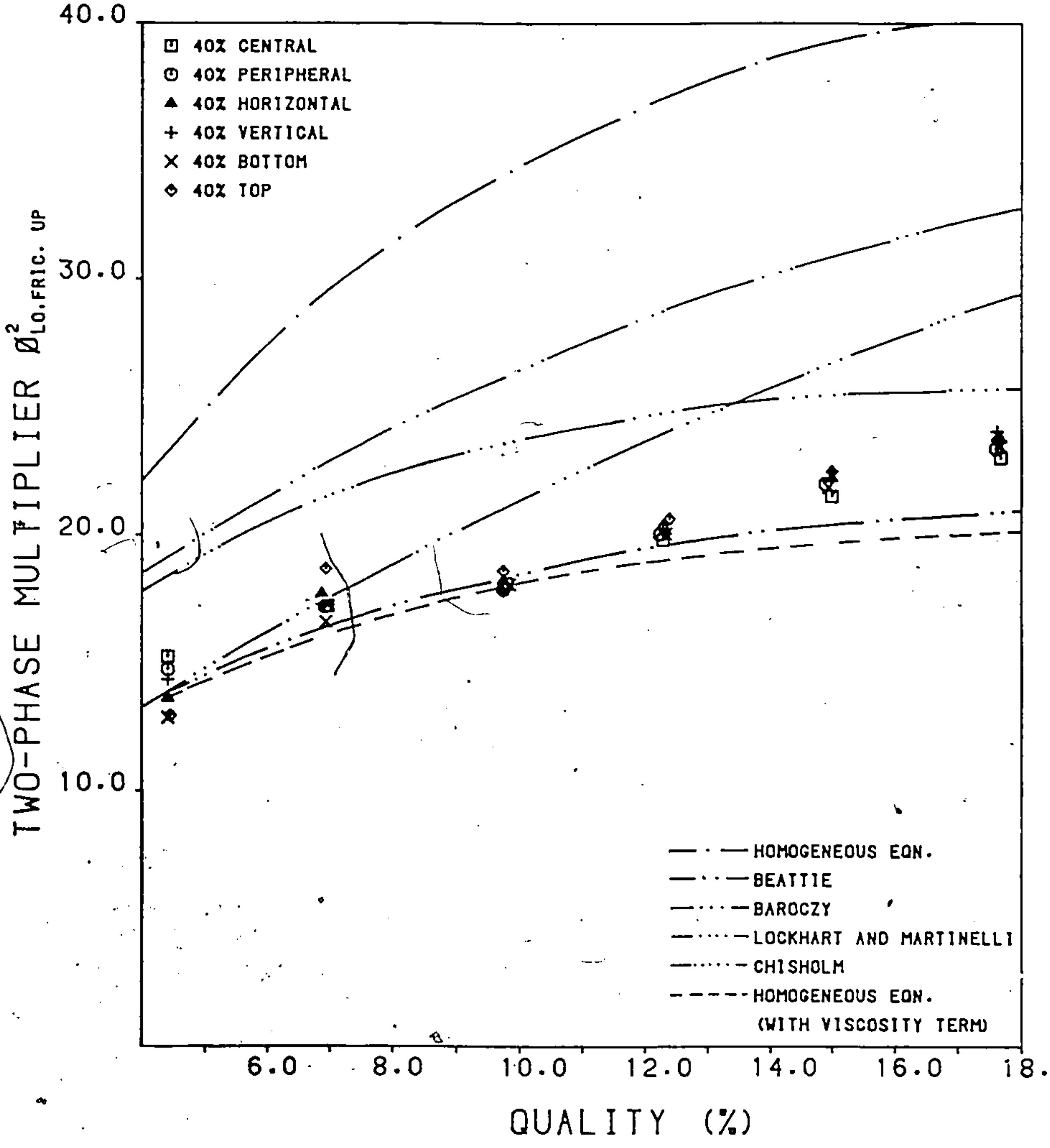


Figure 8.4: Two-phase Upstream Frictional Multipliers for the 40% Obstructions.

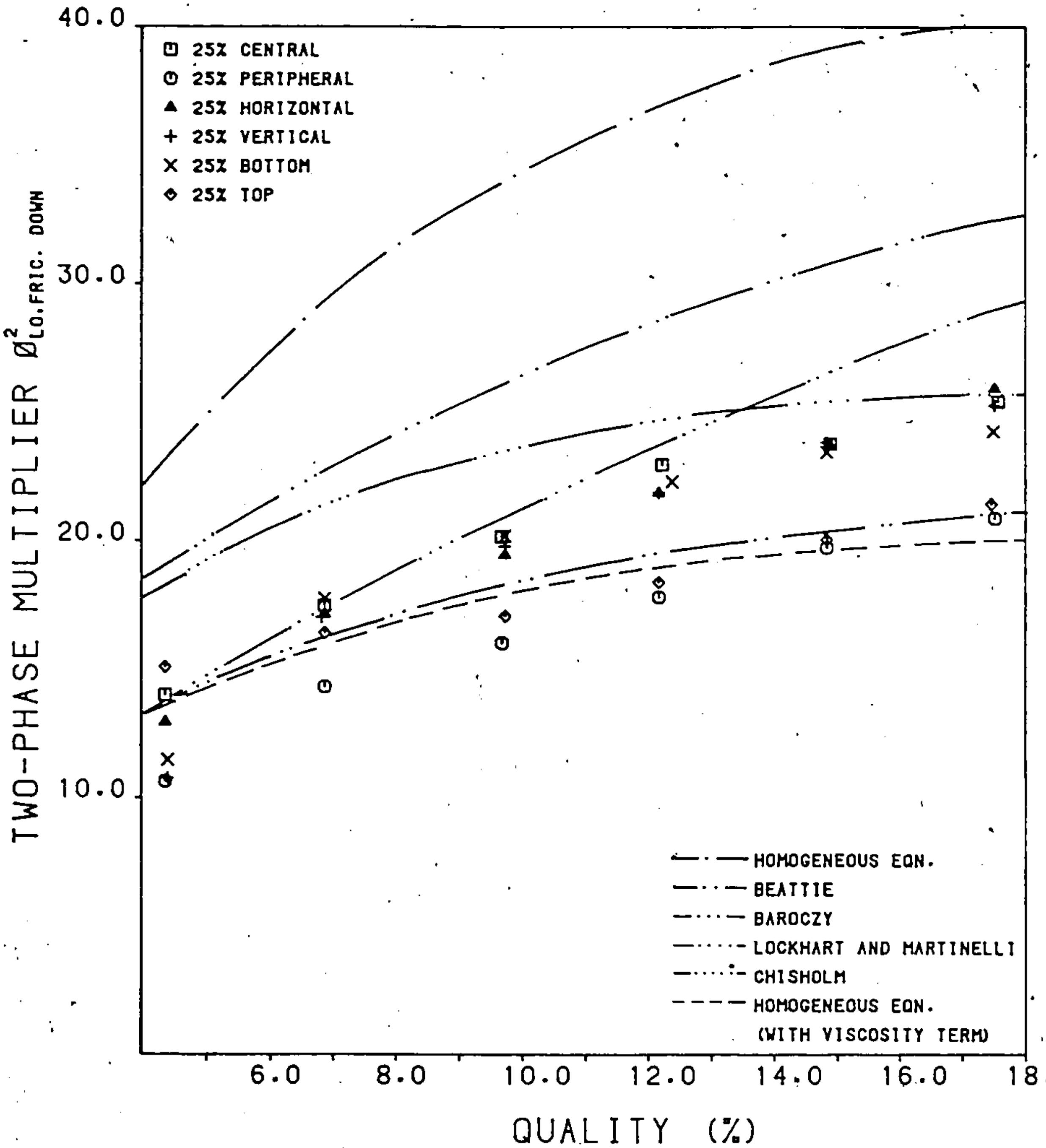


Figure 8.5: Two-phase Downstream Frictional Multipliers for the 25% Obstructions.

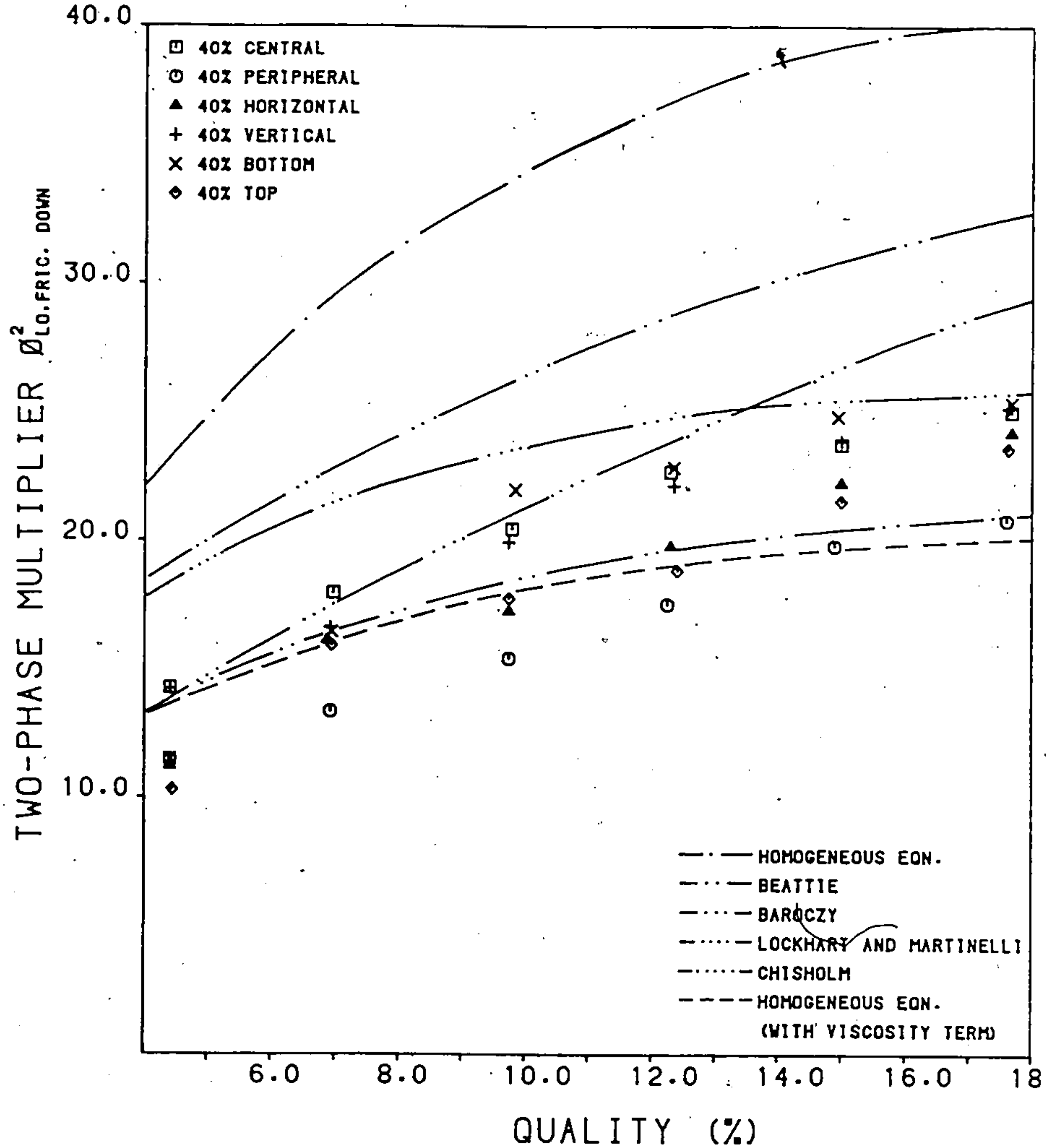


Figure 8.6: Two-phase Downstream Frictional Multipliers for the 40% Obstructions.

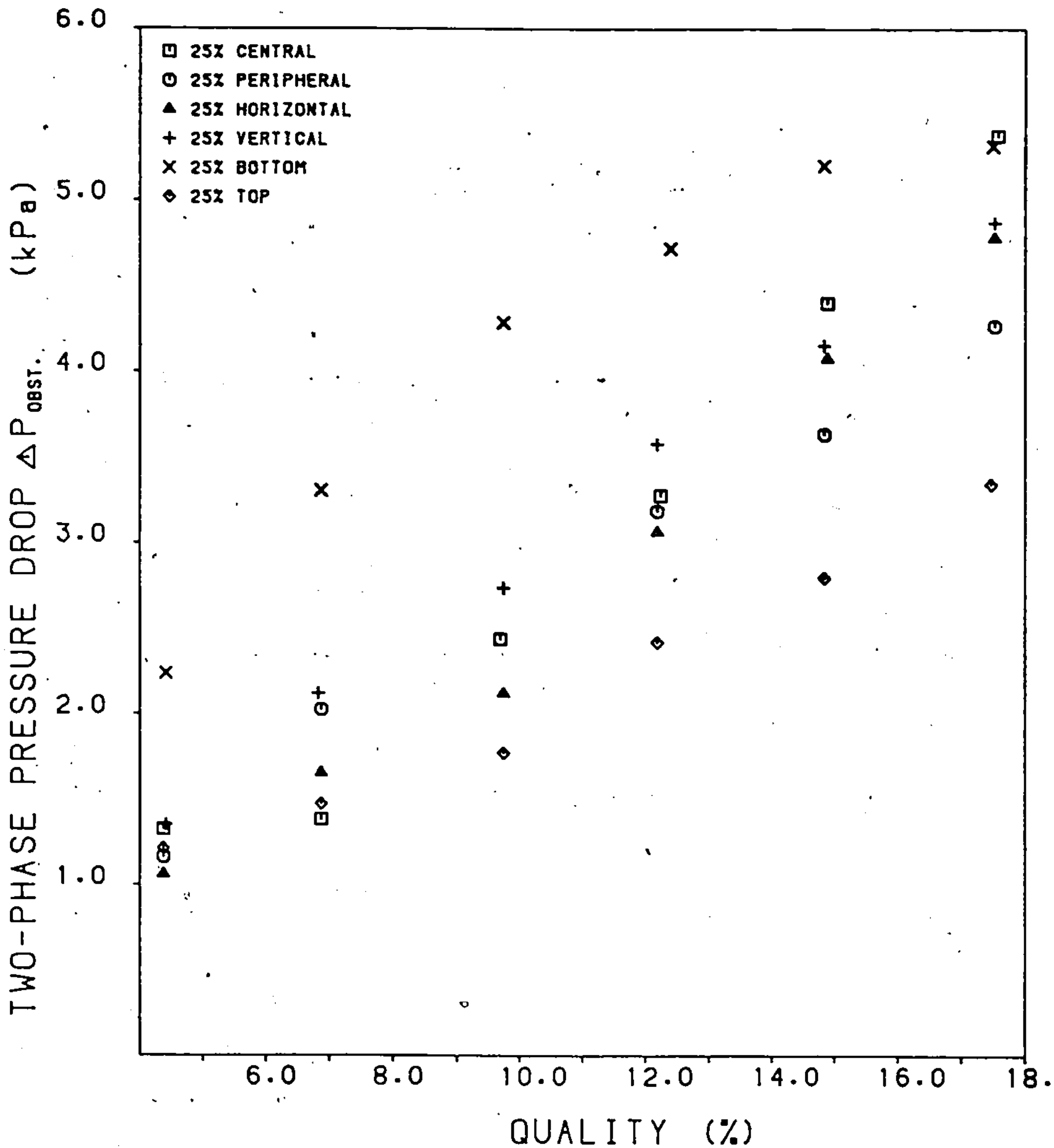


Figure 8.7: Two-phase Local Pressure Loss for the 25% Obstructions.

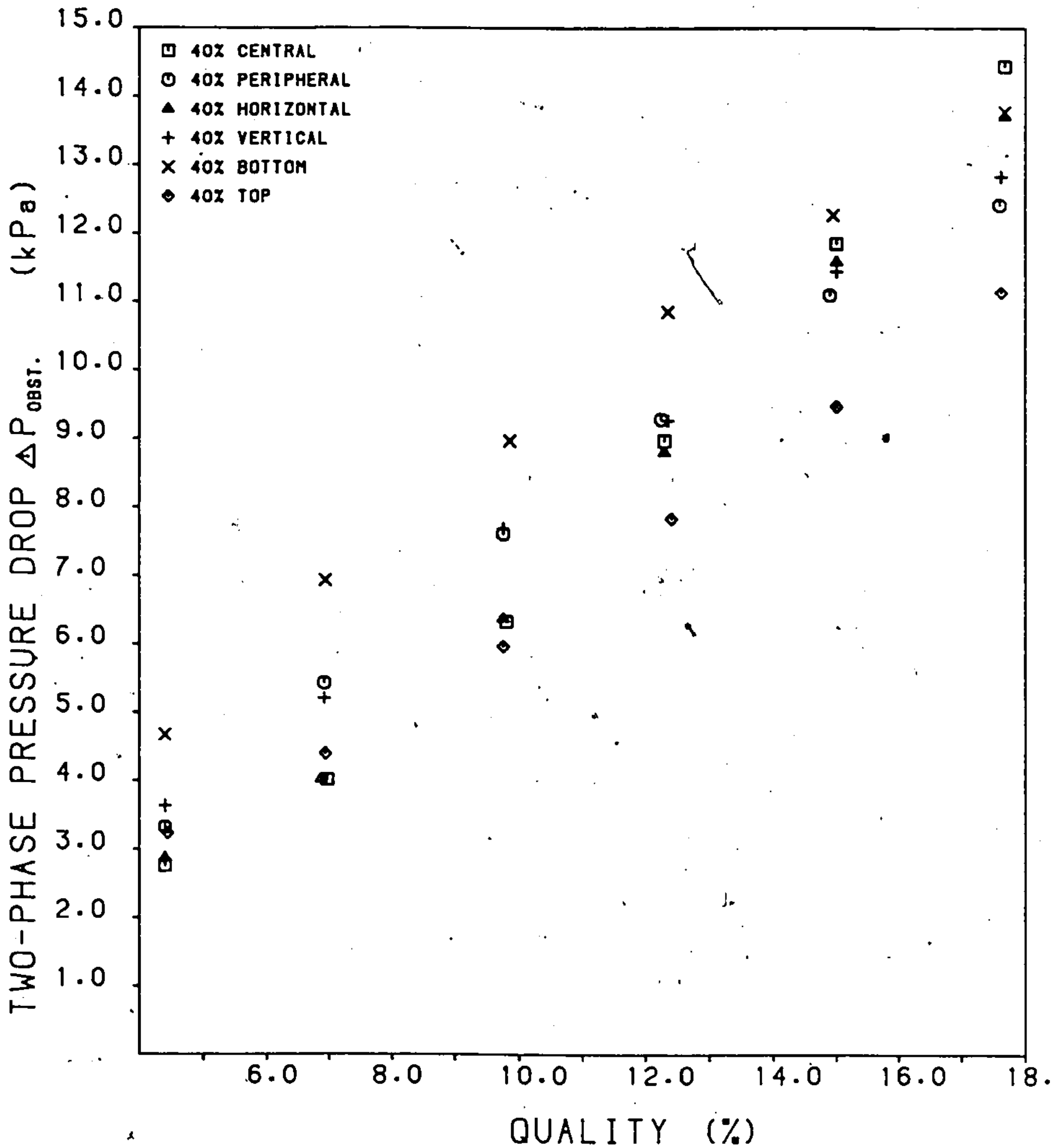


Figure 8.8: Two-phase Local Pressure Loss for the 40% Obstructions.

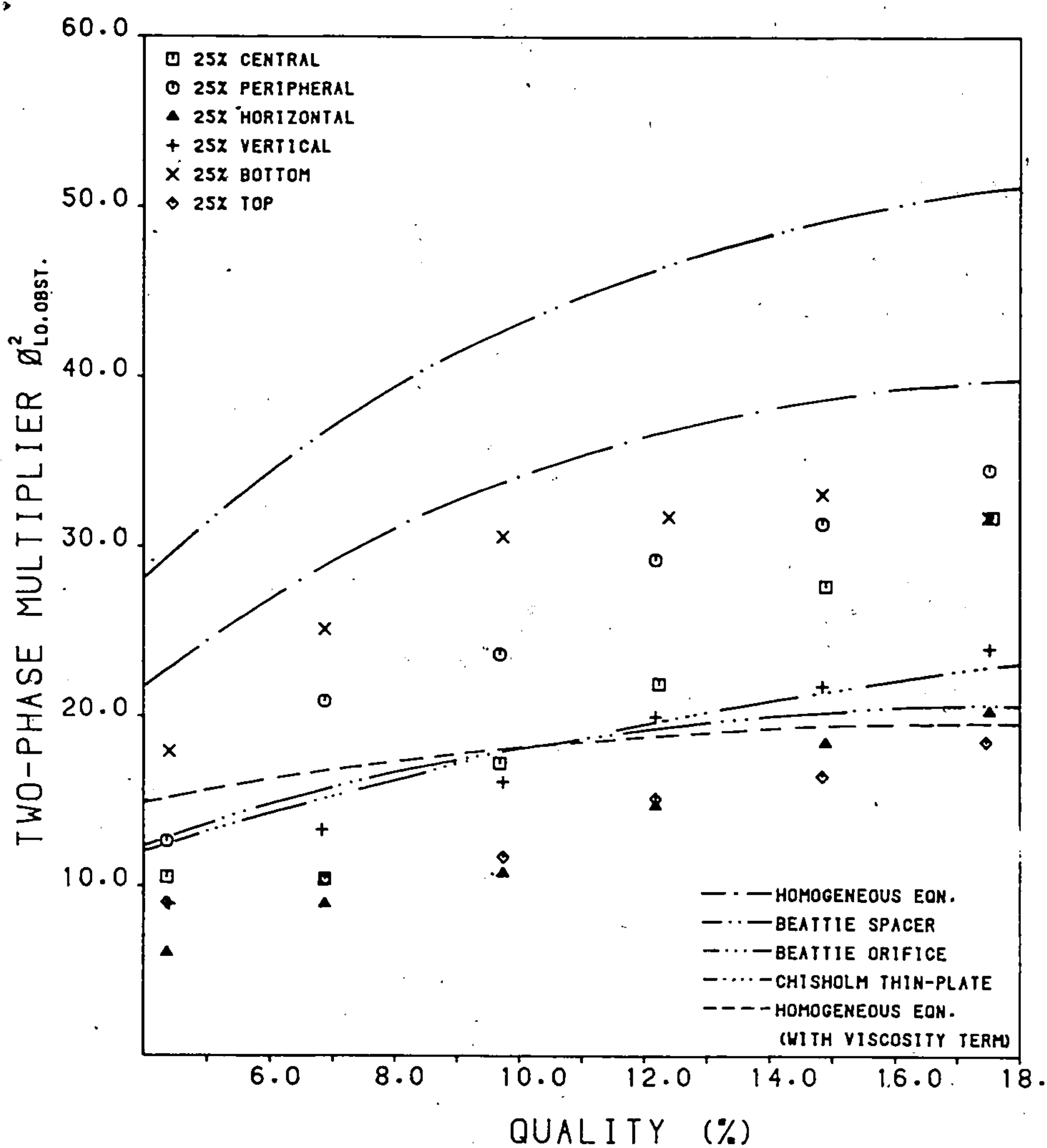


Figure 8.9: Two-phase Obstructional Multipliers for the 25% Obstructions.

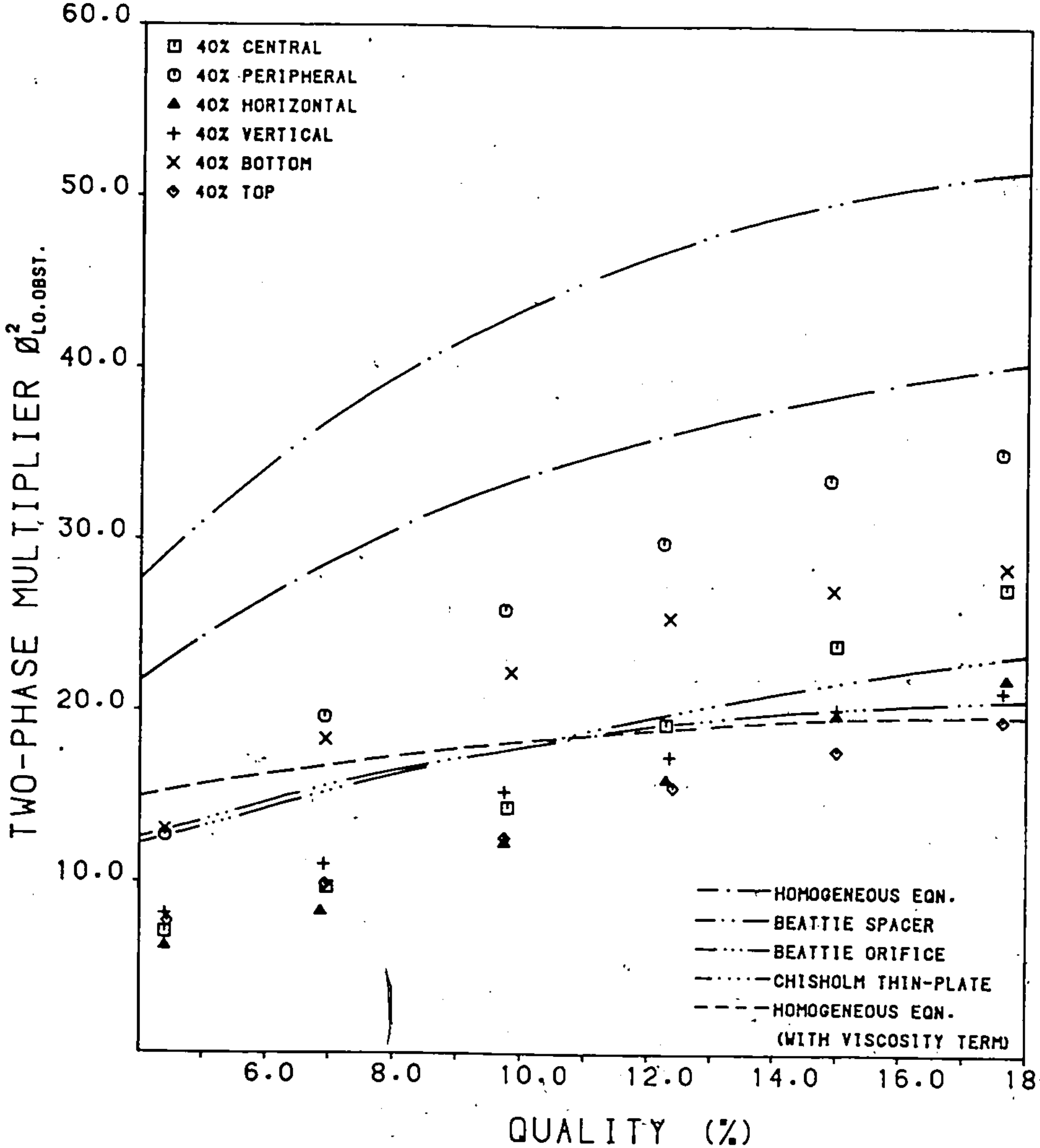


Figure 8.10: Two-phase Obstructional Multipliers for the 40% Obstructions.

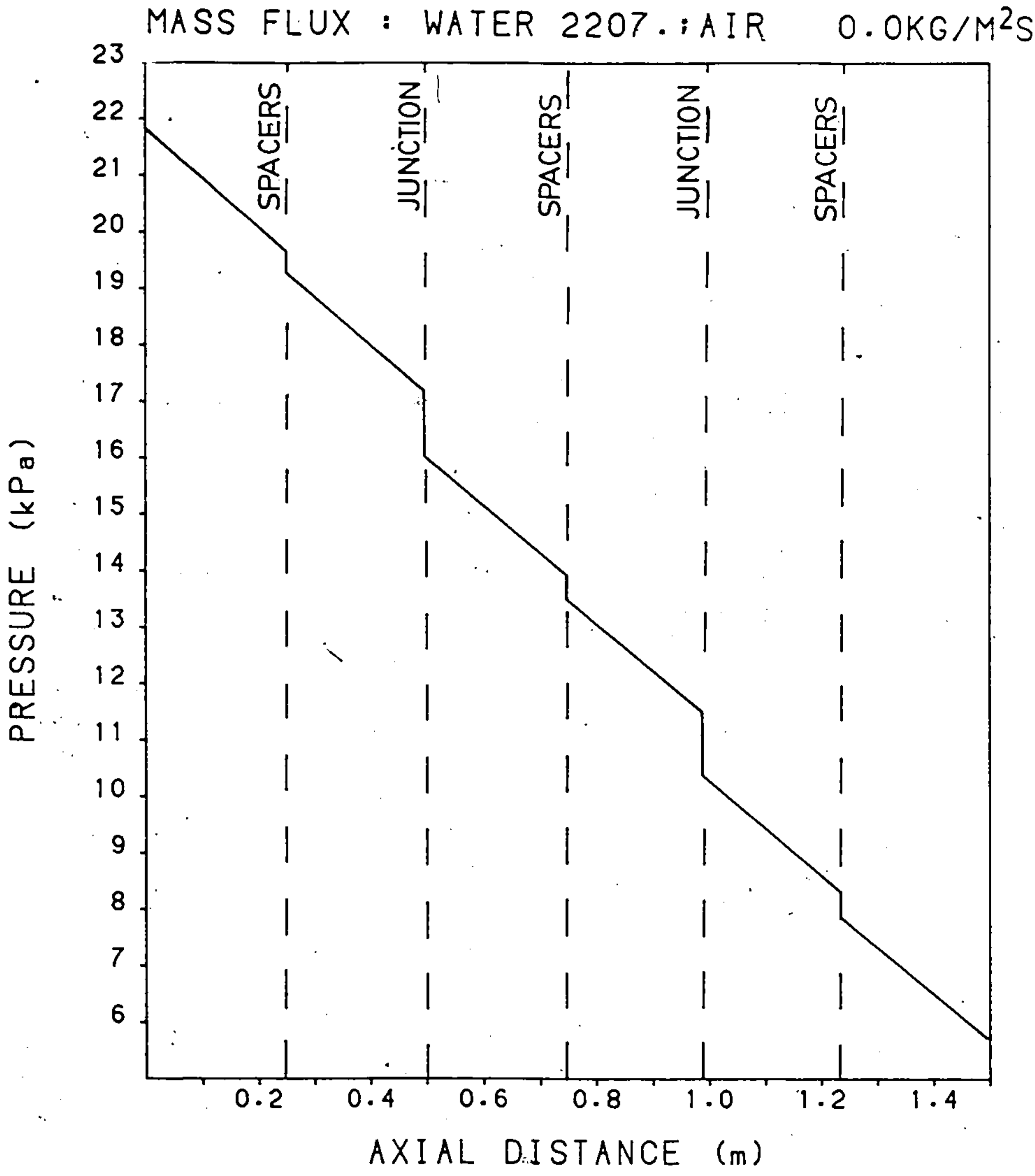


Figure 8.11: Single-phase Pressure Variation for the Aligned Regular Bundles.

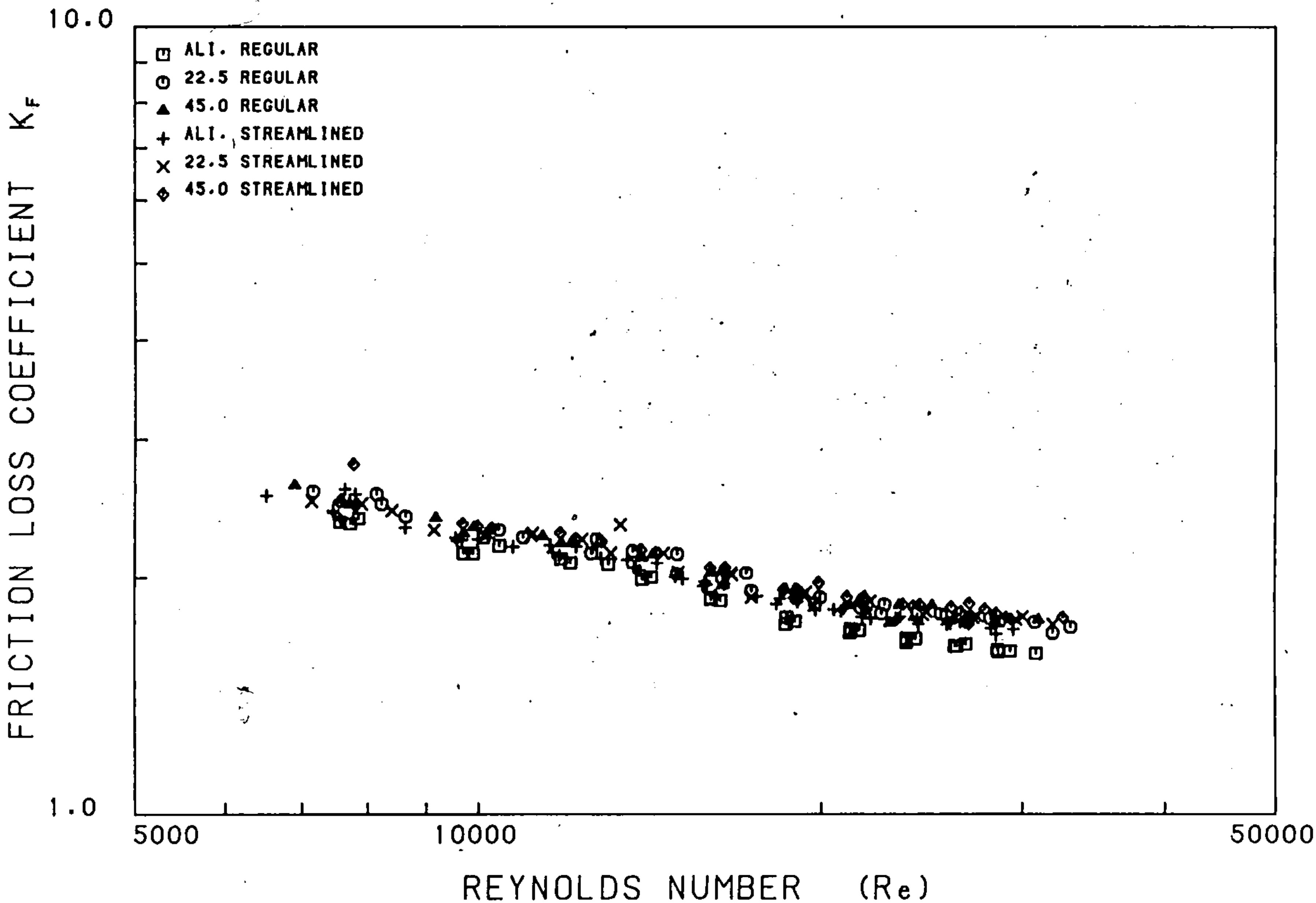


Figure 8.12: Friction Loss Coefficients for Various Bundle Configurations.

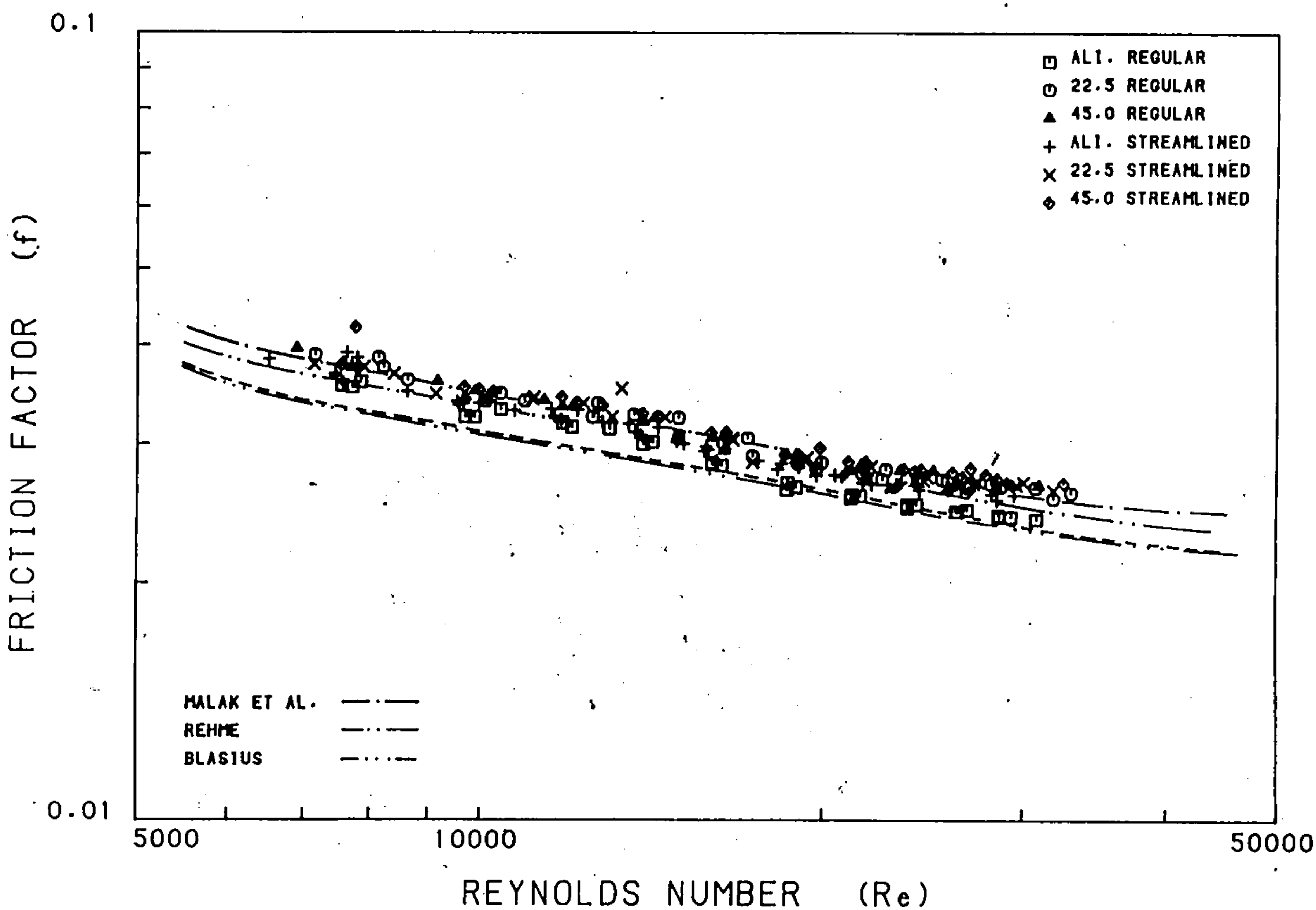


Figure 8.13: Friction Factors for the Bundles.

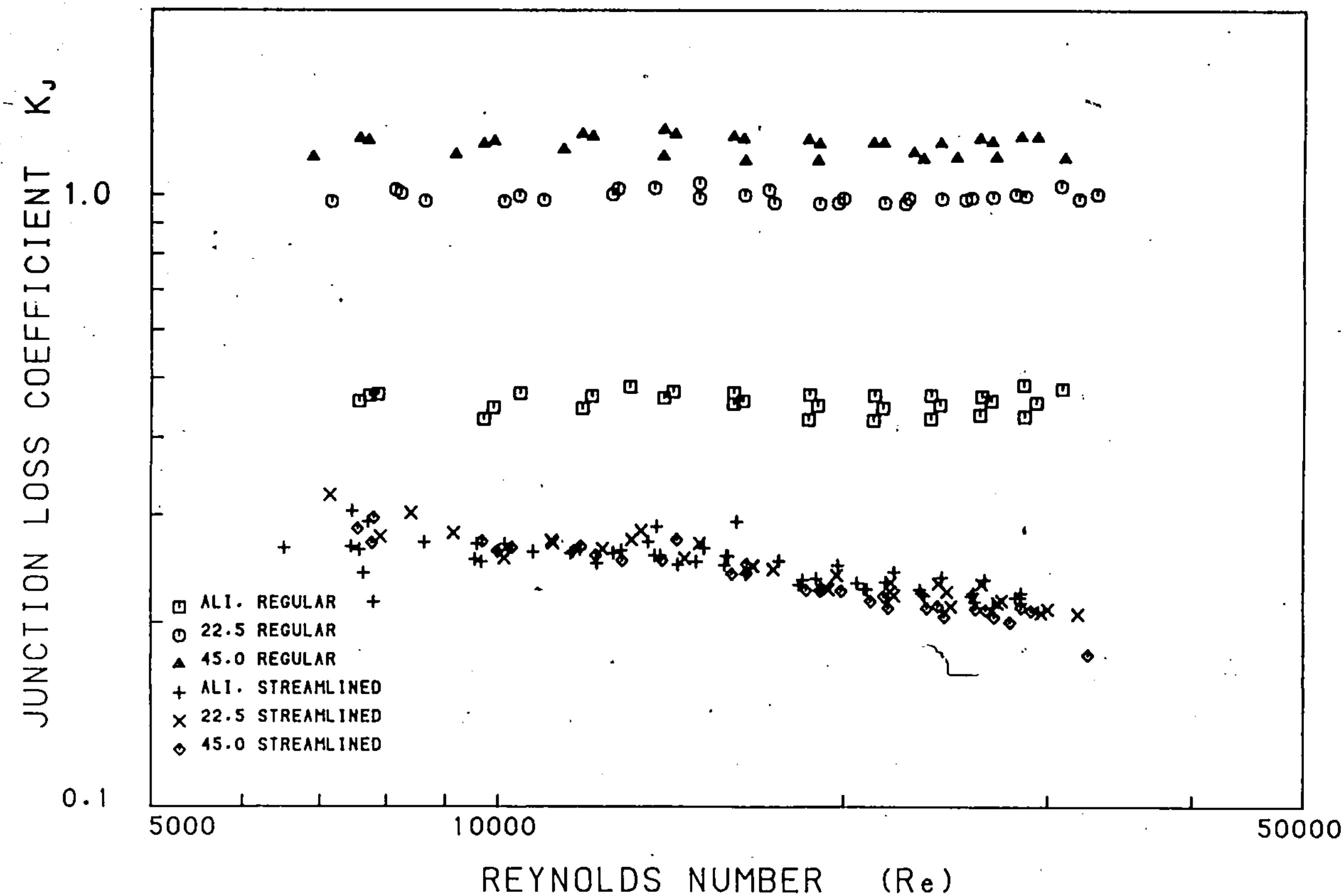


Figure 8.14: Junction Loss Coefficients for Various Bundle Configurations.

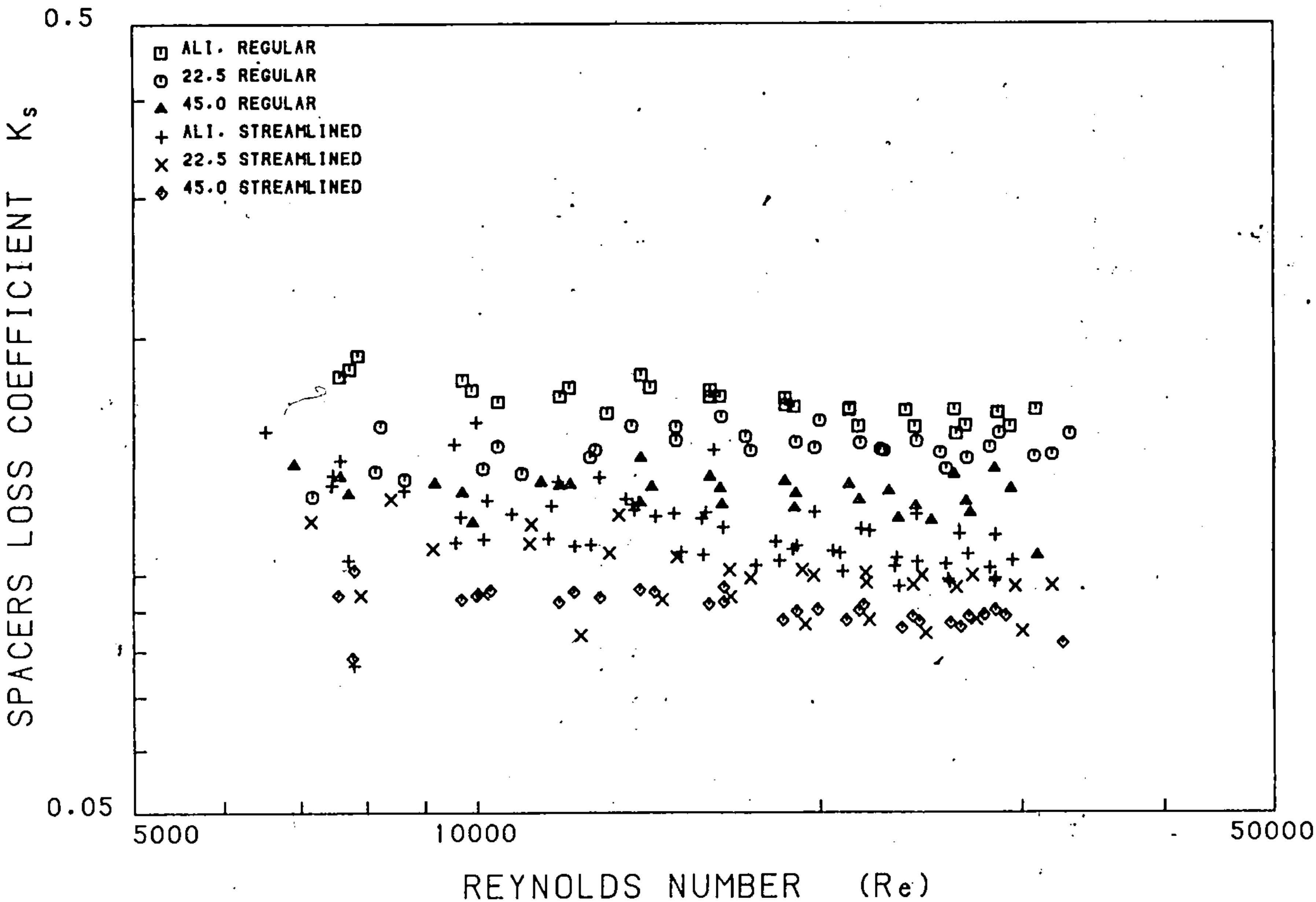


Figure 8.15: Spacer Loss Coefficients for Various Bundle Configurations.

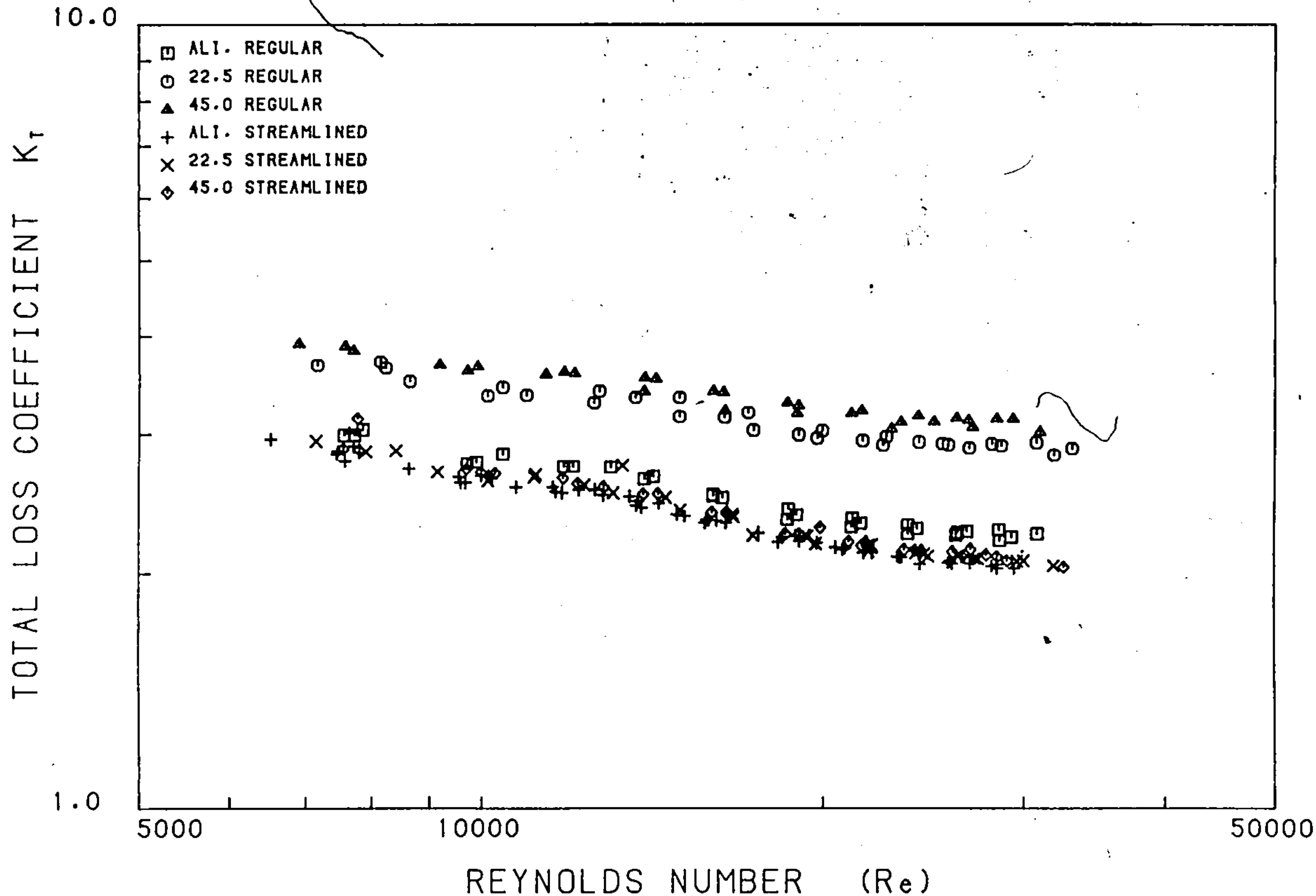


Figure 8.16: Total Loss Coefficients for Various Bundle Configurations.

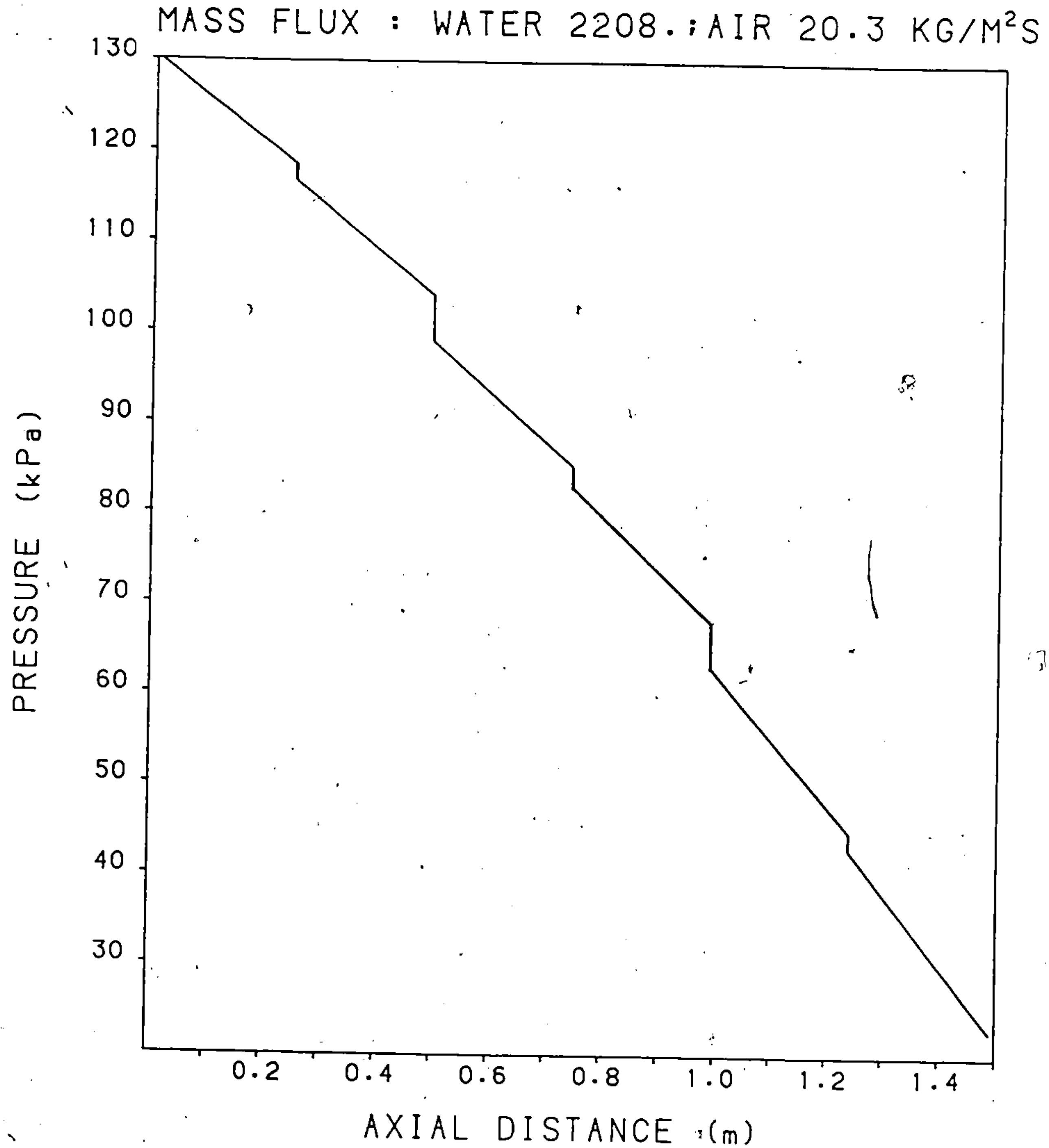


Figure 8.17: Two-phase Pressure Variation for the Aligned Regular Bundles.

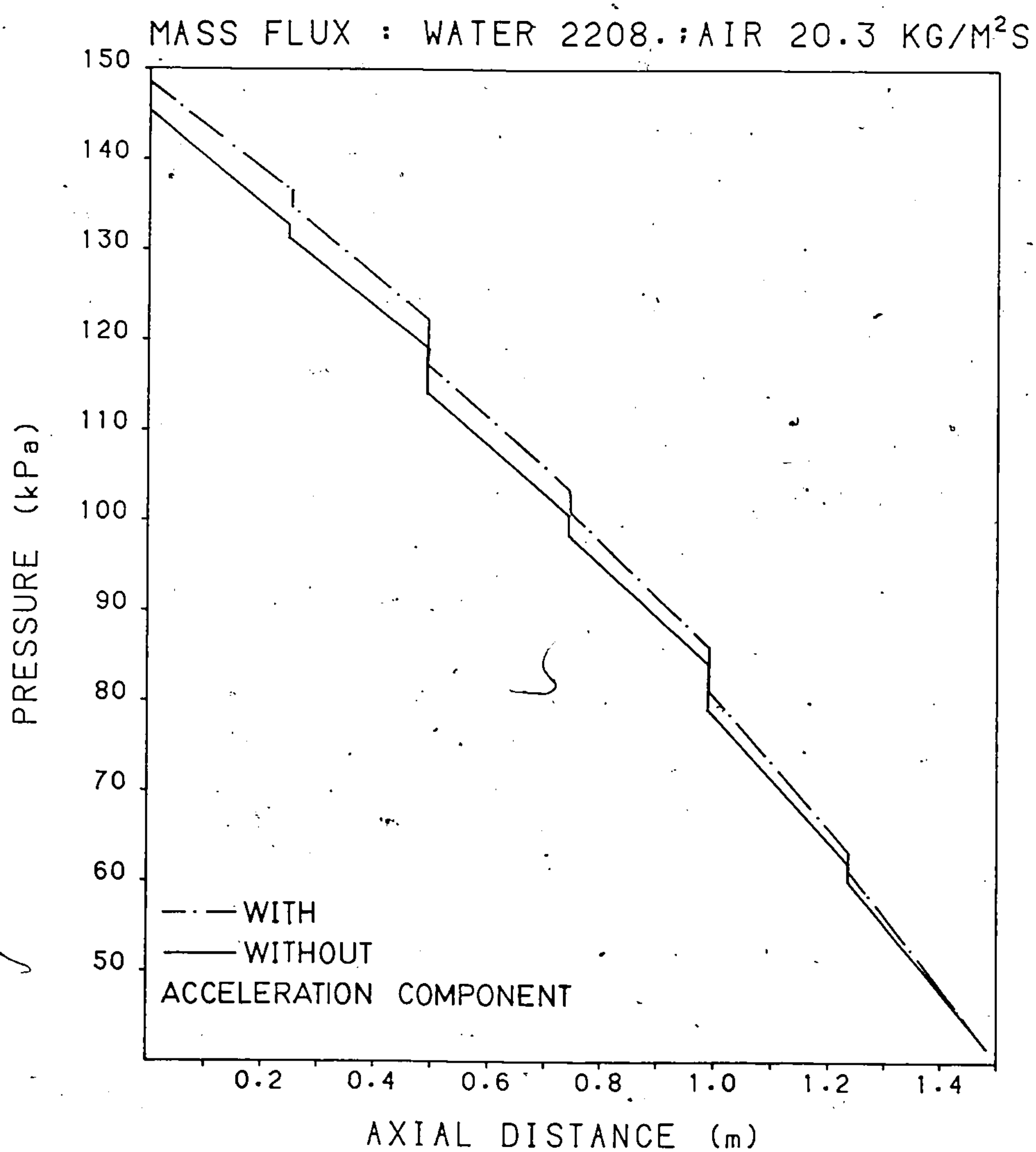


Figure 8.18: Accelerational Effect of the Two-phase Flow on the Pressure Loss.

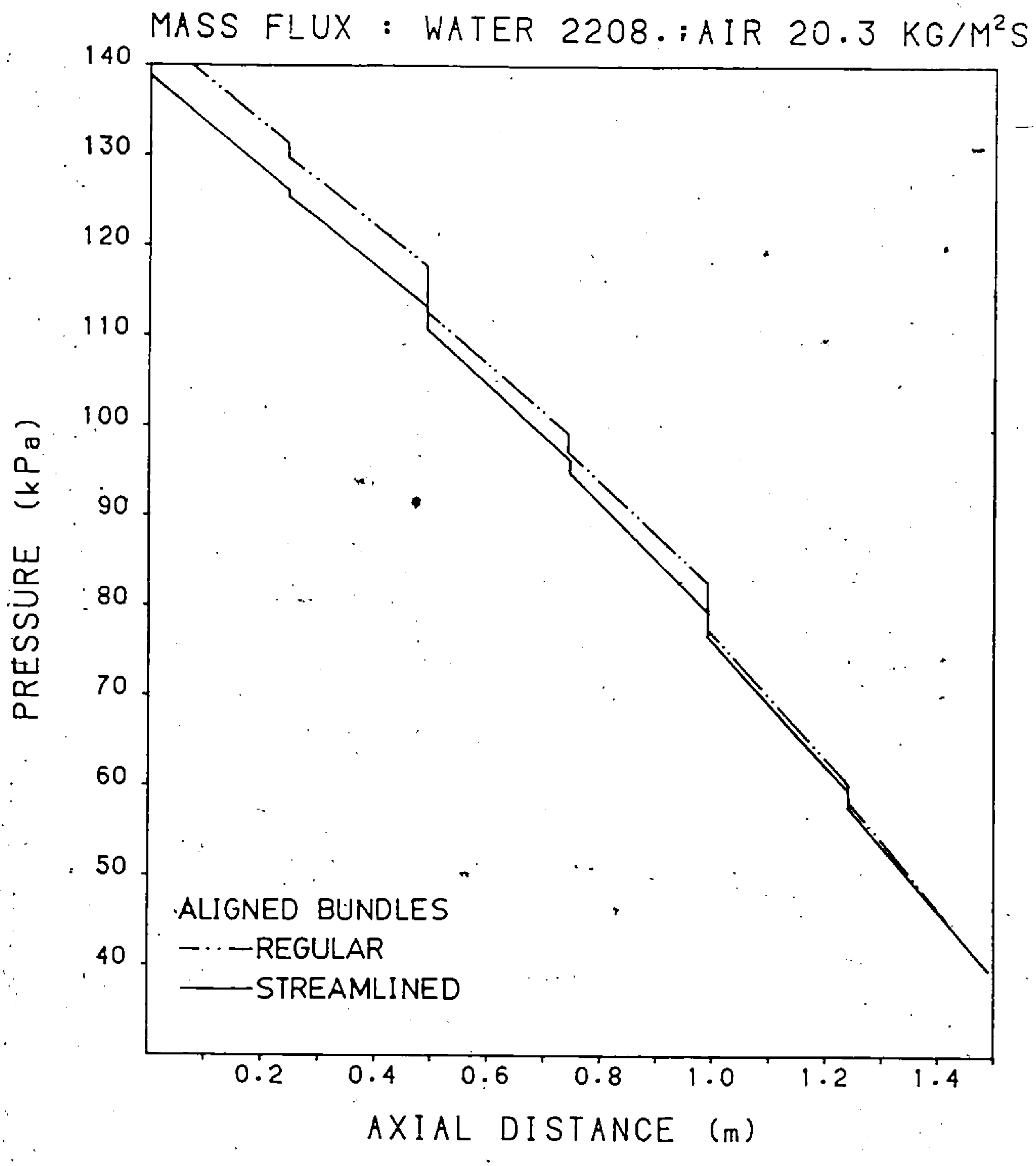


Figure 8.19: Two-phase Frictional Pressure Variation for the Aligned Streamlined Bundles.

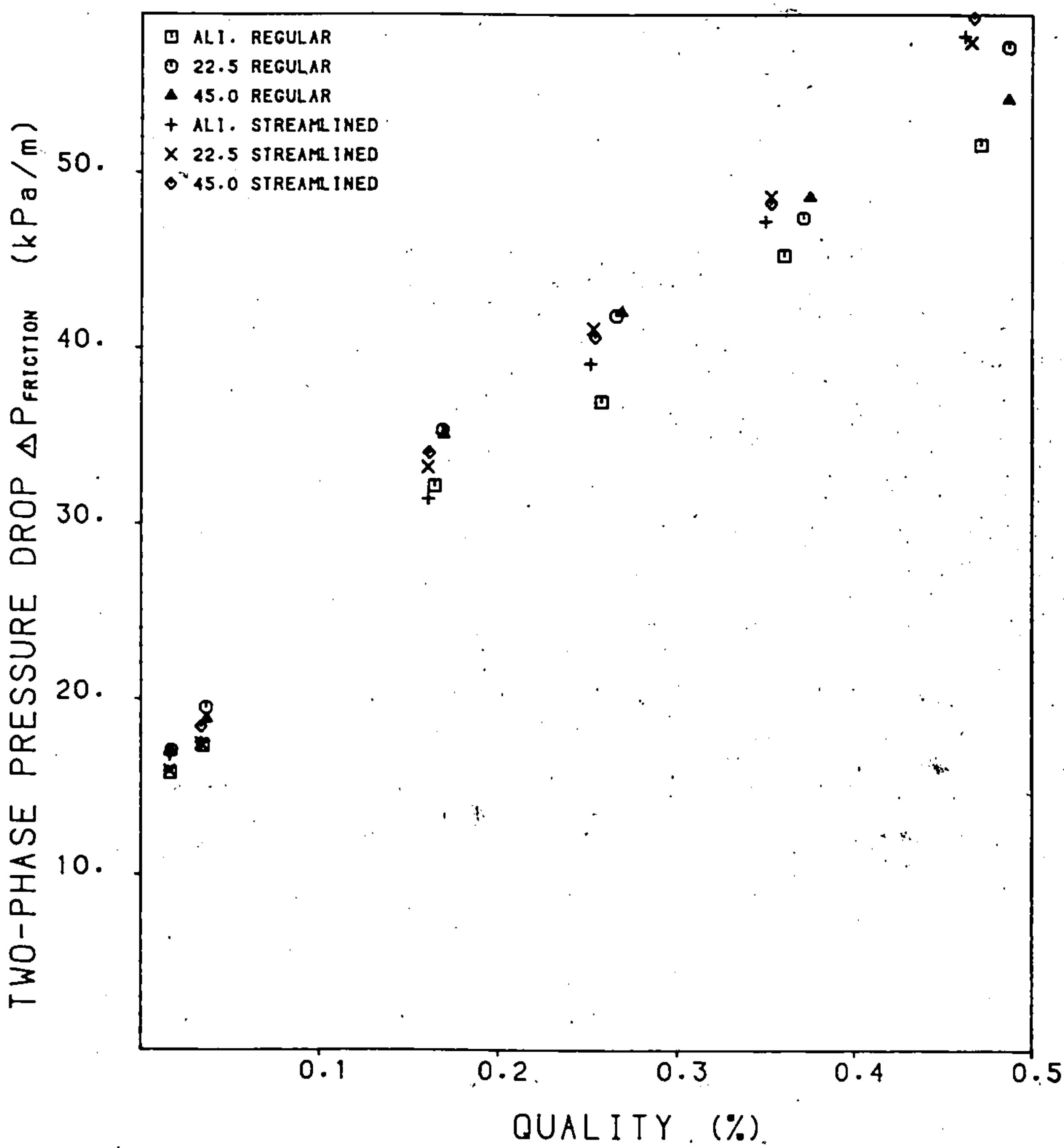


Figure 8.20: Two-phase Frictional Pressure Losses for Various Bundles with a 2760 kg/m²s Liquid Mass Flux.

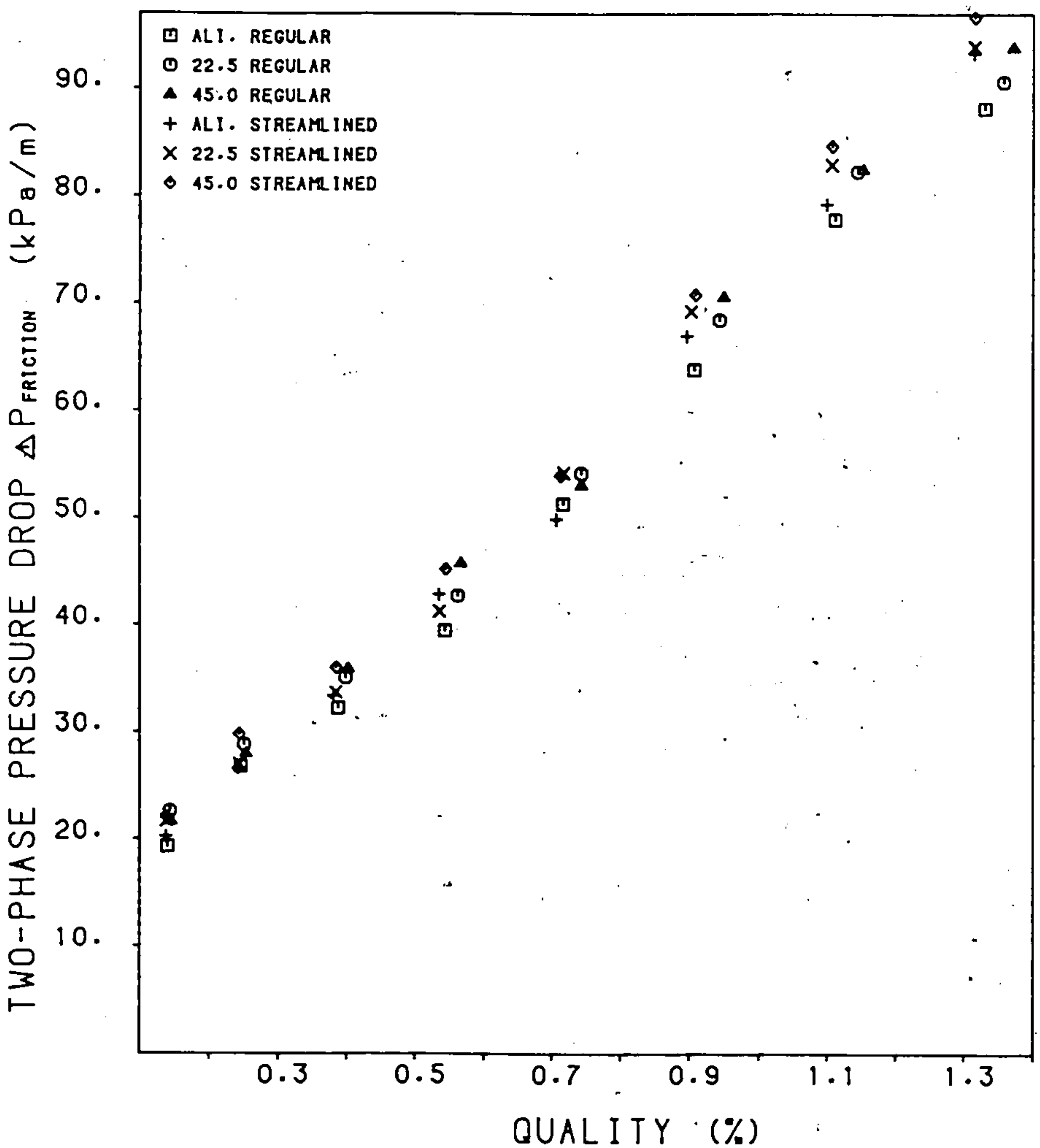


Figure 8.21: Two-phase Frictional Pressure Losses for Various Bundles with a 2210 kg/m²s Liquid Mass Flux.

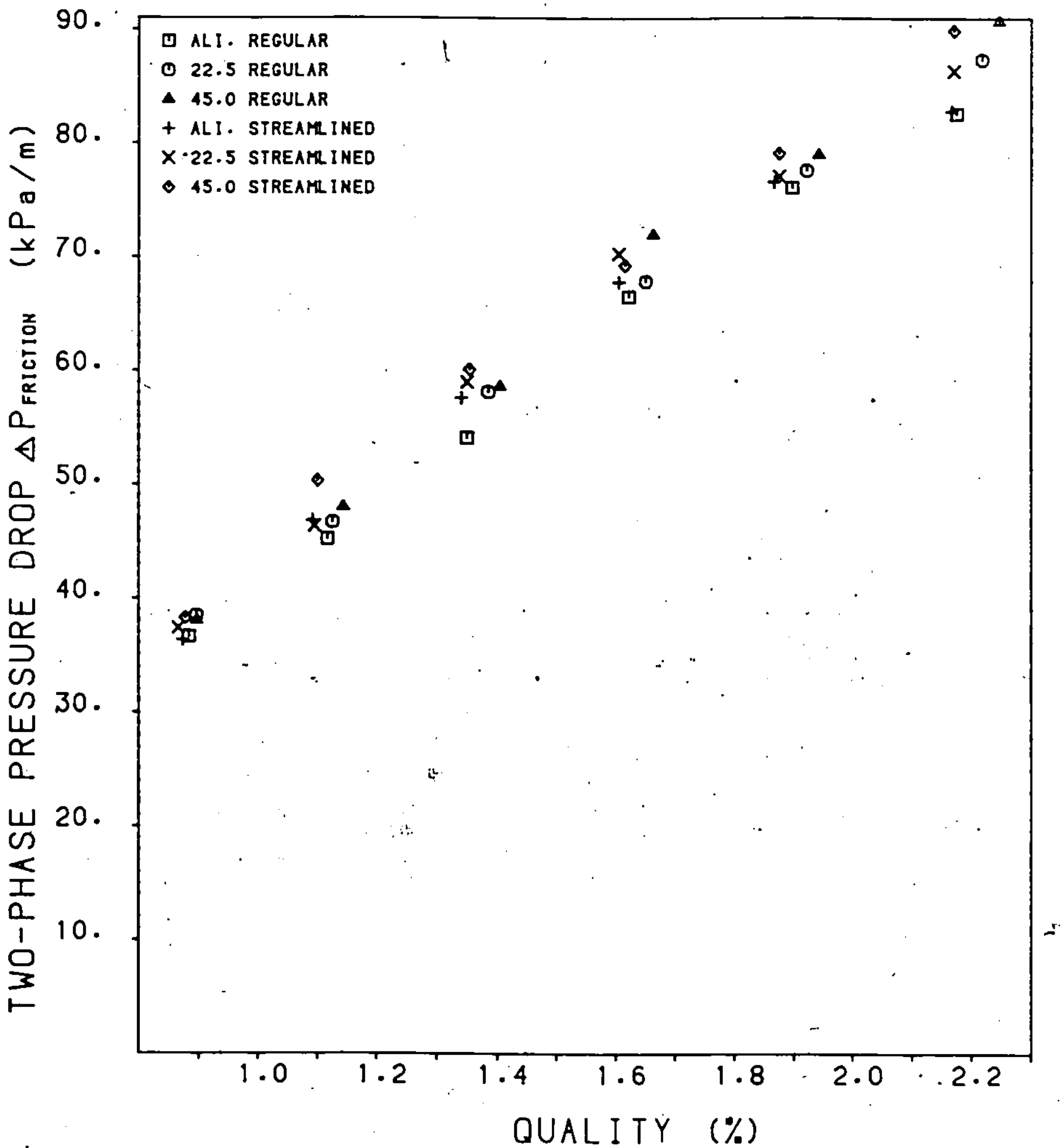


Figure 8.22: Two-phase Frictional Pressure Losses for Various Bundles with a 1660 kg/m²s Liquid Mass Flux.

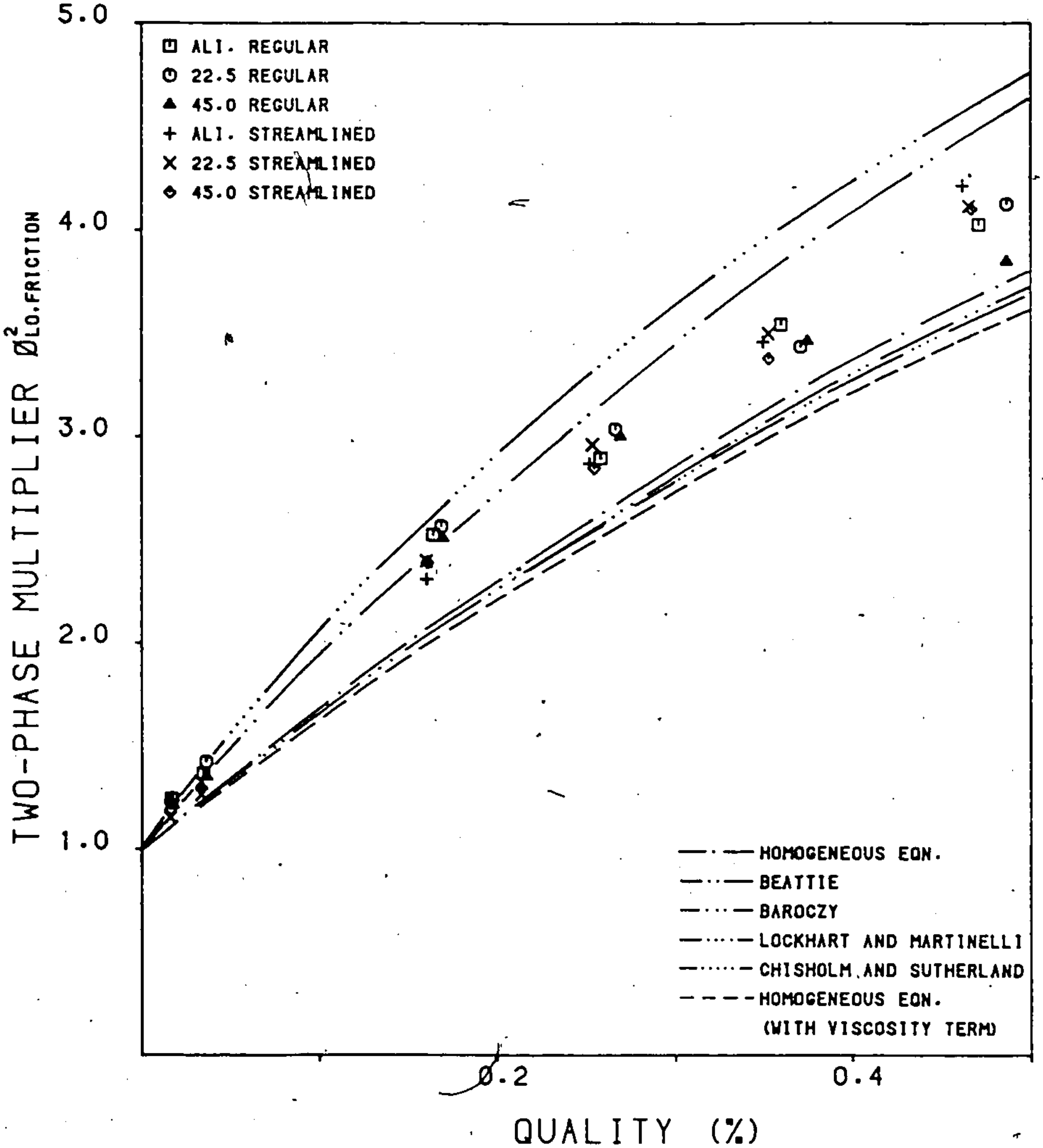


Figure 8.23: Two-phase Frictional Multipliers for Various Bundles with a 2760 kg/m^{2}s Liquid Mass Flux.

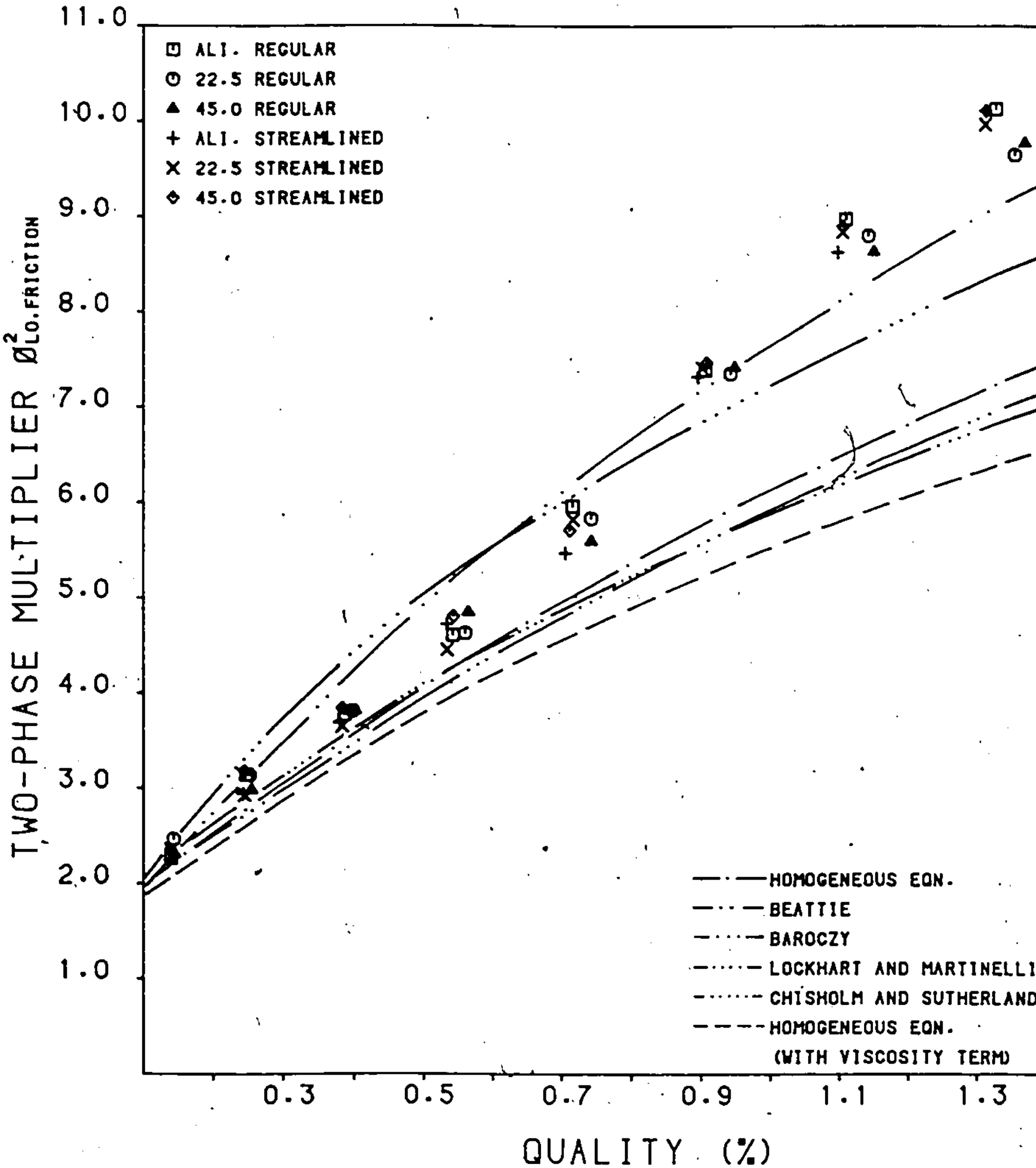


Figure 8.24: Two-phase Frictional Multipliers for Various Bundles with a 2210 kg/m²s Liquid Mass Flux.

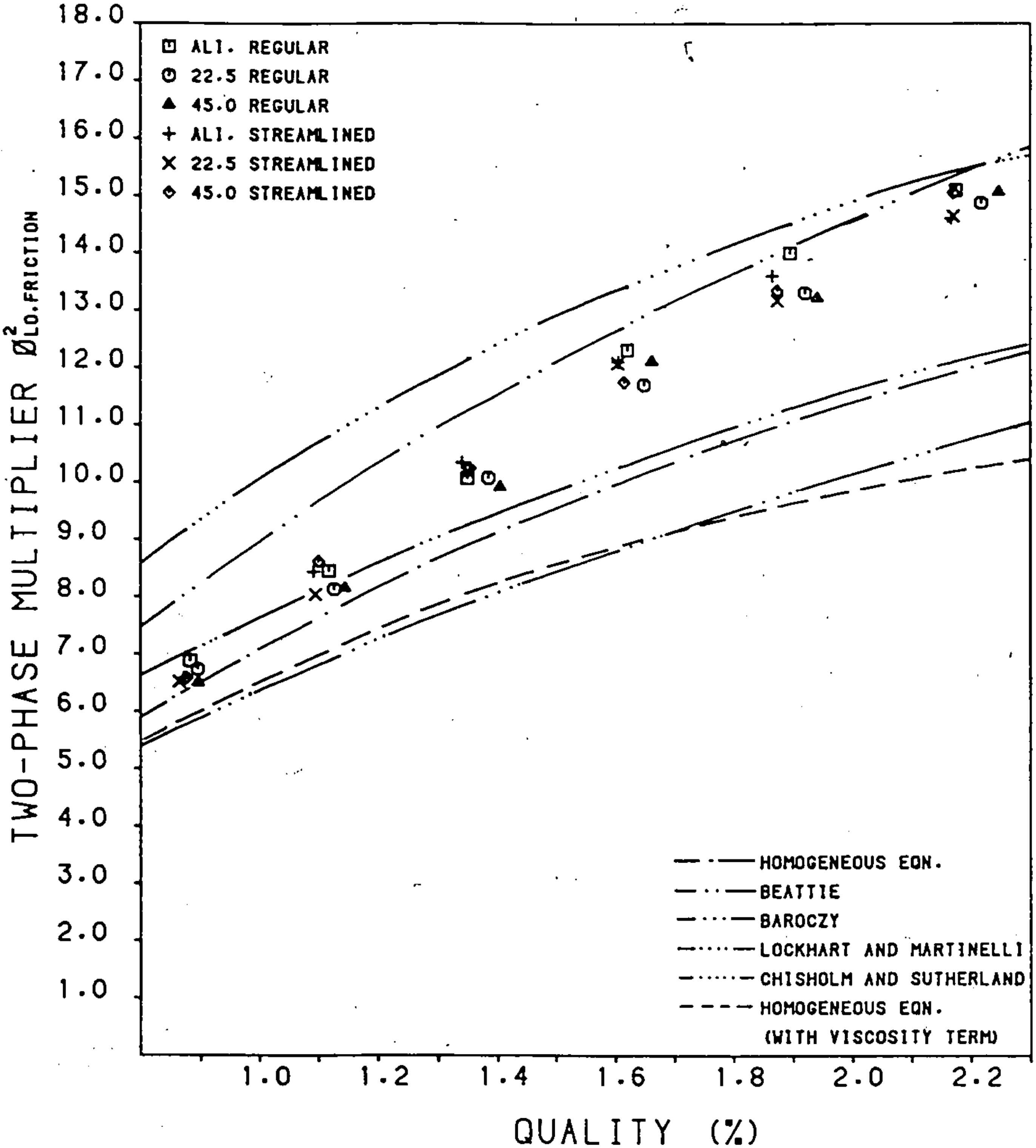


Figure 8.25: Two-phase Frictional Multipliers for Various Bundles with a 1660 kg/m^2s Liquid Mass Flux.

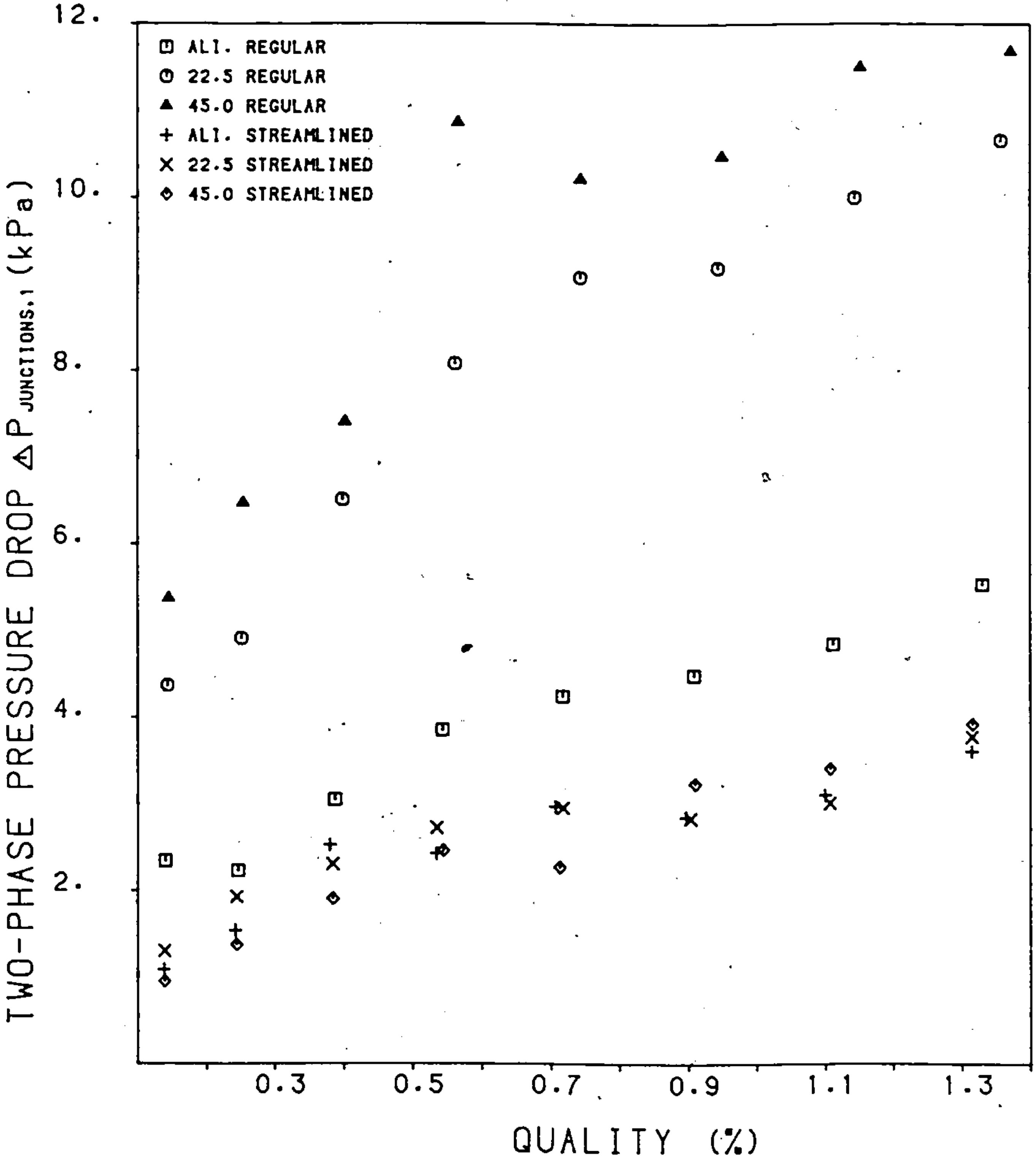


Figure 8.26: Two-phase Pressure Losses in the First Junction of the Bundles with a 2210 kg/m^{2}s Liquid Mass Flux.

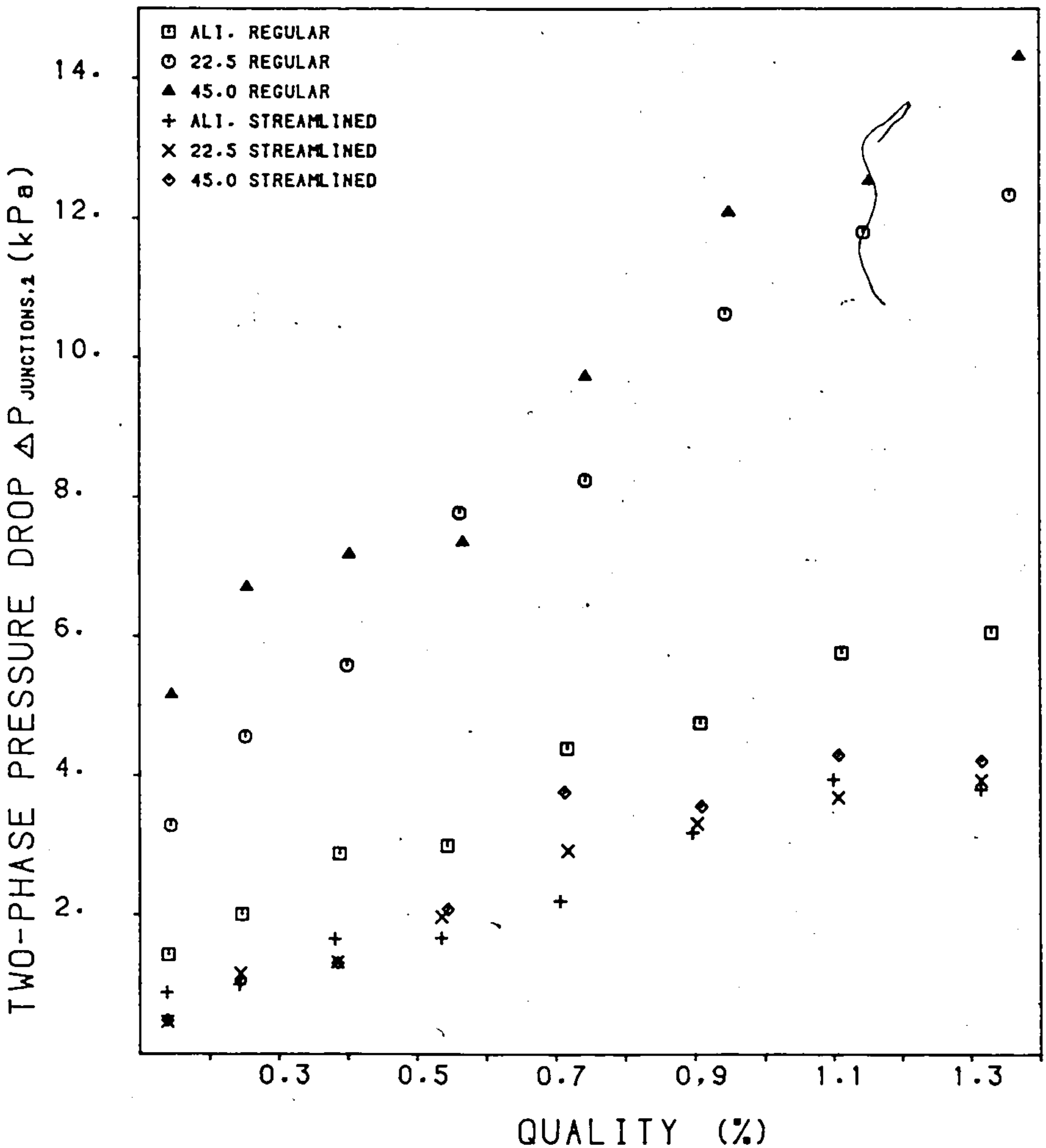


Figure 8.27: Two-phase Pressure Losses in the Second Junction of the Bundles with a 2210 kg/m^{2}s Liquid Mass Flux.

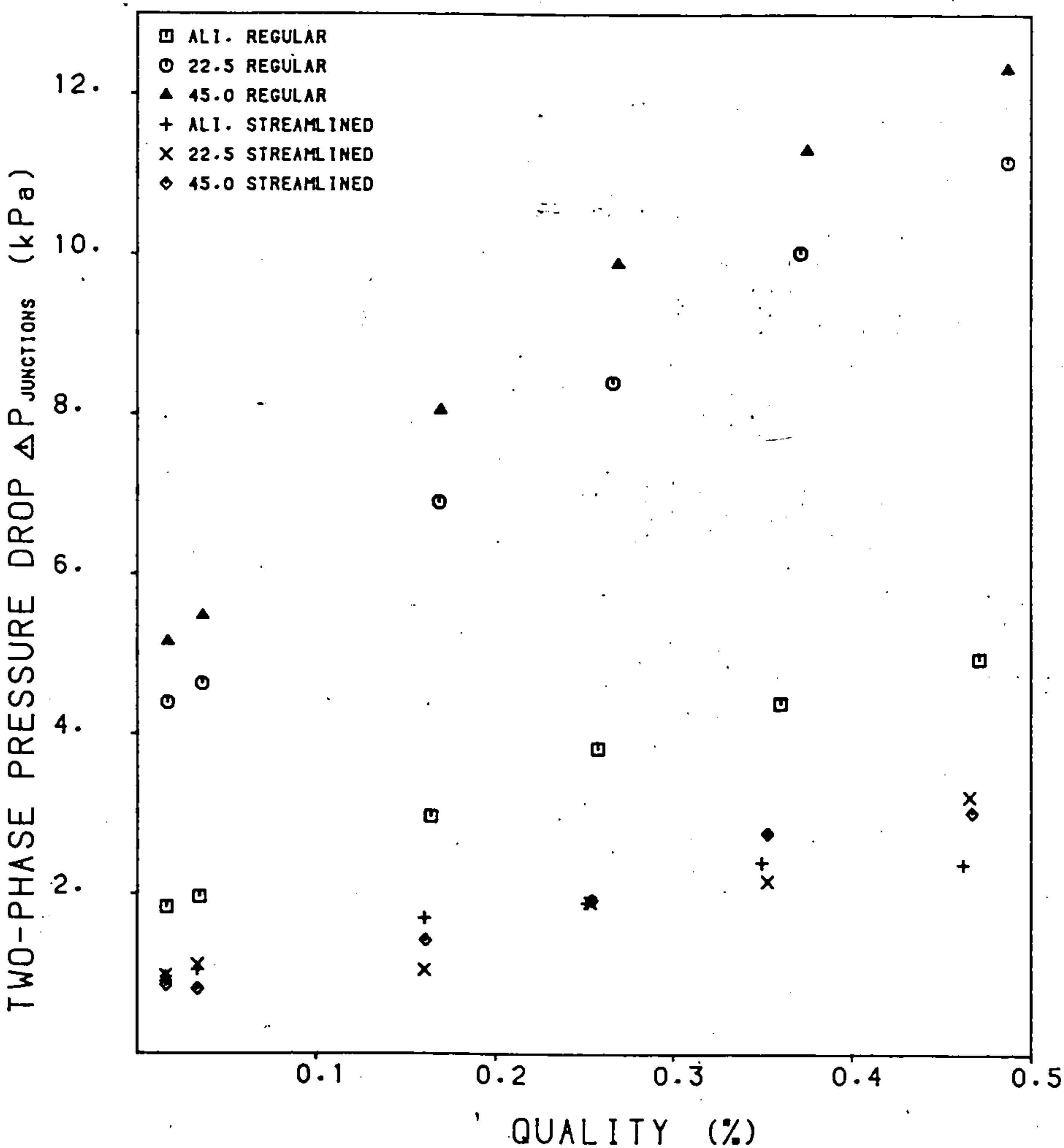


Figure 8.28: Two-phase Average Junction Pressure Losses for the Bundles with a 2760 kg/m^{2}s Liquid Mass Flux.

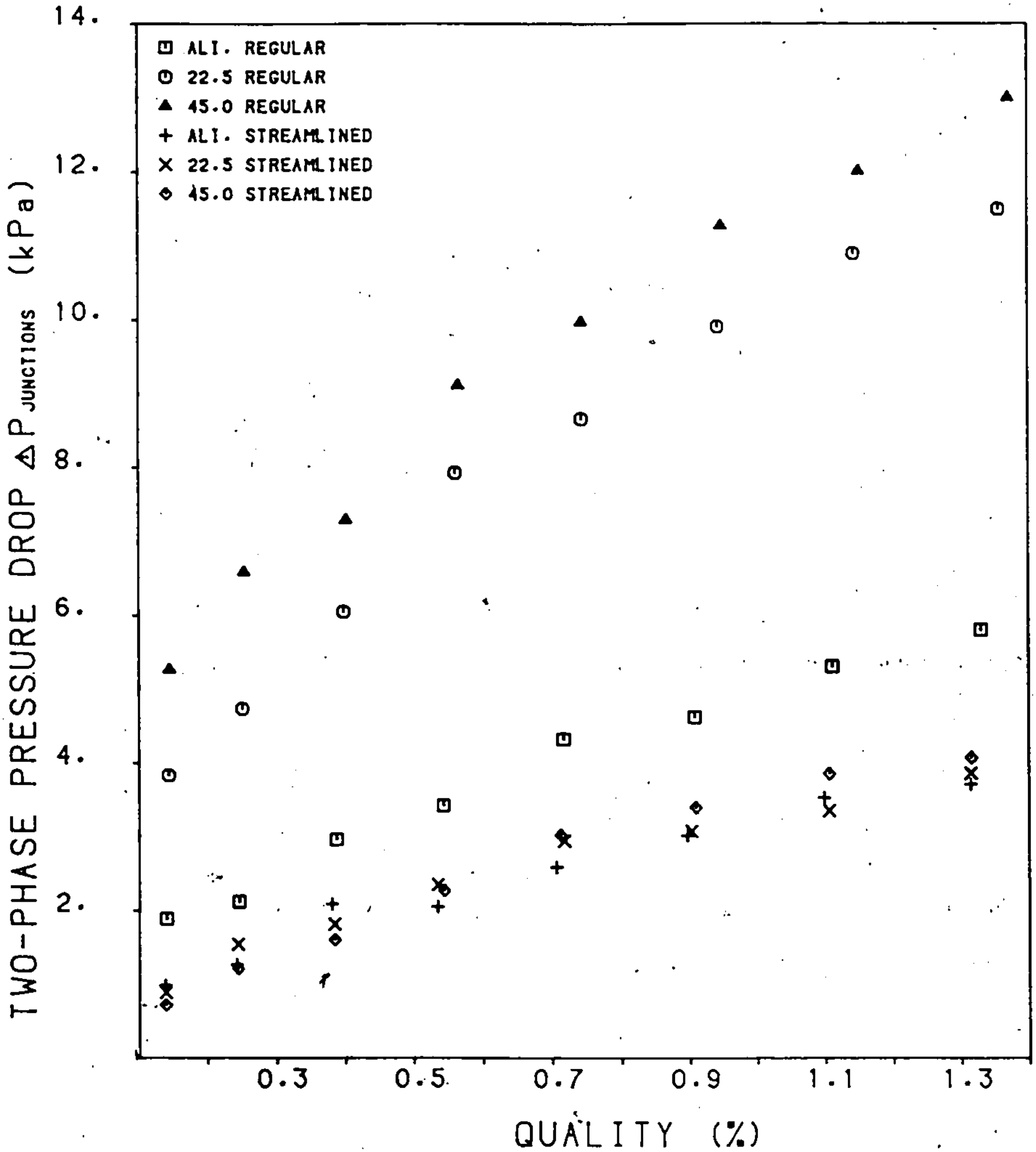


Figure 8.29: Two-phase Average Junction Pressure Losses for the Bundles with a 2210 kg/m^{2}s Liquid Mass Flux.

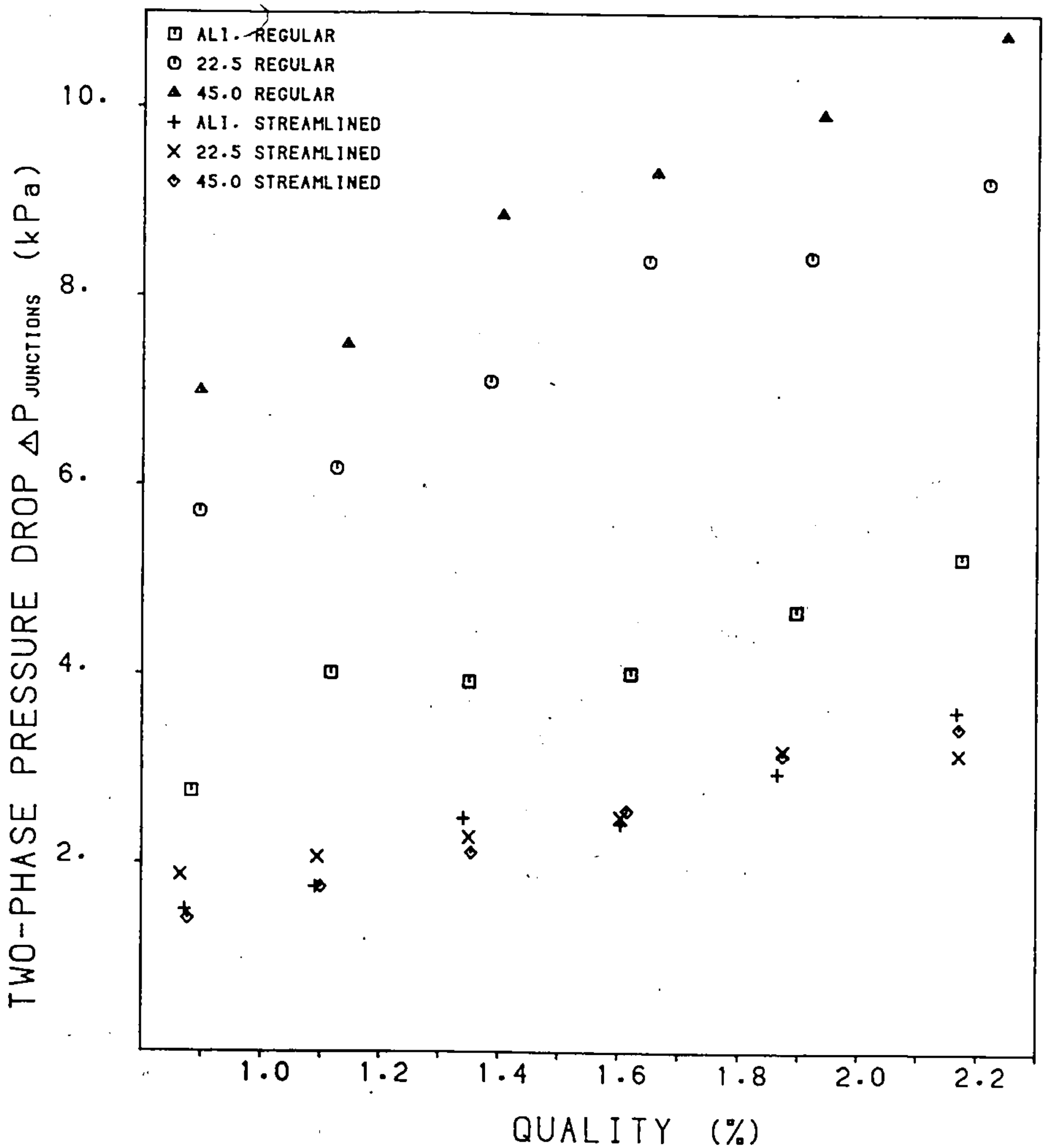


Figure 8.30: Two-phase Average Junction Pressure Losses for the Bundles with a 1660 kg/m^{2}s Liquid Mass Flux.

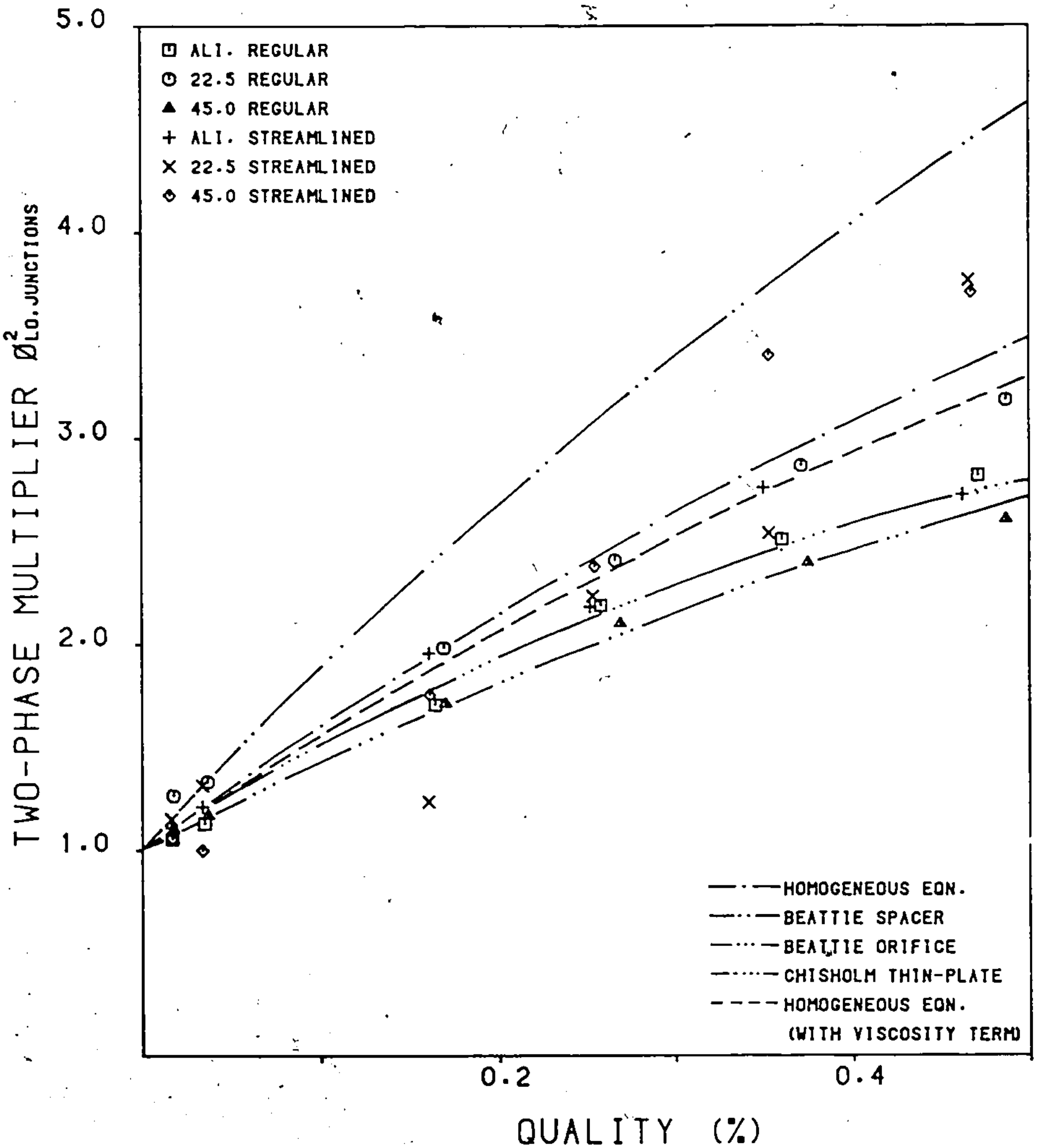


Figure 8.31: Two-phase Junction Multipliers for the Bundles with a 2760 kg/m²s Liquid Mass Flux.

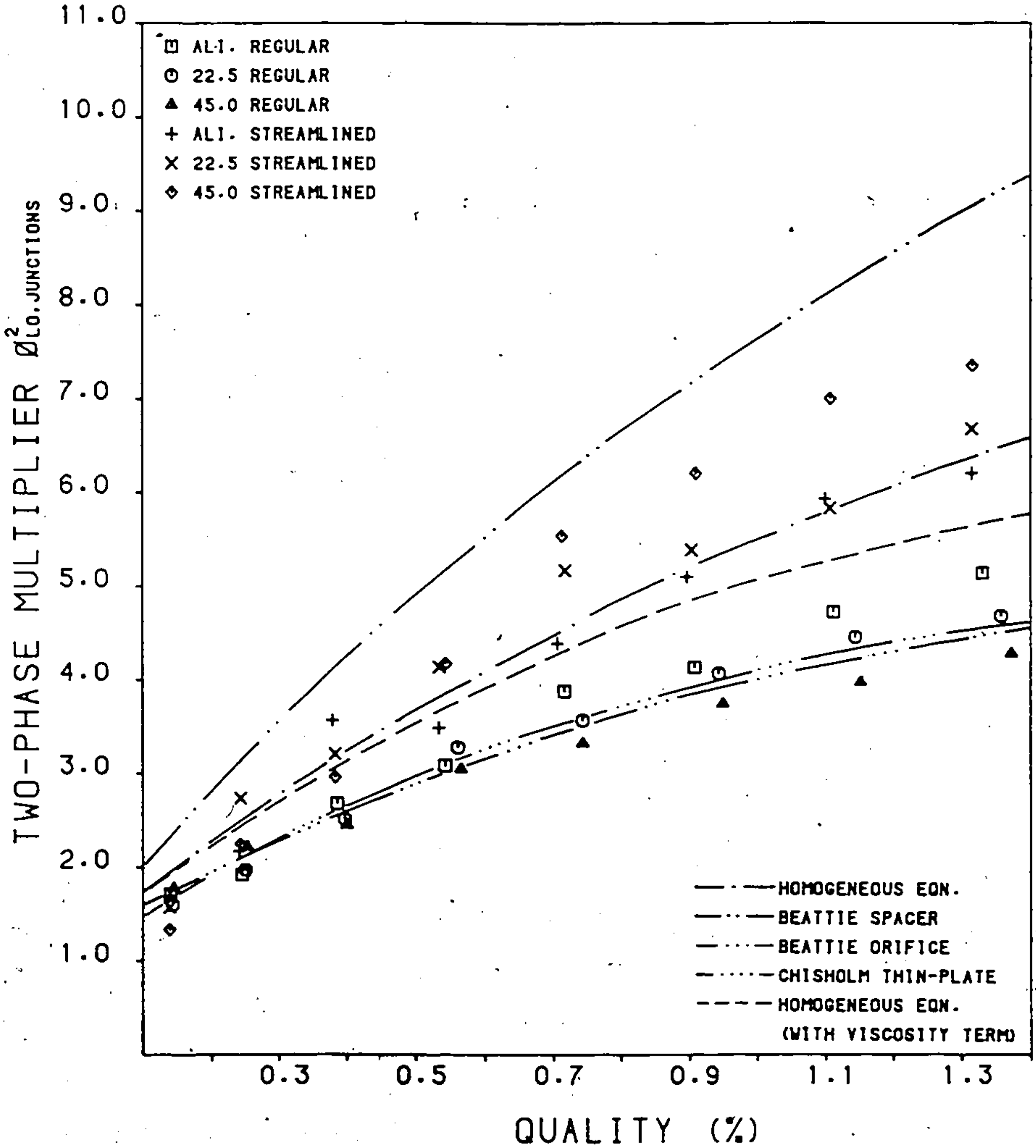


Figure 8.32: Two-phase Junction Multipliers for the Bundles with a 2210 kg/m²s Liquid Mass Flux.

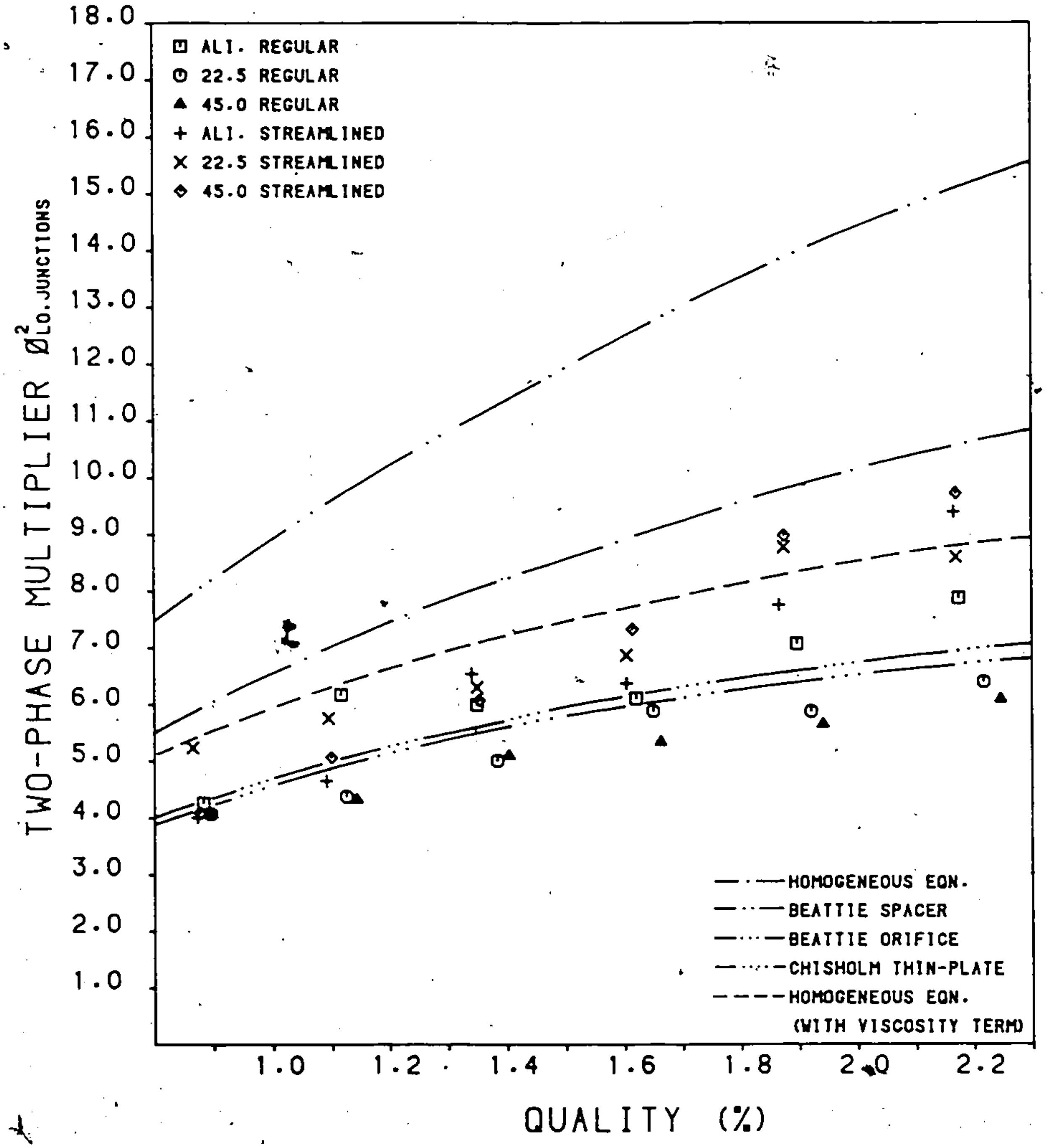


Figure 8.33: Two-phase Junction Multipliers for the Bundles with a 1660 kg/m^2s Liquid Mass Flux.

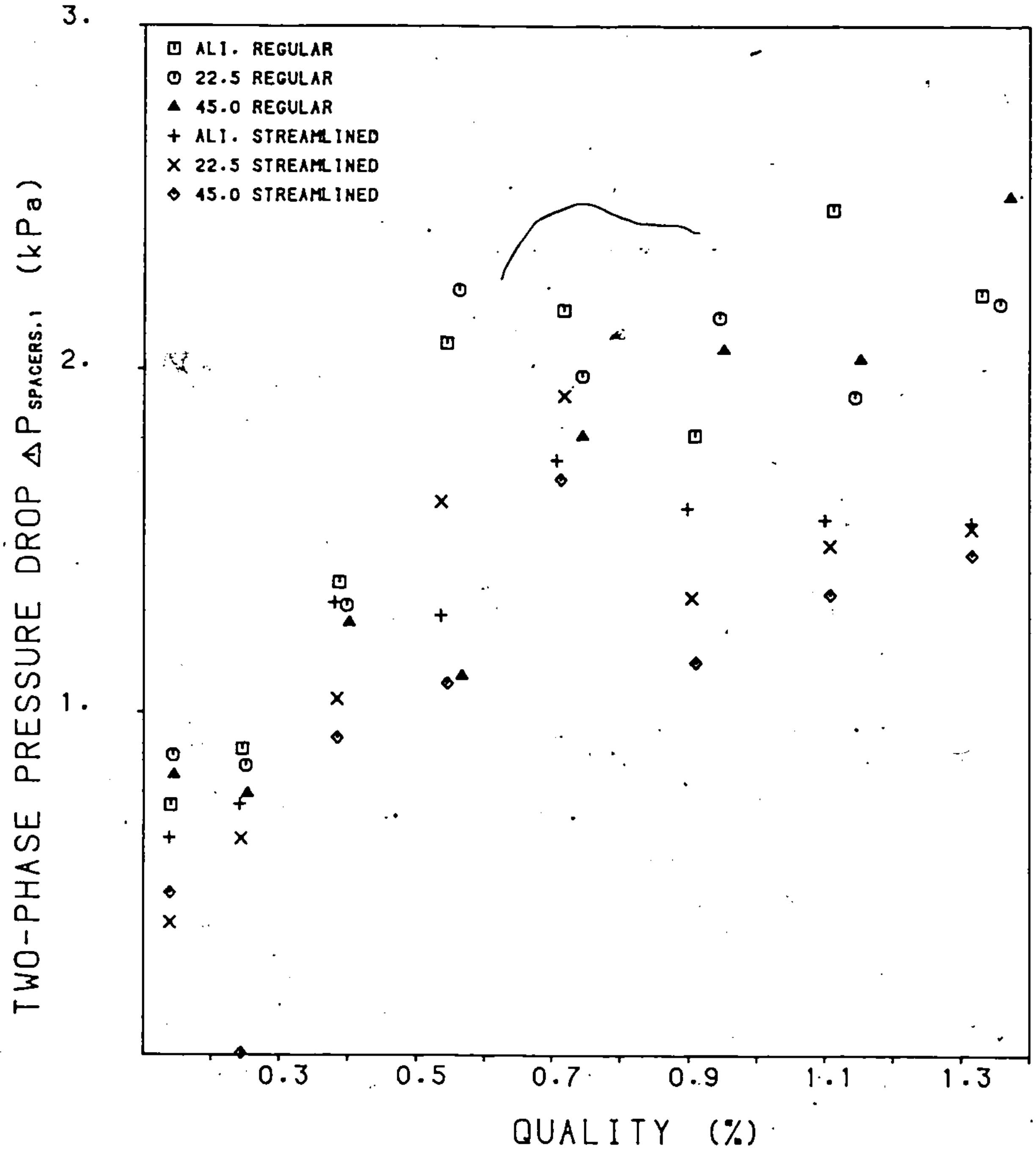


Figure 8.34: Two-phase Pressure Losses in the Second Spacer Plane of the Bundles with a 2210 kg/m²s Liquid Mass Flux.

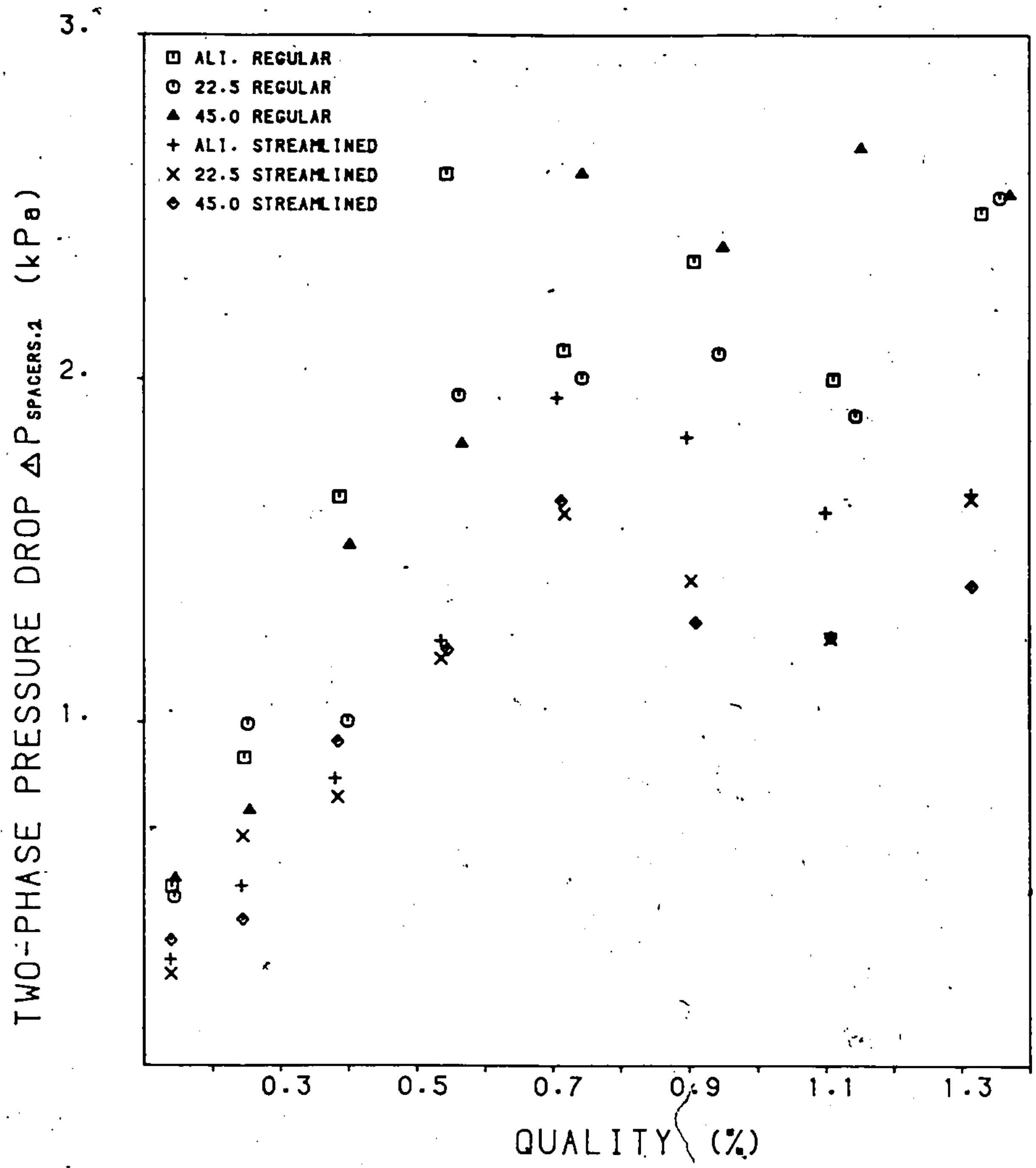


Figure 8.35: Two-phase Pressure Losses in the Third Spacer Plane of the Bundles with a 2210 kg/m^{2}s Liquid Mass Flux.

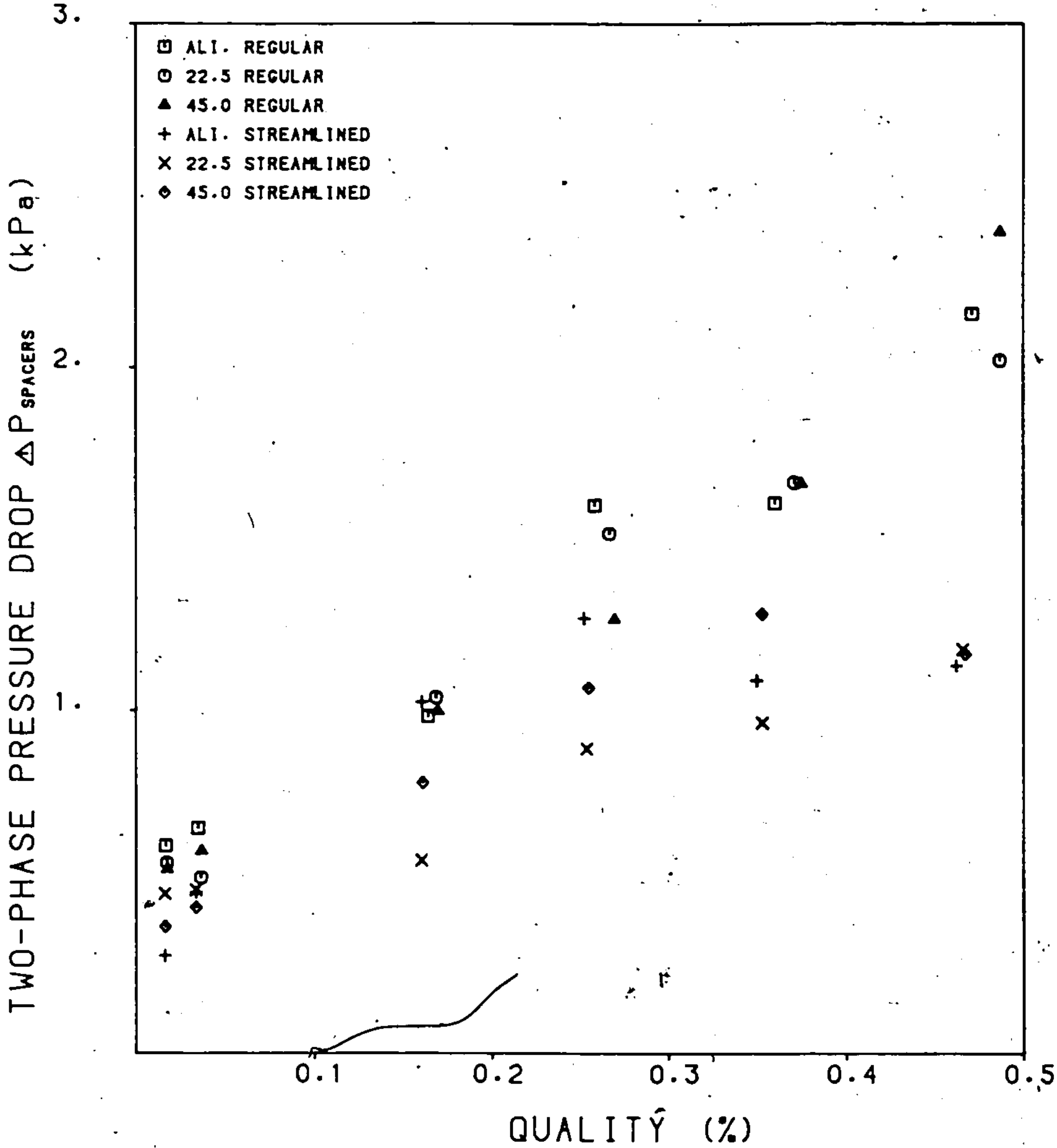


Figure 8.36: Two-phase Average Spacer Pressure Losses for the Bundles with a 2760 kg/m²s Liquid Mass Flux.

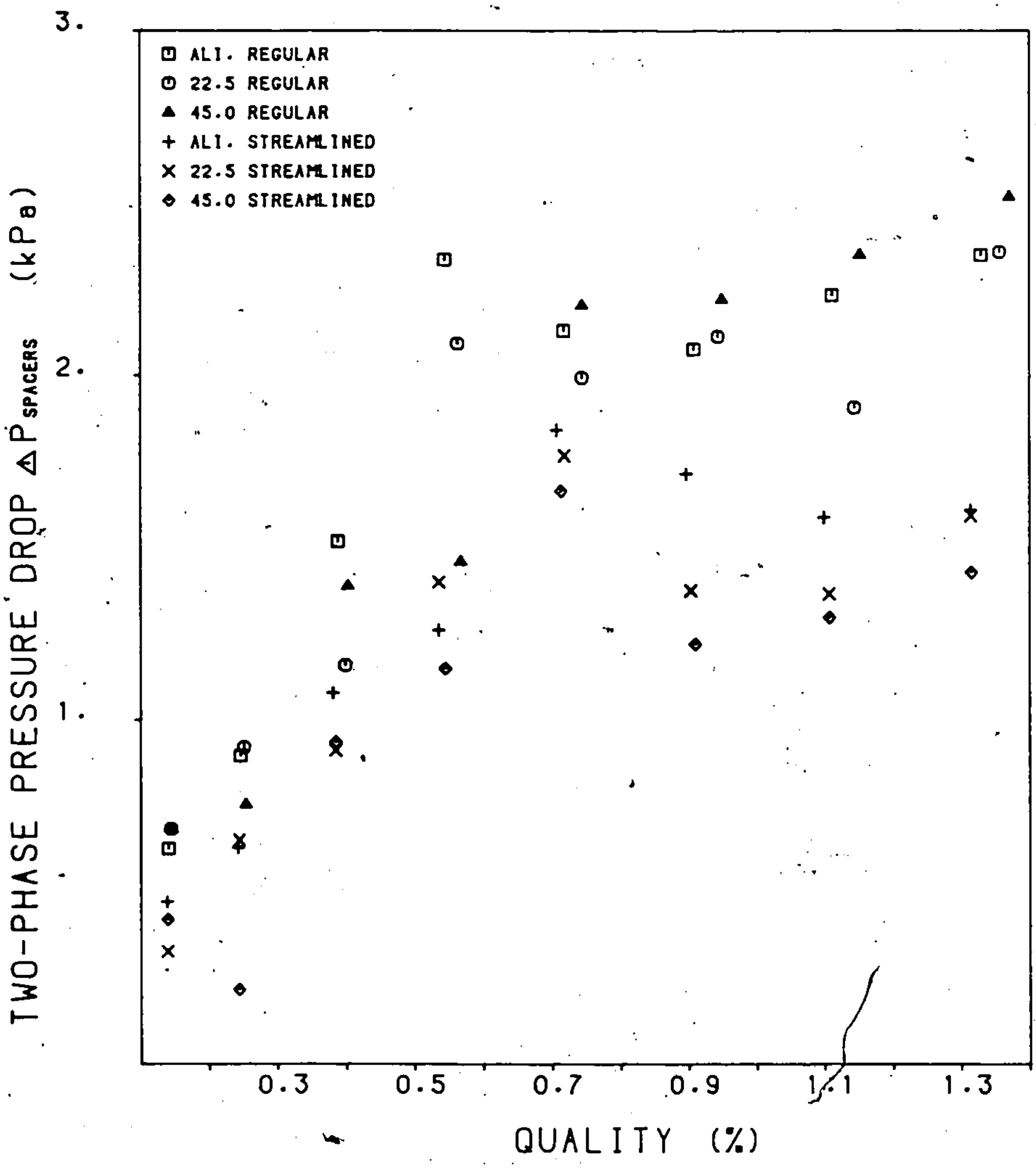


Figure 8.37: Two-phase Average Spacer Pressure Losses for the Bundles with a 2210 kg/m²s Liquid Mass Flux.

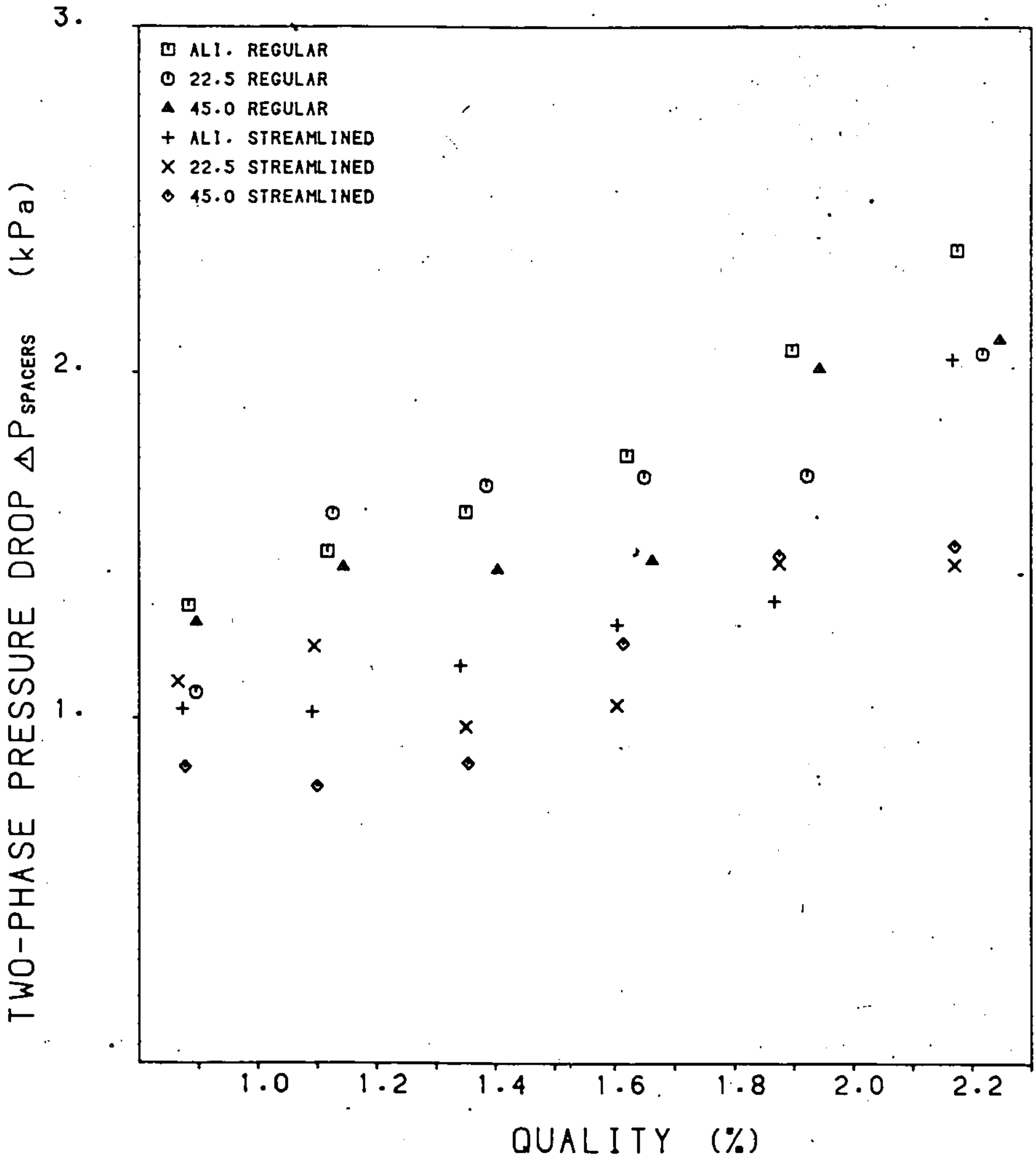


Figure 8.38: Two-phase Average Spacer Pressure Losses for the Bundles with a 1660 kg/m^2s Liquid Mass Flux.

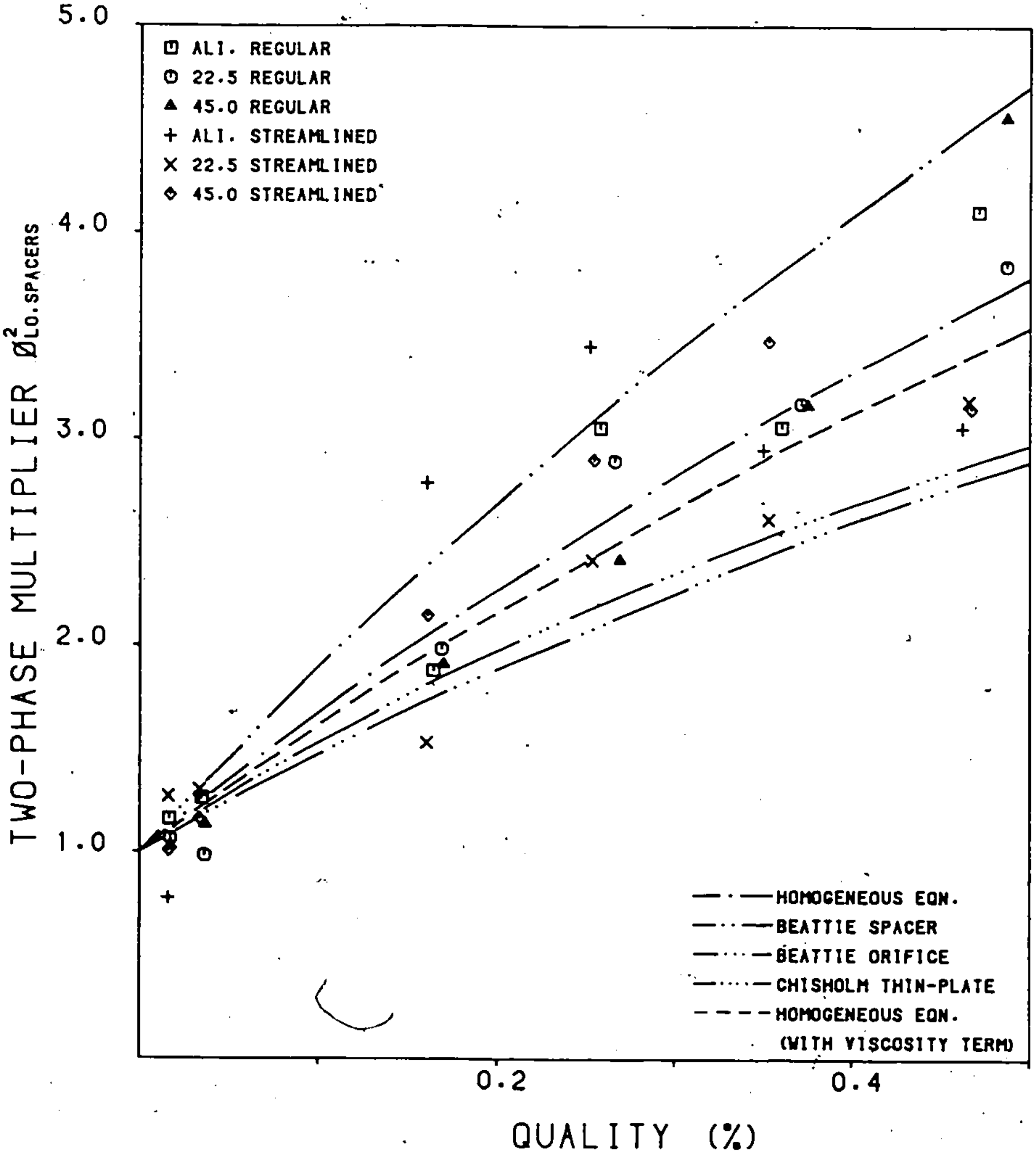


Figure 8.39: Two-phase Spacer Multipliers for the Bundles with a 2760 kg/m²s Liquid Mass Flux.

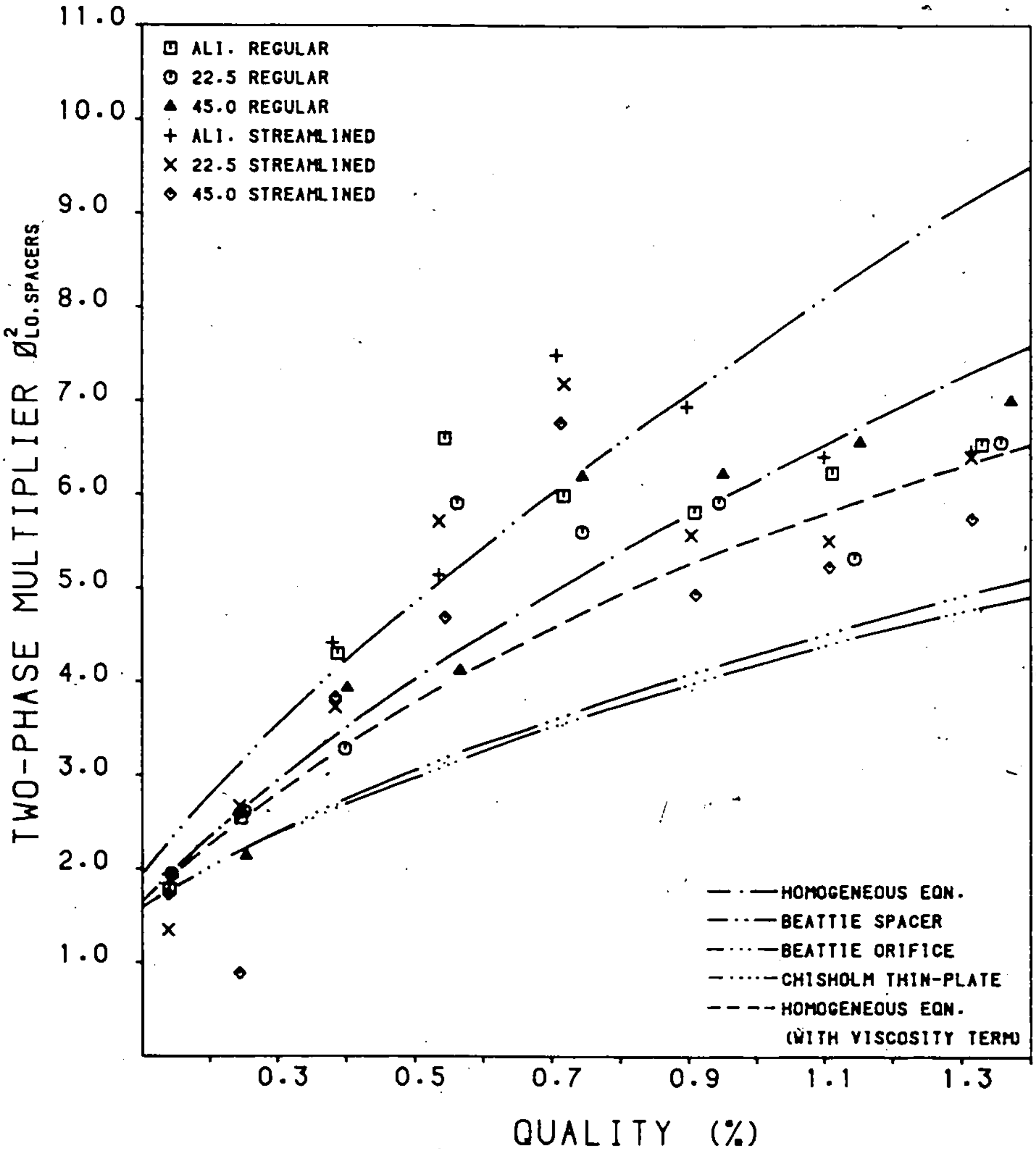


Figure 8.40: Two-phase Spacer Multipliers for the Bundles with a 2210 kg/m^2s Liquid Mass Flux.

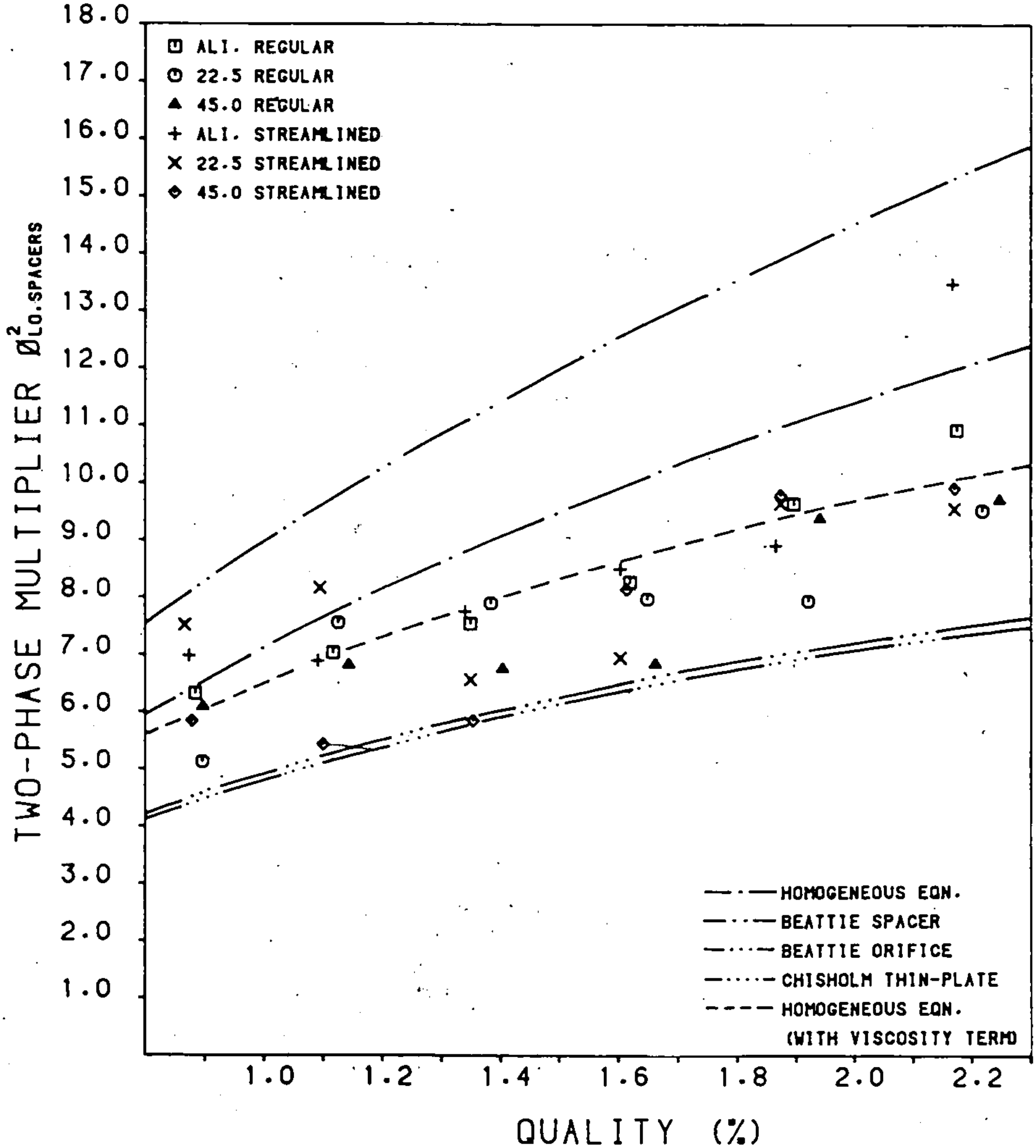


Figure 8.41: Two-phase Spacer Multipliers for the Bundles with a 1660 kg/m^2s Liquid Mass Flux.

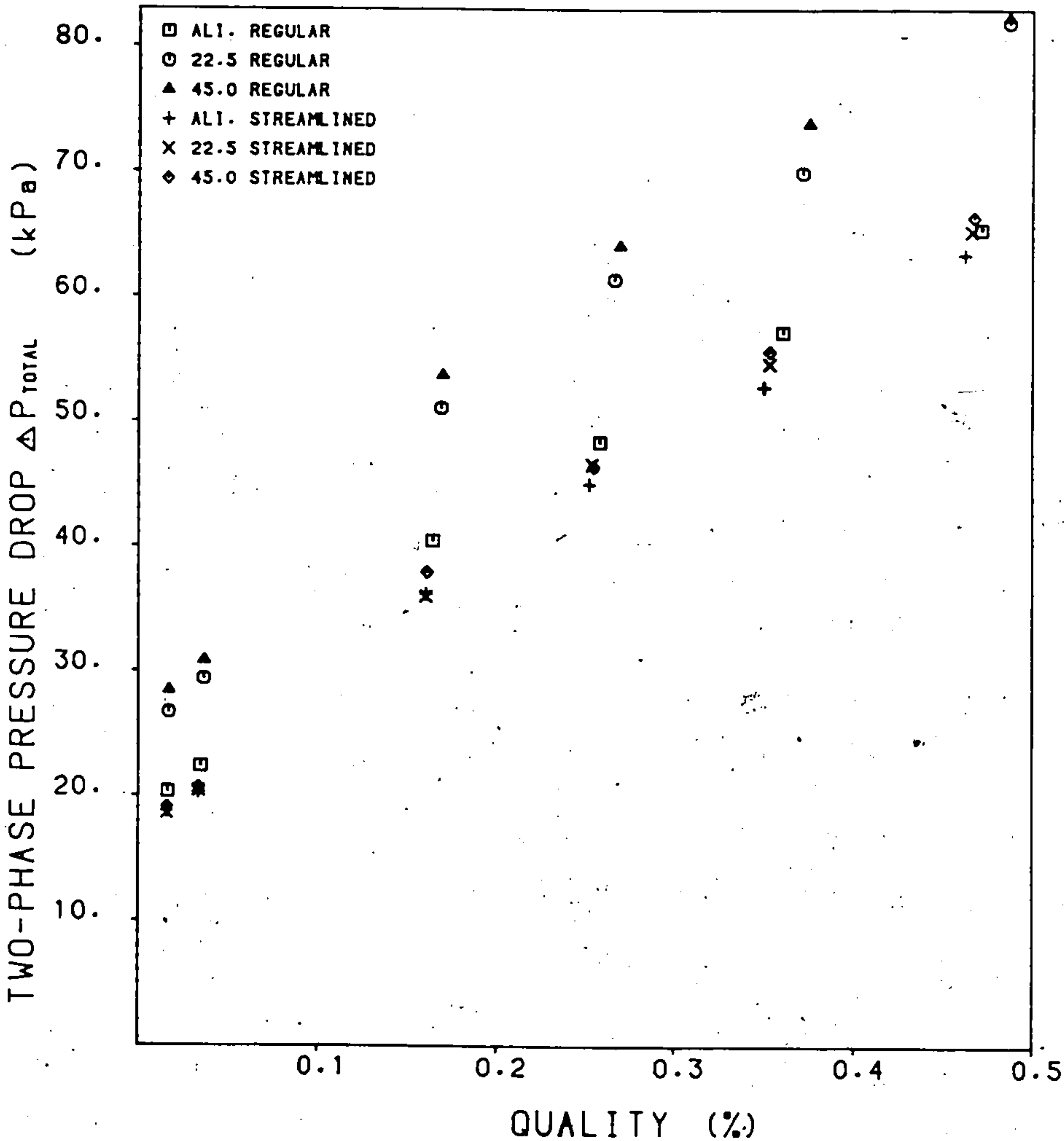


Figure 8.42: Total Two-phase Pressure Loss of the Bundles with a 2760 kg/m²s Liquid Mass Flux.

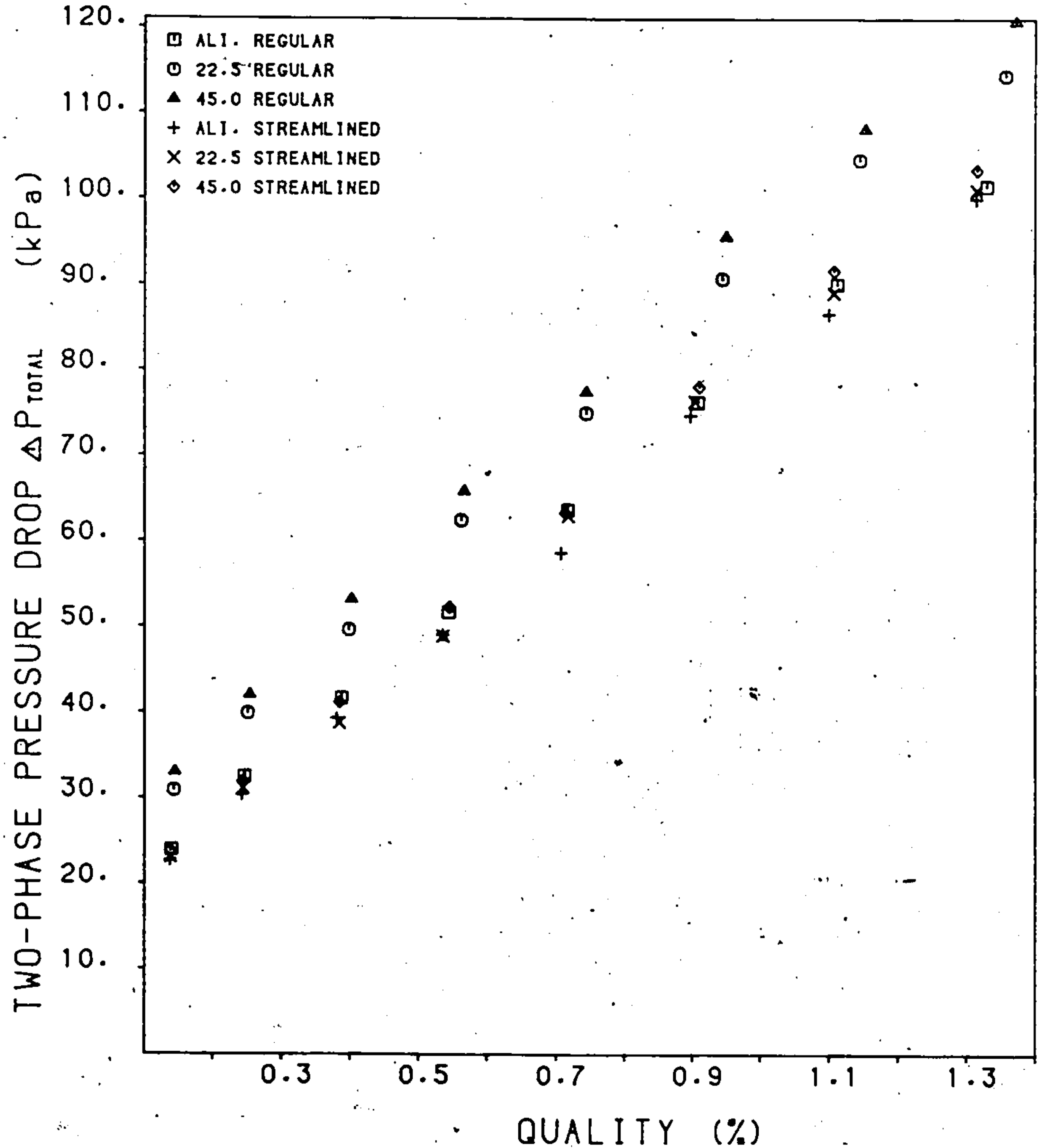


Figure 8.43: Total Two-phase Pressure Loss of the Bundles with a 2210 kg/m²s Liquid Mass Flux.

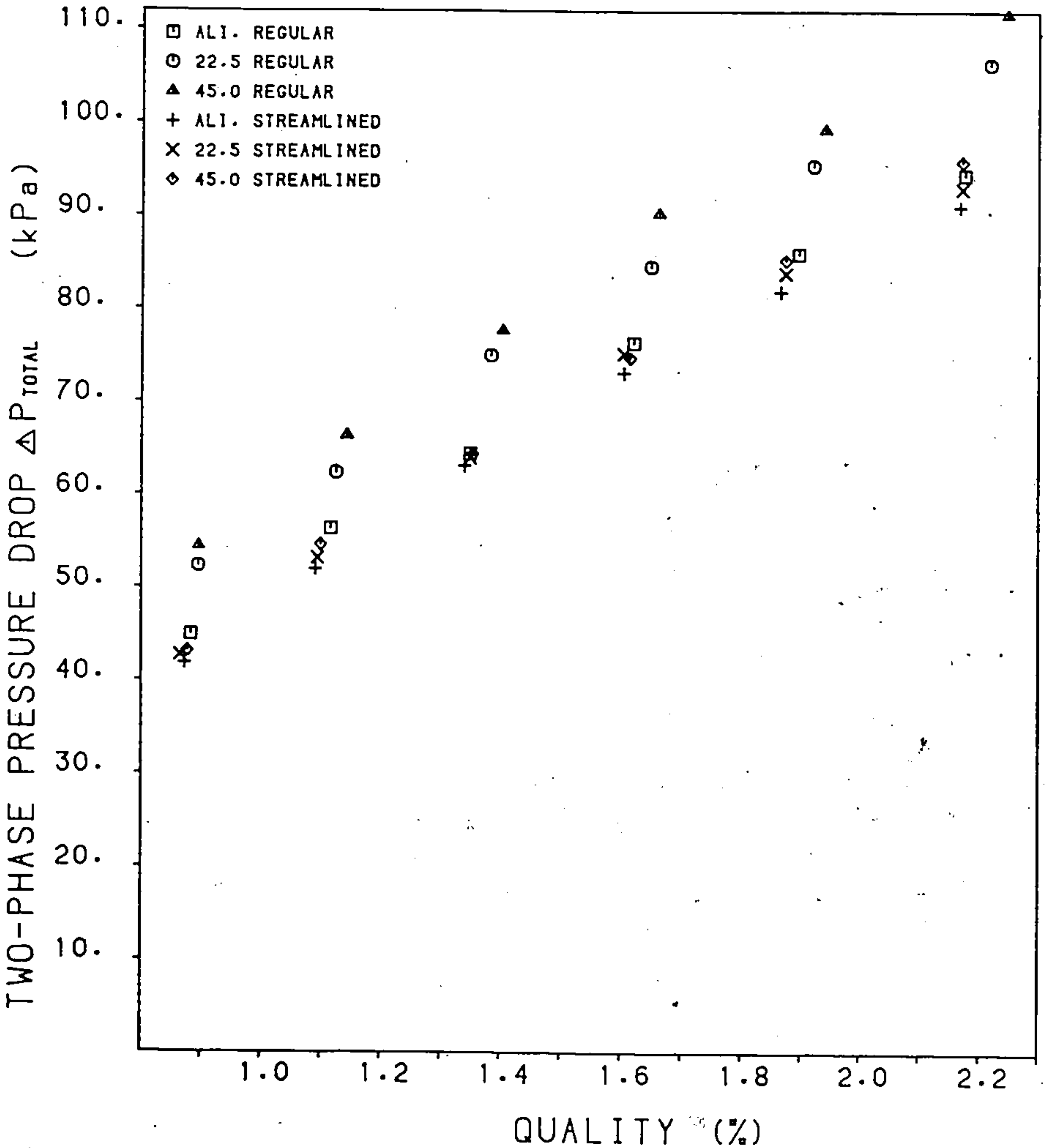


Figure 8.44: Total Two-phase Pressure Loss of the Bundles with a 1660 kg/m^{2}s Liquid Mass Flux.

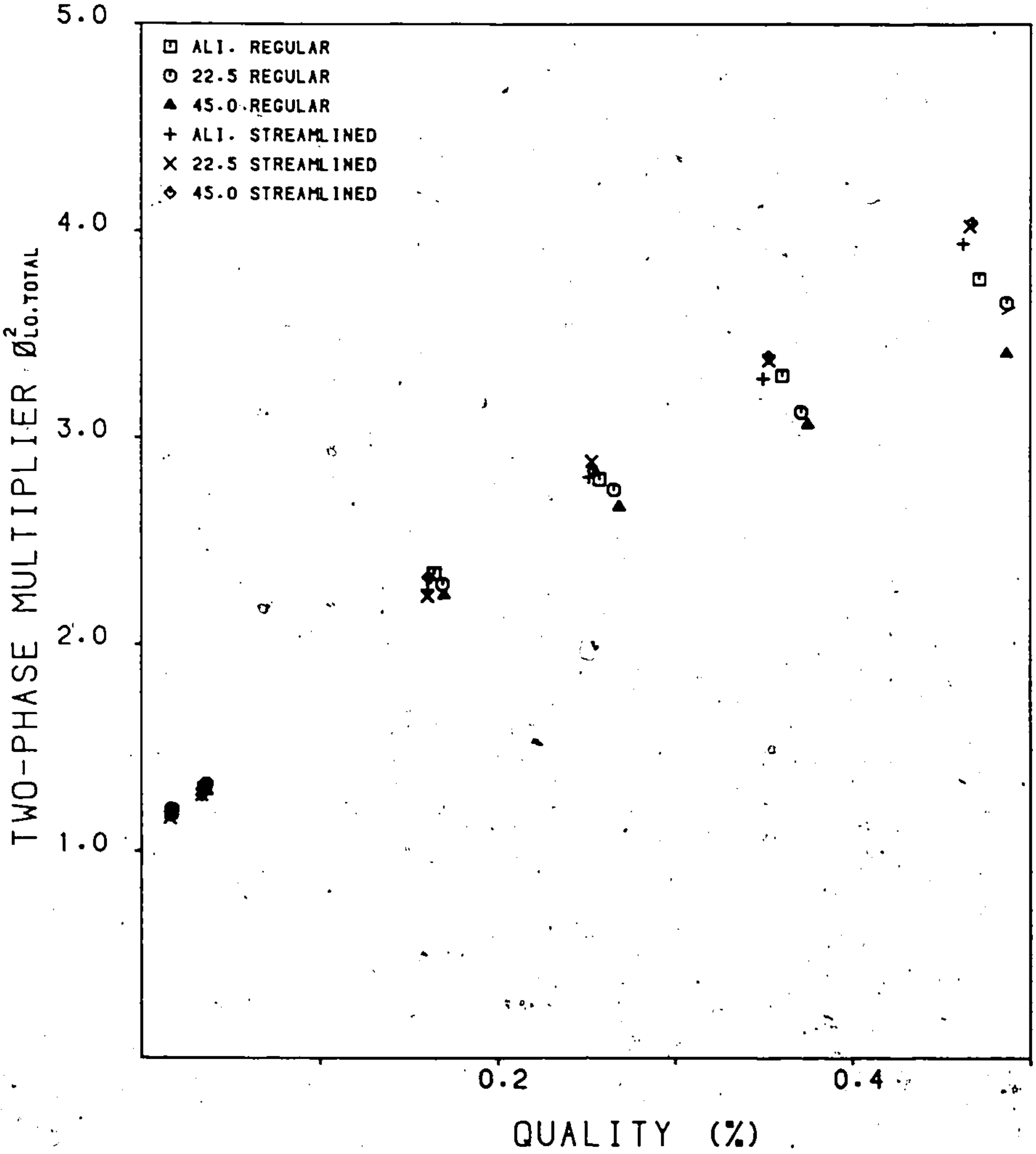


Figure 8.45: Total Two-phase Multipliers for the Bundles with a 2760 kg/m^2s Liquid Mass Flux.

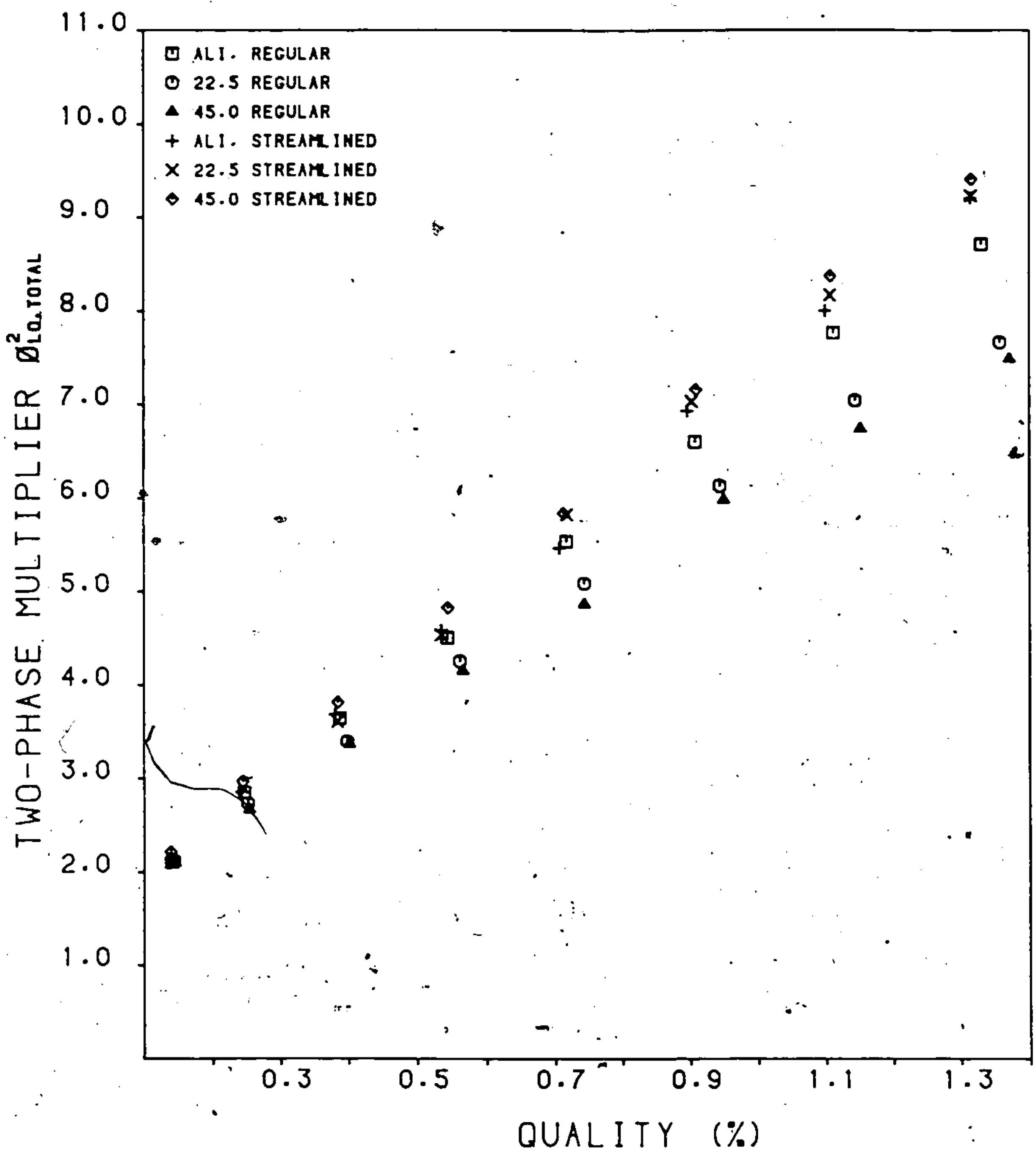


Figure 8.46: Total Two-phase Multipliers for the Bundles with a 2210 kg/m^{2}s Liquid Mass Flux.

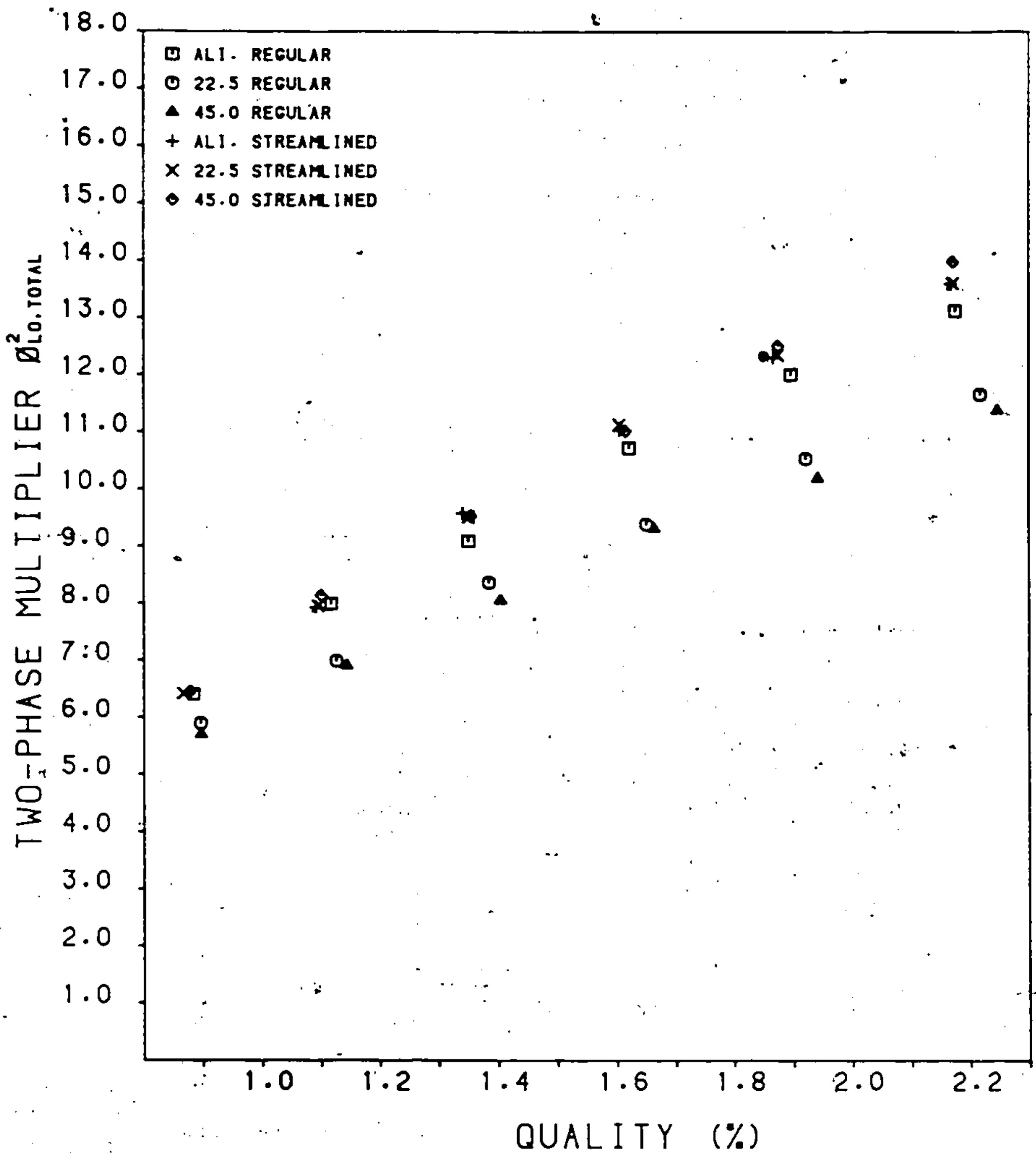


Figure 8.47: Total Two-phase Multipliers for the Bundles with a 1660 kg/m²s Liquid Mass Flux.

Appendix A

EXPERIMENTAL DATA OF EXPERIMENT A

FOR SINGLE-PHASE FLOW

Table A.1: Single-Phase Pressure Data for 25% Obstructions

	CENTRAL	PERIPHERAL	HORIZONTAL SEGMENT	VERTICAL SEGMENT	TOP SEGMENT	BOTTOM SEGMENT
WATER FLOW (KG/S)	0.3	0.3	0.3	0.3	0.3	0.3
DISTANCE (METER)	(HEIGHT,CM) (WATER)	(HEIGHT,CM) (WATER)	(HEIGHT,CM) (WATER)	(HEIGHT,CM) (WATER)	(HEIGHT,CM) (WATER)	(HEIGHT,CM) (WATER)
0.000	155.1	132.2	154.9	134.6	142.6	149.3
0.203	154.6	131.8	154.6	134.2	142.2	148.9
0.406	154.1	131.3	154.0	133.7	141.6	148.3
0.610	153.7	130.8	153.6	133.3	141.2	147.9
0.813	153.3	130.4	153.2	132.9	140.8	147.5
0.864	153.2	130.4	153.1	132.8	140.8	147.4
0.914	153.1	130.2	152.9	132.6	140.3	147.4
1.245	151.1	129.2	150.9	130.6	139.1	145.7
0.940	137.1	148.0	147.1	146.8	139.9	138.9
0.991	138.3	148.9	148.0	147.4	141.1	141.1
1.041	135.0	148.8	147.8	147.1	141.2	141.0
1.143	137.8	148.6	147.4	146.8	141.0	140.8
1.245	137.5	148.3	147.2	146.6	140.8	140.6
1.448	137.0	147.8	146.7	146.1	140.3	140.1
1.651	136.6	147.4	146.3	145.7	139.8	139.7
1.854	136.2	147.0	145.9	145.2	139.4	139.2

Table A.2: Single-Phase Pressure Data for 40% Obstructions

	CENTRAL	PERIPHERAL	HORIZONTAL SEGMENT	VERTICAL SEGMENT	TOP SEGMENT	BOTTOM SEGMENT
WATER FLOW (KG/S)	0.3	0.3	0.3	0.3	0.3	0.3
DISTANCE (METER)	(HEIGHT,CM) (WATER)	(HEIGHT,CM) (WATER)	(HEIGHT,CM) (WATER)	(HEIGHT,CM) (WATER)	(HEIGHT,CM) (WATER)	(HEIGHT,CM) (WATER)
0.000	154.9	134.0	154.6	161.1	151.2	149.1
0.203	154.5	133.6	154.2	160.7	150.8	148.6
0.406	153.9	133.0	153.6	160.2	150.3	148.1
0.610	153.5	132.6	153.2	159.8	149.8	147.6
0.813	153.1	132.2	152.8	159.4	149.4	147.2
0.864	153.0	132.2	152.7	159.3	149.4	147.2
0.914	152.8	132.0	152.5	159.1	148.8	147.3
1.245	148.1	129.0	147.4	154.0	145.1	142.9
0.940	132.2	134.3	131.4	130.4	136.7	131.6
0.991	135.3	137.2	135.1	132.8	138.6	134.9
1.041	135.1	137.2	134.9	132.7	139.7	135.9
1.143	134.8	137.0	134.6	132.4	139.8	135.8
1.245	134.6	136.7	134.4	132.1	139.5	135.6
1.448	134.1	136.2	133.9	131.6	139.0	135.1
1.651	133.7	135.8	133.5	131.2	138.6	134.7
1.854	133.4	135.3	133.0	130.8	138.1	134.2

Appendix B

EXPERIMENTAL DATA OF EXPERIMENT A

FOR TWO-PHASE FLOW

Table B.1: Two-phase Pressure Data of Central Obstruction

AIR (KG/S)	0.0639	0.0525	0.0418	0.0322	0.0222	0.0137
AIR PRESSURE (PSIG)	53.0	44.5	36.0	28.0	18.5	12.0
REF PRESSURE (PSIG)	36.5	30.5	24.6	20.0	13.0	6.4
DISTANCE (METER)	(HEIGHT,CM) (MERIAM OIL)	(HEIGHT,CM) (MERIAM OIL)	(HEIGHT,CM) (MERIAM OIL)	(HEIGHT,CM) (MERIAM OIL)	(HEIGHT,CM) (MERIAM OIL)	(HEIGHT,CM) (MERIAM OIL)
25% CENTRAL OBSTRUCTION						
0.000	138.8	122.2	104.2	86.3	70.3	53.3
0.203	131.7	115.1	98.1	81.3	66.3	50.2
0.406	123.8	108.0	91.4	75.5	60.8	45.2
0.610	115.2	100.6	85.3	70.9	57.1	42.6
0.813	108.2	84.4	80.1	66.5	53.7	38.3
0.864	106.0	92.4	73.4	64.8	51.8	38.1
0.914	103.7	80.5	76.7	63.5	50.6	37.3
1.143	87.3	60.0	52.1	45.4	35.0	28.0
0.940	71.1	60.5	54.1	44.2	38.5	31.0
0.991	73.9	63.4	56.2	49.6	38.2	30.1
1.041	73.6	62.2	54.8	47.6	37.7	28.5
1.143	71.1	60.3	53.3	46.9	37.0	28.3
1.245	67.5	57.0	50.5	44.3	34.9	26.8
1.448	59.7	50.3	44.8	38.8	31.3	23.1
1.651	52.1	43.4	38.8	32.9	26.5	20.4
1.854	42.9	35.0	31.8	26.6	21.9	16.6
1.041	72.6	62.2	54.9	47.8	37.9	30.2
1.143	70.0	59.6	52.9	46.1	36.4	28.7
1.245	66.3	56.3	50.1	43.7	34.4	26.4
1.448	58.6	49.6	44.2	38.6	30.2	23.0
1.651	50.5	43.7	37.7	32.9	25.6	18.8
1.854	41.4	34.5	30.5	26.7	20.6	15.0
2.057	32.3	26.6	23.1	20.7	15.9	12.1
2.261	22.9	17.4	15.7	15.5	11.1	8.8
40% CENTRAL OBSTRUCTION						
0.000	177.6	163.5	134.5	109.1	83.1	62.2
0.203	177.6	153.5	128.5	106.0	76.4	58.[illegible]
0.406	169.3	146.7	122.8	98.6	73.6	53.3
0.610	161.6	139.6	11[illegible].2	93.5	69.5	50.9
0.813	155.0	133.2	111.0	88.9	65.7	41.0
0.864	152.6	131.1	10[illegible].1	87.4	6[illegible].2	46.9
0.914	150.6	120.1	107.[illegible]	86.1	63.6	4[illegible].2
1.143	[illegible]	60.2	[illegible]	56.9	17.[illegible]	21.1
0.940	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.991	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1.041	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1.143	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	72.5	53.5	[illegible]	[illegible]	[illegible]	[illegible]
1.143	70.1	51.5	[illegible]	57.7	[illegible]	[illegible]
1.245	68.4	47.9	50.9	[illegible]	[illegible]	[illegible]
1.448	58.7	41.0	45.1	41.9	[illegible]	22.4
1.651	50.8	44.3	38.9	38.8	31.4	18.1
1.854	41.9	36.2	31.7	33.5	26.5	15.2
2.057	32.8	28.1	24.4	27.1	21.1	11.9
2.261	23.6	19.7	16.8	20.9	16.3	7.8
				14.8	13.9	

Table B.2: Two-phase Pressure Data of Peripheral Obstruction

AIR (KG/S)	0.0637	0.0523	0.0416	0.0322	0.0222	0.0137
AIR PRESSURE (PSIG)	52.5	44.0	35.5	28.0	19.5	12.0
MLF PRESSURE (PSIG)	35.8	30.5	24.0	18.4	13.5	8.2
DISTANCE (METER)	(HEIGHT,CM) (MERIAM OIL)	(HEIGHT,CM) (MERIAM OIL)	(HEIGHT,CM) (MERIAM OIL)	(HEIGHT,CM) (MERIAM OIL)	(HEIGHT,CM) (MERIAM OIL)	(HEIGHT,CM) (MERIAM OIL)
25% PERIPHERAL OBSTRUCTION						
0.000	126.0	109.5	93.8	70.4	68.8	48.9
0.203	117.9	102.3	87.5	74.8	67.5	[illegible]
0.406	109.9	94.8	80.7	68.8	58.0	40.3
0.610	101.4	87.4	74.8	64.0	55.4	38.2
0.813	94.3	81.4	69.8	58.8	53.4	35.2
0.864	92.1	78.4	67.9	58.1	49.8	34.2
0.914	90.1	77.7	66.6	57.2	49.1	33.5
1.143	58.6	50.3	43.1	38.3	34.3	34.1
0.840	55.1	48.4	43.8	38.6	33.6	26.4
0.891	58.6	51.3	45.6	39.6	33.9	26.6
1.041	58.7	51.0	45.4	38.1	32.0	24.9
1.143	58.1	50.3	43.9	37.8	31.9	24.6
1.245	55.8	48.0	41.8	35.9	30.2	23.3
1.448	50.3	43.1	37.4	31.9	26.8	20.9
1.651	44.2	37.5	32.5	27.9	23.4	18.4
1.854	36.3	30.8	26.9	23.0	18.9	15.1
1.041	59.7	50.6	45.0	40.8	33.0	25.2
1.143	58.5	49.5	43.7	39.4	32.1	23.5
1.245	56.1	47.6	41.7	37.5	30.6	22.0
1.448	50.9	42.4	37.6	33.8	27.3	19.4
1.651	44.4	36.8	32.7	29.8	22.8	17.2
1.854	36.4	29.8	27.0	25.0	18.7	13.8
2.057	28.9	23.1	21.2	20.0	15.5	11.4
2.261	20.8	15.8	14.9	14.7	11.6	8.5
40% PERIPHERAL OBSTRUCTION						
0.000	167.5	148.1	124.3	104.3	83.5	61.1
0.203	158.3	141.1	116.8	98.2	75.1	58.1
0.406	151.4	134.0	112.9	94.1	74.1	53.4
0.610	143.1	126.7	106.5	88.8	69.6	50.1
0.813	136.1	120.1	101.3	84.4	66.3	47.2
0.864	133.8	118.1	93.4	82.7	64.4	49.1
0.914	132.3	114.8	93.3	81.9	63.9	45.7
1.143	55.2	49.2	42.2	36.4	30.4	24.6
0.840	43.9	38.5	36.6	32.5	29.2	23.5
0.891	53.4	45.6	41.5	35.8	31.4	24.1
1.041	56.4	47.4	42.2	35.4	30.7	23.2
1.143	58.2	48.6	43.0	35.7	30.6	22.8
1.245	57.0	47.1	41.6	34.3	28.2	21.8
1.448	52.0	42.4	37.4	30.7	25.8	19.4
1.651	45.8	36.8	32.7	26.8	23.4	17.0
1.854	38.0	30.0	27.1	22.2	18.4	14.5
1.041	54.5	48.5	42.1	36.0	34.1	29.7
1.143	55.8	48.3	42.3	35.8	32.9	28.4
1.245	54.8	48.0	40.8	34.3	31.8	26.9
1.448	48.7	43.1	36.5	30.8	28.4	24.0
1.651	43.2	37.3	31.8	28.7	25.3	21.9
1.854	35.4	30.5	24.3	22.1	21.2	18.3
2.057	27.6	23.6	20.4	17.3	18.1	15.3
2.261	18.6	16.5	14.5	12.4	13.4	12.4

Table B.3: Two-phase Pressure Data of Horizontal Central Segment Obstruction

AIR (KG/S)	0.0637	0.0525	0.0416	0.0324	0.0227	0.0137
AIR PRESSURE (PSIG)	52.5	44.5	35.5	26.5	[illegible]	12.0
REF PRESSURE (PSIG)	35.8	30.3	25.4	19.8	13.0	6.8
DISTANCE (METER)	(HEIGHT,CM) (MERIAM OIL)	(HEIGHT,CM) (MERIAM OIL)	(HEIGHT,CM) (MERIAM OIL)	(HEIGHT,CM) (MERIAM OIL)	(HEIGHT,CM) (MERIAM OIL)	(HEIGHT,CM) (MERIAM OIL)
25% HORIZONTAL CENTRAL SEGMENT OBSTRUCTION						
0.000	139.4	121.5	103.2	89.3	70.8	48.5
0.203	131.2	114.2	97.0	80.2	66.5	46.8
0.406	123.2	107.0	91.1	75.2	61.8	42.7
0.610	115.0	99.8	84.5	69.7	56.9	39.8
0.813	108.1	93.5	79.2	65.3	52.8	36.9
0.864	106.0	91.5	77.4	63.7	51.5	36.0
0.914	103.8	89.7	75.8	62.3	50.3	35.6
1.143	69.5	60.5	53.6	45.4	37.8	26.6
0.940	70.3	61.1	53.8	46.4	36.2	28.1
0.991	72.8	62.8	55.4	47.5	40.2	28.4
1.041	72.6	62.8	55.1	47.3	40.1	28.3
1.143	70.1	60.2	53.0	45.4	38.2	26.7
1.245	66.7	57.2	50.4	43.3	35.9	22.9
1.448	59.1	50.7	44.4	38.8	31.4	20.7
1.651	50.3	43.7	38.9	33.8	27.2	18.8
1.854	40.8	35.6	32.2	27.8	22.3	14.4
1.041	71.2	62.8	56.8	50.1	41.4	30.1
1.143	68.4	60.6	54.1	48.1	39.1	28.3
1.245	64.9	57.8	51.6	46.0	36.8	26.9
1.448	57.2	51.0	46.0	41.5	32.9	24.1
1.651	48.6	43.8	39.9	36.8	28.8	21.2
1.854	39.3	35.8	33.1	30.8	23.9	17.3
2.057	30.3	27.9	26.0	24.5	19.1	13.9
2.261	20.8	18.7	18.7	18.4	14.0	10.7
40% HORIZONTAL CENTRAL SEGMENT OBSTRUCTION						
0.000	173.3	157.5	130.8	104.2	83.0	58.1
0.203	173.3	150.4	124.7	98.2	78.5	54.0
0.406	165.2	143.1	118.6	94.0	74.0	51.1
0.610	156.8	135.8	112.1	88.4	68.5	47.4
0.813	150.0	128.6	106.8	83.8	64.7	45.0
0.864	147.8	127.4	104.8	82.3	63.2	43.8
0.914	145.8	125.6	103.5	81.0	62.4	43.4
1.143	65.2	57.4	51.0	42.7	36.8	25.1
0.940	61.1	51.8	45.4	40.1	34.1	25.6
0.991	69.6	57.9	49.9	43.0	36.0	26.4
1.041	70.5	58.5	50.3	43.5	35.8	26.8
1.143	69.1	57.3	49.3	42.5	34.9	25.2
1.245	65.6	54.6	46.9	40.6	32.9	23.7
1.448	58.1	48.0	41.6	36.5	28.8	20.7
1.651	50.1	41.4	36.4	32.4	24.6	17.1
1.854	41.5	33.4	30.7	27.3	18.8	14.2
1.041	70.7	59.6	51.1	42.9	36.6	30.9
1.143	69.2	58.2	50.0	42.8	35.4	28.4
1.245	66.1	55.6	47.8	40.3	33.6	26.8
1.448	58.7	48.8	42.6	36.3	30.3	24.2
1.651	50.5	42.4	37.2	32.3	28.1	22.6
1.854	41.9	34.8	31.1	27.2	21.5	19.3
2.057	33.6	27.5	24.8	21.6	16.6	15.6
2.261	24.7	19.8	17.7	15.6	12.3	12.6

Table B.4: Two-phase Pressure Data of Vertical Central Segment Obstruction

AIR (KG/S)	0.0637	0.0523	0.0416	0.0324	0.0220	0.0130
AIR PRESSURE (PSIG)	52.5	44.0	35.5	24.5	19.0	12.5
REF PRESSURE (PSIG)	35.5	28.3	23.8	18.8	13.0	7.8
DISTANCE (METER)	(HEIGHT,CM) (MERIAM OIL)	(HEIGHT,CM) (MERIAM OIL)	(HEIGHT,CM) (MERIAM OIL)	(HEIGHT,CM) (MERIAM OIL)	(HEIGHT,CM) (MERIAM OIL)	(HEIGHT,CM) (MERIAM OIL)
25% VERTICAL CENTRAL SEGMENT OBSTRUCTION						
0.000	138.0	120.0	103.6	82.4	70.3	51.2
0.203	128.8	112.8	97.5	85.1	65.8	47.7
0.406	121.8	105.6	91.3	78.5	60.6	43.6
0.610	113.4	98.2	85.1	74.1	55.8	40.4
0.813	106.5	92.0	80.0	69.7	52.0	37.5
0.864	104.2	90.0	78.3	68.3	50.4	36.5
0.914	101.9	88.1	76.6	66.7	48.5	36.0
1.143	68.7	59.6	52.1	46.3	34.8	26.8
0.940	72.0	63.5	56.5	50.3	40.3	31.8
0.991	73.0	63.7	56.6	48.5	39.1	30.8
1.041	72.8	63.0	55.2	48.3	37.7	28.4
1.143	70.2	60.5	52.6	45.8	35.9	28.5
1.245	68.4	57.1	49.6	43.3	33.6	27.1
1.448	58.5	50.0	43.4	37.7	29.4	24.2
1.651	50.5	43.0	37.0	32.3	25.4	20.9
1.854	41.4	34.8	30.6	26.3	20.6	17.5
1.041	73.2	61.9	55.3	48.1	38.1	28.5
1.143	70.1	58.4	52.2	45.8	36.4	27.2
1.245	66.4	55.5	49.3	42.8	34.1	25.5
1.448	58.4	48.3	43.0	37.4	29.4	22.6
1.651	50.3	41.1	36.8	32.1	24.8	18.2
1.854	41.1	33.2	29.8	26.3	20.1	15.7
2.057	32.3	25.3	23.1	20.4	15.4	12.9
2.261	23.3	17.3	16.3	14.9	11.4	12.8
40% VERTICAL CENTRAL SEGMENT OBSTRUCTION						
0.000	175.7	161.2	135.2	114.2	89.8	64.8
0.203	175.7	154.0	129.1	109.3	85.4	61.8
0.406	167.6	146.9	123.2	104.1	80.6	57.3
0.610	158.0	139.2	116.7	98.8	75.9	53.9
0.813	152.1	133.2	111.6	94.4	71.9	51.2
0.864	149.9	131.1	108.8	92.6	70.5	49.7
0.914	148.1	129.2	108.3	91.4	69.9	48.4
1.143	70.9	61.7	53.6	46.9	38.4	26.9
0.940	64.6	59.2	54.2	47.4	38.8	30.2
0.991	68.1	61.6	55.1	48.0	35.0	29.3
1.041	69.8	62.5	55.5	47.6	38.0	28.3
1.143	67.4	60.3	53.2	45.4	36.4	27.3
1.245	64.2	57.1	50.3	42.6	34.3	25.3
1.448	56.5	50.1	43.9	37.4	29.4	21.3
1.651	48.6	43.1	38.6	32.0	25.1	18.5
1.854	40.1	35.1	31.0	26.2	20.8	15.6
1.041	73.6	63.4	55.7	48.8	39.0	33.6
1.143	71.3	66.4	52.8	46.1	38.0	31.1
1.245	68.3	57.3	49.9	43.3	33.9	29.4
1.448	60.4	50.1	43.8	38.0	28.8	25.9
1.651	52.3	43.3	37.6	32.5	25.7	22.9
1.854	43.6	35.2	30.6	26.7	21.1	18.7
2.057	34.7	27.2	21.5	20.8	16.4	14.8
2.261	25.0	18.8	16.6	14.9	11.6	11.5

Table B.5: Two-phase Pressure Data of Bottom Peripheral Segment Obstruction

AIR (KG/S)	0.0836	0.0523	0.0425	0.0324	0.0222	0.0138
AIR PRESSURE (PSIG)	52.3	44.0	37.5	28.5	19.5	12.5
REF PRESSURE (PSIG)	35.4	30.3	25.8	18.9	13.6	8.1
DISTANCE (METER)	(HEIGHT,CM) (MERIAM OIL)	(HEIGHT,CM) (MERIAM OIL)	(HEIGHT,CM) (MERIAM OIL)	(HEIGHT,CM) (MERIAM OIL)	(HEIGHT,CM) (MERIAM OIL)	(HEIGHT,CM) (MERIAM OIL)
25% BOTTOM PERIPHERAL SEGMENT OBSTRUCTION						
0.000	138.2	121.1	111.3	93.9	78.9	54.7
0.203	130.2	114.1	104.5	88.5	71.3	51.8
0.406	122.0	106.8	98.4	83.1	66.8	48.3
0.610	114.0	98.8	92.1	77.8	62.1	45.3
0.813	107.3	93.7	86.7	73.2	58.0	41.6
0.864	104.4	91.6	84.8	71.5	56.5	40.8
0.914	101.2	88.5	82.3	68.5	54.9	39.5
1.143	67.9	57.8	54.0	44.9	35.8	26.9
0.940	73.7	68.2	59.0	53.0	43.2	28.9
0.991	70.8	63.5	54.8	48.7	39.4	26.2
1.041	70.4	63.6	54.2	47.9	38.3	25.1
1.143	68.6	60.5	51.5	45.6	36.7	24.2
1.245	64.8	56.2	48.1	42.4	34.0	22.9
1.448	56.0	48.7	40.6	36.2	28.7	19.6
1.651	47.7	41.5	34.2	30.9	24.4	16.5
1.854	39.1	33.9	27.4	25.8	19.9	13.5
1.041	76.3	60.8	55.2	47.8	40.5	27.3
1.143	67.5	58.0	52.8	45.3	38.5	24.8
1.245	63.8	54.5	49.4	42.1	35.9	23.4
1.448	55.5	46.9	41.9	35.7	31.1	20.8
1.651	47.6	39.2	35.3	30.2	26.0	18.5
1.854	39.1	31.5	28.5	24.3	21.1	15.6
2.057	30.7	24.1	21.9	18.8	16.6	12.2
2.261	22.4	16.8	15.4	13.1	12.3	8.8
40% BOTTOM PERIPHERAL OBSTRUCTION						
0.000	173.2	165.9	148.4	127.9	98.3	69.7
0.203	173.2	158.9	142.3	122.8	95.3	66.6
0.406	165.3	151.8	136.6	117.8	90.8	63.2
0.610	156.9	144.6	129.8	112.1	85.8	59.9
0.813	150.0	138.2	124.7	107.7	81.7	56.9
0.864	147.8	136.3	123.0	106.1	80.1	55.3
0.914	142.3	131.5	119.0	102.8	77.7	55.5
1.143	64.0	62.6	58.5	53.0	40.3	28.9
0.940	66.6	62.9	57.8	50.1	38.4	28.9
0.991	63.8	59.9	54.5	46.7	37.2	26.9
1.041	66.4	61.6	55.3	48.9	36.4	26.4
1.143	65.7	60.2	53.8	45.3	35.2	25.5
1.245	63.0	57.5	51.2	42.6	33.2	24.0
1.448	54.5	48.3	43.2	36.1	28.1	20.7
1.651	45.4	41.1	35.6	30.1	22.9	16.2
1.854	37.0	33.9	27.8	24.3	18.9	14.3
1.041	68.7	60.8	54.5	47.8	37.3	29.6
1.143	68.8	60.0	52.8	48.9	35.9	27.2
1.245	65.3	57.4	50.4	44.4	33.3	25.8
1.448	56.6	48.9	42.6	37.2	28.2	22.4
1.651	47.9	40.6	35.5	30.9	24.5	19.8
1.854	38.9	32.6	28.8	24.7	19.9	16.4
2.057	30.4	24.9	22.0	18.8	15.6	13.8
2.261	21.8	17.4	15.6	12.7	11.4	11.1

Table B.6: Two-phase Pressure Data of Top Peripheral Segment Obstruction

AIR (KG/S)	0.0835	0.0523	0.0418	0.0324	0.0222	0.0137
AIR PRESSURE (PSIG)	52.0	44.0	35.5	28.5	19.5	12.0
WET PRESSURE (PSIG)	38.2	30.2	24.8	19.5	13.5	8.6
DISTANCE (METER)	(HEIGHT,CM) (MERIAM OIL)	(HEIGHT,CM) (MERIAM OIL)	(HEIGHT,CM) (MERIAM OIL)	(HEIGHT,CM) (MERIAM OIL)	(HEIGHT,CM) (MERIAM OIL)	(HEIGHT,CM) (MERIAM OIL)
25% TOP PERIPHERAL SEGMENT OBSTRUCTION						
0.000	127.6	107.3	92.4	78.6	66.6	50.4
0.203	118.2	100.1	86.5	74.3	64.2	46.6
0.406	111.1	92.8	80.3	68.2	58.5	43.5
0.610	102.5	85.4	74.1	63.5	54.3	38.7
0.813	95.6	79.3	68.9	59.1	50.4	36.4
0.864	93.5	77.2	67.0	57.9	48.9	35.4
0.914	93.1	76.8	66.4	57.1	48.5	35.2
1.143	63.2	51.6	46.0	40.6	35.4	24.6
0.940	53.4	47.1	42.9	39.8	35.2	25.8
0.991	58.7	51.9	46.6	42.7	37.3	26.7
1.041	60.0	52.6	46.6	42.2	36.8	26.8
1.143	59.4	51.8	46.1	41.4	35.5	24.9
1.245	57.0	48.9	43.9	39.9	33.8	23.1
1.448	52.1	45.3	39.8	35.7	28.6	20.3
1.651	45.8	40.1	34.8	31.1	25.3	17.3
1.854	37.9	33.2	28.9	25.6	20.4	14.3
1.041	62.5	53.0	46.5	42.4	38.9	32.4
1.143	61.6	52.0	45.8	40.8	37.2	30.1
1.245	59.5	50.1	44.0	39.3	35.4	28.4
1.448	54.5	49.9	40.1	35.8	32.0	25.5
1.651	48.3	40.1	35.1	32.0	28.0	22.2
1.854	40.6	33.4	29.3	27.0	23.2	17.9
2.057	32.3	26.0	23.0	21.2	18.2	13.6
2.261	23.1	18.1	16.5	14.8	13.9	9.5
40% TOP PERIPHERAL SEGMENT OBSTRUCTION						
0.000	165.7	144.7	120.9	101.4	84.4	58.1
0.203	157.6	137.4	114.7	96.3	78.7	55.4
0.406	149.5	130.3	108.4	90.9	74.5	51.4
0.610	141.2	122.7	101.9	85.3	69.2	48.3
0.813	134.3	116.5	96.7	80.9	65.4	45.5
0.864	132.1	114.4	94.6	79.1	63.7	44.2
0.914	132.7	115.1	95.0	79.3	63.8	44.4
1.143	54.3	49.6	47.6	38.4	33.8	25.3
0.940	46.8	38.1	36.2	33.0	30.2	24.1
0.991	54.3	45.5	42.9	38.0	33.6	26.4
1.041	57.8	47.8	44.5	38.8	34.0	26.2
1.143	58.9	48.5	44.6	38.4	32.8	25.6
1.245	57.5	47.0	43.3	36.7	31.2	24.2
1.448	52.8	42.6	39.2	32.9	27.9	20.6
1.651	47.2	37.3	34.3	29.0	24.6	17.2
1.854	38.5	30.7	28.4	24.2	20.4	13.1
1.041	58.4	48.6	42.5	38.6	35.9	28.8
1.143	59.3	49.2	42.4	37.9	34.2	25.3
1.245	57.8	47.6	40.9	36.5	32.4	23.9
1.448	53.1	43.1	36.6	33.0	28.6	21.1
1.651	47.4	37.9	32.1	28.7	25.3	18.3
1.854	38.8	31.3	26.5	24.1	20.7	15.3
2.057	31.7	24.6	21.0	19.1	16.6	12.7
2.261	23.1	17.1	14.9	13.5	12.4	10.4

Appendix C

EXPERIMENTAL DATA OF EXPERIMENT B

FOR SINGLE-PHASE FLOW

Table C.1: Experimental Data Obtained for Single-phase Flow

* ALIGNED REGULAR BUNDLES (280781)

WATER FLOW (USGPM)	30.0	27.5	25.0	22.5	20.0	17.5	15.0	12.5	10.0	7.5
TEMP. C	29.8	30.3	31.0	31.2	31.5	31.7	31.8	30.4	30.8	30.8
DISTANCE (METER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)
0.062	230.7	154.0	145.1	139.5	149.1	135.1	139.1	147.7	127.7	122.3
0.124	217.7	142.8	135.9	131.9	142.9	130.3	135.4	144.8	125.9	121.2
0.186	209.2	132.4	127.1	124.8	137.2	125.7	131.9	142.3	124.1	120.1
0.248	182.5	113.0	111.2	111.7	126.7	117.8	125.8	137.8	121.1	118.4
0.309	174.6	106.3	105.8	107.1	122.9	114.8	123.3	135.9	118.9	117.5
0.371	163.9	97.2	98.0	100.8	117.8	110.5	120.2	133.6	118.4	116.6
0.433	151.8	86.6	89.1	93.5	111.9	106.0	116.5	131.0	116.6	115.6
0.495	125.1	62.8	69.8	77.9	99.8	96.4	108.4	125.8	113.2	113.8
0.557	101.7	43.8	54.3	65.1	89.2	88.3	103.2	121.3	110.3	111.6
0.619	91.2	34.6	48.6	58.6	84.1	84.3	100.1	118.8	108.6	110.8
0.681	81.1	26.1	38.8	52.9	78.3	80.4	97.1	116.4	107.0	109.9
0.743	57.0	5.5	23.0	39.0	66.2	71.8	90.5	111.5	103.7	107.9
0.743	234.4	145.1	148.3	140.1	126.9	122.8	89.8	111.8	103.9	104.5
0.804	227.0	138.7	142.8	135.5	133.1	119.7	87.4	109.9	102.6	103.6
0.866	215.7	128.1	134.8	128.8	127.8	115.5	84.2	107.5	101.0	102.6
0.928	203.3	118.5	126.1	121.6	121.9	110.8	80.6	104.8	99.2	101.5
0.990	174.1	93.7	105.9	105.1	108.8	100.7	73.0	98.4	95.7	99.8
1.052	154.9	77.5	92.8	94.2	100.0	93.7	67.8	95.3	93.0	98.0
1.114	143.2	67.7	84.5	87.4	94.5	88.4	64.3	92.8	91.3	96.9
1.176	132.2	58.6	76.7	81.1	88.3	85.2	61.0	90.3	89.6	95.8
1.238	107.3	37.4	59.5	66.6	77.7	78.1	54.1	85.2	86.3	93.8
1.299	100.5	31.8	55.0	62.8	74.5	73.6	52.2	83.7	85.2	93.2
1.361	88.1	21.9	46.4	55.8	68.8	69.2	48.6	81.0	83.5	92.0
1.423	77.1	11.9	38.4	48.0	63.3	64.7	45.2	78.3	81.5	90.8

Table C.2: Experimental Data Obtained for Single-phase Flow

ALIGNED REGULAR BUNDLES (300781)

WATER FLOW (USGPM)	27.5	25.0	22.5	20.0	17.5	15.0	13.0	11.0	9.0	7.0
TEMP. C	31.7	32.0	32.2	32.4	32.6	32.8	33.0	33.2	33.4	33.8
DISTANCE (METER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)
0.062	148.9	146.2	150.0	137.9	144.8	144.0	144.3	130.8	126.5	117.7
0.124	138.2	137.1	142.4	132.0	140.2	140.3	141.3	128.6	125.0	116.7
0.186	127.7	128.4	135.4	128.3	135.7	136.9	138.6	126.6	123.6	115.8
0.248	108.1	112.1	122.0	115.7	127.4	130.5	133.6	122.9	121.2	114.3
0.309	101.8	107.0	117.8	112.2	124.7	128.3	131.8	121.6	120.2	113.6
0.371	92.7	99.3	111.4	107.1	120.6	125.2	129.3	119.7	119.0	112.8
0.433	82.5	91.0	104.5	101.5	116.3	121.7	126.8	117.8	117.5	111.9
0.495	58.3	71.6	88.9	89.2	106.8	114.5	120.9	113.7	114.8	110.2
0.557	41.9	57.3	77.3	79.9	98.5	108.8	116.4	110.4	112.6	108.7
0.619	32.8	49.6	70.9	74.8	95.4	105.7	113.9	108.5	111.3	107.8
0.681	24.3	42.5	65.0	69.9	91.7	102.7	111.4	106.7	110.1	106.9
0.743	4.5	28.1	51.5	59.2	83.2	98.2	106.4	103.0	107.5	105.4
0.681	133.8	125.0	124.8	125.6	83.2	96.0	106.3	102.9	108.0	104.6
0.804	126.8	119.0	120.0	121.5	80.1	93.5	104.2	101.3	107.0	103.8
0.866	117.6	111.2	113.6	116.3	76.0	90.3	101.6	98.5	105.6	102.9
0.928	107.1	102.4	106.3	110.6	71.4	86.8	98.8	97.3	104.2	102.0
0.990	83.4	81.0	89.0	96.9	60.8	78.7	92.5	92.8	101.2	100.1
1.052	67.1	68.8	79.1	88.9	54.5	73.8	88.5	89.5	99.2	98.8
1.114	57.1	66.6	72.4	83.4	50.2	70.5	85.9	88.0	97.8	97.8
1.176	47.9	52.7	65.9	78.2	46.0	67.2	83.3	86.0	96.4	97.0
1.238	28.3	34.7	51.3	68.5	36.9	60.2	77.8	82.0	93.7	95.3
1.299	21.6	30.8	48.0	63.6	34.5	58.3	76.2	80.8	92.9	94.7
1.361	11.8	22.1	40.8	57.9	30.0	54.8	73.4	78.5	91.3	93.7
1.423	1.8	13.8	34.0	52.5	25.7	51.5	70.7	76.6	90.1	92.8

Table C.3: Experimental Data Obtained for Single-phase Flow

ALIGNED REGULAR BUNDLES (050481)

WATER FLOW (USGPM)	27.5	25.0	22.5	20.0	17.5	15.0	13.0	11.0	9.0	7.0
TEMP. C	30.4	30.8	31.2	31.4	31.6	31.8	32.0	32.2	32.4	32.5
DISTANCE (METER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)
0.062	149.3	140.1	145.6	146.3	145.2	150.9	145.8	130.3	123.7	114.8
0.124	138.5	131.0	138.2	140.2	140.5	147.0	142.9	128.1	122.2	113.7
0.186	128.0	122.1	131.0	134.5	136.0	143.6	140.1	126.0	120.8	112.8
0.248	108.5	105.6	117.9	124.0	127.8	137.3	135.1	122.4	118.4	111.2
0.309	102.1	100.6	113.4	120.3	124.8	134.6	133.1	121.0	117.3	110.6
0.371	92.8	92.6	107.2	115.3	120.9	131.8	130.7	119.2	116.1	109.8
0.433	82.6	84.4	100.2	109.8	116.5	128.4	128.0	117.1	114.6	108.9
0.495	58.2	83.8	83.7	96.7	108.5	120.6	122.0	112.8	111.8	107.1
0.557	43.4	51.8	73.8	88.7	100.2	115.6	118.0	108.9	108.8	105.8
0.619	34.6	44.0	67.7	83.7	96.3	112.5	115.5	108.0	108.5	104.9
0.681	25.9	36.7	61.6	78.8	82.4	109.5	113.2	106.2	107.2	104.1
0.743	5.7	19.3	47.4	67.5	83.5	102.8	107.7	102.2	104.5	102.4
0.801	132.5	127.7	125.8	125.4	123.0	116.7	107.6	102.2	103.5	103.4
0.804	125.8	122.7	121.5	122.0	120.3	114.5	106.0	100.8	102.6	102.8
0.866	116.1	114.7	114.8	118.6	116.1	111.2	103.3	99.0	101.2	101.9
0.928	105.5	105.8	107.6	110.8	111.5	107.6	100.4	96.8	99.7	100.8
0.990	79.5	84.3	90.3	87.0	100.9	98.4	94.1	92.2	98.7	99.0
1.052	66.1	72.8	80.9	88.5	95.0	94.8	90.4	88.5	94.8	97.6
1.114	56.4	64.7	74.4	84.1	90.7	91.4	87.8	87.5	93.4	96.8
1.176	47.1	56.8	67.9	78.8	86.6	88.1	85.2	85.5	92.0	95.9
1.238	26.5	38.6	53.9	67.6	77.8	81.3	79.8	81.5	89.5	94.1
1.299	20.8	34.7	49.9	64.2	75.1	79.2	78.0	80.3	88.5	93.5
1.361	10.8	28.2	42.9	58.6	70.7	75.6	75.3	78.2	87.0	92.6
1.423	1.3	18.3	36.4	53.3	66.6	72.3	72.5	76.0	85.8	91.7

Table C.4: Experimental Data Obtained for Single-phase Flow

• 22.5 DEG. MISALIGNED REGULAR BUNDLES (300781)

WATER FLOW (USGPM)	30.0	27.5	25.0	22.5	20.0	17.5	15.0	12.5	10.0	7.5
TEMP. C	31.8	37.9	32.2	32.4	32.8	32.8	33.0	33.1	33.2	33.3
DISTANCE (METER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)
0.062	217.8	213.0	153.3	139.6	146.4	140.2	126.4	148.6	130.7	122.8
0.124	204.4	201.6	143.8	131.8	140.1	135.3	122.6	145.8	128.8	121.6
0.186	192.3	191.2	135.3	124.8	134.5	130.8	119.1	143.2	127.1	120.6
0.248	169.8	161.8	118.4	111.5	124.1	122.8	112.9	138.7	124.3	118.9
0.309	162.4	165.7	114.2	107.2	120.5	118.9	110.6	136.7	123.0	118.1
0.371	151.9	156.5	106.6	100.9	115.5	115.9	107.6	134.7	121.8	117.2
0.433	140.2	146.9	88.3	93.9	110.0	111.8	104.2	132.2	119.9	116.1
0.495	113.3	123.0	78.4	77.5	87.2	101.8	96.8	126.9	116.6	114.3
0.557	64.8	82.5	45.2	50.6	78.0	85.4	84.2	117.7	110.8	110.8
0.619	52.8	71.9	38.5	43.3	70.1	80.8	80.5	114.9	108.9	109.6
0.681	41.3	62.2	28.4	36.5	64.7	76.5	77.1	112.4	107.3	108.8
0.743	17.5	41.6	11.6	22.6	53.8	67.9	70.5	107.5	104.2	106.7
0.743	264.4	241.2	148.6	145.0	147.8	138.8	138.5	114.8	103.5	106.8
0.804	256.5	234.3	142.6	140.1	143.8	135.8	135.8	112.9	102.2	106.0
0.866	245.8	225.1	135.1	133.7	138.6	131.6	132.8	110.5	100.7	105.0
0.928	233.7	214.7	126.4	126.6	133.0	127.1	129.3	107.9	99.0	103.9
0.990	211.2	195.1	110.2	113.3	122.5	118.1	123.3	103.5	98.3	102.4
1.052	151.8	144.7	68.9	78.7	96.1	98.7	107.7	92.3	89.1	98.0
1.114	138.0	133.6	58.3	71.5	89.5	93.5	103.6	88.3	87.1	98.9
1.176	125.7	123.0	50.1	64.0	83.5	88.7	89.9	86.5	85.3	95.8
1.238	100.6	108.6	32.4	49.3	71.8	78.7	83.0	81.4	82.0	93.7
1.299	93.3	95.3	27.0	44.8	68.1	76.7	80.8	78.8	80.8	93.0
1.361	81.5	85.3	18.8	37.9	62.8	72.3	87.3	77.1	79.2	91.8
1.423	68.8	75.2	10.2	30.9	57.0	68.0	83.8	74.5	77.3	90.8

Table C.5: Experimental Data Obtained for Single-phase Flow

22.5 DEG. MISALIGNED REGULAR BUNDLES (300781)

WATER FLOW (USGPM)	27.5	25.0	22.5	20.0	17.5	15.0	12.5	10.0	8.5	7.0
TEMP. C	30.5	29.9	28.7	28.0	28.2	28.4	28.8	29.1	28.3	29.8
DISTANCE (METER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)
0.062	129.0	149.5	144.7	137.8	137.9	144.4	147.1	133.9	130.9	122.3
0.124	117.8	138.8	138.4	131.2	132.8	140.5	144.2	132.0	128.4	121.3
0.186	150.3	131.2	128.5	125.5	128.3	137.1	141.7	130.5	128.2	120.4
0.248	131.2	115.1	118.5	115.0	120.1	130.8	137.3	127.5	128.0	118.9
0.309	124.8	112.5	112.0	111.3	117.1	128.5	135.3	126.2	125.1	119.1
0.371	115.8	104.2	105.8	106.2	113.0	125.4	133.2	124.7	123.8	117.3
0.433	105.5	97.3	98.7	100.8	108.8	122.0	130.7	123.1	122.8	118.4
0.495	81.5	76.7	43.0	88.3	93.0	114.7	125.8	118.8	120.3	114.7
0.557	40.5	44.0	55.5	68.3	82.0	101.8	116.4	113.9	115.9	111.6
0.619	30.0	33.5	48.2	60.3	77.2	98.2	113.7	112.0	114.4	110.6
0.681	20.3	26.3	41.4	54.8	72.8	94.8	111.1	110.3	113.1	109.8
0.743	0.0	8.7	27.7	43.8	64.2	88.3	108.5	107.3	110.9	108.0
0.681	178.7	158.5	134.5	128.8	137.0	125.1	117.8	107.5	110.7	107.8
0.804	171.1	151.3	128.4	124.7	133.8	122.4	115.8	108.1	108.8	107.0
0.866	161.9	143.8	123.1	118.5	128.8	118.2	113.8	104.5	108.4	106.1
0.928	151.2	134.8	115.8	113.7	125.0	115.7	111.0	102.8	107.1	105.1
0.990	131.7	118.8	103.4	103.8	117.3	109.8	106.8	100.1	105.1	103.8
1.052	81.4	77.1	68.8	76.7	98.4	94.0	95.5	92.9	98.8	100.0
1.114	68.3	67.1	61.2	70.0	91.1	88.8	92.6	90.8	98.2	98.9
1.176	58.2	57.8	53.8	63.8	88.2	88.2	88.8	88.1	98.8	97.8
1.238	38.5	40.0	38.2	52.2	77.2	78.3	84.9	85.8	94.4	98.1
1.299	29.9	34.4	34.5	48.4	74.1	78.8	83.1	84.8	93.5	95.4
1.361	18.8	26.0	27.8	42.7	88.7	73.4	80.8	82.8	92.1	94.5
1.423	9.8	17.7	21.1	37.2	85.3	70.0	78.0	81.3	80.8	93.7

Table C.6: Experimental Data Obtained for Single-phase Flow

22.5 DEG. MISALIGNED REGULAR BUNDLES (040881)

WATER FLOW (USGPM)	27.5	25.0	22.5	20.0	17.5	15.0	13.0	11.0	9.0	7.0
TEMP. C	34.3	34.6	34.9	35.1	35.3	35.5	35.7	35.8	36.1	36.3
DISTANCE (METER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)
0.062	213.1	151.1	141.8	140.7	138.3	144.4	142.1	138.5	131.5	120.9
0.124	202.3	142.1	134.8	134.8	133.7	140.7	139.2	138.3	130.0	119.8
0.186	181.6	133.2	127.3	128.9	128.0	137.1	136.4	134.3	128.8	118.0
0.248	172.7	117.5	114.5	118.8	121.1	130.9	131.6	130.7	126.3	117.5
0.309	168.2	112.0	110.1	115.1	118.1	128.5	129.8	128.3	125.2	118.8
0.371	157.0	104.2	103.8	110.0	114.1	125.4	127.2	127.5	124.0	118.0
0.433	1A7.8	98.4	87.3	104.8	109.9	122.2	124.8	125.5	122.8	115.0
0.495	126.2	77.8	82.4	93.0	100.8	115.1	118.1	121.5	119.8	113.3
0.557	78.2	38.3	50.8	67.8	81.1	100.1	107.5	113.3	114.5	110.0
0.619	67.2	29.1	43.3	61.4	76.2	98.3	104.5	111.0	112.9	108.9
0.681	57.2	20.7	36.3	55.8	71.7	92.8	101.7	108.9	111.4	107.8
0.743	35.9	2.6	21.7	44.0	62.5	85.6	96.2	104.9	108.7	108.3
0.681	227.0	135.6	123.4	124.5	123.1	85.5	98.2	104.8	107.0	108.3
0.804	220.5	130.4	119.0	120.9	120.3	83.3	94.3	103.4	106.0	105.6
0.866	211.1	122.5	112.6	115.7	116.2	80.1	91.8	101.5	104.7	104.7
0.928	208.7	113.8	105.5	110.0	118.7	78.5	88.0	99.5	103.3	103.7
0.990	181.7	110.7	102.8	107.8	108.9	75.1	87.8	98.6	102.6	103.3
1.052	132.1	58.8	62.0	75.1	84.8	56.0	72.9	88.0	85.8	98.8
1.114	118.8	48.8	53.8	68.5	79.8	51.8	68.7	85.6	84.0	97.7
1.176	108.0	40.4	46.1	62.3	74.6	48.0	68.7	83.3	92.4	96.8
1.238	88.5	23.2	32.2	51.1	66.0	41.4	61.4	79.8	88.8	95.0
1.299	81.8	17.7	27.6	47.3	62.5	38.9	59.5	78.1	88.8	94.5
1.361	71.8	9.5	20.8	41.8	53.5	35.5	56.7	76.1	87.3	93.4
1.423	62.5	1.8	14.5	36.8	54.4	32.4	54.2	74.1	86.1	92.5

Table C.7: Experimental Data Obtained for Single-phase Flow

* 45.0 DEG. MISALIGNED REGULAR BUNDLES (240781)

WATER FLOW (USGPM)	30.0	27.5	25.0	22.5	20.0	17.5	15.0	12.5	10.0	7.5
TEMP. C	30.0	27.8	28.6	30.4	28.1	25.5	25.0	24.3	24.6	24.7
DISTANCE (METER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)
0.062	235.6	212.4	158.4	144.8	146.8	158.1	148.7	135.3	128.1	112.6
0.124	222.8	200.8	150.0	137.4	140.6	153.2	144.8	132.5	128.2	111.4
0.186	210.1	180.2	141.1	129.9	134.7	148.8	141.1	129.8	124.4	110.4
0.248	187.4	170.8	124.9	116.5	123.8	140.3	134.6	125.0	121.3	108.6
0.309	180.1	164.7	119.5	112.3	120.3	137.2	132.3	123.2	120.1	107.8
0.371	169.6	155.5	112.2	108.2	115.2	133.4	128.2	120.9	118.5	106.8
0.433	153.2	142.4	100.7	96.8	108.0	127.7	125.0	117.7	116.5	105.4
0.495	148.3	136.7	94.6	91.8	98.0	120.0	118.0	113.4	113.6	103.8
0.557	85.4	88.2	39.3	48.9	87.8	96.6	101.3	100.6	105.5	99.1
0.619	52.3	56.8	29.8	38.8	61.3	91.5	97.3	97.7	103.4	97.9
0.681	38.7	45.1	20.1	31.0	54.8	88.3	93.3	94.8	101.6	96.7
0.743	15.4	25.3	3.8	17.5	43.8	77.8	86.9	90.1	98.5	95.1
0.743	282.0	226.6	152.5	146.0	132.8	140.8	86.6	89.9	98.3	94.9
0.804	274.4	218.5	148.3	141.2	128.5	137.4	83.7	87.7	96.7	93.6
0.866	263.1	208.9	138.1	134.5	123.0	133.2	80.3	85.2	95.0	92.6
0.928	251.5	198.9	128.7	127.7	117.3	128.8	78.7	82.8	93.2	91.5
0.990	220.6	173.7	107.6	109.7	108.0	118.1	71.2	78.5	90.7	90.0
1.052	158.4	122.1	85.0	75.5	78.2	97.6	52.8	65.5	82.3	85.1
1.114	145.0	109.6	54.6	67.1	89.0	92.2	48.3	62.1	80.0	83.8
1.176	132.6	98.8	45.4	59.7	62.8	87.4	44.5	58.3	78.1	82.6
1.238	108.4	78.1	28.1	45.5	53.4	78.8	37.8	54.4	74.8	80.7
1.299	101.8	71.8	23.1	41.2	47.6	75.8	35.3	52.5	73.6	79.9
1.361	90.3	62.4	14.1	34.7	42.2	71.5	32.0	50.0	71.9	78.7
1.423	78.8	52.8	8.2	27.9	38.7	67.3	28.6	47.5	70.2	77.7

Table C.8: Experimental Data Obtained for Single-phase Flow

45.0 DEG. MISALIGNED REGULAR BUNDLES (030781)

WATER FLOW (USGPM)	27.5	25.0	21.8	20.0	17.5	15.0	13.0	11.0	9.0	7.0
TEMP. C	30.0	30.8	31.1	31.4	31.6	31.8	32.0	32.2	32.4	32.6
DISTANCE (METER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)
0.062	209.3	188.8	144.3	144.3	135.8	134.5	146.9	142.9	132.2	121.8
0.124	197.9	169.3	137.2	138.0	130.8	130.8	143.8	140.7	130.6	120.9
0.186	187.6	180.7	130.6	132.4	126.3	127.2	141.2	138.7	129.3	120.0
0.248	168.8	165.0	119.2	122.2	118.3	121.1	136.4	135.3	127.0	118.5
0.309	162.1	159.5	115.1	118.4	115.3	118.7	134.4	133.7	125.9	117.8
0.371	153.0	151.9	109.4	113.4	111.3	115.5	132.1	132.0	124.7	117.0
0.433	143.1	143.9	103.4	108.0	106.9	112.2	129.4	130.0	123.3	116.0
0.495	91.2	105.8	78.0	83.9	88.2	98.2	118.7	122.3	118.4	112.9
0.557	63.8	78.3	55.8	66.2	74.3	87.7	110.5	118.5	114.4	110.4
0.619	52.3	68.8	48.7	59.8	69.3	83.8	107.4	114.2	112.9	109.3
0.681	41.7	60.3	42.4	54.2	64.7	80.3	104.7	112.1	111.4	108.4
0.743	21.7	43.5	30.1	43.4	56.2	73.8	99.6	108.5	109.0	108.8
0.681	250.3	217.5	132.1	129.9	126.5	124.2	99.8	108.3	109.0	106.3
0.804	242.7	211.8	127.4	125.8	125.1	121.6	97.7	108.7	107.9	105.9
0.866	233.5	203.7	121.5	120.6	121.1	118.4	95.2	104.9	106.6	104.6
0.928	223.5	195.2	115.3	115.1	116.5	115.0	92.4	102.8	105.2	103.7
0.990	180.8	168.9	86.0	98.2	103.3	105.0	84.7	97.2	101.5	101.4
1.052	144.5	130.5	67.9	73.6	84.1	90.6	73.5	89.3	96.2	98.0
1.114	132.1	120.2	60.3	66.8	78.6	86.4	70.2	86.9	94.8	96.9
1.176	121.8	111.3	53.5	60.8	73.8	82.7	67.3	84.7	93.2	95.9
1.238	99.8	93.3	40.2	49.1	64.5	75.7	61.9	80.8	90.5	94.2
1.299	84.8	88.4	38.8	46.0	82.0	73.7	60.3	78.6	89.6	93.6
1.361	65.0	80.8	30.7	40.6	57.7	70.3	57.8	77.6	88.3	92.8
1.423	75.2	72.8	24.6	35.3	53.4	67.0	55.0	75.6	86.9	91.8

Table C.9: Experimental Data Obtained for Single-phase Flow

45.0 DEG. MISALIGNED REGULAR BUNDLES (060881)

WATER FLOW (USGPM)	27.5	25.0	22.5	20.0	17.5	15.0	13.0	11.0	9.0	7.0
TEMP. C	31.8	32.1	32.3	32.5	32.8	32.9	33.2	33.3	33.5	33.5
DISTANCE (METER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)
0.062	212.2	193.2	150.5	144.4	139.4	143.4	138.4	137.2	125.5	118.6
0.124	201.3	183.9	142.8	138.3	134.5	138.7	135.5	135.1	124.0	117.8
0.186	190.8	175.0	135.8	132.4	129.8	136.1	132.7	133.0	122.8	116.7
0.248	171.4	158.2	122.7	122.0	121.8	128.8	127.9	129.5	120.2	115.3
0.309	164.6	153.8	118.0	118.2	118.8	127.5	125.9	128.0	119.2	114.5
0.371	159.4	145.8	111.7	113.0	114.8	124.4	123.5	126.2	117.9	113.7
0.433	145.4	138.1	105.1	107.8	110.5	121.1	120.8	124.2	116.6	112.8
0.495	111.6	110.5	82.7	90.0	97.0	111.0	113.1	118.7	112.8	110.8
0.557	85.7	73.1	52.3	65.5	78.2	96.7	101.9	110.7	107.5	107.3
0.619	54.0	63.4	44.2	59.0	73.0	92.7	98.8	108.4	105.9	106.2
0.631	43.6	54.7	37.1	53.2	68.5	88.1	96.0	106.3	104.5	105.3
0.743	22.9	37.8	23.2	42.0	59.8	82.5	90.8	102.5	101.9	103.7
0.681	233.0	222.2	132.7	128.5	126.8	125.8	115.7	102.7	101.8	103.9
0.804	226.5	216.8	128.1	124.8	123.8	123.3	113.8	101.3	101.0	103.2
0.866	217.2	209.1	121.6	119.6	119.7	120.0	111.3	99.4	99.6	102.4
0.928	206.8	200.6	114.7	113.9	115.2	116.8	108.8	97.3	98.2	101.4
0.990	173.0	172.7	91.8	95.5	101.3	106.0	100.4	91.6	94.4	98.1
1.052	128.4	138.3	82.5	72.4	83.2	92.4	89.8	83.9	89.2	95.6
1.114	118.7	124.5	54.2	65.6	77.8	88.3	86.7	81.5	87.5	94.8
1.176	106.0	117.6	46.6	59.5	73.1	84.6	83.7	79.3	86.0	93.9
1.238	85.1	100.2	32.4	48.0	64.1	77.8	78.4	75.5	83.4	92.1
1.299	78.2	95.4	26.4	44.6	61.4	75.8	76.7	74.2	82.5	91.5
1.361	68.9	88.9	21.4	39.0	57.0	72.2	73.9	72.3	81.0	90.5
1.423	59.5	78.0	1[illegible]	[illegible].7	52.8	68.0	71.4	70.3	79.7	89.7

Table C.10: Experimental Data Obtained for Single-phase Flow

* ALIGNED STREAMLINED BUNDLES (240781)

WATER FLOW (USGPM)	30.0	27.5	25.0	22.5	20.0	17.5	15.0	12.5	10.0	7.5
TEMP. C	28.1	28.8	27.2	27.7	28.0	32.5	32.2	32.5	29.5	29.8
DISTANCE (METER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)
0.062	223.6	151.0	147.3	137.3	149.7	148.8	143.1	144.0	122.0	120.1
0.124	208.8	138.2	137.4	128.6	143.5	142.2	138.7	141.5	120.4	119.2
0.186	198.4	127.7	127.8	122.0	137.3	137.5	136.0	138.8	118.7	118.2
0.248	177.1	110.9	113.5	110.3	127.8	130.5	130.7	134.9	115.9	116.5
0.309	168.0	102.7	106.8	105.0	123.8	127.1	127.9	132.8	114.7	115.7
0.371	156.1	82.6	98.4	98.2	118.2	123.0	124.7	130.5	113.0	114.7
0.433	143.8	82.4	88.7	91.3	112.5	118.5	121.2	127.9	111.3	113.7
0.495	140.4	79.1	88.7	88.2	110.1	118.5	121.0	127.8	110.2	113.0
0.557	108.2	51.4	63.8	70.0	95.5	105.4	110.0	120.3	106.2	110.6
0.619	99.8	40.8	55.1	62.9	89.7	100.8	107.5	117.7	104.4	108.5
0.681	84.5	31.0	47.0	56.2	84.3	96.5	104.1	115.2	102.8	108.5
0.743	61.7	11.3	30.4	43.0	74.3	88.6	97.8	110.7	100.1	106.7
0.743	150.5	152.0	146.6	146.8	74.1	137.3	122.6	110.3	98.6	106.2
0.804	142.9	145.5	141.1	142.2	85.6	134.0	120.0	108.4	98.0	105.4
0.866	130.8	135.0	132.4	135.2	64.0	129.5	116.7	106.0	98.3	104.4
0.928	118.8	124.5	123.6	128.0	58.3	125.1	113.2	103.3	94.5	103.2
0.990	115.6	121.4	120.9	125.5	55.8	129.2	113.2	103.0	93.4	102.8
1.052	81.2	91.9	98.5	106.0	40.3	111.4	102.8	95.5	89.3	100.0
1.114	68.5	80.8	87.1	98.5	34.1	106.5	99.1	92.8	87.5	98.7
1.176	56.5	70.4	78.5	91.4	26.4	102.0	95.8	90.2	85.5	97.8
1.238	35.6	52.4	63.4	79.3	18.5	94.5	89.9	88.0	82.7	96.0
1.299	28.5	44.5	56.8	73.8	14.1	91.1	87.1	83.8	81.3	95.3
1.361	15.0	34.1	48.4	67.0	8.5	86.4	83.6	81.3	78.5	94.0
1.423	3.3	24.1	38.8	60.1	2.8	82.1	80.3	78.7	77.8	93.0

Table C.11: Experimental Data Obtained for Single-phase Flow

• ALIGNED STREAMLINED BUNDLES (280781)

WATER FLOW (USGPM)	30.0	27.5	25.0	22.5	20.0	17.5	15.0	12.5	10.0	7.5
TEMP. C	28.1	30.0	30.1	30.0	29.7	28.7	28.8	28.9	29.2	29.4
DISTANCE (METER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)
0.062	223.6	148.7	148.0	145.4	144.2	135.1	153.9	140.1	122.8	120.8
0.124	208.8	138.3	136.5	138.7	138.1	130.5	150.3	137.8	121.0	118.8
0.186	186.4	127.1	127.0	130.8	131.8	125.7	146.8	134.9	118.2	118.6
0.248	177.1	108.9	112.8	118.1	122.3	118.1	141.0	130.8	116.4	117.0
0.309	168.0	103.1	106.8	114.4	118.4	115.3	138.8	128.8	115.2	116.0
0.371	158.1	93.8	98.9	107.8	113.1	111.0	135.8	126.4	113.6	115.1
0.433	143.8	83.1	90.0	100.6	107.3	106.6	132.2	123.7	111.9	113.9
0.495	140.4	74.8	88.0	97.1	104.3	103.6	130.0	122.0	110.7	113.2
0.557	108.2	53.0	64.7	79.8	80.4	92.9	121.7	118.0	106.8	110.8
0.619	95.9	42.7	56.0	72.7	84.6	88.3	118.3	113.3	105.0	109.8
0.681	84.5	32.8	47.8	65.8	78.1	84.0	114.9	110.8	103.3	108.7
0.743	61.7	14.9	32.8	53.6	69.2	78.2	108.0	108.4	100.4	108.9
0.743	150.5	140.7	144.8	145.0	138.8	134.0	114.4	108.8	100.3	103.9
0.804	142.9	133.1	138.4	139.7	134.2	130.5	111.7	104.7	98.9	103.0
0.866	130.8	123.4	130.3	132.9	128.8	126.1	108.4	102.2	97.3	102.0
0.928	118.8	112.7	121.4	125.8	122.9	121.6	104.8	98.5	95.5	100.8
0.990	115.6	110.5	119.2	123.5	120.8	118.6	103.2	98.2	94.4	100.3
1.052	81.2	81.6	95.5	104.5	105.7	107.8	94.3	91.7	90.3	97.7
1.114	66.5	70.6	88.3	87.0	99.6	103.0	90.8	88.8	88.5	96.6
1.176	56.5	60.4	77.8	80.0	93.9	98.6	87.1	86.2	86.7	95.0
1.238	35.6	42.3	62.8	77.8	84.0	90.7	81.0	81.6	83.7	93.6
1.299	26.5	35.5	57.1	73.0	80.0	87.8	78.7	79.9	82.5	92.9
1.361	15.0	25.0	48.1	65.7	74.3	83.1	75.0	77.2	80.7	81.8
1.423	3.3	15.0	38.9	59.0	66.7	78.5	71.5	74.4	78.8	80.6

Table C.12: Experimental Data Obtained for Single-phase Flow

ALIGNED STREAMLINED BUNDLES (050881)

WATER FLOW (USGPM)	27.5	25.0	22.5	20.0	17.5	15.0	13.0	11.0	9.0	7.0
TEMP. C	32.0	32.3	32.5	32.7	32.9	33.2	33.6	33.8	33.9	34.1
DISTANCE (METER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)
0.062	144.6	141.9	144.8	138.0	138.4	148.7	137.8	123.2	115.5	112.2
0.124	133.2	132.3	137.0	131.8	131.8	143.1	134.9	121.3	114.2	111.4
0.186	122.3	123.3	128.6	125.8	127.0	138.6	132.1	118.2	112.9	110.5
0.248	104.9	100.6	118.0	118.4	118.5	133.8	127.5	115.8	110.5	109.1
0.309	84.0	103.1	113.3	112.5	116.5	131.3	125.6	114.4	109.7	108.4
0.371	88.5	95.1	106.8	107.2	112.3	128.2	123.1	112.5	108.3	107.5
0.433	78.4	86.8	98.9	101.7	107.8	124.8	120.4	110.5	107.0	108.6
0.495	75.8	84.2	97.8	98.7	106.1	123.3	118.0	108.4	106.1	105.0
0.557	49.1	62.2	80.2	85.4	95.1	114.9	112.5	104.7	102.3	104.0
0.619	36.6	53.3	72.9	79.5	90.4	111.3	109.6	102.5	101.4	103.0
0.681	29.6	45.2	66.3	74.1	86.1	108.0	106.8	100.6	100.0	102.1
0.743	11.9	30.3	54.3	64.3	78.5	102.1	102.3	97.1	97.7	100.8
0.681	128.7	130.1	125.8	123.2	119.0	102.0	102.2	96.9	94.5	100.8
0.804	121.0	123.6	120.7	118.8	115.5	98.3	100.0	95.3	97.1	98.9
0.866	111.2	115.3	114.1	113.5	111.3	96.0	97.4	93.4	95.7	99.0
0.928	100.8	106.7	107.0	107.7	106.7	92.4	94.6	91.3	94.3	97.8
0.990	88.5	105.1	105.5	108.2	105.3	91.2	93.5	90.4	93.5	97.5
1.052	70.3	81.0	88.3	90.3	93.2	82.1	86.4	85.3	90.0	95.3
1.114	58.6	72.0	79.1	85.0	88.7	78.5	83.5	83.1	88.7	94.3
1.176	48.3	63.5	72.1	79.3	84.1	75.0	80.7	81.0	87.2	93.4
1.238	31.4	48.3	60.0	68.5	76.4	68.1	76.1	77.7	84.9	91.8
1.299	24.7	42.5	55.2	65.8	73.3	66.6	74.0	78.1	83.8	91.2
1.361	14.2	34.0	48.2	58.7	68.7	63.1	71.2	74.0	82.2	90.2
1.423	4.8	25.7	41.6	54.4	64.4	58.8	68.6	71.9	81.0	89.3

Table C.13: Experimental Data Obtained for Single-phase Flow

ALIGNED STREAMLINED BUNDLES (063081)

WATER FLOW (USGPM)	27.5	25.0	22.5	20.0	17.5	15.0	13.0	11.0	9.0	7.0
TEMP. C	30.1	30.3	30.5	30.7	31.0	31.1	31.3	31.0	31.7	31.8
DISTANCE (METER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)
0.062	143.5	146.9	144.4	136.8	141.4	145.8	145.2	130.8	124.4	117.0
0.124	131.8	137.3	136.9	130.4	136.7	142.4	142.5	128.9	123.2	116.2
0.186	121.2	126.5	129.5	124.9	132.1	134.9	139.7	126.8	121.8	115.5
0.248	103.1	113.6	117.5	115.2	124.5	133.1	135.1	123.5	119.6	114.0
0.309	96.6	108.1	112.6	111.2	121.3	130.6	133.0	122.0	118.6	113.3
0.371	87.1	100.3	106.1	105.9	117.1	127.4	130.6	120.1	117.3	112.5
0.433	76.8	91.8	99.1	100.3	112.7	124.0	127.8	118.1	115.9	111.8
0.495	73.8	89.0	86.3	97.8	110.5	122.2	126.3	116.9	115.0	111.0
0.557	46.5	66.6	78.2	83.4	99.3	113.7	118.4	112.1	111.8	108.9
0.619	36.3	56.0	71.1	77.7	94.8	110.2	116.8	110.0	110.3	107.9
0.681	26.5	49.7	64.2	72.1	90.4	106.8	114.3	108.0	109.0	107.0
0.743	7.1	33.3	50.8	61.3	82.0	100.4	109.1	104.3	106.5	105.4
0.681	124.7	127.4	123.8	121.9	119.4	118.3	108.1	104.3	106.3	105.5
0.804	122.4	122.7	119.9	118.6	116.8	116.2	107.6	103.0	105.5	104.8
0.866	112.3	114.3	113.0	113.0	112.4	112.8	104.9	101.0	104.1	103.9
0.928	101.9	105.8	105.9	107.3	107.8	109.3	102.1	98.8	102.7	102.9
0.990	100.8	104.4	104.4	105.6	106.4	107.9	101.0	97.5	101.8	102.4
1.052	71.2	80.3	84.9	90.3	94.4	98.8	93.9	92.9	98.5	100.1
1.114	60.3	71.3	77.5	84.2	89.7	95.1	91.0	90.7	97.0	99.2
1.176	49.8	62.8	70.3	78.4	85.1	91.7	88.2	88.8	95.6	98.3
1.238	31.8	47.8	58.2	68.6	77.3	85.8	83.5	85.1	93.3	96.7
1.258	25.1	42.1	53.4	64.7	74.2	83.4	81.6	83.6	92.2	96.1
1.361	14.5	33.4	48.1	58.8	67.8	79.8	78.7	81.5	90.6	95.1
1.423	4.8	25.2	38.4	53.4	65.3	76.4	76.0	78.4	88.4	94.3

Table C.14: Experimental Data Obtained for Single-phase Flow

ALIGNED STREAMLINED BUNDLES (070881)

WATER FLOW (USGPM)	27.5	25.0	22.5	20.0	17.5	15.0	13.0	11.0	9.0	7.0
TEMP. C	29.6	29.9	30.2	30.4	30.6	30.8	31.1	31.3	31.5	31.7
DISTANCE (METER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)
0.062	147.4	145.4	145.8	137.0	138.9	148.1	133.5	119.4	113.5	108.3
0.124	135.4	135.7	137.8	130.8	134.2	144.5	130.9	117.5	112.3	105.5
0.186	125.1	126.9	130.6	124.9	128.6	141.1	124.1	115.4	110.9	104.8
0.248	107.3	112.2	118.7	115.3	122.1	135.3	123.5	112.1	108.6	103.3
0.309	100.3	106.3	113.7	111.3	113.0	132.7	121.6	110.6	107.6	102.6
0.371	91.0	98.5	107.3	106.1	115.0	128.7	119.1	108.6	106.3	101.8
0.433	80.6	88.8	100.2	100.4	110.5	126.2	116.3	106.7	104.9	100.8
0.495	77.8	87.2	88.0	98.3	106.7	124.7	114.9	105.6	103.9	100.2
0.557	50.1	64.4	78.4	83.5	97.4	116.0	108.2	100.7	100.7	98.2
0.619	39.8	55.8	72.3	77.8	92.9	112.8	105.5	98.7	98.7	97.3
0.681	30.2	47.6	65.7	72.5	88.7	109.3	102.8	96.7	97.8	96.3
0.743	11.6	32.3	53.0	62.2	80.7	103.1	98.0	93.1	95.4	94.6
0.681	128.3	130.7	127.2	122.0	119.2	103.1	97.9	93.0	95.5	95.2
0.804	121.1	124.7	122.2	118.0	116.1	100.7	96.0	91.5	94.5	94.5
0.866	111.4	116.5	115.5	112.6	111.9	97.4	93.4	89.6	93.1	93.6
0.928	100.8	107.7	108.2	106.6	107.2	93.8	90.5	87.5	91.6	92.6
0.990	96.2	105.2	105.9	104.6	105.4	92.3	89.2	86.4	90.7	92.0
1.052	70.6	82.5	87.4	89.9	94.1	83.6	82.5	81.5	87.5	89.9
1.114	58.7	73.4	80.0	83.6	83.3	80.0	79.6	79.3	86.0	89.0
1.176	49.7	65.0	73.0	78.2	84.9	76.6	76.9	77.3	84.5	88.1
1.238	32.6	50.8	61.4	64.9	77.6	70.9	72.5	74.1	82.3	86.6
1.288	25.1	44.4	56.0	64.4	74.1	68.2	70.3	72.4	81.1	85.8
1.361	14.5	35.5	46.6	58.5	69.5	64.5	67.4	70.2	79.6	84.8
1.423	4.5	27.2	41.8	53.1	65.3	61.3	64.8	68.3	78.3	83.9

Table C.15: Experimental Data Obtained for Single-phase Flow

ALIGNED STREAMLINED BUNDLES (070881)

WATER FLOW (USGPM)	15.0	14.0	13.0	12.0	11.0	10.0	9.0	8.0	7.0	6.0
TEMP. C	31.3	31.6	31.7	31.8	32.0	32.1	32.2	32.4	32.6	32.8
DISTANCE (METER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)
0.062	148.9	140.7	133.1	128.6	118.2	113.5	114.2	110.4	105.8	102.1
0.124	145.2	137.6	130.5	124.6	117.3	112.0	112.9	109.4	105.1	101.5
0.186	141.8	134.4	127.7	121.8	115.3	110.3	111.6	108.4	104.4	101.0
0.248	136.0	129.3	123.2	118.0	111.9	107.5	109.3	106.6	103.0	98.9
0.309	133.5	127.1	121.2	116.3	110.4	106.2	108.3	105.8	102.3	99.4
0.371	130.4	124.3	118.7	114.0	108.6	104.7	107.0	104.7	101.4	98.7
0.433	126.9	121.1	118.0	111.6	106.5	102.9	105.5	103.5	100.5	98.0
0.495	125.3	118.7	114.7	110.4	105.4	101.9	104.7	102.7	98.9	97.5
0.557	116.5	112.0	109.0	104.6	100.6	98.0	101.5	100.2	97.9	96.0
0.619	113.1	109.3	105.3	102.2	98.5	96.2	100.0	99.0	97.0	95.2
0.681	108.9	106.0	102.7	99.9	96.8	94.6	98.7	97.9	96.1	94.5
0.743	103.5	100.5	97.8	95.6	93.0	91.8	96.2	95.9	94.5	93.3
0.881	102.8	100.4	97.4	95.6	92.9	91.8	95.7	96.4	94.7	93.0
0.804	100.5	98.2	95.9	93.9	91.5	90.5	94.7	95.6	94.1	92.4
0.866	97.2	95.3	93.3	91.5	89.5	88.8	93.4	94.4	93.2	91.8
0.928	93.6	92.1	90.5	89.1	87.6	87.0	91.9	93.2	92.2	91.0
0.990	92.0	90.6	89.1	87.8	86.3	86.0	91.1	92.5	91.6	90.5
1.052	87.3	82.9	82.4	82.0	81.4	82.0	87.9	89.8	88.8	89.0
1.114	79.7	79.7	79.6	79.5	79.3	80.3	86.3	88.7	88.7	88.3
1.176	76.2	76.6	76.9	77.1	77.3	78.6	85.0	87.5	87.7	87.5
1.238	70.6	71.7	72.8	73.2	74.0	75.9	82.7	85.7	86.3	88.4
1.299	67.8	69.2	70.3	71.2	72.3	74.4	81.5	84.7	85.5	85.8
1.361	64.1	65.9	67.5	68.7	70.2	72.7	80.1	83.5	84.5	84.9
1.423	60.8	63.0	64.9	66.5	68.3	71.0	78.7	82.4	83.8	84.4

Table C.16: Experimental Data Obtained for Single-phase Flow

22.5 DEG. MISALIGNED STREAMLINED BUNDLES (290781)

WATER FLOW (USGPM)	30.0	27.5	25.0	22.5	20.0	17.5	15.0	12.0	10.0	7.5
TEMP. C	31.8	32.3	32.8	33.0	33.2	33.5	33.9	33.9	34.2	34.4
DISTANCE (METER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)
0.062	211.5	150.4	152.9	142.8	153.0	141.5	125.4	137.7	120.4	120.2
0.124	197.7	138.4	143.5	135.2	146.8	138.9	122.3	135.8	119.2	119.3
0.186	184.6	128.3	134.3	127.6	140.7	132.1	118.6	132.5	117.5	118.3
0.248	165.2	111.9	120.8	116.4	131.9	125.2	113.3	128.5	114.9	116.8
0.309	156.6	104.3	114.3	111.3	127.8	121.7	110.5	126.7	113.5	116.0
0.371	145.0	94.9	108.5	104.8	122.3	117.6	107.3	124.3	111.9	115.0
0.433	132.9	84.2	97.8	97.7	118.6	113.1	103.8	121.9	110.2	114.0
0.495	132.2	87.5	100.1	98.7	117.8	113.8	104.1	121.7	110.0	113.6
0.557	98.8	53.7	72.3	76.6	99.8	99.8	93.4	114.2	105.1	110.8
0.619	83.9	42.9	63.2	69.3	93.8	95.2	89.8	111.4	103.3	109.8
0.681	72.3	33.0	55.1	62.4	88.3	90.8	86.4	108.8	101.6	108.8
0.743	50.1	14.2	39.6	49.9	78.1	82.9	80.3	104.4	98.8	107.0
0.743	152.8	147.4	141.5	140.2	138.7	137.3	117.7	107.9	106.0	107.4
0.804	144.8	140.5	135.8	135.5	132.8	134.4	115.2	106.0	104.5	106.6
0.866	133.3	130.7	127.6	128.8	127.3	129.8	111.9	103.6	102.9	105.7
0.928	120.8	120.1	118.9	121.6	121.5	125.3	108.4	101.0	101.2	104.5
0.990	122.5	121.8	118.5	121.9	121.4	125.0	107.5	100.5	100.3	104.3
1.052	84.8	89.6	93.1	100.3	104.3	111.8	97.8	93.2	98.0	101.4
1.114	70.8	77.6	83.4	92.4	97.8	106.8	93.8	90.3	93.9	100.2
1.176	58.1	66.8	74.3	85.0	91.9	102.1	90.0	87.6	92.0	99.2
1.238	37.4	49.1	59.7	73.0	82.3	94.6	84.0	83.4	89.2	97.4
1.299	28.2	41.3	53.1	67.5	77.8	90.9	81.4	81.2	87.8	96.6
1.361	15.5	31.1	44.4	60.8	72.2	86.4	78.0	78.7	88.0	95.5
1.423	5.2	21.4	36.4	54.0	68.7	82.1	74.5	78.2	84.3	94.4

Table C.17: Experimental Data Obtained for Single-phase Flow

22.5 DEG. MISALIGNED STREAMLINED BUNDLES (040881)

WATER FLOW (USGPM)	27.5	25.0	22.5	20.0	17.5	15.0	13.0	11.0	9.0	7.0
TEMP. C	26.5	26.8	27.4	27.9	28.2	28.5	28.8	29.1	29.3	29.5
DISTANCE (METER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)
0.062	143.3	144.5	143.3	148.1	138.2	149.2	136.8	127.3	123.8	115.7
0.124	131.5	134.9	135.5	141.8	133.5	145.6	134.1	125.4	122.5	114.8
0.186	120.5	125.8	128.1	136.0	128.8	142.1	131.3	123.3	121.1	114.1
0.248	103.1	111.4	118.4	126.7	121.6	136.4	126.8	120.0	118.9	112.7
0.309	96.1	105.5	111.6	122.7	118.4	133.6	124.8	118.5	117.9	112.0
0.371	86.7	97.7	105.2	117.6	114.4	130.8	122.2	116.8	116.6	111.1
0.433	78.3	89.0	98.2	111.9	109.9	127.1	119.4	114.5	115.1	110.2
0.495	75.1	87.8	88.8	110.5	106.7	125.8	118.3	113.5	114.3	108.6
0.557	44.4	62.8	76.6	94.5	96.3	116.3	110.9	108.2	110.8	107.4
0.619	33.2	53.4	69.1	88.5	91.6	112.8	107.9	106.0	109.3	106.3
0.681	22.9	44.8	62.2	82.8	87.2	108.1	105.1	103.9	107.8	105.4
0.743	4.0	28.1	49.4	72.8	79.2	102.8	100.3	100.3	105.4	103.8
0.681	130.2	128.3	126.6	123.9	118.8	102.7	100.2	100.2	105.0	104.0
0.804	122.9	122.3	121.7	118.4	115.4	100.2	98.1	98.7	104.0	103.4
0.866	113.3	114.2	115.1	114.0	111.2	96.9	95.5	96.3	102.6	102.4
0.928	102.6	105.3	107.8	108.2	106.8	93.2	92.8	94.6	101.1	101.4
0.990	103.4	105.8	107.8	107.8	108.1	92.6	92.0	94.1	100.6	101.1
1.052	70.9	78.9	88.3	90.8	93.0	82.4	84.1	88.2	98.8	98.5
1.114	59.0	68.1	78.3	84.4	87.9	78.4	80.9	85.9	95.2	97.4
1.176	48.0	59.9	70.8	78.3	83.2	74.7	78.0	83.7	93.7	96.8
1.238	30.5	45.4	59.1	68.9	75.9	68.0	73.9	80.4	91.5	95.0
1.299	22.7	38.8	53.8	64.5	72.4	66.2	71.3	78.8	90.3	94.3
1.361	12.7	30.4	46.7	58.8	67.9	62.8	68.5	76.8	88.8	93.1
1.423	2.8	22.1	40.1	53.5	63.8	59.4	65.9	74.5	87.5	92.4

Table C.18: Experimental Data Obtained for Single-phase Flow

22.5 DEG. MISALIGNED STREAMLINED BUNDLES (050881)

WATER FLOW (USGPM)	27.5	25.0	22.5	20.0	17.5	15.0	13.0	11.0	9.0	7.0
TEMP. C	33.0	33.2	33.4	33.8	33.8	34.0	34.3	34.4	34.6	34.8
DISTANCE (METER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)
0.062	148.3	143.6	145.8	143.6	137.9	147.8	136.7	125.0	122.1	110.1
0.124	137.7	134.0	137.8	137.3	133.1	144.2	134.0	123.1	120.8	109.4
0.186	128.9	125.0	130.5	131.3	128.5	140.7	131.1	121.0	119.5	108.6
0.248	109.8	110.9	118.0	122.1	121.2	135.1	128.7	117.8	117.4	107.2
0.309	102.8	105.0	114.2	118.0	118.1	132.4	124.7	118.2	116.3	106.4
0.371	93.1	97.0	107.7	112.7	113.9	128.4	122.1	114.4	115.0	105.8
0.433	83.2	88.8	101.0	107.2	109.7	126.0	119.5	112.4	113.8	104.7
0.495	67.4	81.8	103.0	108.8	110.4	128.4	119.6	112.4	113.5	104.5
0.557	52.3	63.2	80.2	90.2	96.4	115.7	111.3	106.4	108.5	102.0
0.619	41.0	53.9	72.5	84.0	91.5	111.9	108.2	104.1	108.0	101.0
0.681	30.0	44.7	65.1	77.9	86.8	108.3	105.4	102.0	106.5	100.0
0.743	11.1	29.2	52.5	67.7	78.8	107.1	100.5	98.5	104.2	98.5
0.681	134.1	128.8	124.5	123.9	118.1	101.9	100.7	98.3	102.9	98.8
0.804	127.8	121.3	120.1	120.2	115.2	98.7	98.9	96.9	102.0	97.9
0.866	117.9	113.1	113.5	114.8	111.0	96.4	96.2	95.0	100.6	97.1
0.928	107.9	104.8	106.6	109.2	106.8	93.0	93.5	93.0	99.3	96.1
0.990	109.8	105.9	107.1	109.3	106.3	92.8	93.1	92.5	98.7	95.7
1.052	77.0	78.8	85.7	92.0	93.2	82.5	85.2	88.8	95.1	93.4
1.114	65.4	69.5	77.8	85.8	88.2	78.6	82.1	84.5	93.6	92.4
1.176	54.6	60.5	70.5	79.7	83.5	75.0	79.2	82.4	92.0	91.4
1.238	36.6	45.6	58.3	69.8	75.8	69.0	74.5	79.0	89.8	89.9
1.299	28.8	38.8	53.8	65.9	72.7	66.6	72.6	77.6	88.7	88.2
1.361	18.7	31.4	46.6	60.2	68.2	63.2	68.8	75.4	87.2	88.3
1.423	9.9	23.3	40.0	54.8	64.0	59.8	67.1	73.4	86.0	87.4

Table C.19: Experimental Data Obtained for Single-phase Flow

45.0 DEG. MISALIGNED STREAMLINED BUNDLES (280781)

WATER FLOW (USGPM)	30.0	27.5	25.0	22.5	20.0	17.5	15.0	12.5	10.0	7.5
TEMP. C	32.7	28.1	32.4	32.7	33.0	35.1	33.3	29.7	28.8	30.2
DISTANCE (METER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)
0.062	217.4	149.6	139.8	138.9	148.8	150.9	140.3	145.3	122.0	124.8
0.124	203.9	137.8	130.0	132.0	142.3	148.0	138.7	142.7	120.4	123.8
0.186	190.6	126.5	120.5	124.3	136.1	141.2	133.0	140.1	118.6	122.8
0.248	171.0	110.1	106.5	113.0	127.0	134.0	127.5	138.1	116.0	121.4
0.309	162.4	102.5	100.8	108.3	123.2	130.8	125.1	134.1	114.6	120.8
0.371	151.3	92.8	92.7	101.8	117.8	128.8	121.8	131.8	113.1	118.8
0.433	138.8	82.3	88.1	94.8	112.3	122.4	118.5	129.2	111.3	118.5
0.495	148.8	83.1	84.1	84.8	112.0	121.8	117.8	128.6	110.7	118.0
0.557	104.8	52.0	58.4	74.2	95.5	109.0	108.2	121.5	108.1	115.4
0.619	91.0	39.9	48.5	66.0	86.0	103.8	104.2	118.5	104.1	114.1
0.681	78.3	29.2	39.4	58.7	83.1	99.1	100.5	115.8	102.3	113.1
0.743	56.5	9.3	23.1	45.5	72.5	90.7	94.2	111.2	98.3	111.3
0.743	148.8	151.0	147.8	138.4	150.2	134.3	118.5	110.7	100.3	124.7
0.804	141.4	144.8	142.5	132.0	146.6	131.4	117.3	108.0	98.2	123.8
0.866	128.8	134.8	134.2	125.4	140.8	127.2	114.0	106.5	97.5	122.8
0.928	118.2	124.8	125.8	118.6	135.8	122.8	110.7	104.0	95.8	121.6
0.990	121.3	124.8	125.6	118.1	134.9	122.1	108.9	103.2	95.2	121.1
1.052	82.5	93.4	88.7	87.3	118.5	108.0	100.0	96.1	90.5	118.2
1.114	67.7	80.9	88.4	89.0	111.7	103.7	95.9	93.1	88.7	116.7
1.176	54.5	69.5	73.6	81.2	105.4	98.7	92.1	90.2	86.7	115.4
1.238	34.4	51.6	64.7	68.1	95.6	91.0	88.2	85.8	83.8	113.5
1.299	25.4	44.0	58.4	64.0	91.5	87.6	83.5	83.8	82.4	112.5
1.361	13.1	33.6	48.2	57.0	85.8	83.2	80.2	81.1	80.8	111.2
1.423	2.8	24.1	41.4	50.4	80.5	78.7	78.6	78.6	78.8	110.1

Table C.20: Experimental Data Obtained for Single-phase Flow

45.0 DEG. MISALIGNED STREAMLINED BUNDLES (040881)

WATER FLOW (USGPM)	27.5	25.0	22.5	20.0	17.5	15.0	13.0	11.0	9.0	7.0
TEMP. C	30.1	30.4	30.8	31.1	31.4	31.7	31.8	32.1	32.3	32.4
DISTANCE (METER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)
0.062	148.7	144.1	144.0	144.0	147.3	141.8	138.8	128.8	118.8	112.8
0.124	135.0	134.4	138.2	137.8	142.7	138.3	136.4	124.7	118.6	112.0
0.186	124.0	125.2	128.7	131.9	138.0	134.7	133.5	122.6	117.2	111.2
0.248	107.1	111.1	117.2	122.6	130.8	128.1	129.1	119.3	115.0	109.8
0.309	99.4	104.8	112.0	118.5	127.4	126.5	127.0	117.7	113.8	109.1
0.371	90.0	96.8	105.8	113.2	123.4	123.3	124.5	115.8	112.8	108.2
0.433	78.6	88.3	98.5	107.5	118.9	118.8	121.7	113.8	111.1	107.3
0.495	68.7	83.3	102.3	110.3	121.0	121.2	122.7	114.4	111.5	107.4
0.557	48.4	62.3	77.4	90.4	105.5	109.3	113.4	107.5	106.9	104.8
0.619	36.6	52.4	69.2	83.9	100.4	105.3	110.2	105.2	105.3	103.5
0.681	25.5	43.3	61.8	77.9	95.7	101.7	107.3	103.0	103.7	102.8
0.743	5.9	28.9	48.5	67.3	87.5	95.3	102.3	98.4	101.3	101.0
0.681	131.5	128.7	125.7	125.7	87.1	95.2	102.3	98.3	103.3	100.8
0.804	125.2	123.5	121.4	122.1	84.3	93.0	100.5	97.8	102.3	100.0
0.866	115.7	115.5	114.9	116.8	80.2	89.8	97.9	95.9	100.9	99.1
0.928	105.6	107.1	107.9	111.3	75.8	88.3	95.2	93.8	99.5	98.1
0.990	101.1	101.4	109.5	112.1	78.2	86.3	95.0	93.6	98.1	97.8
1.052	74.5	81.1	88.8	94.2	62.4	75.8	88.8	87.6	95.2	95.3
1.114	62.2	70.8	78.3	87.4	57.1	71.6	83.6	85.2	93.5	94.3
1.176	51.1	61.4	70.7	81.3	52.3	67.9	80.6	83.0	92.0	93.3
1.238	32.7	46.0	58.1	71.2	44.8	61.9	75.9	79.8	89.7	91.8
1.299	25.8	40.3	53.5	67.4	41.5	59.4	73.9	78.0	88.8	91.2
1.361	15.7	31.8	46.5	61.8	37.0	55.8	71.1	75.9	87.1	90.1
1.423	6.3	23.8	38.9	58.3	32.8	52.8	68.5	73.8	85.8	89.3

Table C.21: Experimental Data Obtained for Single-phase Flow

45.0 DEG. MISALIGNED STREAMLINED BUNDLES (040081)

WATER FLOW (USGPM)	27.5	25.0	22.5	20.0	17.5	15.0	13.0	11.0	9.0	7.0
TEMP. C	31.2	31.5	32.0	32.5	32.9	33.3	33.5	33.7	33.9	34.1
DISTANCE (METER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)	(HEIGHT.CM) (WATER)
0.062	146.3	145.8	146.0	144.9	138.9	148.5	147.1	132.2	125.8	118.4
0.124	134.8	136.3	138.2	138.8	132.3	145.8	144.4	130.3	124.4	117.8
0.186	123.9	127.1	130.7	132.8	127.8	142.4	141.8	128.2	123.0	116.8
0.248	107.0	113.0	119.2	123.6	123.3	136.7	137.1	124.9	120.9	115.4
0.309	99.5	106.7	114.0	119.4	117.0	133.9	134.8	123.4	119.8	114.6
0.371	90.1	98.8	107.5	114.3	113.0	131.0	132.8	121.5	118.5	113.8
0.433	80.1	80.2	100.5	108.7	109.5	127.5	128.8	118.5	117.1	112.8
0.495	88.4	87.0	105.7	112.5	111.3	128.4	131.1	120.4	117.6	113.1
0.557	48.3	84.4	79.3	91.7	93.1	117.0	121.3	113.4	113.0	110.2
0.619	37.6	54.5	71.2	85.3	90.0	113.1	118.3	111.0	111.4	109.1
0.681	26.8	45.4	63.8	79.3	85.3	108.4	115.3	108.8	109.9	108.2
0.743	7.4	28.8	50.3	68.7	77.0	103.0	110.5	105.3	107.5	106.6
0.681	130.0	127.0	126.3	131.6	120.1	102.7	110.7	105.0	109.2	106.6
0.804	123.8	122.1	122.2	128.2	117.3	100.5	108.8	103.6	108.2	108.0
0.866	114.3	114.3	115.6	122.8	113.3	97.4	108.3	101.7	106.8	105.1
0.928	104.4	108.0	108.8	117.5	108.9	94.0	103.8	99.7	105.4	104.1
0.990	107.1	107.8	109.7	117.6	108.8	83.7	103.2	89.3	104.9	103.8
1.052	73.8	80.5	87.7	100.5	95.5	83.5	95.3	93.6	101.1	101.3
1.114	61.8	70.3	79.3	93.8	80.2	79.4	92.0	91.2	98.4	100.2
1.176	50.6	61.0	71.7	87.8	65.4	75.7	89.1	88.0	97.9	99.4
1.238	32.1	45.8	58.9	77.8	77.5	68.6	84.3	85.5	95.5	97.7
1.299	25.7	40.2	54.5	74.1	74.5	67.3	82.5	84.1	94.5	97.1
1.361	15.7	31.6	47.4	68.4	70.0	63.7	78.7	82.0	93.0	96.1
1.423	6.3	23.8	40.9	63.3	65.9	60.8	77.1	80.1	91.7	95.3

Appendix D

EXPERIMENTAL DATA OF EXPERIMENT B

FOR TWO-PHASE FLOW

Table D.1: Experimental Data for 25 USGPM Water Flow Rate

ALIGNED REGULAR BUNDLES - TWO PHASE (05/08/82)

AIR (KG/S)	0.0074	0.0057	0.0041	0.0026	0.0006	0.0003
TEMPERATURE C	28.0	28.0	28.0	28.0	28.0	28.0
AIR PRESSURE (PSIG)	20.6	17.5	14.6	12.0	6.7	5.8
REF PRESSURE (PSIG)	1.2	0.4	0.0	0.0	0.0	0.0
DISTANCE (METER)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)
			RUN NUMBER 1			
0.062	79.3	70.4	62.2	54.9	37.2	34.1
0.124	76.4	68.7	60.7	53.8	36.5	33.3
0.186	74.2	66.4	59.1	52.8	35.8	32.9
0.309	68.7	61.9	54.7	48.2	33.5	30.6
0.371	66.6	59.9	52.7	46.5	32.5	28.7
0.433	64.1	57.9	51.1	44.9	31.7	29.0
0.557	56.0	50.3	44.8	39.5	28.1	26.0
0.619	53.3	48.1	42.9	38.0	27.2	25.2
0.681	51.4	46.3	41.4	36.6	26.4	24.4
0.804	44.1	40.1	37.0	32.6	24.1	22.4
0.866	42.1	38.3	34.4	30.9	23.3	21.7
0.928	39.6	36.2	32.7	29.4	22.5	20.8
1.052	29.2	28.1	25.5	23.3	19.1	17.8
1.114	25.5	24.6	23.1	21.1	18.2	17.0
1.176	22.3	21.9	21.0	19.2	17.3	16.3
1.299	14.3	15.9	15.3	14.8	15.0	14.1
1.361	11.8	12.7	13.4	13.0	14.1	13.3
1.423	8.6	9.7	10.1	10.3	13.2	12.5
			RUN NUMBER 2			
0.062	79.6	70.8	62.6	54.5	37.1	34.2
0.124	77.0	68.8	61.2	53.3	36.2	33.5
0.186	74.5	66.7	58.5	52.0	35.5	33.0
0.308	68.9	62.0	55.2	48.0	33.0	30.7
0.371	66.9	59.8	53.3	46.4	32.1	29.8
0.433	63.9	57.7	51.5	45.0	31.2	28.1
0.557	56.1	50.5	44.8	39.0	28.5	26.0
0.619	53.3	48.2	42.9	37.5	27.5	25.1
0.681	51.2	46.3	41.2	36.0	26.7	24.1
0.804	44.3	40.3	36.3	31.8	24.5	22.3
0.866	41.9	38.4	34.7	30.5	23.6	21.6
0.928	39.5	36.1	32.9	28.0	22.8	20.8
1.052	28.4	27.0	25.0	23.6	18.2	17.8
1.114	24.9	23.8	22.6	21.4	18.3	17.0
1.176	21.9	21.2	20.5	18.7	17.4	16.2
1.299	14.3	14.7	14.8	15.6	15.0	14.1
1.361	11.3	12.2	13.6	13.8	14.1	13.2
1.423	8.0	8.3	10.1	11.3	13.1	12.4
			RUN NUMBER 3			
0.062	79.1	70.7	62.4	54.6	37.2	34.1
0.124	76.7	68.7	60.7	53.3	36.4	33.4
0.186	74.0	66.5	59.0	52.0	35.8	32.8
0.309	69.0	61.4	54.6	48.1	33.3	30.6
0.371	66.9	59.6	52.8	46.6	32.3	29.7
0.433	64.6	57.6	50.9	45.0	31.6	29.0
0.557	55.6	49.7	45.3	39.3	28.2	25.8
0.619	52.9	47.9	43.5	37.7	27.4	25.1
0.681	50.8	45.6	42.1	36.3	26.6	24.9
0.804	43.5	39.6	36.8	32.2	24.4	22.4
0.866	41.5	37.6	35.2	30.6	23.5	21.6
0.928	38.8	35.6	33.5	28.9	22.6	20.6
1.052	29.5	26.8	25.0	23.0	19.1	17.8
1.114	25.9	23.8	22.6	21.0	18.1	16.9
1.176	22.5	21.3	20.5	19.3	17.3	16.2
1.299	14.9	14.8	14.7	14.8	14.8	14.1
1.361	11.8	12.2	12.5	13.2	14.0	13.2
1.423	7.7	8.5	8.8	11.3	13.2	12.5

Table D.2: Experimental Data for 25 USGPM Water Flow Rate

45.0 DEG. MISALIGNED REGULAR BUNDLES - TWO PHASE (05/08/82)

AIR (KG/S)	0.0077	0.0059	0.0042	0.0027	0.0006	0.0003
TEMPERATURE C	[illegible]	27.2	27.4	27.6	27.8	28.0
AIR PRESSURE (PSIG)	[illegible]	20.2	17.2	13.8	7.8	6.8
REF PRESSURE (PSIG)	1.6	0.6	0.0	0.0	0.0	0.0
DISTANCE (METER)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)
RUN NUMBER 1						
0.062	90.5	82.7	74.0	64.7	44.7	29.3
0.124	88.0	81.0	72.3	63.3	43.8	28.4
0.186	85.6	79.0	70.8	61.9	42.9	27.4
0.309	80.2	74.1	66.3	57.8	40.7	25.8
0.371	78.6	72.1	64.8	56.5	39.8	25.0
0.433	75.7	70.0	62.6	54.9	38.8	24.2
0.557	61.4	56.8	51.5	45.5	32.9	18.3
0.619	58.5	54.0	49.2	43.4	31.8	17.3
0.681	56.5	52.3	47.6	42.1	30.8	16.4
0.804	49.1	46.0	42.2	37.3	28.6	14.3
0.866	47.3	44.3	40.6	35.8	27.7	13.5
0.928	44.9	42.1	39.0	34.4	26.9	12.8
1.052	28.9	26.7	25.8	23.7	20.2	6.9
1.114	25.2	23.2	22.7	21.4	19.0	5.9
1.176	21.6	20.2	20.2	19.4	18.0	5.0
1.299	13.1	13.0	14.5	14.8	15.4	2.8
1.361	9.7	9.8	11.8	12.6	14.5	2.1
1.423	5.1	6.6	9.8	10.3	13.7	1.0
RUN NUMBER 2						
0.062	93.7	82.7	74.0	64.8	44.8	28.7
0.124	88.4	80.8	72.5	63.3	43.8	27.9
0.186	86.1	78.8	70.8	62.0	42.9	26.8
0.309	81.0	73.7	66.5	58.3	40.7	25.3
0.371	78.2	72.2	64.7	56.8	39.9	24.4
0.433	76.4	69.8	62.9	55.0	38.8	23.7
0.557	62.0	56.8	51.8	45.1	32.8	17.8
0.619	59.0	54.0	49.0	43.2	31.8	16.7
0.681	56.9	51.8	47.2	41.8	30.9	16.0
0.804	49.6	45.9	42.1	37.4	28.7	13.8
0.866	47.4	43.8	40.5	35.8	27.7	13.1
0.928	44.7	41.5	38.6	34.6	26.8	12.4
1.052	27.8	27.1	25.5	24.8	20.2	6.8
1.114	24.1	23.8	22.6	21.3	19.0	5.5
1.176	20.7	20.9	20.0	19.2	18.0	4.6
1.299	12.3	13.9	13.8	14.8	15.4	2.3
1.361	8.8	11.2	11.6	12.8	14.6	1.4
1.423	4.9	6.2	8.2	8.5	13.5	0.4
RUN NUMBER 3						
0.062	89.0	82.0	73.8	64.4	44.8	28.6
0.124	86.7	80.0	72.3	63.0	44.0	27.7
0.186	84.6	78.2	70.8	61.8	43.2	26.6
0.309	79.5	73.3	66.7	57.8	40.9	25.1
0.371	78.0	71.7	64.9	56.5	40.0	24.3
0.433	75.3	69.7	63.1	54.9	39.1	23.6
0.557	61.1	56.5	50.6	44.8	32.5	17.7
0.619	58.1	53.9	48.3	42.9	31.5	16.7
0.681	56.4	52.4	46.7	41.6	30.5	18.0
0.804	48.9	45.9	41.4	37.3	28.3	14.0
0.866	47.3	44.2	40.0	36.0	27.4	13.2
0.928	45.0	42.3	38.5	34.8	26.7	12.4
1.052	28.8	27.0	25.6	24.2	20.2	6.5
1.114	25.1	23.8	22.6	21.7	19.0	5.4
1.176	22.7	20.8	20.1	18.8	18.1	4.5
1.299	13.5	13.8	14.1	15.0	15.5	2.3
1.361	10.2	10.7	11.7	13.3	14.6	1.5
1.423	6.1	7.5	8.5	10.9	13.8	0.5

Table D.3: Experimental Data for 25 USGPM Water Flow Rate

ALIGNED STREAMLINED BUNDLES - TWO PHASE (06/08/82)

AIR (KG/S)	0.0073	0.0095	0.0040	0.0025	0.0005	0.0003
TEMPERATURE C	30.0	29.6	29.6	29.4	28.2	28.0
AIR PRESSURE (PSIG)	19.2	15.8	13.2	10.6	6.0	5.2
REF PRESSURE (PSIG)	0.0	0.0	0.0	0.0	0.0	0.0
DISTANCE (METER)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)
RUN NUMBER 1						
0.062	88.5	73.9	62.4	48.6	26.8	23.8
0.124	86.1	72.0	60.8	48.2	25.8	23.0
0.186	83.9	69.9	59.1	48.6	24.6	22.2
0.309	78.8	65.6	55.3	43.3	22.8	20.3
0.371	76.2	63.5	53.5	42.1	22.0	18.8
0.433	73.8	61.3	51.5	40.4	21.2	18.0
0.557	67.1	55.0	46.2	36.7	18.7	16.4
0.619	64.3	52.6	44.4	35.1	17.8	15.5
0.681	62.0	50.6	43.1	33.8	17.0	14.6
0.804	54.8	44.8	38.3	28.8	14.6	12.7
0.866	52.2	42.8	38.5	28.3	14.0	11.8
0.928	49.4	40.5	34.7	26.9	13.1	11.1
1.052	41.6	34.3	28.5	22.0	10.4	8.6
1.114	37.6	31.1	26.0	18.8	8.4	7.8
1.176	34.5	28.6	23.5	18.2	8.5	6.8
1.299	27.4	22.8	17.4	13.9	6.3	4.8
1.361	23.6	19.8	15.4	12.0	5.4	4.0
1.423	19.1	16.7	12.9	10.2	4.5	3.3
RUN NUMBER 2						
0.062	88.4	73.8	61.8	49.5	26.8	23.5
0.124	86.2	71.9	60.1	48.2	25.8	22.7
0.186	83.8	70.1	58.5	46.7	24.6	21.8
0.309	78.6	65.1	54.6	43.8	22.9	20.1
0.371	76.2	63.5	52.9	42.2	22.0	19.2
0.433	73.7	61.1	50.9	40.7	21.2	18.5
0.557	66.6	55.6	45.9	36.0	18.6	16.2
0.619	63.6	53.4	44.0	34.4	17.7	15.3
0.681	61.5	51.8	42.6	33.2	16.8	14.5
0.804	54.3	45.9	37.8	29.3	14.7	12.6
0.866	52.3	44.0	36.0	27.9	13.9	11.8
0.928	50.1	42.0	34.1	26.5	13.0	11.0
1.052	42.1	34.9	28.6	21.9	10.3	8.6
1.114	38.1	31.6	26.1	19.9	9.3	7.7
1.176	34.9	28.8	23.8	18.3	8.5	6.9
1.299	27.4	22.5	18.2	14.0	6.3	4.9
1.361	23.7	19.3	15.7	12.3	5.3	4.1
1.423	19.7	16.5	12.7	10.3	4.4	3.3
RUN NUMBER 3						
0.062	88.8	74.2	61.7	50.1	26.8	23.5
0.124	86.5	72.4	60.1	48.6	25.8	22.6
0.186	84.1	70.3	58.5	47.2	24.8	21.8
0.309	78.7	65.9	54.8	43.5	22.7	20.1
0.371	76.3	64.0	53.3	42.1	21.9	19.3
0.433	73.7	61.8	51.3	40.3	21.0	18.6
0.557	66.5	55.7	46.3	36.2	18.8	16.1
0.619	63.5	53.4	44.3	34.6	17.9	15.2
0.681	61.3	51.8	42.6	33.3	17.1	14.4
0.804	54.3	46.0	37.7	29.3	14.9	12.5
0.866	52.0	44.1	35.7	27.9	14.1	11.8
0.928	49.3	42.0	33.8	26.5	13.2	11.0
1.052	41.6	34.7	28.3	21.8	10.5	8.5
1.114	37.7	31.5	25.6	18.9	9.5	7.7
1.176	34.4	28.9	23.5	18.1	8.8	6.6
1.299	27.2	22.5	18.4	13.6	6.4	4.8
1.361	23.6	19.6	16.1	11.6	5.5	4.0
1.423	18.6	15.9	13.6	9.6	4.6	3.3

Table D.4: Experimental Data for 25 USGPM Water Flow Rate

22.5 DEG. MISALIGNED REGULAR BUNDLES - TWO PHASE (05/08/82)

AIR (KG/S)	0.0077	0.0059	0.0042	0.0027	0.0006	0.0003
TEMPERATURE C	27.0	27.0	27.0	27.8	28.0	28.4
AIR PRESSURE (PSIG)	23.0	19.5	16.5	13.5	7.7	6.8
REF PRESSURE (PSIG)	1.6	0.5	0.0	0.0	0.0	0.0
DISTANCE (METER)	(HEIGHT,CM) (MERCURY)	(HEIGHT,CM) (MERCURY)	(HEIGHT,CM) (MERCURY)	(HEIGHT,CM) (MERCURY)	(HEIGHT,CM) (MERCURY)	(HEIGHT,CM) (MERCURY)
			RUN NUMBER 1			
0.062	88.8	78.1	71.0	61.8	42.8	39.3
0.124	86.4	77.3	69.4	60.5	41.8	38.8
0.186	83.8	75.3	67.9	58.1	40.9	37.8
0.308	78.5	70.7	63.6	55.7	38.6	35.8
0.371	76.5	68.8	61.7	53.7	37.6	35.0
0.433	73.9	66.8	59.8	52.2	36.8	34.2
0.557	60.7	54.9	49.9	43.3	31.1	28.9
0.619	57.9	52.5	47.6	41.9	30.1	28.0
0.681	55.6	50.6	46.0	40.2	29.1	27.2
0.804	48.4	44.4	40.3	35.6	27.0	25.1
0.866	46.5	42.7	38.8	34.3	26.0	24.3
0.928	43.8	40.6	37.1	32.8	25.2	23.5
1.052	27.5	26.1	24.8	23.4	19.3	18.3
1.114	23.3	23.0	21.9	21.0	18.2	17.3
1.176	19.6	20.1	19.5	18.9	17.2	16.5
1.299	11.4	13.2	13.4	13.8	14.6	14.3
1.361	7.6	10.4	10.8	11.8	13.6	13.5
1.423	3.7	6.4	7.9	8.0	12.6	12.6
			RUN NUMBER 2			
0.062	88.9	78.7	70.9	61.9	42.6	39.4
0.124	86.6	76.8	69.4	60.6	41.8	38.6
0.186	84.0	74.9	67.6	59.2	40.9	37.9
0.309	78.6	70.0	63.3	55.2	38.6	35.8
0.371	76.4	68.6	61.3	53.7	37.7	35.0
0.433	74.0	66.3	59.7	52.2	36.8	34.3
0.557	60.6	54.5	50.0	43.7	31.3	29.0
0.619	57.8	52.1	47.7	41.9	30.2	28.1
0.681	55.6	50.1	46.1	40.3	29.3	27.2
0.804	48.3	44.0	40.6	35.9	27.0	25.1
0.866	46.2	42.2	38.9	34.5	26.0	24.3
0.928	44.1	40.1	37.4	32.9	25.1	23.5
1.052	28.0	26.6	25.0	22.7	18.3	18.2
1.114	23.9	22.3	21.9	20.4	18.2	17.2
1.176	20.2	20.5	19.3	18.5	17.1	16.3
1.299	11.7	13.8	13.3	13.7	14.8	14.1
1.361	7.7	10.8	10.7	11.8	13.5	13.2
1.423	3.6	7.3	7.6	9.0	12.6	12.4
			RUN NUMBER 3			
0.062	88.3	78.9	71.3	61.9	42.5	39.3
0.124	86.1	77.1	69.8	60.4	41.5	38.6
0.186	83.6	75.0	68.1	58.1	40.7	37.8
0.309	78.3	70.0	63.8	55.0	38.3	35.7
0.371	76.4	68.0	61.7	53.8	37.5	34.9
0.433	74.0	66.1	60.1	51.7	36.6	34.2
0.557	59.7	55.1	49.3	43.8	31.4	29.0
0.619	57.0	52.8	47.1	42.1	30.3	28.1
0.681	55.0	50.8	45.3	40.0	29.4	27.2
0.804	47.5	44.4	40.1	36.1	27.2	25.1
0.866	45.7	42.6	38.4	34.6	26.3	24.3
0.928	43.4	40.9	36.6	33.0	25.4	23.8
1.052	28.4	28.2	25.2	22.9	19.4	18.3
1.114	25.1	22.8	22.3	20.5	18.3	17.3
1.176	21.3	19.8	19.6	18.5	17.3	16.4
1.299	12.7	12.8	13.5	13.9	14.7	14.1
1.361	8.3	9.7	11.3	11.8	13.8	13.3
1.423	4.1	6.3	7.8	9.3	12.9	12.5

Table D.5: Experimental Data for 25 USGPM Water Flow Rate

22.5 DEG. MISALIGNED STREAMLINED BUNDLES - TWO PHASE (06/08/82)

AIR (KG/S)	0.0074	0.0056	0.0040	0.0025	0.0005	0.0003
TEMPERATURE C	27.0	21.8	26.6	26.4	26.2	26.0
AIR PRESSURE (PSIG)	19.8	16.2	13.6	10.8	6.0	5.2
REF PRESSURE (PSIG)	0.0	0.0	0.0	0.0	0.0	0.0
DISTANCE (METER)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)
RUN NUMBER 1						
0.062	91.2	77.1	64.2	49.7	27.6	23.8
0.124	88.6	75.0	62.3	48.2	26.7	23.0
0.186	86.3	72.8	60.4	46.7	25.7	22.1
0.309	80.6	67.7	56.2	43.2	23.8	20.4
0.371	74.2	65.7	54.3	41.7	22.9	18.6
0.433	75.5	63.4	52.4	40.1	22.1	18.9
0.557	68.4	56.6	47.9	36.6	19.4	16.6
0.619	65.5	54.1	45.3	34.8	18.4	15.7
0.681	63.7	52.0	43.7	33.3	17.6	15.0
0.804	56.8	46.4	38.7	29.3	15.5	13.0
0.866	54.6	44.1	37.0	27.9	14.6	12.3
0.928	52.2	41.8	35.0	26.6	13.7	11.5
1.052	42.8	35.0	28.8	21.9	11.1	9.1
1.114	38.6	31.5	26.1	19.7	10.0	8.1
1.176	35.3	28.5	23.9	18.0	9.1	7.3
1.299	27.6	22.2	18.3	13.7	6.8	5.3
1.361	24.3	19.4	15.9	11.8	6.0	4.5
1.423	20.5	15.9	12.9	8.6	4.9	3.7
RUN NUMBER 2						
0.062	91.9	75.7	63.3	49.9	27.4	23.7
0.124	89.4	73.6	61.5	48.4	26.4	22.9
0.186	86.8	71.5	59.8	47.0	25.5	22.1
0.309	81.0	66.7	55.5	43.9	23.4	20.3
0.371	78.4	64.8	54.0	42.0	22.6	18.5
0.433	75.7	62.4	51.8	40.4	21.6	18.8
0.557	68.7	56.3	46.7	36.5	19.2	16.5
0.619	65.9	53.7	44.5	34.8	18.3	15.8
0.681	63.7	51.9	42.9	33.7	17.6	14.9
0.804	57.0	46.0	37.8	29.7	15.5	12.8
0.866	54.5	44.0	36.0	28.4	14.7	12.2
0.928	51.6	41.8	34.1	27.1	13.9	11.4
1.052	42.6	34.9	28.7	22.8	11.0	9.0
1.114	38.0	31.6	26.3	19.6	9.9	8.1
1.176	34.7	28.8	24.0	17.9	9.0	7.3
1.299	27.3	22.5	18.6	13.8	6.7	5.2
1.361	23.8	19.9	16.4	12.1	5.9	4.5
1.423	19.8	16.8	13.4	10.1	5.1	3.8
RUN NUMBER 3						
0.062	92.1	75.3	64.2	49.7	27.4	23.9
0.124	89.8	73.1	62.4	48.1	26.4	23.0
0.186	87.3	71.1	60.4	46.5	25.4	22.2
0.309	81.5	66.7	56.6	43.0	23.3	20.4
0.371	79.0	64.5	54.7	41.7	22.6	18.6
0.433	76.4	62.7	52.8	40.0	21.7	18.8
0.557	69.2	56.6	46.6	36.1	19.3	16.6
0.619	66.0	54.0	44.4	34.3	18.3	15.7
0.681	63.7	52.0	42.5	32.4	17.6	15.0
0.804	56.6	46.1	37.6	28.9	15.5	13.0
0.866	54.3	44.0	35.9	27.6	14.8	12.3
0.928	51.7	41.7	34.1	26.1	13.9	11.5
1.052	42.0	34.9	28.4	21.9	11.2	8.0
1.114	37.8	31.5	25.5	19.8	10.1	8.1
1.176	34.5	28.6	23.1	18.1	9.1	7.3
1.299	26.9	22.4	18.0	13.9	6.9	5.2
1.361	23.6	19.7	15.5	12.0	5.9	4.4
1.423	20.1	16.1	12.2	8.8	5.1	3.6

Table D.6: Experimental Data for 25 USGPM Water Flow Rate

45.3 DEG. MISALIGNED STREAMLINED BUNDLES - TWO PHASE (06/08/82)

AIR (KG/S)	0.0074	0.0056	0.0040	0.0025	0.0005	0.0003
TEMPERATURE C	27.6	27.4	27.2	27.0	26.8	26.8
AIR PRESSURE (PSIG)	20.0	16.2	13.4	11.0	6.0	5.4
REF PRESSURE (PSIG)	0.0	0.0	0.0	0.0	0.0	0.0
DISTANCE (METER)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)
RUN NUMBER 1						
0.062	91.9	78.4	63.1	51.6	27.3	24.3
0.124	89.7	74.5	61.2	50.2	26.3	23.4
0.186	87.2	72.3	58.3	48.4	25.3	22.5
0.308	81.6	67.8	55.4	45.1	23.3	20.6
0.371	79.3	65.8	53.3	43.6	22.4	19.8
0.433	76.7	63.7	51.7	41.9	21.7	19.1
0.557	69.3	56.4	46.7	37.0	19.4	16.8
0.619	66.1	53.8	44.5	35.0	18.4	15.8
0.681	63.6	51.7	42.8	33.5	17.5	15.0
0.804	56.9	48.1	38.0	28.4	15.4	13.0
0.866	54.7	44.4	36.3	27.9	14.5	12.2
0.928	52.0	42.3	34.5	26.4	13.6	11.4
1.052	43.3	35.2	28.3	22.3	10.9	8.9
1.114	38.7	31.5	25.4	19.9	9.8	8.0
1.176	35.3	28.6	23.0	18.1	8.8	7.1
1.299	27.4	22.8	17.7	13.8	6.5	5.0
1.361	24.1	19.4	15.4	11.8	5.6	4.2
1.423	20.0	15.8	12.3	9.8	4.7	3.5
RUN NUMBER 2						
0.062	92.8	76.5	63.2	51.2	27.2	24.1
0.124	90.3	74.4	61.4	49.8	26.2	23.2
0.186	88.0	72.3	58.7	48.1	25.1	21.4
0.308	82.3	67.4	55.4	44.5	23.1	20.5
0.371	79.9	65.5	53.7	43.0	22.4	19.8
0.433	77.1	63.1	51.8	41.3	21.5	19.0
0.557	69.1	56.8	47.5	37.4	19.0	16.6
0.619	65.9	54.2	45.1	35.5	17.9	15.7
0.681	63.5	52.2	43.5	34.1	17.1	14.8
0.804	56.6	46.1	38.3	30.0	14.9	12.9
0.866	54.3	44.3	36.7	28.7	14.1	12.0
0.928	51.8	42.3	34.8	27.3	13.3	11.3
1.052	43.1	35.4	28.1	22.3	11.0	8.9
1.114	38.9	31.9	25.4	20.0	9.8	7.9
1.176	35.4	28.8	23.1	18.2	8.8	7.0
1.299	27.4	22.2	17.6	13.7	6.5	4.8
1.361	23.9	19.4	15.5	11.8	5.6	4.1
1.423	20.3	16.3	12.5	9.7	4.6	3.3
RUN NUMBER 3						
0.062	92.1	76.8	63.2	51.1	27.2	24.1
0.124	89.8	74.7	61.4	49.6	26.3	23.2
0.186	87.2	72.5	58.8	48.0	25.3	22.4
0.308	81.7	67.8	55.4	44.8	23.4	20.8
0.371	79.1	65.8	54.0	43.3	22.5	19.8
0.433	76.6	63.6	52.1	41.9	21.6	19.0
0.557	69.2	57.8	47.0	37.9	19.0	16.7
0.619	66.1	55.1	44.9	35.8	17.9	15.7
0.681	63.7	53.0	43.3	34.1	17.1	14.9
0.804	56.7	47.2	38.2	29.9	14.9	12.9
0.866	54.4	45.0	36.5	28.4	14.1	12.2
0.928	51.8	42.9	34.6	26.9	13.3	11.3
1.052	43.0	34.7	28.6	22.3	10.9	9.0
1.114	38.8	31.2	25.9	20.0	9.7	8.0
1.176	35.2	28.4	23.3	18.1	8.8	7.1
1.299	27.7	22.0	17.7	13.8	6.4	5.1
1.361	24.3	19.3	15.3	11.9	5.5	4.3
1.423	19.9	16.2	12.7	10.0	4.6	3.5

Table D.7: Experimental Data for 20 USGPM Water Flow Rate

ALIGNED REGULAR BUNDLES - TWO PHASE (08/08/82)

AIR (KG/S)	0.0176	0.0141	0.0115	0.0091	0.0068	0.0049	0.0031	0.0018
TEMPERATURE C	23.0	23.5	24.0	24.5	25.0	25.5	24.2	24.7
AIR PRESSURE (PSIG)	31.2	27.0	23.0	19.0	15.5	12.5	10.0	7.5
REF PRESSURE (PSIG)	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DISTANCE (METER)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)
RUN NUMBER 1								
0.062	123.3	127.5	103.8	87.7	72.1	57.6	48.0	33.8
0.124	121.1	125.5	102.1	85.8	70.5	56.2	44.8	33.0
0.186	118.1	122.8	99.4	83.7	68.8	54.6	43.6	32.0
0.309	110.2	115.9	93.5	78.2	64.2	50.8	40.6	29.6
0.371	106.8	112.9	91.0	76.3	62.9	49.7	39.6	28.9
0.433	102.9	109.5	88.0	73.7	60.8	47.8	38.1	27.8
0.557	91.1	99.0	78.8	65.8	54.4	42.6	34.1	24.3
0.619	87.3	95.6	75.4	63.3	52.2	41.0	32.8	23.3
0.681	83.7	92.5	72.6	61.1	50.8	39.4	31.8	22.5
0.804	73.7	83.4	64.9	54.5	45.2	35.2	28.3	19.8
0.866	69.4	78.7	62.0	52.0	43.4	33.5	27.0	18.0
0.928	65.0	75.8	58.6	48.4	41.5	31.8	25.8	16.1
1.052	50.5	62.9	48.0	40.3	33.7	26.2	20.6	15.4
1.114	45.6	58.6	44.3	37.1	31.1	24.3	19.5	14.3
1.176	40.8	54.4	40.8	34.2	28.7	22.5	17.8	13.3
1.299	28.3	43.9	31.5	26.9	22.2	17.4	14.2	10.6
1.361	22.8	38.7	27.9	23.5	20.2	15.8	12.7	8.9
1.423	17.4	33.8	23.5	18.8	17.4	13.3	11.1	8.5
RUN NUMBER 2								
0.062	123.6	126.7	103.8	87.8	72.7	57.7	45.8	34.1
0.124	121.8	124.6	101.8	86.0	71.1	56.1	44.7	33.3
0.186	118.4	121.9	98.4	83.8	68.1	54.5	43.5	32.3
0.309	110.3	115.0	93.0	78.0	64.5	50.8	40.5	30.2
0.371	106.8	111.9	90.3	76.9	62.7	48.5	39.7	29.5
0.433	102.9	108.7	87.3	73.6	60.8	47.8	38.2	28.5
0.557	90.8	98.3	78.0	65.9	53.7	42.3	34.4	24.8
0.619	87.0	94.7	74.8	63.3	51.4	40.5	32.9	23.8
0.681	83.4	91.6	72.3	61.5	48.9	38.1	31.8	23.0
0.804	73.5	82.4	64.7	54.9	44.0	34.8	28.3	20.5
0.866	69.4	78.9	61.9	52.3	42.3	33.4	27.1	19.7
0.928	64.8	75.0	58.6	49.8	40.1	31.8	25.8	18.8
1.052	50.8	62.4	47.9	40.5	33.5	26.1	21.2	15.2
1.114	45.8	58.0	44.1	37.4	31.0	24.0	19.6	14.2
1.176	40.9	53.7	40.6	34.5	28.5	22.1	18.1	13.3
1.299	28.5	43.0	31.5	26.6	21.7	17.3	14.3	10.8
1.361	22.9	38.1	28.0	23.8	18.8	15.6	12.8	9.7
1.423	17.4	33.5	23.7	20.7	16.8	13.3	11.1	8.5
RUN NUMBER 3								
0.062	123.2	126.7	104.1	88.2	72.0	58.2	45.6	34.0
0.124	121.0	124.7	102.2	86.9	70.3	56.8	44.5	33.2
0.186	118.0	122.0	99.6	84.2	68.6	55.3	43.3	32.2
0.309	110.1	115.1	93.3	78.7	63.4	51.8	40.7	30.1
0.371	106.8	112.0	90.7	76.4	62.3	50.4	38.5	28.3
0.433	103.0	108.7	87.8	74.1	59.8	48.6	38.2	26.2
0.557	91.2	98.3	78.7	66.1	53.5	43.0	33.3	24.6
0.619	87.3	94.8	75.5	63.5	51.5	41.2	32.0	23.6
0.681	83.6	91.7	73.0	61.2	48.9	39.8	30.6	22.8
0.834	73.6	82.4	65.2	54.5	44.5	35.4	27.6	20.3
0.866	69.5	78.7	62.1	51.8	42.5	34.0	26.1	19.5
0.928	64.8	74.6	58.8	49.2	40.5	32.3	24.8	18.3
1.052	50.6	61.6	48.0	40.2	34.1	25.9	20.7	15.1
1.114	45.7	57.3	44.1	37.1	31.6	23.8	19.2	14.0
1.176	40.8	53.1	40.6	34.3	28.2	21.8	17.8	13.1
1.299	28.6	42.4	31.3	27.0	22.5	18.8	14.3	10.8
1.361	23.2	37.5	27.5	24.1	20.5	15.4	12.8	9.5
1.423	17.6	32.8	23.4	20.6	17.0	12.8	10.9	8.1

Table D.8: Experimental Data for 20 USGPM Water Flow Rate

22.5 DEG. MISALIGNED REGULAR BUNDLES - TWO PHASE (08/09/82)

AIR (KG/S)	0.0173	0.0145	0.0120	0.0094	0.0071	0.0050	0.0032	0.0014
TEMPERATURE C	28.0	28.2	28.4	28.6	28.8	28.0	28.0	28.0
AIR PRESSURE (PSIG)	33.0	29.4	26.0	21.5	17.5	14.0	11.0	8.5
REF PRESSURE (PSIG)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DISTANCE (METER)	(HEIGHT, CM) (MERCURY)	(HEIGHT, CM) (MERCURY)	(HEIGHT, CM) (MERCURY)	(HEIGHT, CM) (MERCURY)	(HEIGHT, CM) (MERCURY)	(HEIGHT, CM) (MERCURY)	(HEIGHT, CM) (MERCURY)	(HEIGHT, CM) (MERCURY)
RUN NUMBER 1								
0.062	148.3	134.9	117.7	98.6	82.1	65.1	52.1	40.3
0.124	146.2	132.9	115.8	96.7	80.4	63.9	50.8	39.3
0.186	143.4	130.2	113.2	94.5	78.5	62.3	48.8	38.3
0.309	135.8	123.6	107.0	89.1	73.8	58.8	46.8	35.5
0.371	132.5	120.7	104.3	87.1	72.4	57.5	45.8	35.0
0.433	128.6	117.5	101.7	84.8	70.2	56.1	44.5	33.7
0.557	112.5	102.7	88.3	72.8	60.4	47.7	37.9	28.6
0.619	108.5	98.7	84.8	69.7	57.7	45.7	36.4	27.3
0.681	104.8	95.3	82.0	67.4	55.8	44.1	35.1	26.3
0.804	95.1	86.2	73.9	60.6	49.9	39.6	31.7	23.6
0.866	91.2	82.4	70.7	58.3	48.0	37.9	30.4	22.9
0.928	86.9	78.8	67.4	55.7	46.1	36.4	28.2	21.8
1.052	67.2	60.4	51.7	43.3	34.5	27.8	22.1	16.2
1.114	61.9	55.6	47.6	40.1	31.8	25.7	20.4	14.9
1.176	56.6	50.8	43.5	36.8	29.1	23.7	18.7	13.6
1.299	43.6	39.4	34.0	28.6	22.9	18.9	14.6	10.7
1.361	37.8	34.0	30.0	25.7	20.9	17.0	13.2	9.3
1.423	32.3	29.2	25.6	21.6	17.7	14.3	11.6	8.1
RUN NUMBER 2								
0.062	148.4	134.8	117.9	98.5	80.4	65.1	52.3	39.2
0.124	146.2	132.8	115.9	96.6	78.7	63.7	51.2	38.2
0.186	143.3	130.1	113.5	94.5	76.9	62.2	49.9	37.3
0.309	135.9	123.6	107.4	89.2	72.2	58.9	47.3	35.8
0.371	132.4	120.6	104.8	87.2	71.1	57.2	46.1	34.3
0.433	128.4	117.4	102.1	84.7	69.2	55.7	45.0	33.4
0.557	112.3	102.3	88.8	73.0	58.8	47.4	37.4	27.7
0.619	108.1	98.4	85.4	70.1	56.3	45.3	37.0	26.4
0.681	104.5	94.9	82.5	67.7	54.1	43.8	34.4	25.4
0.804	94.8	86.1	74.5	61.0	48.5	39.1	31.3	22.7
0.866	91.6	82.5	71.3	58.8	46.8	37.7	29.8	21.7
0.928	87.0	78.6	67.8	55.9	45.3	36.1	28.4	20.6
1.052	67.3	60.5	51.8	42.8	35.4	27.9	22.1	16.4
1.114	62.3	55.8	47.8	39.5	32.8	25.7	20.4	15.2
1.176	57.0	51.0	43.6	36.0	28.8	23.5	18.6	13.9
1.299	43.9	39.7	33.9	28.4	23.0	18.4	14.8	10.8
1.361	38.3	34.8	30.0	25.9	20.7	16.8	13.0	8.5
1.423	32.7	29.6	25.7	21.7	17.5	14.1	11.1	8.1
RUN NUMBER 3								
0.062	147.5	134.6	118.4	98.5	82.2	64.8	52.1	40.1
0.124	145.4	132.6	116.3	96.7	80.6	63.6	50.9	39.2
0.186	142.6	130.0	113.7	94.5	78.7	62.2	49.8	38.3
0.309	135.2	123.4	107.3	88.8	74.0	58.8	46.8	35.8
0.371	132.0	120.4	104.8	86.7	73.0	57.6	46.0	35.0
0.433	128.2	117.1	101.9	84.2	70.5	56.1	44.9	33.9
0.557	112.2	102.2	88.5	71.2	59.7	47.1	38.5	28.1
0.619	108.1	98.2	84.9	68.9	57.1	45.2	36.8	26.5
0.681	104.6	94.9	82.3	66.4	55.7	43.8	35.5	25.7
0.804	94.6	85.8	73.9	59.8	49.7	39.3	31.8	22.5
0.866	90.6	82.4	71.2	57.4	48.3	37.8	30.4	21.7
0.928	86.4	78.8	68.3	55.3	46.8	36.2	28.1	20.9
1.052	66.9	60.3	51.7	42.8	35.3	27.7	21.9	15.9
1.114	61.7	55.6	47.7	39.5	32.8	25.5	20.2	14.6
1.176	56.4	50.8	43.6	36.1	29.8	23.3	18.6	13.4
1.299	43.4	39.4	33.6	28.0	22.9	18.8	14.4	10.6
1.361	37.5	34.6	29.8	24.9	20.6	17.0	13.3	9.4
1.423	32.3	29.9	25.8	21.3	17.1	14.5	11.3	8.0

Table D.9: Experimental Data for 20 USGPM Water Flow Rate

45.0 DEG. MISALIGNED REGULAR BUNDLES - TWO PHASE (09/08/82)

AIR (KG/S)	0.0175	0.0146	0.0121	0.0094	0.0072	0.0051	0.0032	0.0018
TEMPERATURE C	29.5	29.6	29.7	29.8	30.1	30.3	30.5	30.8
AIR PRESSURE (PSIG)	34.0	30.0	26.5	21.5	18.8	14.5	11.5	8.8
REF PRESSURE (PSIG)	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DISTANCE (METER)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)
RUN NUMBER 1								
0.062	150.3	137.3	121.5	100.4	84.9	68.4	54.0	41.6
0.124	148.0	135.2	119.4	98.5	83.2	66.6	52.8	41.0
0.186	144.8	132.2	116.7	95.5	81.3	65.4	51.8	40.0
0.309	137.5	129.4	110.3	91.3	78.7	61.6	49.1	37.8
0.371	134.5	122.7	107.9	89.7	75.4	60.3	48.3	37.0
0.433	130.9	[illegible]	105.1	87.5	73.5	58.7	47.1	36.2
0.557	114.2	103.5	91.1	74.1	60.5	50.1	39.5	29.8
0.619	110.6	99.7	87.5	71.2	58.4	48.3	38.2	28.5
0.681	106.3	96.2	84.8	69.1	56.8	46.8	37.1	27.7
0.804	98.2	87.2	76.8	62.4	52.1	42.2	33.7	25.0
0.866	92.1	83.5	73.8	60.0	50.0	40.7	32.4	24.1
0.928	87.6	79.3	70.3	57.2	47.8	39.2	31.2	23.1
1.052	65.7	60.7	52.3	43.4	35.7	28.3	22.5	16.3
1.114	59.9	55.7	48.0	40.0	33.0	26.0	20.7	15.1
1.176	54.2	50.6	43.6	36.7	29.9	23.7	19.0	13.9
1.299	40.5	38.7	33.3	28.8	23.0	18.2	15.0	11.2
1.361	34.6	33.7	29.4	26.2	20.4	16.5	13.4	10.1
1.423	28.9	28.4	24.8	21.9	17.4	13.8	11.6	8.8
RUN NUMBER 2								
0.062	148.8	136.9	121.2	100.3	83.4	67.2	53.8	41.3
0.124	147.5	134.8	119.0	98.4	81.8	66.0	52.8	40.2
0.186	144.4	131.8	116.3	96.1	80.0	64.4	51.6	38.3
0.309	137.0	124.9	110.0	91.1	76.0	60.8	49.1	37.3
0.371	134.1	122.3	107.7	89.3	74.6	58.8	48.0	36.4
0.433	130.8	119.4	104.9	87.2	73.1	58.1	47.0	35.7
0.557	114.2	103.6	90.4	75.3	60.5	48.1	39.3	29.4
0.619	108.9	99.8	87.0	72.3	58.5	47.5	37.9	28.2
0.681	106.3	96.4	84.2	70.1	56.1	45.7	36.8	27.9
0.804	85.7	87.3	76.0	63.6	51.0	41.9	33.9	24.7
0.866	81.9	83.7	72.9	61.4	48.7	39.8	32.2	23.8
0.928	67.5	79.8	68.6	58.9	46.5	37.8	30.8	22.8
1.052	65.4	60.4	52.5	43.8	36.3	29.0	22.2	16.8
1.114	58.9	55.7	48.2	40.2	33.5	26.8	20.6	15.4
1.176	54.4	50.6	44.0	36.6	30.7	24.4	19.0	14.2
1.299	41.1	38.4	33.4	28.1	23.8	18.9	15.3	11.0
1.361	35.5	33.7	29.5	25.4	21.4	17.0	13.9	9.8
1.423	29.9	28.7	25.1	21.8	18.1	14.2	12.4	8.5
RUN NUMBER 3								
0.062	149.6	136.5	121.9	99.0	83.3	67.8	54.3	42.1
0.124	147.3	134.2	119.7	97.1	81.8	66.4	53.0	41.1
0.186	144.1	131.4	116.9	94.9	80.1	64.9	51.8	40.0
0.309	136.8	124.5	110.7	88.5	78.0	61.5	49.1	37.8
0.371	134.0	122.0	108.0	88.1	74.8	60.1	47.9	36.9
0.433	130.6	118.8	105.4	85.8	72.9	58.8	46.8	36.0
0.557	114.0	103.4	91.0	73.0	60.8	49.0	39.1	29.9
0.619	109.8	99.5	87.6	70.4	58.8	47.3	37.6	28.8
0.681	106.1	96.5	84.4	68.0	58.8	45.7	36.2	27.6
0.804	95.8	87.3	76.6	61.4	51.4	41.4	33.2	24.9
0.866	91.7	83.8	73.5	58.9	49.8	39.6	31.8	24.0
0.928	87.3	78.8	70.2	56.5	47.3	37.9	30.5	23.0
1.052	65.8	60.2	52.4	43.5	36.1	27.8	22.1	16.4
1.114	60.2	55.2	48.0	40.2	33.3	25.8	20.5	15.1
1.176	54.4	50.2	43.5	36.7	30.4	23.5	18.9	13.8
1.299	41.0	38.3	33.3	28.4	23.8	18.3	15.2	11.0
1.361	35.3	33.3	28.9	25.8	20.9	16.2	13.5	9.7
1.423	29.7	28.4	24.7	21.8	17.9	13.8	11.7	8.8

Table D.10: Experimental Data for 20 USGPM Water Flow Rate

ALIGNED STREAMLINED BUNDLES - TWO PHASE (08/09/82)

AIR (KG/S)	0.0167	0.0140	0.0114	0.0069	0.0058	0.0048	0.0031	0.0017
TEMPERATURE C	24.0	28.0	27.5	27.0	26.5	26.0	25.5	25.0
AIR PRESSURE (PSIG)	33.0	26.0	22.0	18.0	14.5	11.5	8.2	4.8
REF PRESSURE (PSIG)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DISTANCE (METER)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)
RUN NUMBER 1								
0.062	133.3	115.7	102.1	82.5	67.5	54.3	42.8	32.2
0.124	130.5	113.1	99.5	80.3	65.7	52.8	41.5	31.2
0.186	127.0	110.1	96.6	77.8	64.0	51.4	40.3	30.0
0.309	119.9	103.6	90.2	72.9	60.3	48.0	37.7	27.7
0.371	116.7	100.9	87.6	70.8	58.5	46.8	36.4	26.8
0.433	112.8	97.7	84.6	68.2	56.8	45.4	35.5	25.8
0.557	102.5	88.7	76.5	61.0	51.7	40.6	31.6	23.0
0.619	98.1	85.2	73.1	58.4	49.3	38.9	30.1	21.8
0.681	94.1	82.0	70.3	56.3	48.0	37.9	28.0	21.0
0.804	84.2	73.3	62.6	50.3	42.5	33.4	25.8	18.6
0.866	79.8	68.8	59.4	48.0	40.8	31.8	24.8	17.8
0.928	75.2	65.7	55.6	45.3	38.7	29.9	23.5	16.9
1.052	62.7	54.1	46.7	38.5	31.4	24.9	19.6	14.4
1.114	57.4	49.8	43.0	35.4	28.8	22.8	18.0	13.1
1.176	52.3	45.5	39.2	32.3	26.3	20.8	16.6	12.0
1.299	40.1	34.9	30.1	24.7	20.2	16.2	13.3	9.2
1.361	34.4	30.3	26.2	21.8	17.8	14.3	12.0	8.0
1.423	29.1	25.3	21.9	18.1	14.7	12.3	10.3	6.9
RUN NUMBER 2								
0.062	133.1	116.1	102.6	79.4	67.5	54.3	43.1	31.7
0.124	130.3	113.4	100.0	78.0	65.6	52.8	41.6	30.7
0.186	127.1	110.3	97.0	76.3	63.7	51.3	40.2	29.6
0.309	120.1	103.9	91.2	71.4	59.7	47.9	37.3	27.4
0.371	116.9	101.1	88.4	70.0	57.7	46.7	36.0	26.5
0.433	113.3	97.7	85.6	67.5	56.2	45.1	34.8	25.6
0.557	102.7	89.0	77.8	61.7	50.1	41.0	31.1	23.2
0.619	98.4	85.1	74.3	58.8	47.9	38.3	29.5	21.9
0.681	94.4	81.8	71.9	57.5	45.7	38.0	28.5	21.1
0.804	84.2	73.1	63.8	50.7	40.6	33.9	25.3	18.6
0.866	80.0	68.5	60.9	48.8	38.5	32.3	24.2	17.8
0.928	75.3	65.3	57.6	46.2	36.1	30.5	22.9	16.8
1.052	62.3	53.9	47.2	38.9	31.2	25.5	19.3	14.2
1.114	57.1	48.4	43.3	35.8	28.7	23.4	17.7	13.0
1.176	52.0	45.0	39.5	32.9	26.2	21.4	16.2	11.8
1.299	39.7	34.5	30.3	25.8	20.1	16.7	12.7	9.3
1.361	34.1	28.8	26.4	23.2	17.6	14.8	11.2	8.1
1.423	28.4	25.0	22.5	19.4	14.8	12.4	9.4	7.0
RUN NUMBER 3								
0.062	132.2	116.7	101.8	81.8	66.6	54.9	43.2	32.1
0.124	129.4	114.0	99.2	79.7	64.8	53.4	41.7	31.1
0.186	126.0	110.9	96.3	77.6	62.9	51.8	40.4	30.1
0.309	119.1	104.3	90.7	72.5	59.1	48.6	37.4	28.0
0.371	116.0	101.4	88.0	70.8	57.8	47.3	36.3	27.1
0.433	112.5	98.2	85.2	68.1	55.8	45.8	35.0	26.3
0.557	102.3	89.2	77.0	61.2	49.9	40.2	31.3	23.3
0.619	98.0	85.4	73.7	58.6	47.9	38.2	29.7	22.2
0.681	94.1	82.3	70.8	56.5	46.0	37.7	28.5	21.4
0.804	84.1	73.5	63.3	50.4	40.8	33.3	25.1	18.8
0.866	79.8	69.9	60.2	48.6	38.0	31.9	23.9	18.0
0.928	74.9	65.8	56.8	46.0	35.8	30.2	22.5	17.0
1.052	62.3	54.3	46.9	38.6	31.2	25.2	18.3	14.0
1.114	57.3	49.8	43.0	35.4	28.6	23.1	17.6	12.8
1.176	52.3	45.1	39.2	32.4	26.3	21.3	16.1	11.9
1.299	40.3	34.5	29.9	24.8	20.7	16.8	12.6	9.6
1.361	34.5	29.4	26.1	21.8	18.3	15.0	11.2	8.6
1.423	28.9	24.8	22.3	18.0	15.3	12.5	9.4	7.4

Table D.11: Experimental Data for 20 USGPM Water Flow Rate

... DEG. MISALIGNED STREAMLINED BUNDLES – TWO PHASE (09/06/82)

AIR (KG/S)	0.0167	0.0142	0.0115	0.0091	0.0068	0.0048	0.0031	0.0017
TEMPERATURE C	29.5	29.5	29.4	29.3	29.2	29.1	29.0	29.0
AIR PRESSURE (PSIG)	33.0	26.5	22.5	19.0	14.5	12.0	8.5	7.0
REF PRESSURE (PSIG)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DISTANCE (METER)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)
RUN NUMBER 1								
0.062	134.3	119.0	103.8	86.0	67.2	55.5	43.1	32.2
0.124	131.4	116.3	101.2	83.8	65.4	54.1	42.0	31.4
0.186	128.1	113.0	98.3	81.4	63.9	52.5	40.8	30.3
0.309	121.3	106.7	92.5	76.3	59.6	49.1	38.0	28.2
0.371	118.1	103.7	89.7	73.9	54.7	47.6	37.0	27.3
0.433	114.5	100.5	87.1	71.6	56.6	46.2	35.7	26.3
0.557	104.1	91.6	78.8	64.7	51.4	41.0	31.9	23.5
0.619	99.6	87.5	75.3	61.9	48.3	38.1	30.4	22.4
0.681	95.6	84.0	72.5	59.5	47.8	37.9	29.4	21.5
0.804	85.6	75.2	64.6	52.5	42.5	33.7	26.3	19.2
0.866	81.4	71.5	61.7	50.1	40.6	32.3	25.2	18.2
0.928	77.1	67.4	58.4	47.3	38.7	30.8	24.1	17.1
1.052	64.0	55.9	48.2	39.8	32.8	25.7	20.0	14.3
1.114	58.3	51.9	43.9	36.6	30.2	23.8	18.3	13.0
1.176	52.9	46.2	40.0	33.4	27.6	21.6	16.8	11.8
1.299	40.6	35.4	30.7	25.7	21.8	16.9	13.1	9.2
1.361	34.8	30.3	26.6	22.8	19.6	15.1	11.6	8.0
1.423	28.2	25.6	22.5	18.0	16.5	12.9	9.8	7.0
RUN NUMBER 2								
0.062	133.8	119.2	103.6	86.3	68.8	54.6	43.7	31.6
0.124	131.0	116.6	101.0	84.0	66.9	53.2	42.6	30.6
0.186	127.8	113.5	98.1	81.4	65.1	51.8	41.3	29.8
0.309	120.9	106.9	92.0	76.4	61.1	48.3	38.5	27.8
0.371	117.7	104.1	89.3	74.1	59.4	47.1	37.3	26.8
0.433	114.3	101.0	86.4	71.7	57.8	45.5	36.1	25.8
0.557	103.8	91.8	77.8	64.4	51.6	40.6	32.2	23.0
0.619	99.4	87.7	74.6	61.4	49.4	38.7	30.6	22.0
0.681	95.5	84.2	71.5	59.4	47.7	37.4	29.5	21.1
0.804	85.9	75.2	64.0	52.9	42.3	33.3	26.1	18.9
0.866	81.5	71.5	60.8	50.6	40.5	31.8	24.9	18.0
0.928	76.9	67.7	57.2	48.1	38.5	30.2	23.6	17.1
1.052	64.1	56.0	47.9	39.7	32.1	25.2	20.0	14.5
1.114	58.5	50.9	43.8	36.4	29.3	23.1	18.3	13.2
1.176	53.3	46.3	39.9	33.0	26.8	21.3	17.0	12.0
1.299	40.6	35.6	30.5	25.3	20.9	17.2	13.4	9.2
1.361	34.8	30.7	26.5	22.1	18.8	15.3	11.8	7.9
1.423	29.5	25.8	22.2	18.6	15.6	13.3	10.1	7.0
RUN NUMBER 3								
0.062	134.0	119.4	103.4	86.7	68.8	53.8	43.8	31.9
0.124	131.1	116.6	100.7	84.8	66.9	52.4	42.6	31.0
0.186	127.9	113.5	97.9	82.1	64.9	50.8	41.2	30.1
0.309	121.2	106.9	92.1	77.0	60.7	47.6	38.4	28.0
0.371	118.0	103.8	89.3	74.8	59.0	46.5	37.3	27.2
0.433	114.4	100.8	86.7	72.5	57.2	45.0	35.9	26.2
0.557	103.7	91.5	78.0	64.9	53.0	40.8	31.5	23.2
0.619	99.1	87.5	75.6	61.6	48.7	39.0	30.1	22.0
0.681	95.3	84.2	72.9	59.5	46.9	37.6	28.9	21.1
0.804	85.3	75.4	65.3	52.6	41.5	33.6	26.1	18.7
0.866	81.3	71.9	62.3	50.4	39.7	31.8	24.8	17.9
0.928	76.8	67.9	58.7	47.9	37.8	30.3	23.6	16.9
1.052	63.9	55.9	48.2	39.5	31.8	26.2	20.1	14.6
1.114	58.4	51.1	44.1	36.1	29.2	23.9	18.4	13.3
1.176	53.3	46.4	40.0	33.0	26.7	21.9	16.8	12.1
1.299	40.8	35.8	30.9	25.6	21.1	17.0	13.1	9.3
1.361	35.4	30.9	27.0	22.5	18.9	15.2	11.7	8.0
1.423	28.8	26.2	22.7	18.0	15.7	12.8	9.8	7.0

Table D.12: Experimental Data for 20 USGPM Water Flow Rate

45.0 DEG. MISALIGNED STREAMLINED BUNDLES - TWO PHASE (08/09/82)

AIR (KG/S)	0.0167	0.0141	0.0115	0.0090	0.0069	0.0048	0.0031	0.0017
TEMPERATURE C	31.0	31.0	31.0	30.9	30.8	30.7	30.6	30.5
AIR PRESSURE (PSIG)	30.0	28.5	23.0	18.5	15.5	12.0	8.5	7.0
REF PRESSURE (PSIG)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DISTANCE (METER)	(HEIGHT,CM) (MERCURY)	(HEIGHT,CM) (MERCURY)	(HEIGHT,CM) (MERCURY)	(HEIGHT,CM) (MERCURY)	(HEIGHT,CM) (MERCURY)	(HEIGHT,CM) (MERCURY)	(HEIGHT,CM) (MERCURY)	(HEIGHT,CM) (MERCURY)
RUN NUMBER 1								
0.062	135.0	120.8	103.8	85.8	70.1	55.8	44.4	32.4
0.124	132.4	118.3	101.5	83.7	68.2	54.2	43.0	31.5
0.186	129.1	116.4	98.7	81.5	66.2	52.8	41.6	30.4
0.339	122.0	108.8	92.8	76.1	62.0	49.2	38.7	28.6
0.371	118.9	105.9	90.3	74.4	60.5	47.6	37.5	27.5
0.433	115.4	102.9	87.4	71.8	58.5	46.3	36.3	26.6
0.557	105.0	93.1	79.3	66.0	52.4	41.4	32.6	23.4
0.619	100.5	89.1	75.7	62.7	50.0	39.4	31.1	22.1
0.681	98.7	85.7	72.8	60.7	47.8	37.8	29.9	21.2
0.804	86.8	77.0	65.4	54.3	42.8	33.8	26.7	18.8
0.866	82.5	73.1	62.3	51.8	40.7	32.1	25.5	17.8
0.928	78.1	68.9	59.0	49.0	38.5	30.3	24.3	17.0
1.052	64.2	56.7	48.2	40.0	32.6	25.5	20.0	14.8
1.114	56.3	51.4	43.6	36.5	29.5	23.1	18.0	13.3
1.176	52.6	46.2	39.5	33.3	28.8	20.9	16.2	12.1
1.299	39.7	35.0	30.1	25.8	20.7	15.8	12.4	9.2
1.361	34.1	30.0	26.2	23.3	18.4	14.0	10.8	7.8
1.423	28.8	25.2	22.1	18.8	14.7	11.6	9.3	6.6
RUN NUMBER 2								
0.062	135.0	120.2	104.8	85.9	70.5	55.8	44.2	32.8
0.124	132.3	117.8	102.2	83.8	68.7	54.3	43.1	31.7
0.186	129.1	114.9	98.4	81.6	66.7	52.6	41.8	30.7
0.309	122.3	108.5	93.8	76.5	62.0	49.3	39.1	28.1
0.371	119.3	105.7	91.2	74.6	60.7	47.8	38.0	27.5
0.433	115.8	102.3	88.4	72.2	59.0	46.3	36.7	26.2
0.557	105.2	92.8	79.3	65.8	53.2	41.6	32.9	23.9
0.619	100.6	88.6	75.6	62.8	50.8	38.5	31.3	22.5
0.681	96.6	85.2	72.7	60.8	48.9	37.8	30.1	21.8
0.804	86.6	76.4	65.0	53.8	43.6	33.6	26.8	19.3
0.866	82.4	72.7	61.8	51.5	41.4	32.3	25.5	18.3
0.928	78.0	68.6	58.5	48.2	38.8	30.9	24.1	17.4
1.052	64.1	56.3	48.2	38.8	32.3	25.8	19.8	14.6
1.114	58.2	51.0	43.7	36.3	28.4	23.3	18.1	13.1
1.176	52.5	46.1	39.9	33.0	26.8	21.2	16.5	11.8
1.299	38.7	34.8	30.2	25.3	20.7	16.3	12.9	9.0
1.361	34.0	30.0	26.1	22.5	18.4	14.5	11.4	8.0
1.423	28.8	25.4	22.0	18.7	15.2	11.8	9.9	6.8
RUN NUMBER 3								
0.062	135.2	120.8	104.2	86.8	70.9	55.7	43.7	32.7
0.124	132.5	118.1	101.7	84.6	68.1	54.2	42.4	31.8
0.186	128.3	115.0	98.0	82.1	67.2	52.4	41.1	30.5
0.309	122.2	108.5	93.1	76.9	63.1	48.1	38.4	28.1
0.371	118.2	105.4	90.4	74.7	61.4	47.8	37.3	27.4
0.433	115.9	102.3	87.7	72.1	58.6	46.4	35.2	26.2
0.557	105.2	93.2	79.3	65.2	54.3	41.7	32.0	23.8
0.619	100.6	89.1	75.6	62.1	51.6	38.8	30.5	22.6
0.681	96.7	85.8	72.6	60.0	48.9	38.1	28.1	21.7
0.804	86.7	76.8	65.1	53.4	44.2	33.9	26.0	19.3
0.866	82.3	73.0	61.9	50.9	42.3	32.2	24.7	18.2
0.928	77.6	68.2	58.5	48.4	40.0	30.8	23.3	17.2
1.052	64.1	56.0	48.1	39.7	32.6	25.7	20.2	14.3
1.114	58.1	50.7	43.6	36.0	28.6	23.2	18.3	13.0
1.176	52.1	45.8	38.5	32.7	27.0	21.1	16.7	11.8
1.299	38.6	35.0	30.0	24.9	20.8	16.2	13.0	9.0
1.361	34.2	30.1	26.2	22.0	18.6	14.4	11.5	7.8
1.423	26.7	25.6	22.3	18.4	15.2	11.8	9.8	6.4

Table D.13: Experimental Data for 15 USGPM Water Flow Rate

ALIGNED REGULAR BUNDLES -TWO PHASE (05/08/82)

AIR (KG/S)	0.0210	0.0182	0.0145	0.0128	0.0107	0.0084
TEMPERATURE C	26.0	26.2	26.4	26.8	26.8	27.0
AIR PRESSURE (PSIG)	30.2	27.2	23.8	20.0	17.5	14.2
REF PRESSURE (PSIG)	3.1	2.2	1.4	0.4	0.1	0.0
DISTANCE (METER)	(HEIGHT,CM) (MERCURY)	(HEIGHT,CM) (MERCURY)	(HEIGHT,CM) (MERCURY)	(HEIGHT,CM) (MERCURY)	(HEIGHT,CM) (MERCURY)	(HEIGHT,CM) (MERCURY)
RUN NUMBER 1						
0.062	95.3	89.8	82.6	73.9	67.9	58.0
0.124	93.0	87.5	80.4	72.2	66.1	56.8
0.186	90.2	84.6	77.6	70.6	64.5	55.4
0.309	84.3	79.1	72.6	65.6	59.2	51.8
0.371	81.6	76.6	70.5	63.8	57.8	50.4
0.433	78.7	73.7	67.8	61.6	56.0	48.2
0.557	68.0	64.2	59.2	53.9	49.1	43.4
0.619	64.3	61.0	56.0	51.3	46.9	41.7
0.681	60.7	57.7	53.0	49.0	45.2	40.7
0.804	51.3	49.0	45.5	42.4	38.1	35.5
0.866	47.4	45.4	42.3	39.9	37.4	34.3
0.928	43.1	41.7	39.0	37.0	35.3	32.7
1.052	33.3	30.2	28.0	28.5	28.5	27.5
1.114	26.0	28.4	24.4	25.2	25.8	25.3
1.176	21.4	22.4	20.8	22.2	23.2	23.1
1.238	10.4	12.1	12.2	15.4	17.0	17.8
1.361	5.3	7.3	8.4	12.5	14.8	16.0
1.423	0.6	2.6	4.1	8.2	10.5	12.2
RUN NUMBER 2						
0.062	96.4	89.4	82.3	75.0	68.6	58.6
0.124	94.0	87.2	80.1	73.6	66.8	57.1
0.186	91.0	84.5	77.3	71.4	65.3	56.1
0.309	85.1	78.8	72.4	66.3	60.5	52.2
0.371	82.4	76.5	70.4	64.1	58.8	51.3
0.433	79.3	73.5	67.9	62.3	56.7	48.4
0.557	68.4	64.1	58.1	53.9	48.6	44.4
0.619	64.8	61.0	56.1	51.3	47.5	42.8
0.681	61.2	57.5	53.1	48.8	45.4	41.4
0.804	51.3	49.0	45.1	41.7	38.6	36.8
0.866	47.4	45.4	42.1	39.5	37.5	35.0
0.928	43.1	41.6	38.8	36.9	34.8	33.1
1.052	30.2	30.1	28.5	28.1	27.4	27.0
1.114	26.1	26.3	25.5	24.9	24.2	24.6
1.176	21.6	22.2	21.4	21.9	21.6	22.6
1.238	10.1	12.1	12.4	14.4	15.8	18.1
1.361	5.3	7.2	8.4	10.8	12.7	15.9
1.423	0.3	2.5	3.8	7.6	8.9	13.0
RUN NUMBER 3						
0.062	95.9	90.5	82.2	74.1	68.2	58.0
0.124	93.7	88.4	80.0	72.8	66.6	57.8
0.186	90.7	85.6	77.3	70.8	65.0	56.5
0.309	84.8	80.0	72.5	65.4	60.8	52.8
0.371	82.2	77.6	69.6	63.6	59.3	51.1
0.433	78.9	74.8	67.0	61.4	57.4	48.7
0.557	67.8	65.0	59.0	53.5	49.3	43.8
0.619	64.3	61.5	56.1	51.3	47.4	41.8
0.681	60.6	58.2	53.5	49.0	45.7	40.2
0.804	51.2	49.2	45.3	42.8	38.9	35.2
0.866	47.4	45.6	42.4	40.2	38.4	33.6
0.928	43.2	41.7	38.1	37.0	36.2	31.7
1.052	30.7	29.6	28.3	28.2	27.7	26.0
1.114	26.4	25.7	24.6	26.0	24.9	23.6
1.176	22.0	21.9	21.2	23.0	22.2	21.3
1.238	10.7	11.6	12.7	15.8	16.4	16.5
1.361	5.8	7.0	8.9	13.2	14.0	14.1
1.423	0.6	2.7	4.6	8.9	10.1	11.0

Table D.14: Experimental Data for 15 USGPM Water Flow Rate

22.5 DEG. MISALIGNED REGULAR BUNDLES - TWO PHASE (05/08/82)

AIR (KG/S)	0.0214	0.0185	0.0158	0.0132	0.0107	0.0085
TEMPERATURE C	27.2	27.4	27.6	27.8	28.0	28.2
AIR PRESSURE (PSIG)	32.0	28.3	25.2	21.8	18.0	15.0
REF. PRESSURE (PSIG)	3.6	2.5	1.7	0.7	0.1	0.0
DISTANCE (METER)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)
RUN NUMBER 1						
0.062	102.6	95.2	88.6	80.9	72.2	62.6
0.124	100.6	93.4	86.9	79.3	70.9	61.1
0.186	97.5	90.9	84.7	77.3	68.1	59.9
0.309	91.3	84.5	78.8	72.1	64.4	56.1
0.371	88.5	82.1	76.7	69.9	62.8	55.0
0.433	85.3	79.0	74.2	67.8	60.0	53.8
0.557	71.6	66.3	62.5	57.4	51.0	45.9
0.619	67.8	63.1	59.5	54.6	48.7	43.8
0.681	64.1	59.8	56.8	52.2	46.8	42.5
0.804	54.4	51.6	48.8	45.4	41.0	37.8
0.866	50.6	48.0	4[illegible].2	43.0	38.5	36.1
0.928	46.5	44.1	[illegible]	40.0	37.3	34.4
1.052	29.0	29.2	28.8	28.0	27.8	26.6
1.114	23.9	24.4	24.4	24.2	24.5	24.2
1.176	18.7	20.4	20.4	20.8	21.8	22.1
1.299	7.1	10.1	11.4	12.8	15.1	16.7
1.361	2.0	5.7	7.8	9.3	12.5	14.6
1.423	-3.0	0.4	3.3	5.1	8.0	10.6
RUN NUMBER 2						
0.062	102.7	95.0	88.6	80.7	71.8	64.8
0.124	100.8	93.3	86.7	78.9	70.7	63.1
0.186	97.8	90.6	84.5	76.9	69.0	61.7
0.309	91.3	84.5	78.7	71.5	64.6	57.7
0.371	88.6	81.9	76.5	69.6	62.8	56.3
0.433	85.4	79.0	74.0	67.3	61.0	54.8
0.557	71.8	66.4	62.7	57.8	51.4	46.1
0.613	68.0	63.1	59.8	55.0	48.6	44.0
0.681	64.4	60.0	57.1	52.6	47.0	42.0
0.804	55.0	51.8	48.1	45.8	40.7	37.4
0.866	51.1	48.3	46.4	43.2	38.5	35.7
0.928	46.9	44.5	43.1	40.6	37.6	33.6
1.052	29.7	29.3	28.5	28.8	27.8	25.0
1.114	24.2	24.8	24.5	24.9	24.5	22.7
1.176	19.2	20.4	20.6	21.3	21.8	20.5
1.299	7.2	9.7	11.8	13.5	15.2	15.5
1.361	2.2	5.0	7.3	10.3	12.5	13.2
1.423	-2.8	0.3	4.6	5.7	8.7	10.2
RUN NUMBER 3						
0.062	102.8	95.9	88.5	81.0	71.4	62.9
0.124	100.4	93.8	86.9	79.6	69.6	61.4
0.186	97.7	91.2	84.6	77.6	66.5	60.2
0.309	91.2	85.1	79.1	72.8	63.9	56.5
0.371	88.4	82.7	76.8	70.8	62.0	55.2
0.433	85.3	79.7	74.4	68.8	60.1	54.0
0.557	71.7	67.2	62.2	57.3	52.4	45.5
0.619	68.0	63.8	59.2	54.4	50.1	43.5
0.681	64.3	60.5	56.3	52.4	48.3	42.1
0.804	54.8	52.1	48.5	44.9	42.2	37.4
0.866	50.8	48.5	45.7	43.1	40.4	36.8
0.928	46.6	44.5	42.6	40.6	38.5	34.3
1.052	29.4	28.7	28.7	28.8	28.0	26.9
1.114	24.3	24.8	24.6	24.9	24.8	24.2
1.176	19.1	20.2	20.8	21.8	21.9	21.8
1.299	7.3	9.8	11.8	13.8	15.8	18.5
1.381	2.1	4.9	7.6	10.6	12.7	14.5
1.423	-2.9	-0.7	4.0	6.2	9.0	1[illegible].0

Table D.15: Experimental Data for 15 USGPM Water Flow Rate

45.0 DEG. MISALIGNED REGULAR BUNDLES - TWO PHASE (05/08/82)

AIR (KG/S)	0.0217	0.0187	0.0159	0.0134	0.0108	0.0085
TEMPERATURE C	29.6	29.8	30.0	30.2	30.4	30.6
AIR PRESSURE (PSIG)	33.2	29.2	25.8	22.8	19.0	15.0
REF PRESSURE (PSIG)	4.8	2.7	1.9	1.7	1.1	1.0
DISTANCE (METER)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)
RUN NUMBER 1						
0.062	109.3	99.0	91.9	70.9	66.4	63.1
0.124	107.3	97.2	89.8	78.3	64.8	61.5
0.186	104.7	94.9	87.6	76.4	63.8	60.2
0.309	98.6	89.1	81.8	71.5	59.3	56.3
0.371	95.6	86.8	78.4	69.2	58.1	54.8
0.433	92.8	83.9	76.5	67.3	56.0	53.3
0.557	77.5	68.6	63.3	55.5	48.0	44.8
0.619	73.5	66.0	60.1	52.8	43.3	43.1
0.681	70.1	63.6	57.2	50.9	41.1	41.3
0.804	63.3	54.3	49.4	43.9	35.5	36.8
0.866	56.4	50.8	46.6	41.4	33.4	35.2
0.928	52.1	47.2	43.0	38.7	31.1	33.3
1.052	33.4	31.0	28.0	24.7	21.9	23.1
1.114	28.2	26.3	23.5	20.8	18.4	20.4
1.176	22.2	21.8	19.5	17.4	15.8	17.9
1.299	10.1	10.8	10.1	10.0	8.9	12.5
1.361	4.6	6.1	5.8	6.6	6.2	10.3
1.423	-0.4	1.1	1.6	2.6	1.3	8.1
RUN NUMBER 2						
0.062	112.7	98.4	90.5	78.5	67.9	62.0
0.124	110.7	97.3	88.8	76.4	66.3	60.8
0.186	107.8	95.2	86.8	74.9	64.9	58.6
0.309	101.5	89.1	81.4	68.8	60.6	56.3
0.371	98.6	87.0	79.0	68.3	59.3	54.9
0.433	95.5	83.9	76.3	65.8	57.0	53.5
0.557	80.5	68.8	63.1	54.7	46.2	43.7
0.619	76.6	66.4	59.8	51.7	43.6	41.8
0.681	72.8	63.1	56.7	49.7	41.6	40.5
0.804	63.1	54.5	48.9	42.7	35.9	35.8
0.866	59.5	51.1	45.8	40.4	34.2	34.4
0.928	55.3	47.3	42.4	37.5	[illegible]	32.7
1.052	36.3	30.6	27.3	23.8	20.6	24.1
1.114	31.0	26.0	23.0	20.0	17.6	21.5
1.176	25.7	21.5	18.9	16.6	14.6	18.3
1.299	13.1	10.7	9.3	8.8	8.3	13.8
1.361	7.8	5.9	4.9	5.2	5.5	11.6
1.423	2.8	1.0	0.8	2.0	0.6	8.8
RUN NUMBER 3						
0.062	112.5	99.0	90.6	78.5	67.7	61.7
0.124	110.4	97.0	88.7	76.7	66.0	60.7
0.186	107.6	94.2	86.6	75.1	64.4	59.7
0.309	101.2	88.6	80.8	70.3	59.8	56.5
0.371	98.3	86.3	78.5	68.1	58.4	55.0
0.433	95.1	83.1	75.8	66.0	56.1	53.8
0.557	80.2	69.8	62.9	54.3	45.4	43.3
0.619	76.3	66.2	59.6	51.9	43.2	41.5
0.681	72.8	62.9	56.7	49.0	42.0	38.8
0.804	63.2	54.5	48.8	42.2	35.8	35.2
0.866	59.4	50.9	45.8	38.8	33.8	34.3
0.928	55.3	47.3	42.7	37.0	32.0	32.8
1.052	36.6	31.3	27.1	23.6	21.5	24.5
1.114	31.2	26.6	22.8	19.8	18.3	21.8
1.176	26.0	22.1	18.8	16.4	15.4	19.7
1.299	13.6	11.3	9.3	8.5	8.8	14.4
1.361	7.9	6.3	5.0	5.3	6.0	12.3
1.423	3.3	1.6	1.4	1.0	1.8	8.2

Table D.16: Experimental Data for 15 USGPM Water Flow Rate

ALIGNED STREAMLINED BUNDLES - TWO PHASE (06/08/82)

AIR (M3/S)	0.0269	0.0179	0.0154	0.0124	0.0104	0.0083
TEMPERATURE C	28.6	28.4	28.2	28.0	27.8	27.8
AIR PRESSURE (PSIG)	29.8	25.8	23.0	19.5	16.0	13.5
REF PRESSURE (PSIG)	0.0	0.0	0.0	0.0	0.0	0.0
DISTANCE (METER)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)
RUN NUMBER 1						
0.062	117.2	106.0	95.4	83.7	70.3	56.8
0.124	115.1	104.0	93.3	81.8	68.5	55.5
0.186	112.6	101.5	91.1	79.6	66.6	54.1
0.309	106.9	96.4	85.8	74.8	62.8	50.3
0.371	104.4	94.0	83.9	72.8	60.9	48.5
0.433	101.1	91.0	80.9	70.5	58.1	47.6
0.557	92.0	82.3	73.6	63.8	52.5	43.0
0.619	88.1	78.9	70.5	61.0	50.1	41.2
0.681	84.6	75.6	67.6	58.6	47.9	39.5
0.804	75.3	67.3	60.0	51.7	42.3	35.1
0.866	71.5	63.8	57.0	49.1	40.4	33.8
0.928	67.2	58.9	53.4	46.4	38.1	31.9
1.052	55.4	49.6	45.0	38.8	32.7	27.8
1.114	51.1	45.5	41.0	35.3	29.8	25.5
1.176	48.8	41.4	37.3	32.3	27.3	23.4
1.299	35.7	31.7	28.8	25.3	21.4	18.6
1.361	31.0	27.0	24.6	22.1	18.9	16.3
1.423	26.0	22.9	20.2	18.3	15.2	12.8
RUN NUMBER 2						
0.062	117.3	106.0	95.9	82.9	69.2	57.4
0.124	115.2	103.8	93.9	81.0	67.7	56.3
0.186	112.6	101.5	91.5	79.0	65.8	54.9
0.309	106.9	96.0	86.6	74.3	62.2	51.4
0.371	104.3	93.7	84.3	72.2	60.4	50.5
0.433	101.0	90.4	81.6	69.9	58.5	48.7
0.557	91.5	82.3	74.2	63.1	52.7	44.5
0.619	87.6	78.8	71.1	60.7	50.4	42.6
0.681	84.6	75.7	68.2	58.4	48.3	41.1
0.804	74.8	67.4	60.6	52.0	42.6	36.6
0.866	73.9	63.7	57.4	49.7	40.8	35.0
0.928	66.5	59.9	53.8	46.8	38.5	33.2
1.052	55.1	50.0	44.4	39.1	32.6	27.6
1.114	50.8	45.8	40.4	35.6	28.6	25.5
1.176	46.5	41.9	36.9	32.4	27.2	23.7
1.299	35.4	32.2	28.5	25.0	21.6	18.8
1.361	30.2	27.9	24.9	21.4	19.2	17.2
1.423	25.2	23.4	21.1	17.5	15.7	14.0
RUN NUMBER 3						
0.062	117.7	106.2	95.4	83.7	68.9	57.0
0.124	115.5	104.1	93.3	81.7	67.1	55.8
0.186	112.9	101.7	91.1	79.4	65.3	54.3
0.309	107.1	96.3	86.0	74.8	61.1	50.6
0.371	104.3	93.8	83.8	72.7	58.5	48.9
0.433	101.2	91.1	81.1	70.4	57.5	47.8
0.557	91.6	82.1	73.5	63.5	52.1	43.6
0.619	88.0	78.8	70.5	60.7	49.7	41.6
0.681	84.3	75.5	67.5	58.2	47.8	40.1
0.804	75.1	67.3	59.6	51.6	42.3	35.5
0.866	71.2	63.7	56.8	49.2	40.4	34.0
0.928	66.9	59.6	53.2	46.7	38.2	32.1
1.052	55.6	49.9	44.5	38.9	32.8	27.8
1.114	51.3	45.5	40.8	35.5	29.8	25.6
1.176	46.8	41.4	37.3	32.4	27.3	23.8
1.299	35.5	31.6	28.8	25.2	21.1	19.0
1.361	30.7	26.9	24.9	21.6	18.1	15.9
1.423	25.5	22.5	20.4	17.9	14.6	13.0

Table D.17: Experimental Data for 15 USGPM Water Flow Rate

22.5 DEG. MISALIGNED STREAMLINED BUNDLES - TWO PHASE (06/08/82)

AIR (KG/S)	0.0208	0.0180	0.0154	0.0128	0.0104	0.0082
TEMPERATURE C	26.8	27.0	27.2	27.4	27.8	27.8
AIR PRESSURE (PSIG)	30.0	26.2	23.0	20.0	16.2	13.0
REF PRESSURE (PSIG)	0.0	0.0	0.0	0.0	0.0	0.0
DISTANCE (METER)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)
RUN NUMBER 1						
0.062	118.9	108.3	96.9	85.0	70.8	58.3
0.124	116.8	106.1	94.8	83.0	68.1	57.1
0.186	114.2	103.6	92.6	80.8	67.1	55.6
0.309	108.5	98.3	87.3	75.8	63.8	52.6
0.371	105.7	95.8	84.9	73.8	61.6	51.4
0.433	102.4	92.7	82.3	71.4	60.0	49.8
0.557	92.9	84.2	74.7	64.5	54.1	45.2
0.619	88.9	80.5	71.4	61.6	51.6	43.4
0.681	85.3	77.3	68.8	59.0	49.6	42.2
0.804	76.6	68.7	61.1	52.6	43.8	37.1
0.866	72.5	65.3	57.8	49.9	41.9	35.8
0.928	68.1	61.7	54.5	47.1	39.5	33.8
1.052	56.4	50.5	45.4	39.5	32.7	28.5
1.114	51.3	45.9	41.0	35.5	29.6	25.8
1.176	46.5	41.5	37.2	32.3	26.8	24.0
1.299	35.3	31.5	28.6	24.9	20.9	19.0
1.361	30.6	27.2	24.5	21.7	19.2	17.1
1.423	25.6	23.0	20.4	18.0	14.8	14.2
RUN NUMBER 2						
0.062	119.3	107.8	97.4	84.7	69.7	57.8
0.124	117.1	105.7	95.3	82.2	67.8	56.4
0.186	114.6	103.3	93.0	80.5	66.1	54.8
0.309	108.8	97.9	87.9	75.7	61.7	51.3
0.371	105.9	95.2	85.5	73.5	60.0	50.4
0.433	102.4	92.1	82.9	71.1	57.9	48.7
0.557	93.2	83.4	75.0	64.6	52.0	44.1
0.619	89.2	79.8	71.6	61.8	49.6	42.3
0.681	85.8	76.6	68.5	59.2	47.5	41.0
0.804	76.6	68.4	60.8	52.5	41.6	36.4
0.866	72.7	64.9	57.6	50.1	39.8	35.0
0.928	68.4	61.2	54.1	47.3	37.6	33.4
1.052	56.4	50.7	45.1	38.4	31.9	28.6
1.114	51.3	46.1	40.8	35.8	28.8	25.9
1.176	46.4	41.9	37.0	32.4	26.1	23.6
1.299	35.2	32.2	28.3	24.9	20.0	18.4
1.361	30.6	27.8	24.3	21.6	17.3	16.0
1.423	25.2	22.7	20.0	18.0	14.3	12.8
RUN NUMBER 3						
0.062	118.8	107.6	97.4	84.3	71.7	57.2
0.124	116.6	105.5	95.3	82.3	70.1	56.0
0.186	114.2	103.1	93.0	80.1	68.4	54.4
0.309	108.5	97.8	88.3	75.5	64.9	51.1
0.371	105.7	95.4	85.9	73.5	62.9	50.1
0.433	102.3	92.3	83.1	71.2	61.3	48.5
0.557	92.8	83.1	75.4	64.3	55.7	43.7
0.619	88.9	79.6	72.0	61.5	53.4	41.7
0.681	85.2	76.2	69.2	59.0	51.8	40.3
0.804	76.2	68.0	61.8	52.8	46.2	35.5
0.866	72.1	64.5	58.6	50.2	44.1	34.7
0.928	67.6	60.8	55.2	47.4	42.1	32.3
1.052	56.3	50.8	45.5	39.4	35.2	27.6
1.114	50.9	46.3	41.1	35.8	31.9	25.2
1.176	46.2	41.8	37.2	32.7	29.2	23.1
1.299	34.9	31.8	28.3	25.4	23.4	18.4
1.361	29.8	27.3	24.6	22.0	20.8	16.1
1.423	24.9	22.8	20.7	18.5	17.5	13.4

Table D.18: Experimental Data for 15 USGPM Water Flow Rate

45.0 DEG. MISALIGNED STREAMLINED BUNDLES -TWO PHASE (06/08/82)

AIR (KG/S)	0.0209	0.0180	0.0155	0.0128	0.0105	0.0084
TEMPERATURE C	26.8	27.0	27.2	27.4	27.6	27.8
AIR PRESSURE (PSIG)	30.0	26.2	23.5	20.2	16.5	13.8
REF PRESSURE (PSIG)	0.0	0.0	0.0	0.0	0.0	0.0
DISTANCE (METER)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)	(HEIGHT.CM) (MERCURY)
RUN NUMBER 1						
0.062	122.4	105.8	98.0	85.2	72.4	57.3
0.124	120.3	108.0	86.1	83.6	70.7	56.1
0.186	117.7	105.4	93.7	81.5	68.7	54.7
0.309	111.6	98.3	88.1	76.6	64.8	50.8
0.371	108.8	96.6	85.8	74.6	62.8	50.1
0.433	105.6	93.7	83.2	72.1	61.0	48.2
0.557	96.2	85.2	75.9	64.8	55.0	43.1
0.619	91.9	81.4	72.4	61.9	52.6	41.4
0.681	88.4	77.9	69.4	59.3	50.1	39.7
0.804	79.3	69.2	61.9	52.8	44.5	35.4
0.866	75.2	66.2	58.8	50.4	42.2	33.8
0.928	70.7	62.4	55.4	47.6	38.6	32.0
1.052	57.9	51.4	46.4	40.8	33.3	28.2
1.114	52.6	46.8	41.6	36.9	30.2	25.6
1.176	47.3	42.1	37.8	33.5	27.5	23.5
1.299	35.5	31.8	29.4	26.0	21.2	18.5
1.361	30.6	27.2	25.6	22.9	18.6	16.5
1.423	25.9	23.0	21.8	19.3	15.4	13.7
RUN NUMBER 2						
0.062	122.3	109.8	99.0	85.1	72.8	58.5
0.124	120.3	108.0	97.1	83.3	71.3	58.2
0.186	117.6	105.5	94.6	81.3	69.4	56.8
0.309	111.3	98.4	88.7	76.5	65.4	53.3
0.371	108.6	96.9	86.3	74.4	63.3	51.8
0.433	105.3	93.8	83.5	72.2	61.6	50.3
0.557	95.7	85.6	75.6	65.4	55.4	[illegible]
0.619	91.4	81.7	72.2	62.4	52.8	43.7
0.681	87.7	78.5	69.1	59.6	50.5	42.2
0.804	78.6	70.1	61.7	53.2	45.0	37.1
0.866	74.6	66.8	58.6	50.6	42.9	35.5
0.928	70.3	62.9	55.0	47.7	40.4	33.3
1.052	58.3	51.7	45.4	40.0	33.7	28.0
1.114	53.2	47.0	41.4	36.1	30.4	25.1
1.176	48.0	42.4	37.4	32.8	27.8	23.0
1.299	35.8	32.2	28.4	25.4	21.6	18.3
1.361	30.9	27.8	24.6	22.0	18.9	16.8
1.423	26.4	23.7	21.0	18.5	15.8	13.1
RUN NUMBER 3						
0.062	122.6	110.0	97.6	86.0	71.7	58.7
0.124	120.6	108.1	95.6	84.1	70.2	57.6
0.186	117.8	105.7	93.3	82.0	68.4	56.1
0.309	111.8	100.1	88.4	77.0	64.2	52.6
0.371	109.0	97.5	86.0	74.8	62.5	51.5
0.433	105.8	94.5	83.4	72.5	60.3	49.8
0.557	96.1	85.8	75.4	66.1	53.9	44.8
0.619	92.0	82.0	72.1	62.9	51.5	42.8
0.681	88.2	78.6	69.0	60.4	49.3	40.9
0.804	79.1	70.2	61.5	53.8	42.7	36.1
0.866	75.0	66.6	58.4	51.4	41.6	34.2
0.928	70.4	62.6	55.3	48.9	38.3	32.1
1.052	58.1	51.4	45.7	40.4	34.0	27.2
1.114	53.0	46.6	41.8	36.3	30.5	24.7
1.176	47.6	42.0	37.6	32.9	27.9	22.6
1.299	35.9	31.7	28.8	25.5	21.8	18.1
1.361	30.6	27.3	25.2	22.1	18.8	16.1
1.423	25.8	23.1	21.3	18.9	15.6	13.8

Appendix E

EVALUATION OF RESULTS

E.1 WATER MASS FLOW RATE

E.1.1 Experiment A

The water mass flow rate (W_l) was obtained from the scale provided with the rotameter.

E.1.2 Experiment B

The water flow rate in USGPM was obtained from the scale provided with the rotameter. The water mass flow rate (W_l) was calculated with equation E.1.

$$W_l = USGPM(0.00228(ft^3/s)/USGPM)(0.02831m^3/ft^3)$$

$$(\rho_l(kg/m^3)) \qquad (E.1)$$

E.2 AIR MASS FLOW RATE

E.2.1 Experiment A

The air mass flow rate (W_g) in percentage of 0.22 kg/s was obtained from the scale provided with the rotameter. Since the flow rate shown in the scale was calibrated at the pressure of 120 psig, pressure correction was performed. The air mass flow rate was calculated with equation E.2.

$$W_g = (\%)(0.22\ kg/s)((PA+14.7)/(120+14.7))^{0.5} \qquad (E.2)$$

where PA was the air pressure obtained from the Bourdon gage installed at the exit of the rotameter.

E.2.2 Experiment B

The scale provided with the rotameter used in the Experiment B was the percentage of 0.02 kg/s air mass flow rate and was calibrated at the atmospheric pressure. The air mass flow rate was then calculated with equation E.3.

$$W_g = (\%)(0.02\ kg/s)((PA+14.7)/14.7)^{0.5} \qquad (E.3)$$

E.3 FLOW AREA

E.3.1 Experiment A

The flow area (A) was obtained with equation E.4.

$$A_c = D^2/4 \qquad (E.4)$$

where D is the diameter of the channel.

E.3.2 Experiment B

The channel area was calculated with equation E.4. The obstructed area by the rods of the bundle was

$$A_{rod} = 4(D_{rod}^2/4) \qquad (E.5a)$$

The obstructed area by the central rod of the bundle was

$$A_{Crod} = D_{Crod}^2/4 \tag{E.5b}$$

The flow area (A) was then obtained by substracting (E.5a) and (E.5b) from (E.4), i.e.

$$A = A_c - A_{rod} - A_{Crod} \tag{E.5}$$

E.4 MASS FLUX

The mass flux (G) of each phase was obtained from dividing the mass flow rate by the flow area, i.e.

$$G = W/A \tag{E.6}$$

In two-phase flow, the mass flux calculated with equation E.6 was the superficial mass flux. To evaluate the actual mass flux, the superficial mass flux had to be divided by the void fraction (α) for the gas phase, and the liquid holdup ($1-\alpha$) for the liquid phase.

E.5 QUALITY

The quality (x) of a two-phase mixture is the ratio of the gas phase mass flow rate and the total mass flow rate of both phases. It was calculated with

$$x = W_g/(W_l+W_g) \tag{E.7}$$

E.6 LOCAL PRESSURE

The local pressure (p) at each pressure tap location was evaluated with the pressure head equation. From Figure E.1,

$$p = p_{ref.} + ha\gamma_{water} - ha\gamma_{water} + (ht-hm)\gamma_{water}$$
$$+ hm\gamma_{mano} - ht\gamma_{water}$$

or

$$p = p_{ref.} + hm\gamma_{mano} - hm\gamma_{water}$$

or

$$= p_{ref.} + (\gamma_{mano} - \gamma_{water})hm$$

or

$$= p_{ref.} + (S_{mano}\,\gamma_{water} - \gamma_{water})hm$$

or

$$= p_{ref.} + (S_{mano} - 1)\gamma_{water}\,hm \quad \text{(E.8)}$$

where $p_{ref.}$ is the local pressure at the reference tap,

S_{mano} is the specific gravity or the manometric fluid, which is 2.95 for Meriam fluid and 13.6 for mercury;

γ_{water} is the specific weight of water; and

hm is the height of manometric fluid.

The reference pressure $p_{ref.}$ is calculated with

$$p_{ref.} = PG - hg\gamma_{water} + 14.7 \quad \text{(E.9)}$$

where PG is the gauge pressure obtained from the Bourdon gage, and hg is the increase in elevation of the reference pressure tap over the Bourdon gage.

E.7 FRICTION PRESSURE LOSS

The friction pressure loss was evaluated by obtaining the regression line from the local pressure data at various locations using the linear regression method. A computing subroutine had been set up to perform the evaluation.

E.8 LOCAL PRESSURE LOSS

With the subroutine provided, two local pressure values in the obstruction location were extrapolated. One of them (e.g., U1) was obtained when calculating the upstream friction pressure loss. The other (say, U2) was found when the downstream friction pressure loss was calculated. The local pressure loss, as defined in Figures 8.1 and 8.2, was found by substracting the extrapolated value of the downstream from the one obtained from upstream, i.e.

$$\Delta P_{LOC} = U1 - U2$$

```
      SUBROUTINE LNREG(DIST,PKPA,FTAP,LTAP,SLOP,U,Z)
C        DIST - THE AXIAL DISTANCE OF EACH PRESSURE TAP FROM
C               THE FIRST PRESSURE TAP.
C        PKPA - THE LOCAL PRESSURE AT EACH LOCATION.
C        FTAP - THE FIRST TAP TO BE CONSIDERED.
C        LTAP - THE LAST TAP TO BE CONSIDERED.
C        SLOP - THE SLOPE OF THE REGRESSION LINE (THE
C               FRICTION PRESSURE LOSS PER METER).
C        U    - THE DISTANCE OF THE OBSTRUCTION FROM THE
C               FIRST TAP.
C        Z    - THE EXTRAPOLATED LOCAL PRESSURE AT THE
C               OBSTRUCTION.
C
C        DECLARE THE VARIABLES.
C
      INTEGER N,FTAP,LTAP,I
      REAL DIST(22),PKPA(22),SLOP,U,Z,YINT,SX,SY,
     +     RX,RY,RXY,YMEAN,XMEAN
C
C        YINT - THE Y-INTERCEPT OF THE REGRESSION LINE.
C        SX   - THE SUM OF ALL X-VALUES,I.E. DIST(I)
C        SY   - THE SUM OF ALL Y-VALUES,I.E. PKPA(I)
C        XMEAN- THE MEAN VALUE OF THE X VALUES.
C        YMEAN- THE MEAN VALUE OF THE Y VLAUES.
C        N    - NUMBER OF VALUES.
C        RX   - THE SUM OF THE X-VARIANCE TIMES N
C        RY   - THE SUM OF THE Y-VARIANCE TIMES N
C        RXY  - THE SUM OF THE PRODUCT OF X-DEVIATION AND
C               Y-DEVIATION.
C
C        INITIALIZE THE VARIABLES TO ZERO.
C
      SX  = 0.
      SY  = 0.
      RX  = 0.
      RY  = 0.
      RXY = 0.
C
C        TO CALCULATE THE SUM OF X AND Y.
C
      DO 61 I=FTAP,LTAP
           SX = SX + DIST(I)
           SY = SY + PKPA(I)
61    CONTINUE
C
C        TO CALCULATE THE MEAN VALUES OF X AND Y.
C
      N = LTAP - FTAP + 1
      XMEAN = SX/N
      YMEAN = SY/N
```

```
C
C        TO CALCULATE THE SUM OF THE VARIANCE TIMES N.
C
      DO 64 I=FTAP,LTAP
            RX = RX + (DIST(I) - XMEAN)**2
            RY = RY + (PKPA(I) - YMEAN)**2
           RXY = RXY+ (DIST(I) - XMEAN)*(PKPA(I) - YMEAN)
64    CONTINUE
C
C        TO CALCULATE THE SLOPE, Y-INTERCEPT, AND THE
C        EXTRAPOLATING POINT AT THE OBSTRUCTION.
C
      SLOP = RXY/RX
      YINT = YMEAN - SLOP * XMEAN
      Z    = SLOP * U + YINT
      RETURN
      END
```

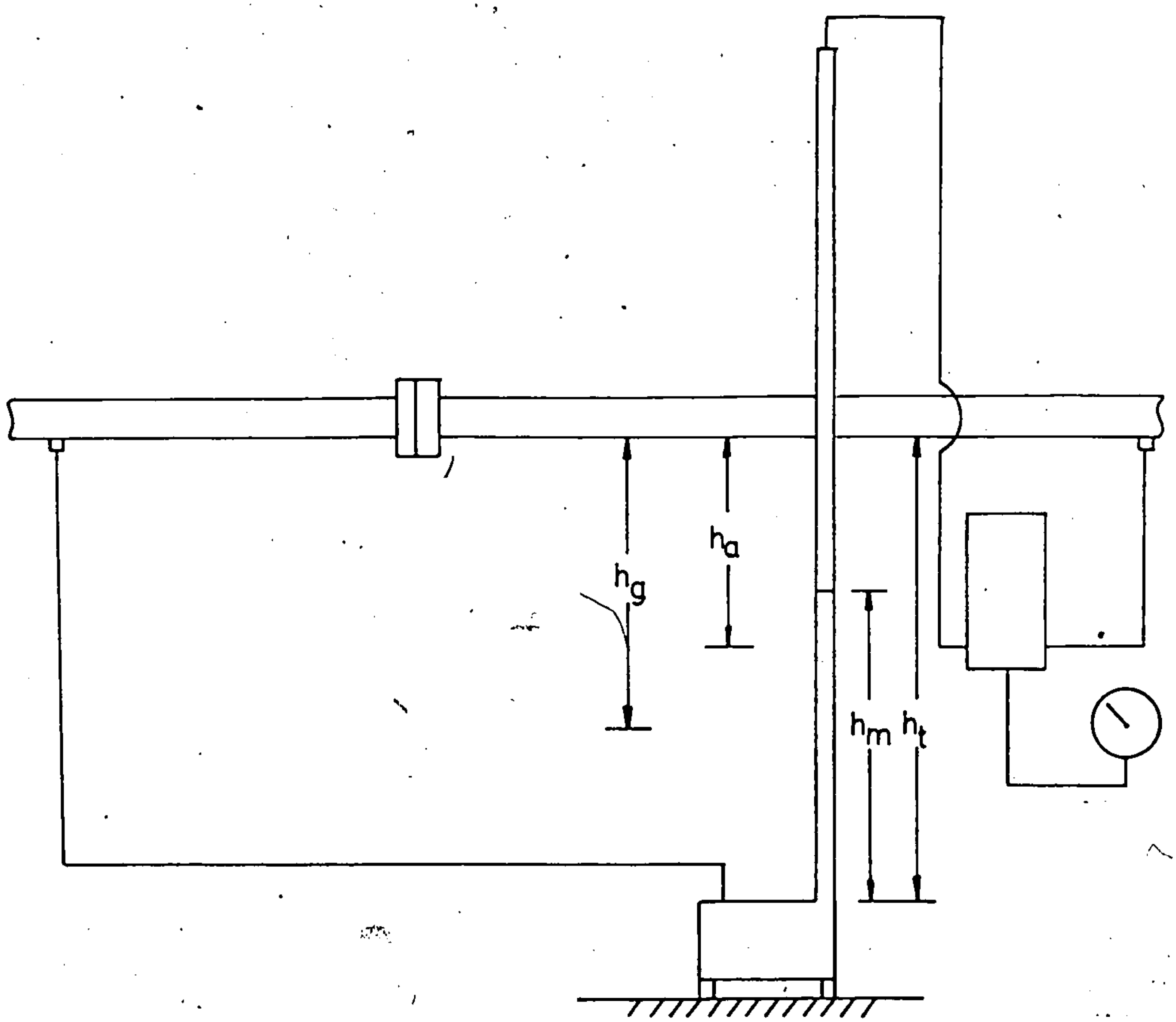


Figure E.1: Evaluation of Local Pressure.

Appendix F

SINGLE-PHASE PRESSURE DISTRIBUTIONS

FOR VARIOUS OBSTRUCTION IN EXPERIMENT A

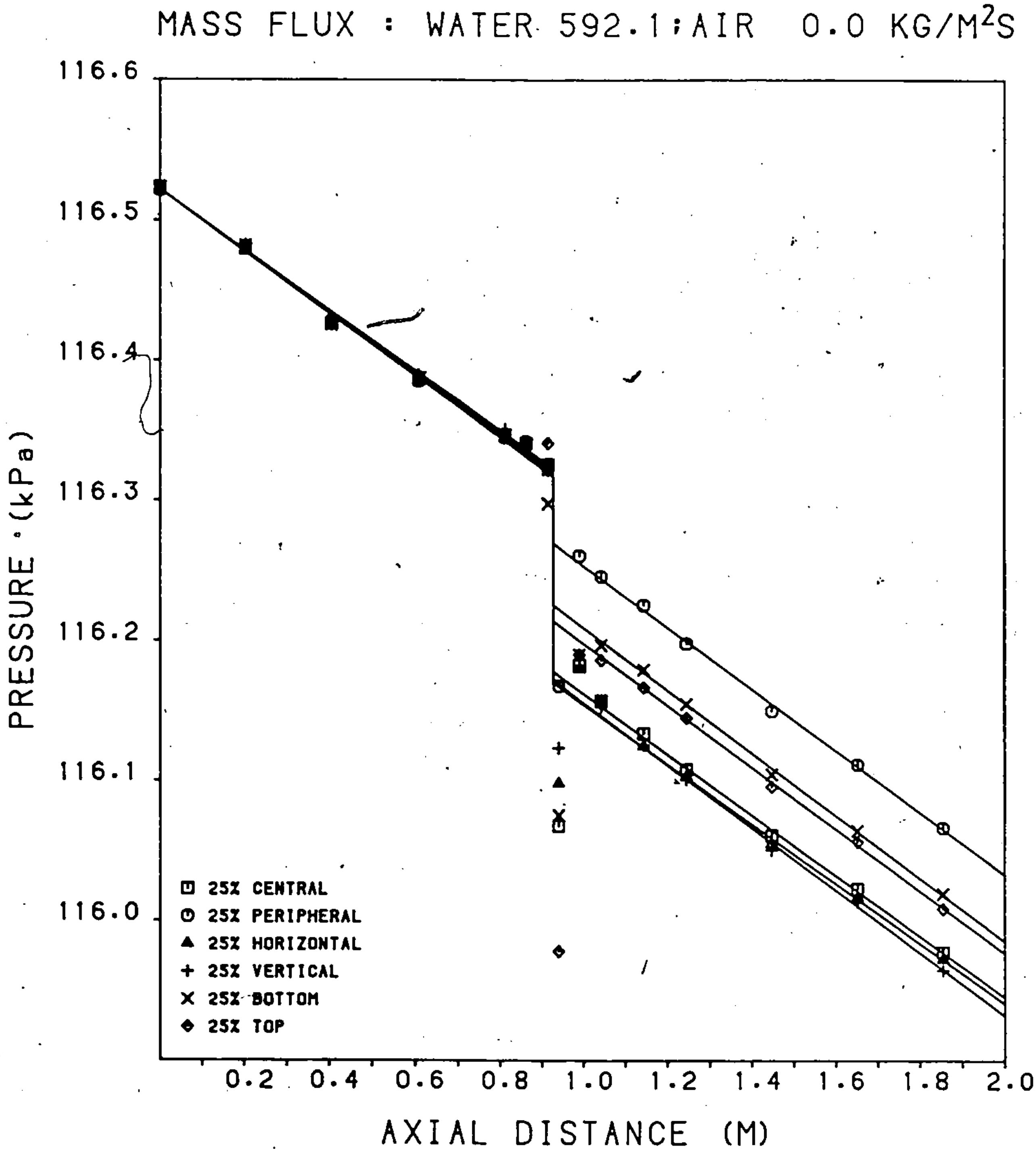


Figure F.1: Single-phase Pressure Distributions for the 25% Obstructions

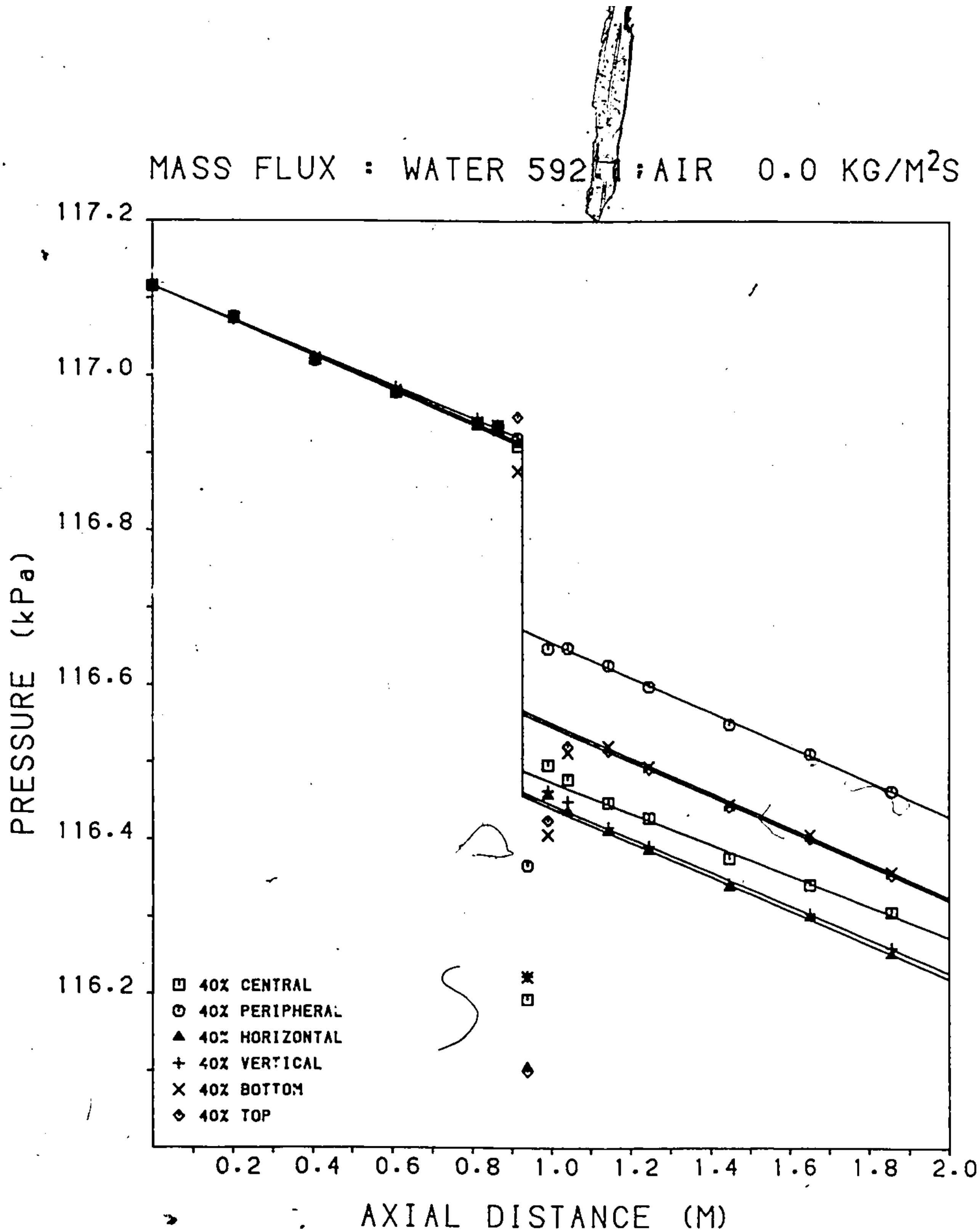


Figure F.2: Single-phase Pressure Distributions for the 40% Obstructions

Appendix G

TWO-PHASE PRESSURE DISTRIBUTIONS

FOR VARIOUS OBSTRUCTIONS IN EXPERIMENT A

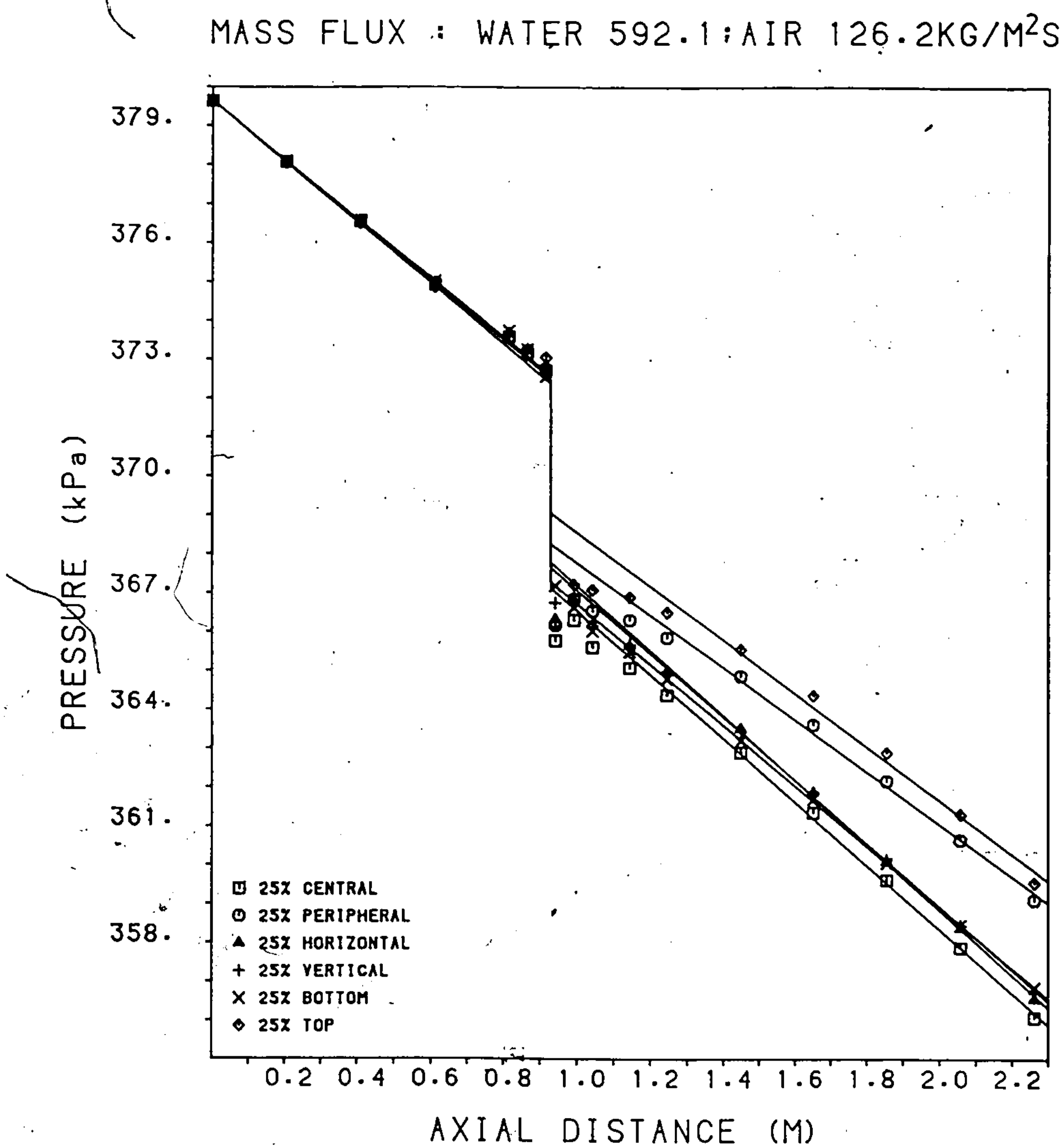


Figure G.1: Two-phase Pressure Distributions for the 25% Obstructions with a 126.2 kg/m^{2}s Air Mass Flux

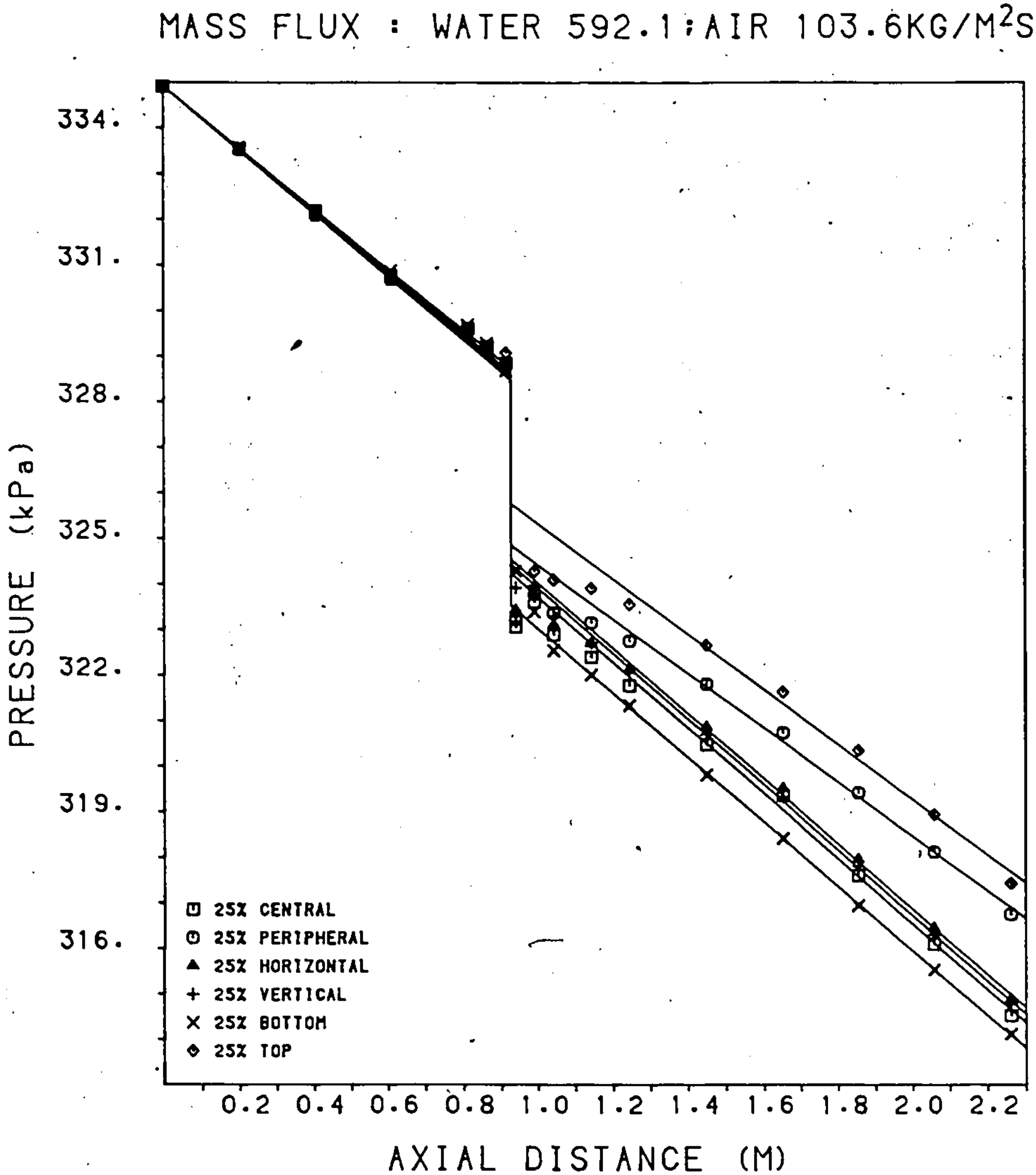


Figure G.2: Two-phase Pressure Distributions for the 25% Obstructions with a 103.6 kg/m^2s Air Mass Flux

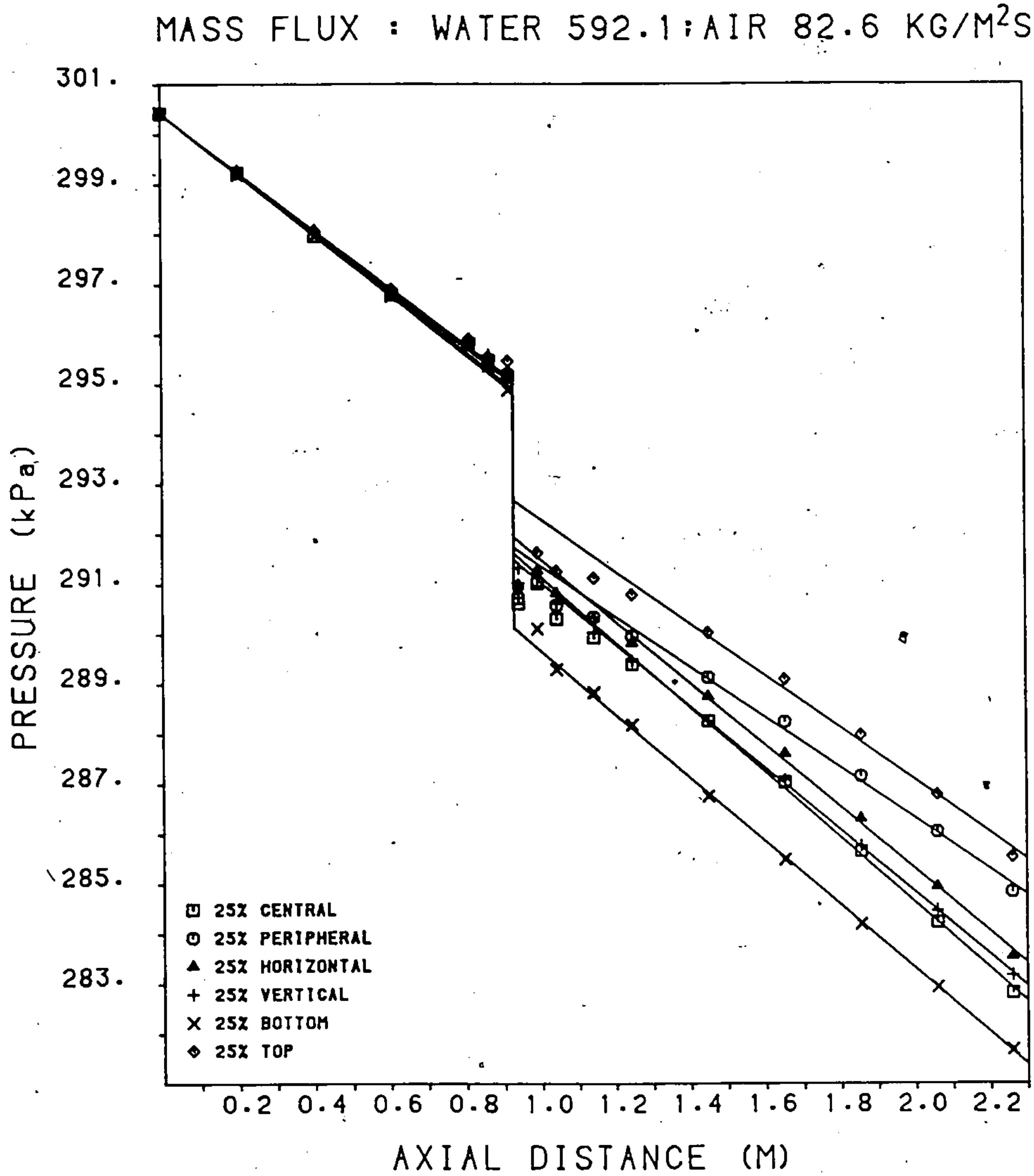


Figure G.3: Two-phase Pressure Distributions for the 25% Obstructions with a 82.6 kg/m^2s Air Mass Flux

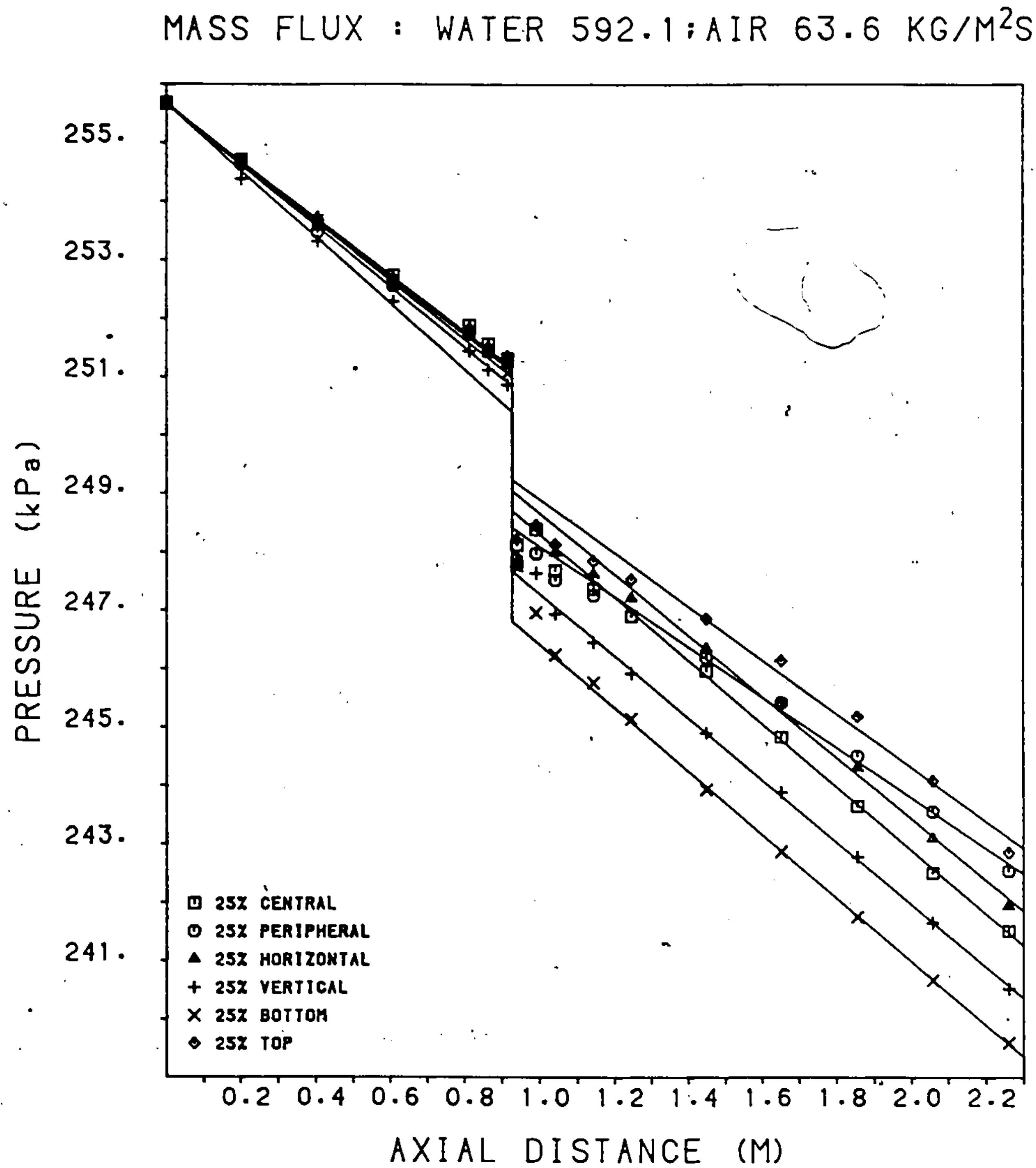


Figure G.4: Two-phase Pressure Distributions for the 25% Obstructions with a 63.6 kg/m²s Air Mass Flux

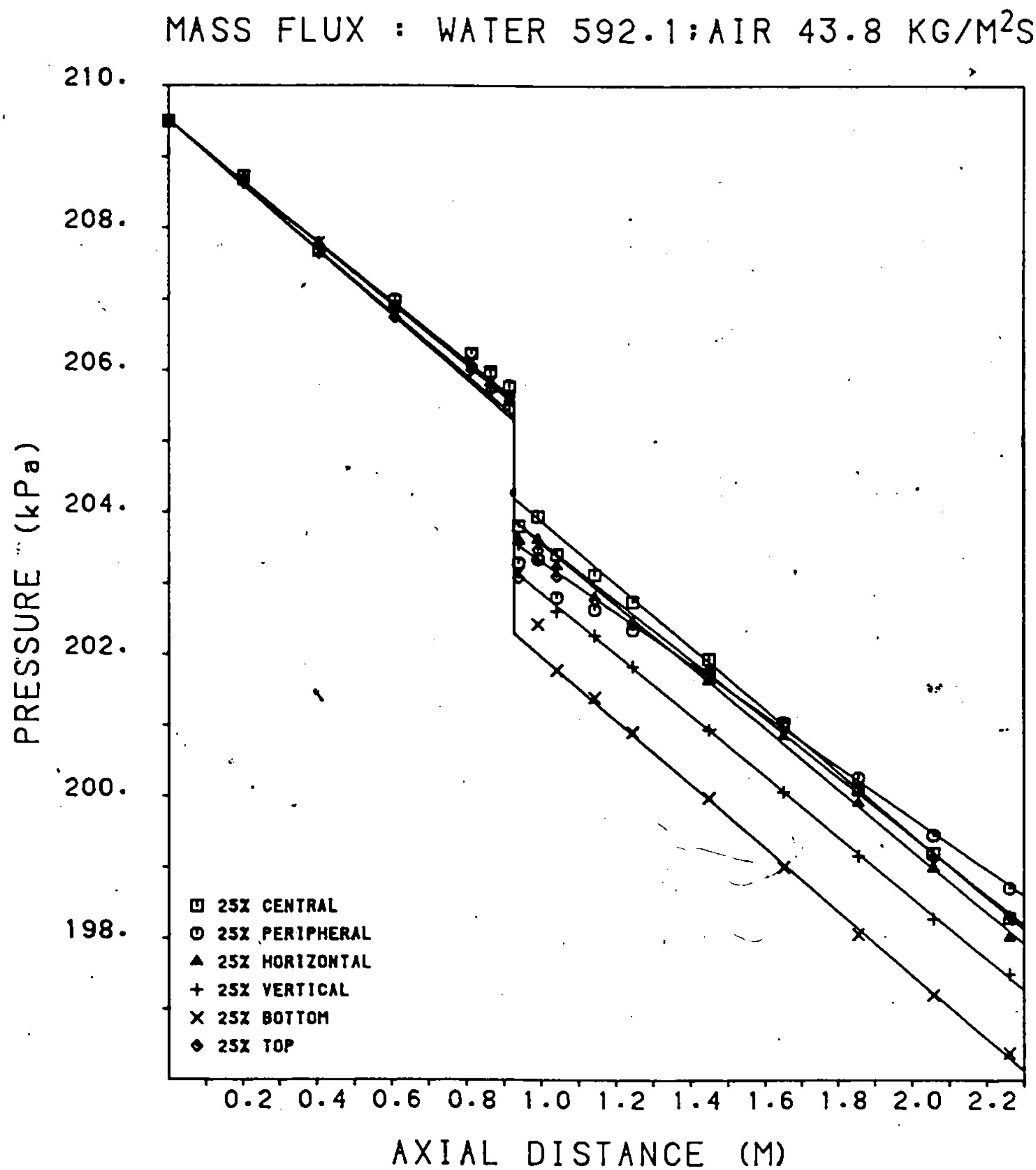


Figure G.5: Two-phase Pressure Distributions for the 25% Obstructions with a 43.8 kg/m²s Air Mass Flux

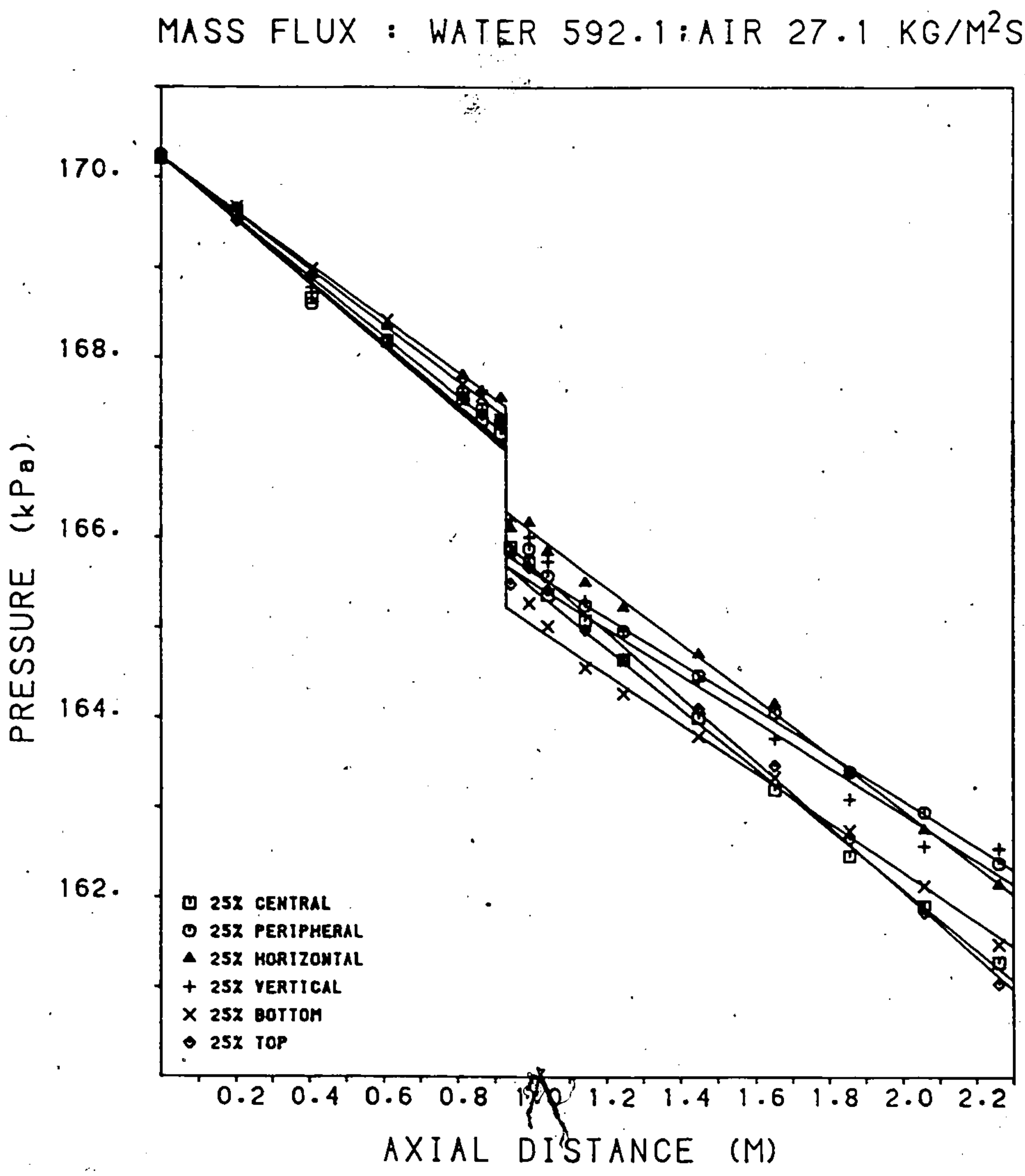


Figure G.6: Two-phase Pressure Distributions for the 25% Obstructions with a 27.3 kg/m^2s Air Mass Flux

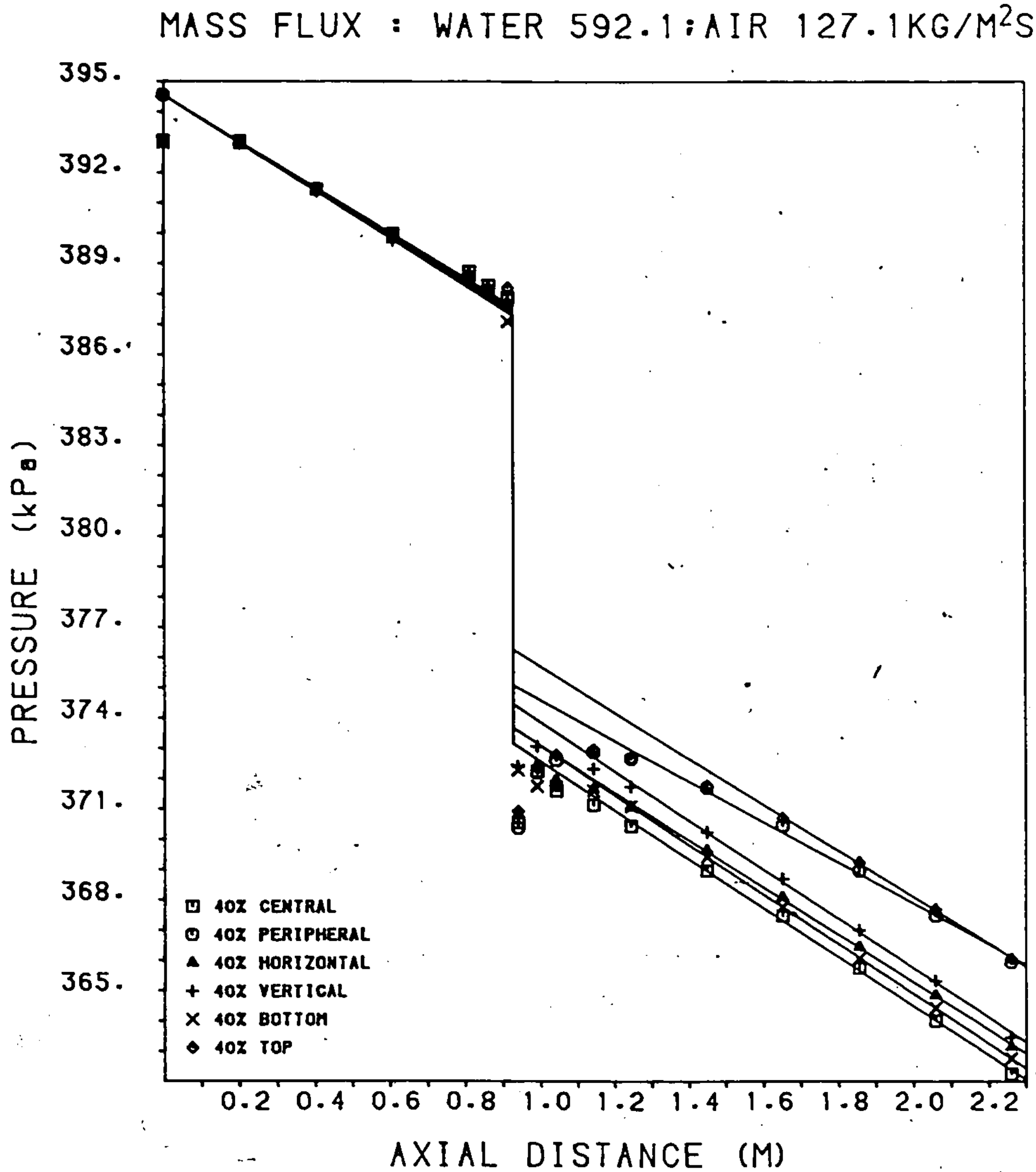


Figure G.7: Two-phase Pressure Distributions for the 40% Obstructions with a 127.1 kg/m²s Air Mass Flux

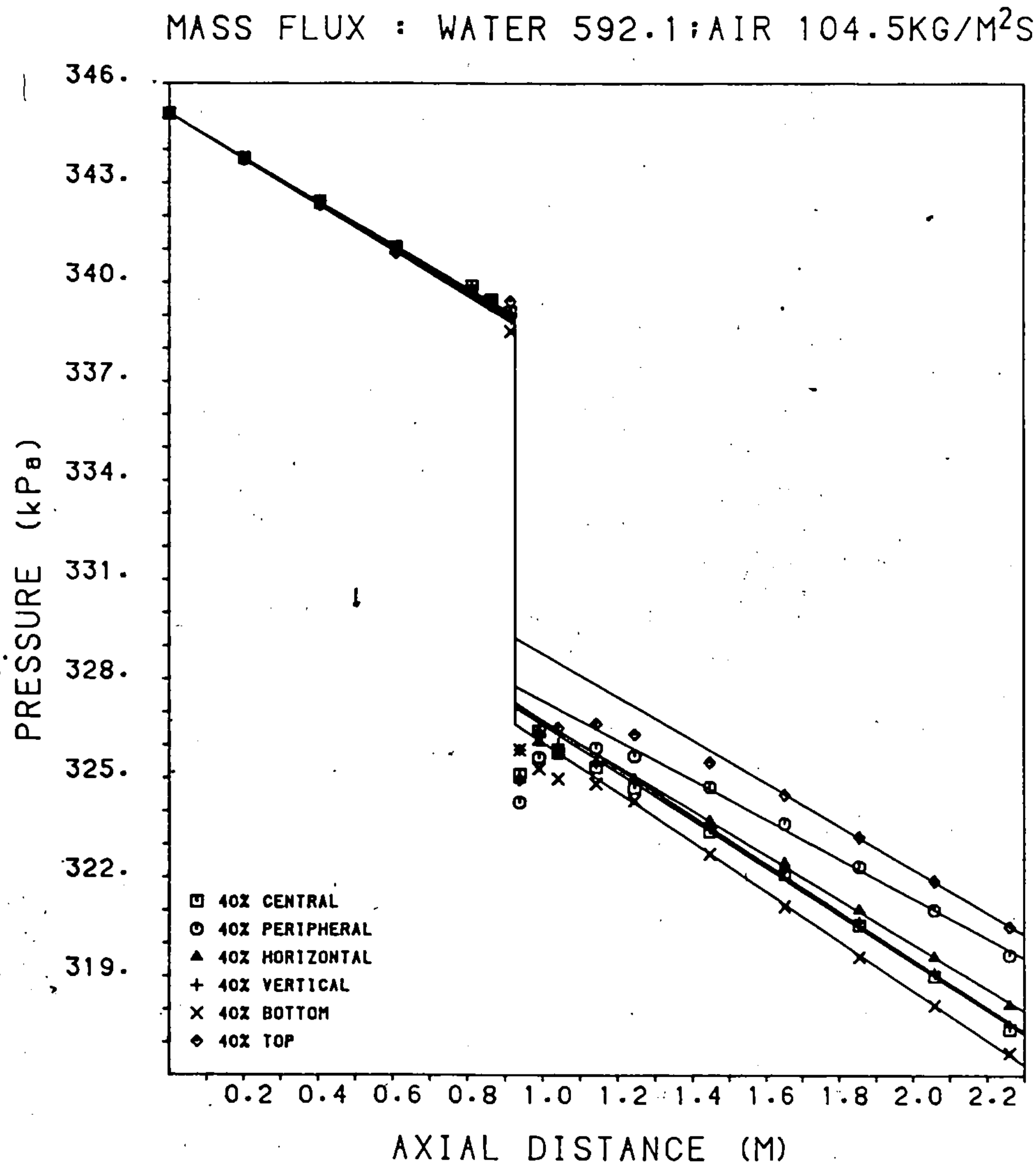


Figure G.8: Two-phase Pressure Distributions for the 40% Obstructions with a 104.5 kg/m^{2}s Air Mass Flux

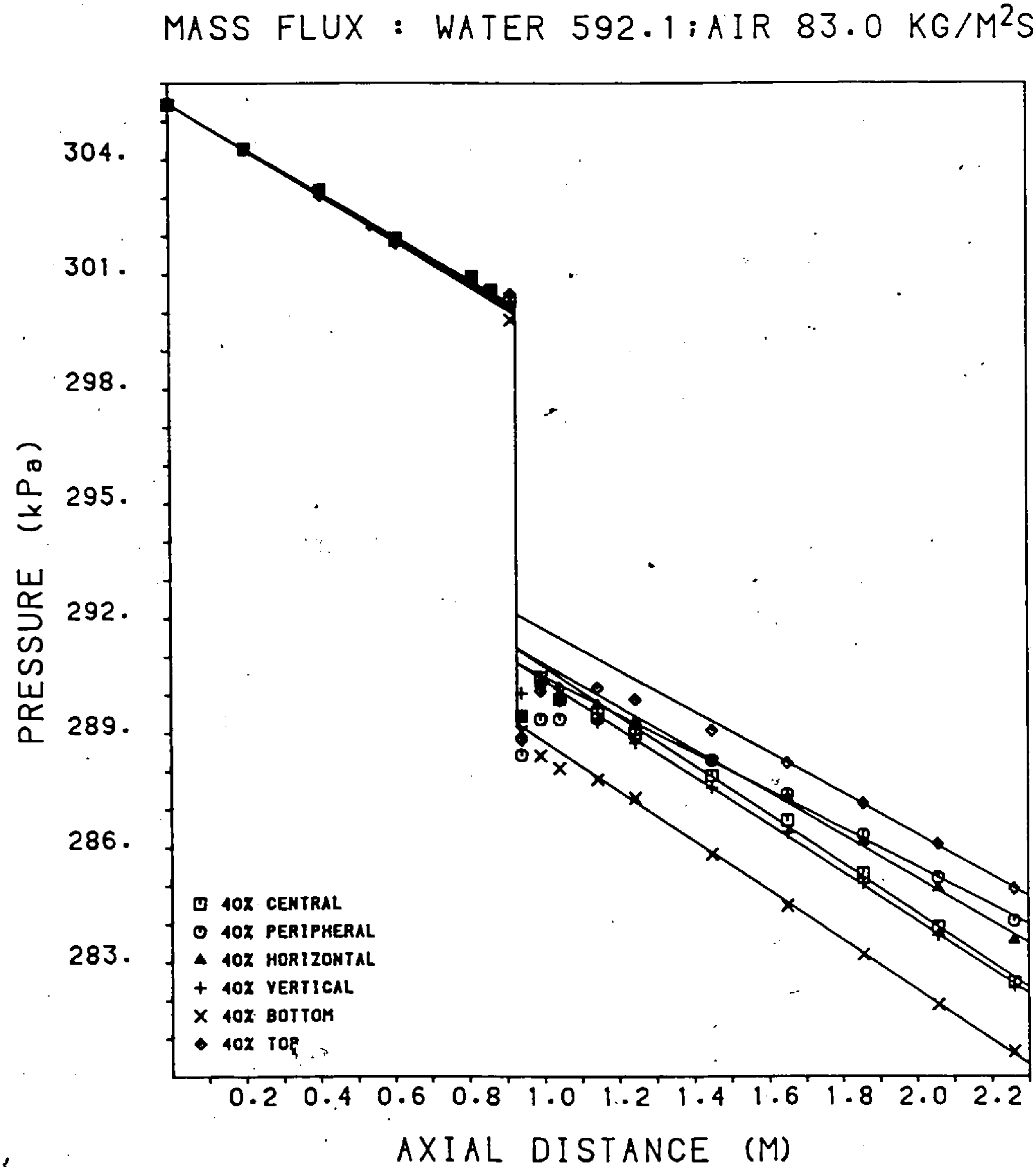


Figure G.9: Two-phase Pressure Distributions for the 40% Obstructions with a 83.0 kg/m²s Air Mass Flux

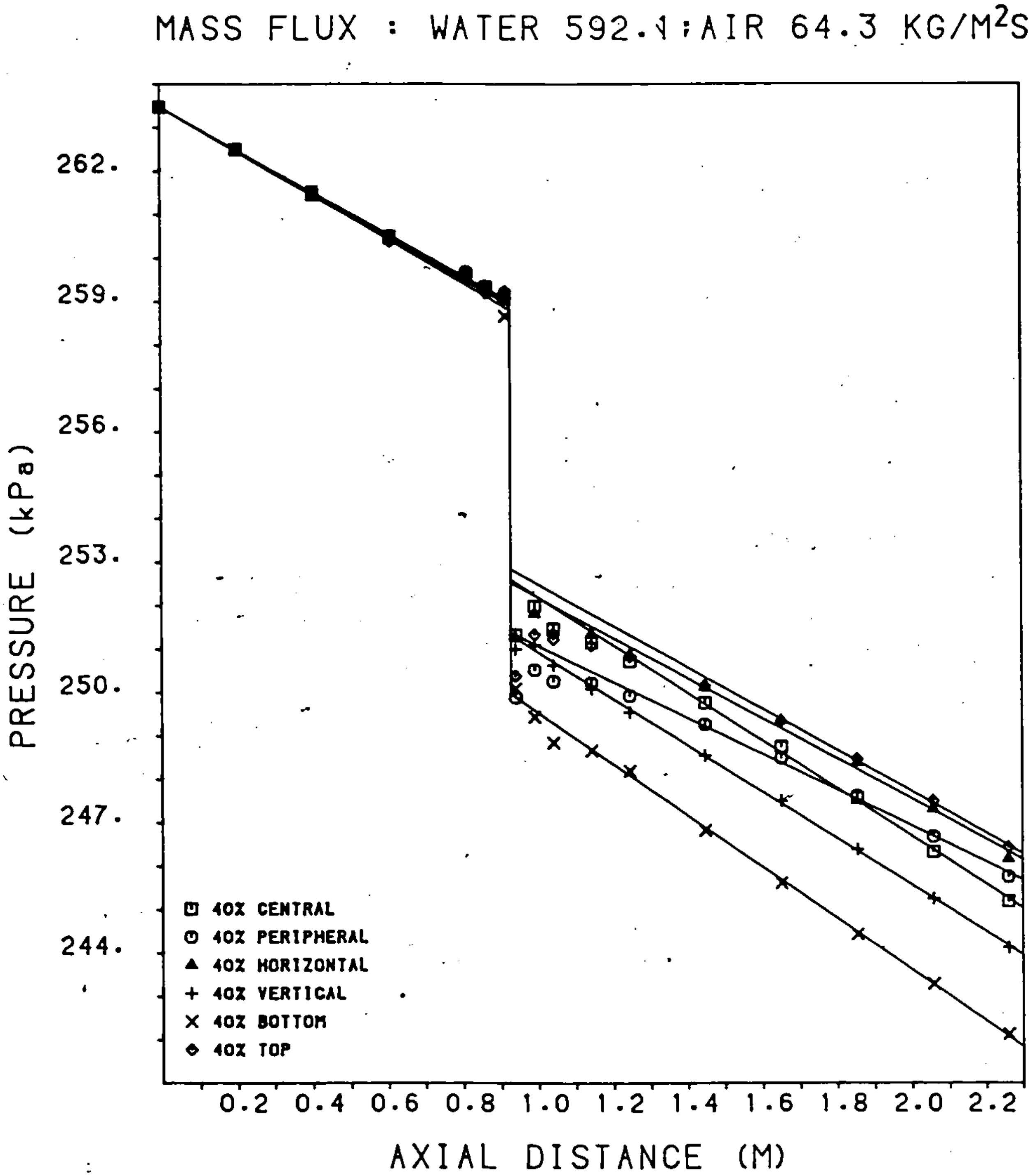


Figure G.10: Two-phase Pressure Distributions for the 40% Obstructions with a 64.3 kg/m^{2}s Air Mass Flux

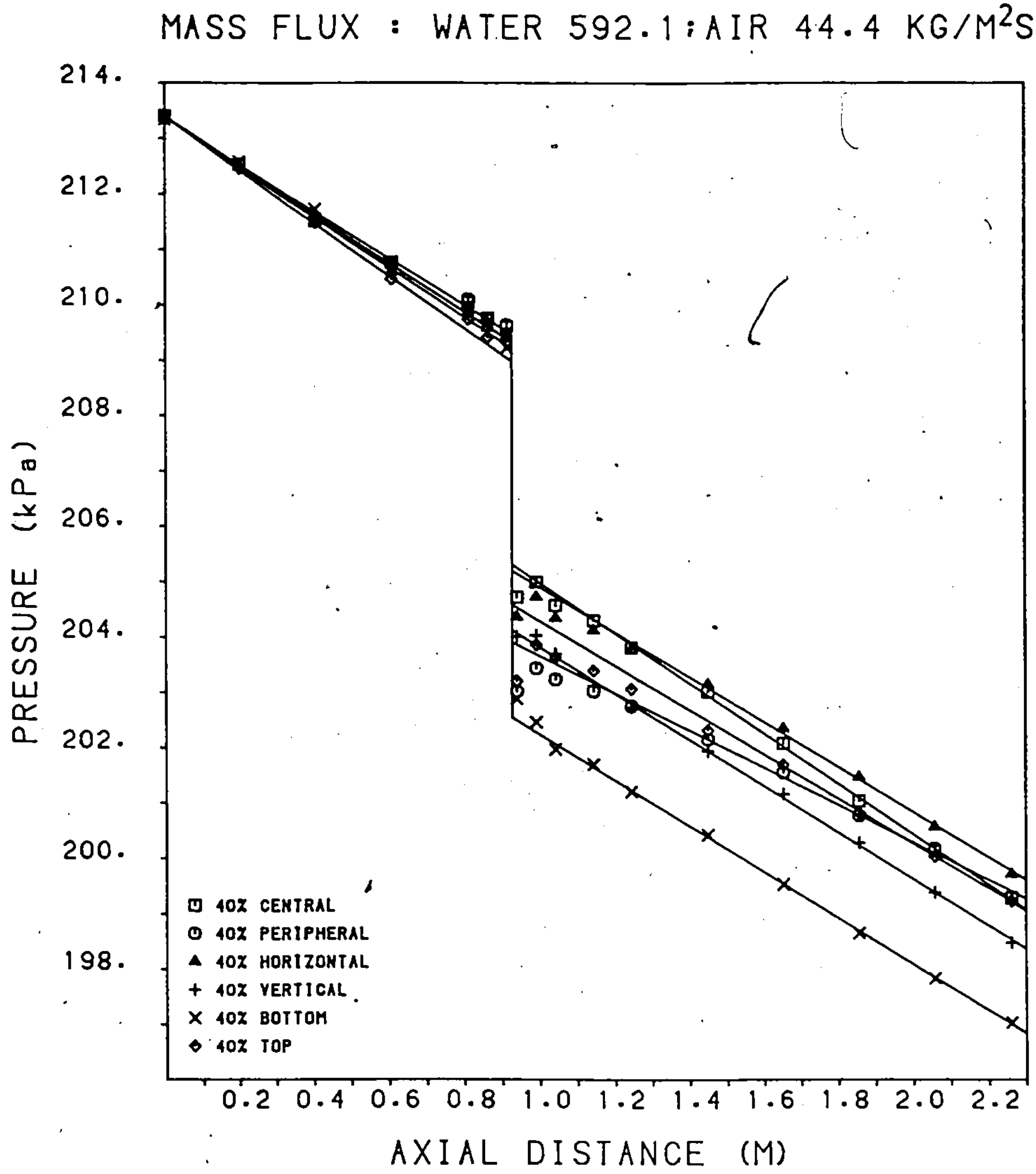


Figure G.11: Two-phase Pressure Distributions for the 40% Obstructions with a 44.4 kg/m²s Air Mass Flux

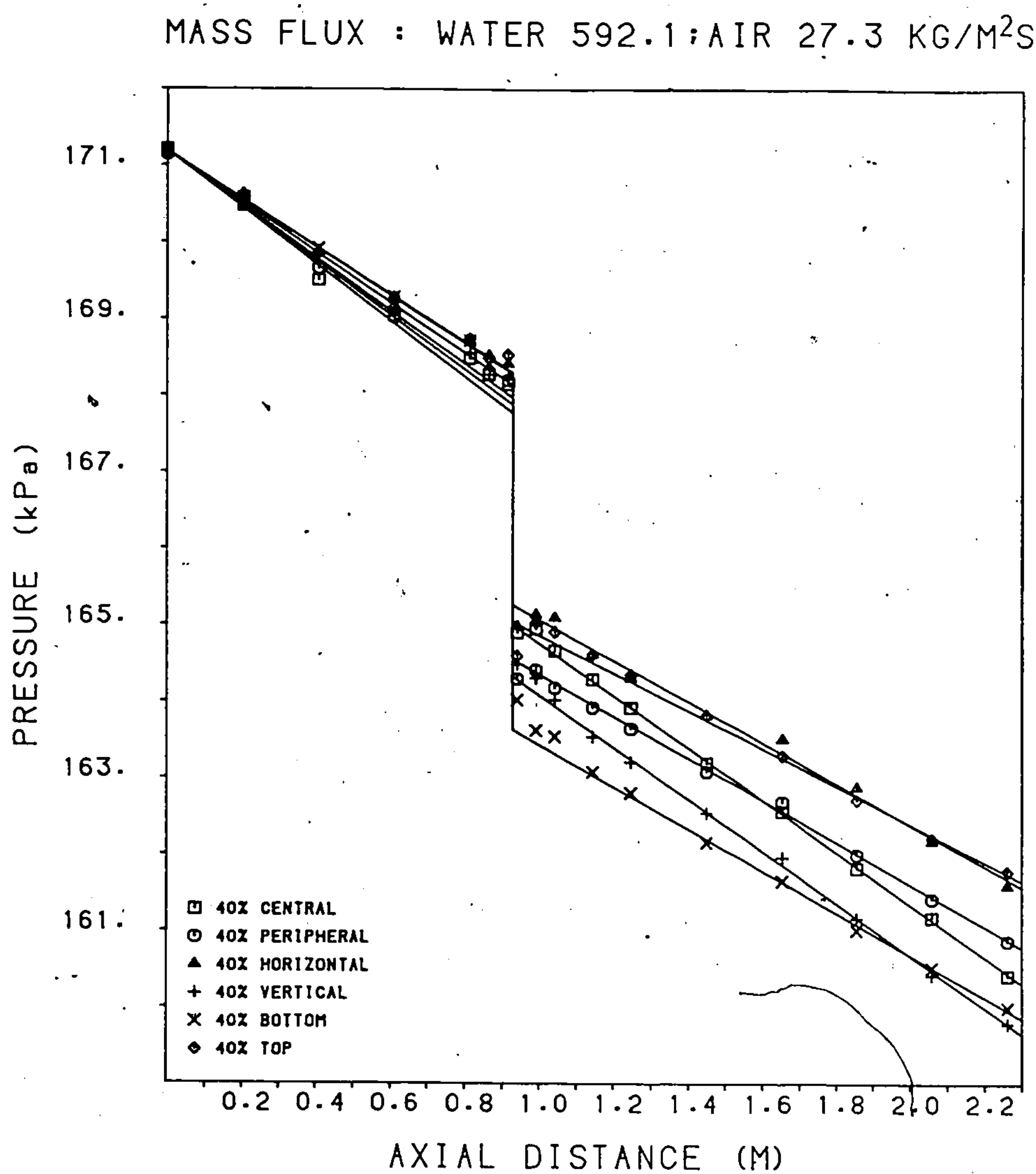


Figure G.12: Two-phase Pressure Distributions for the 40% Obstructions with a 27.3 kg/m^{2}s Air Mass Flux

Appendix H

SINGLE-PHASE PRESSURE DISTRIBUTIONS

FOR VARIOUS BUNDLE ARRANGEMENTS IN EXPERIMENT B

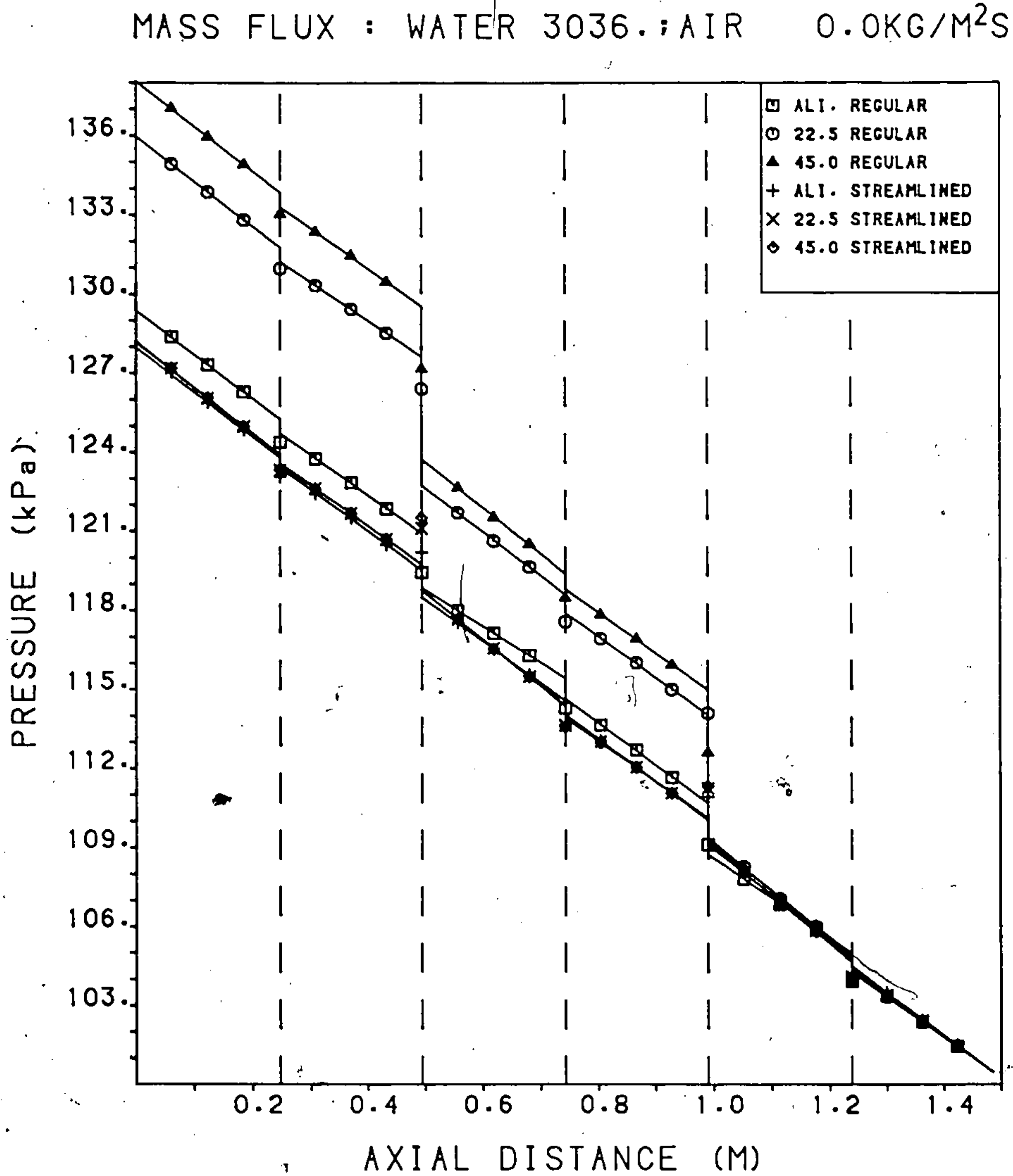


Figure H.1: Single-phase Pressure Distributions with a 3036 kg/m²s Liquid Mass Flux

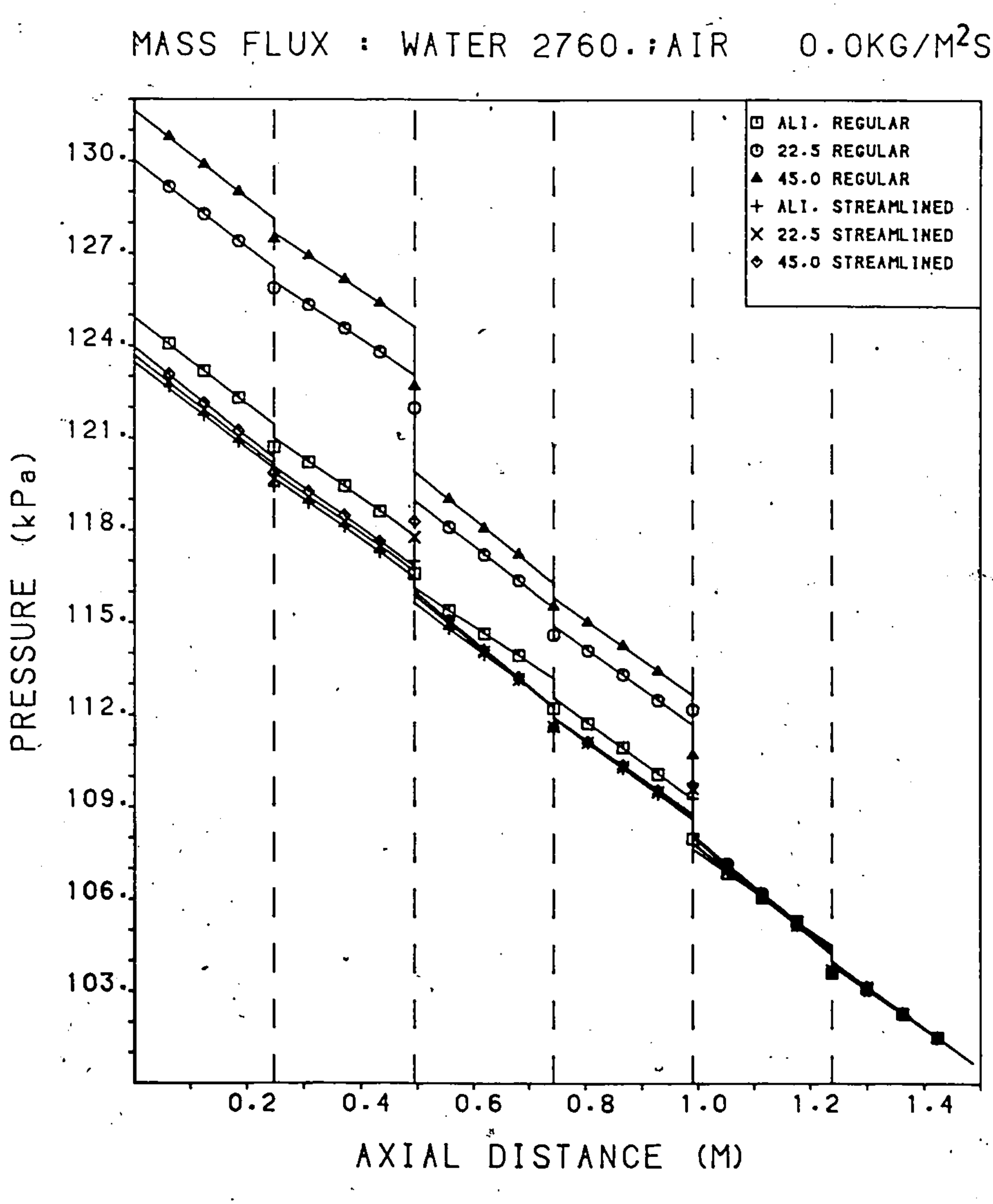


Figure H.2: Single-phase Pressure Distributions with a 2760 kg/m^{2}s Liquid Mass Flux

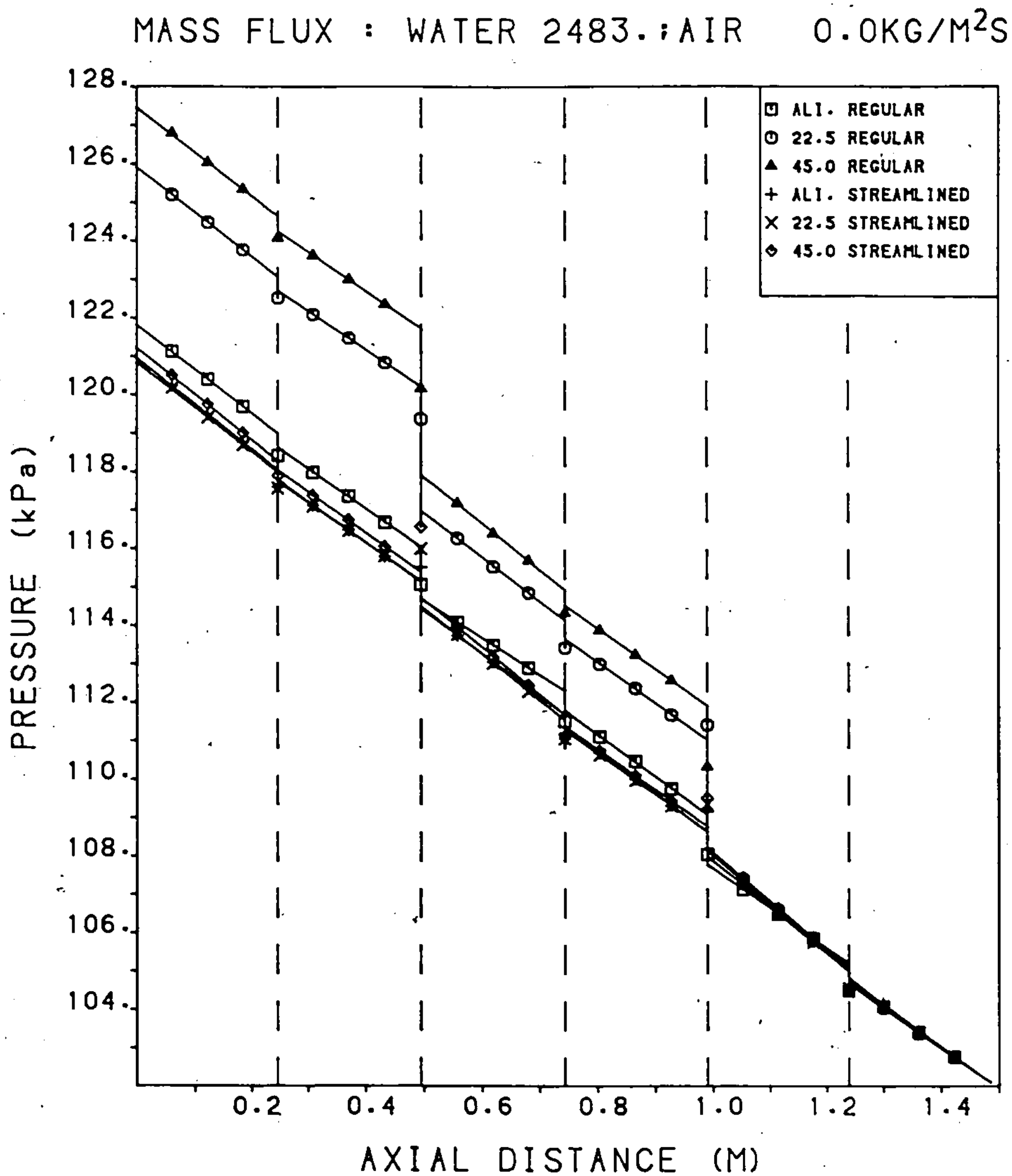


Figure H.3: Single-phase Pressure Distributions with a 2483 kg/m²s Liquid Mass Flux

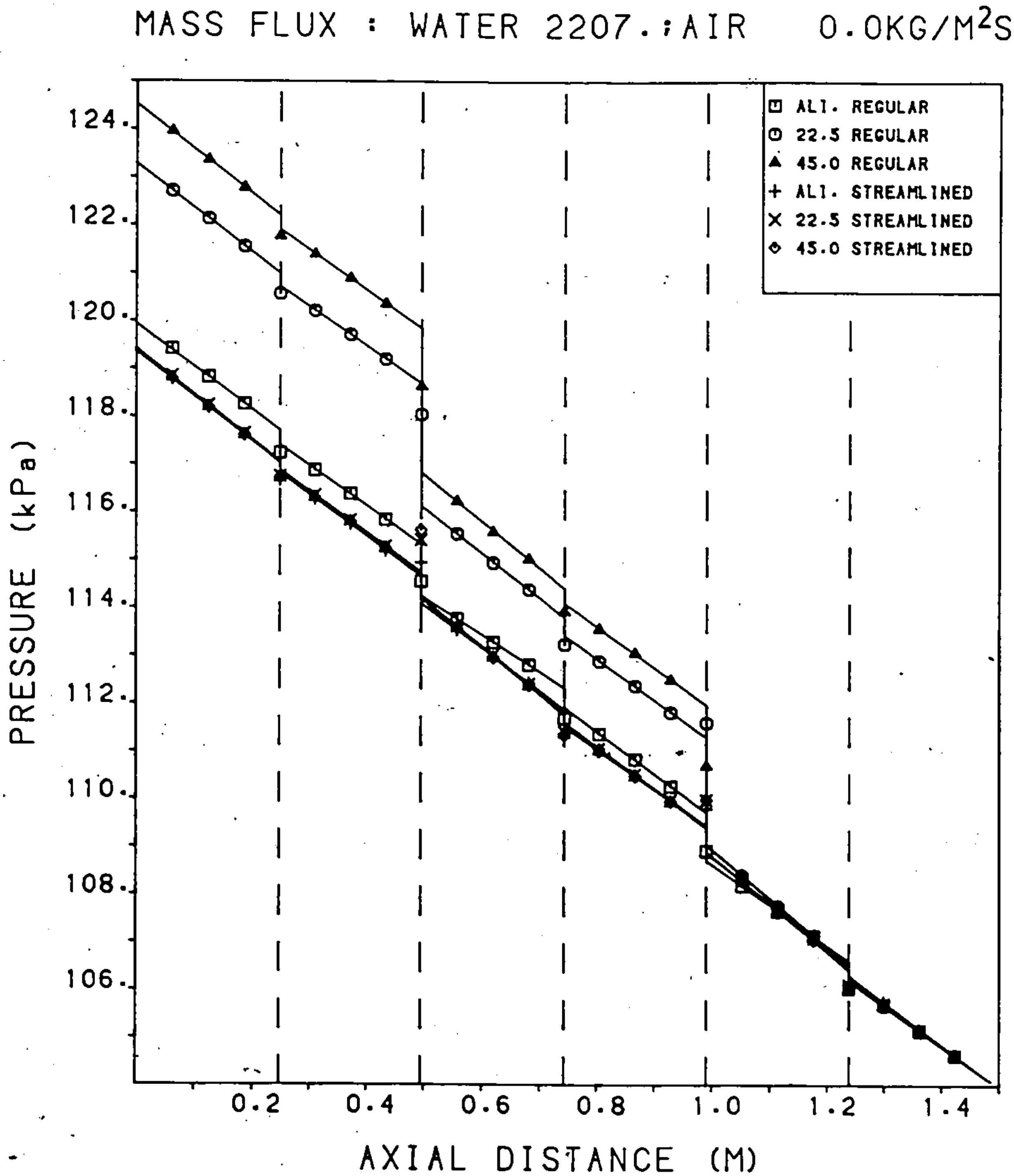


Figure H.4: Single-phase Pressure Distributions with a 2207 kg/m²s Liquid Mass Flux

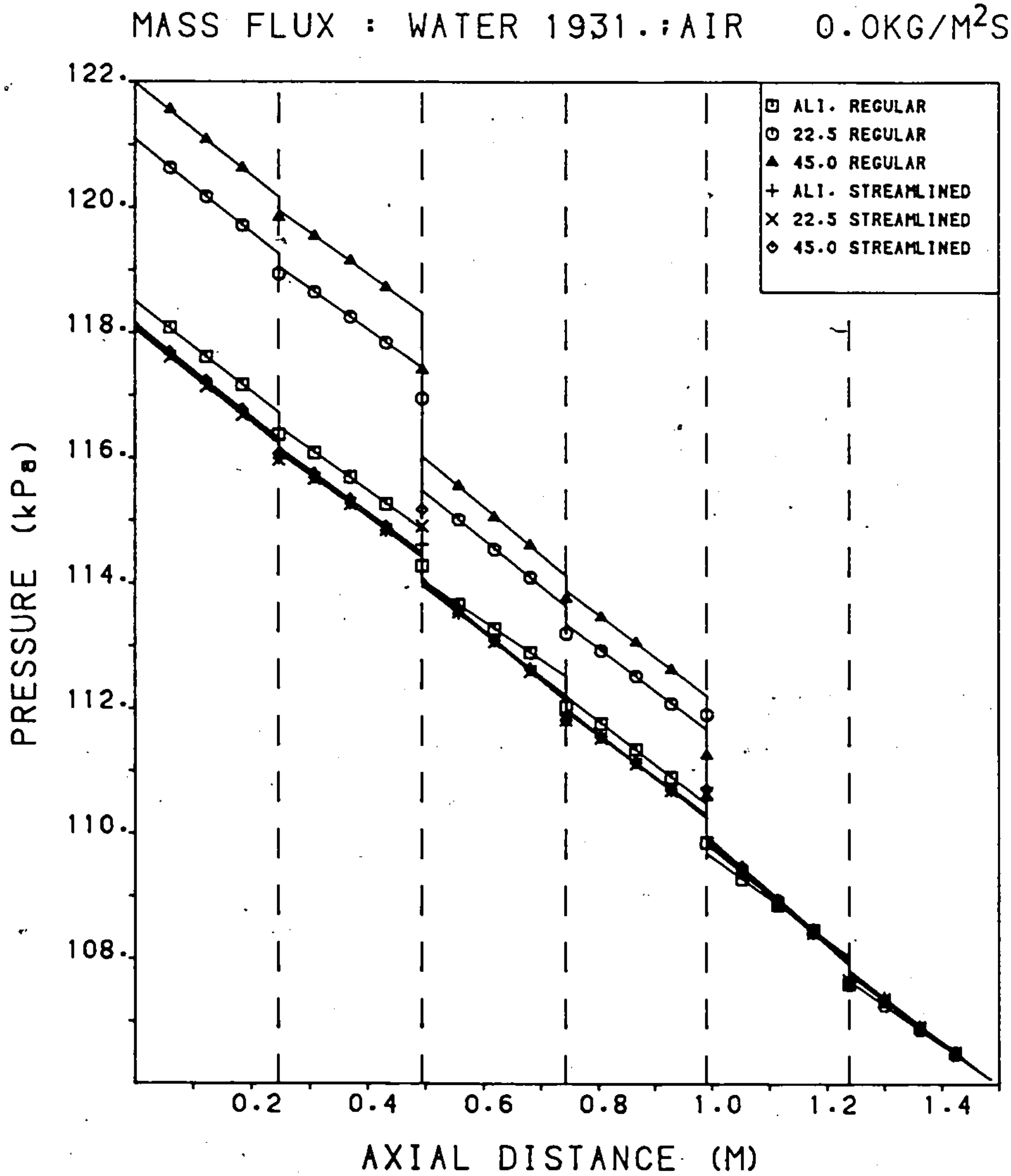


Figure H.5: Single-phase Pressure Distributions with a 1931 kg/m²s Liquid Mass Flux

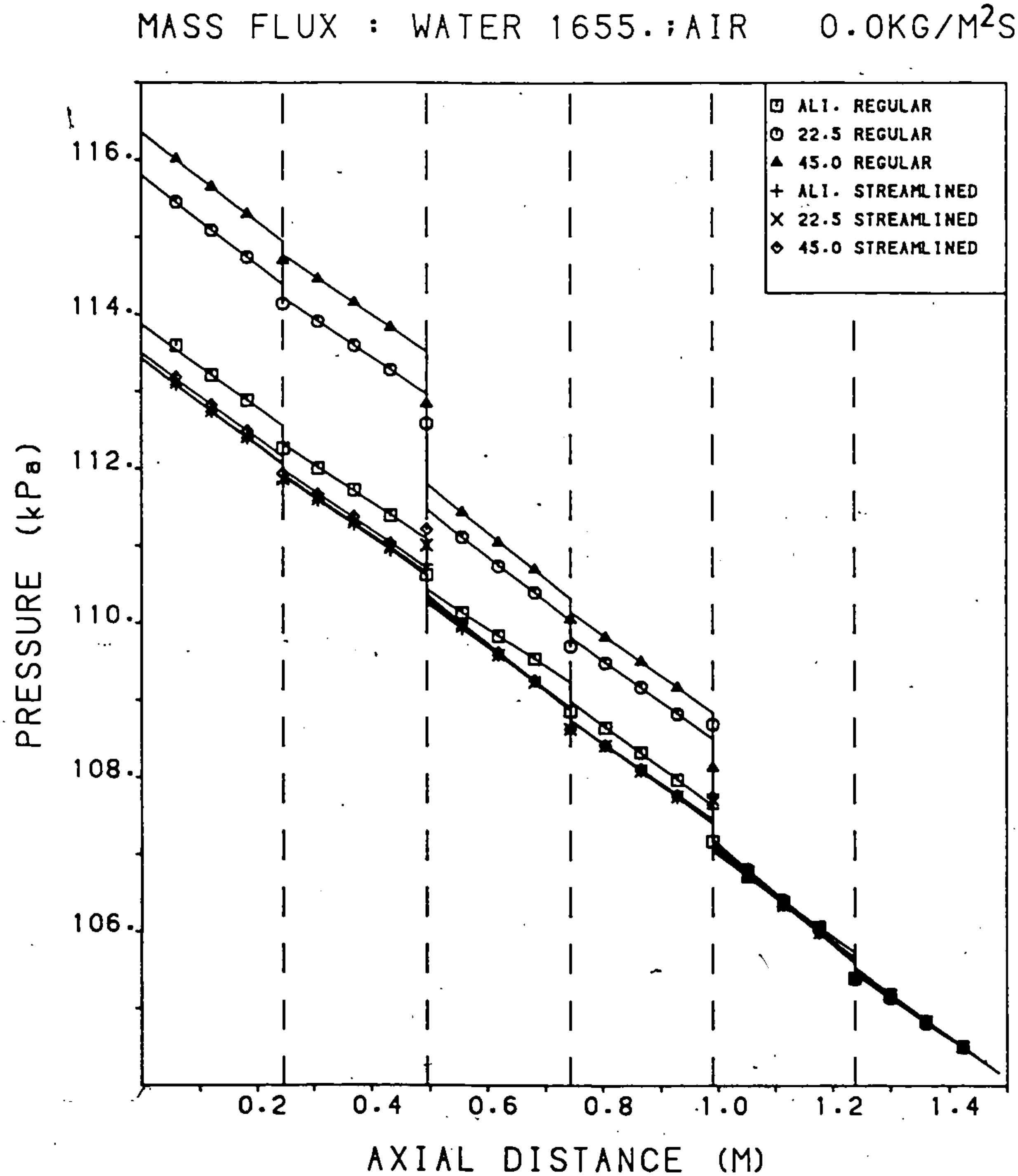


Figure H.6: Single-phase Pressure Distributions with a 1655 kg/m²s Liquid Mass Flux

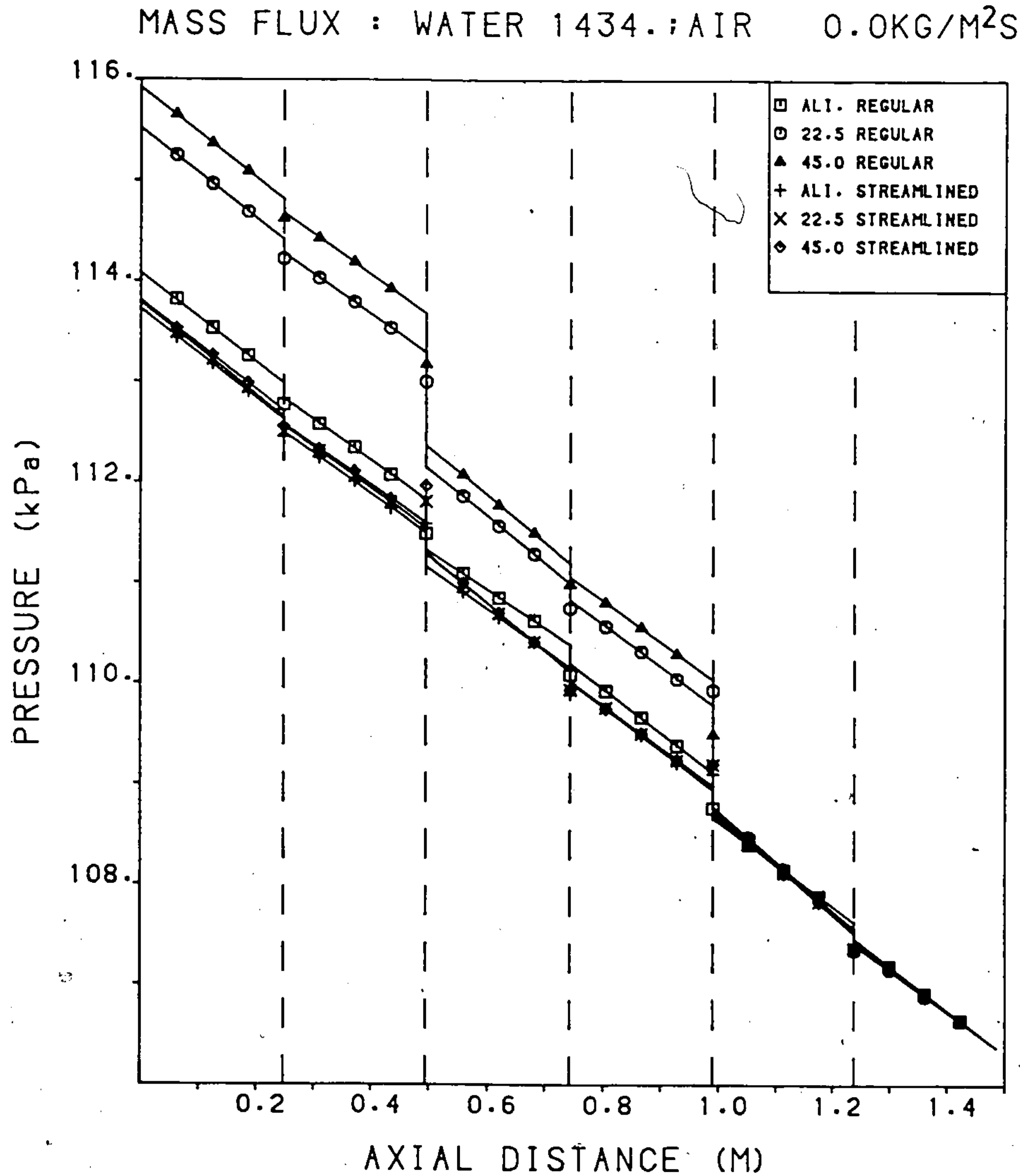


Figure H.7: Single-phase Pressure Distributions with a $1434\ kg/m^2s$ Liquid Mass Flux

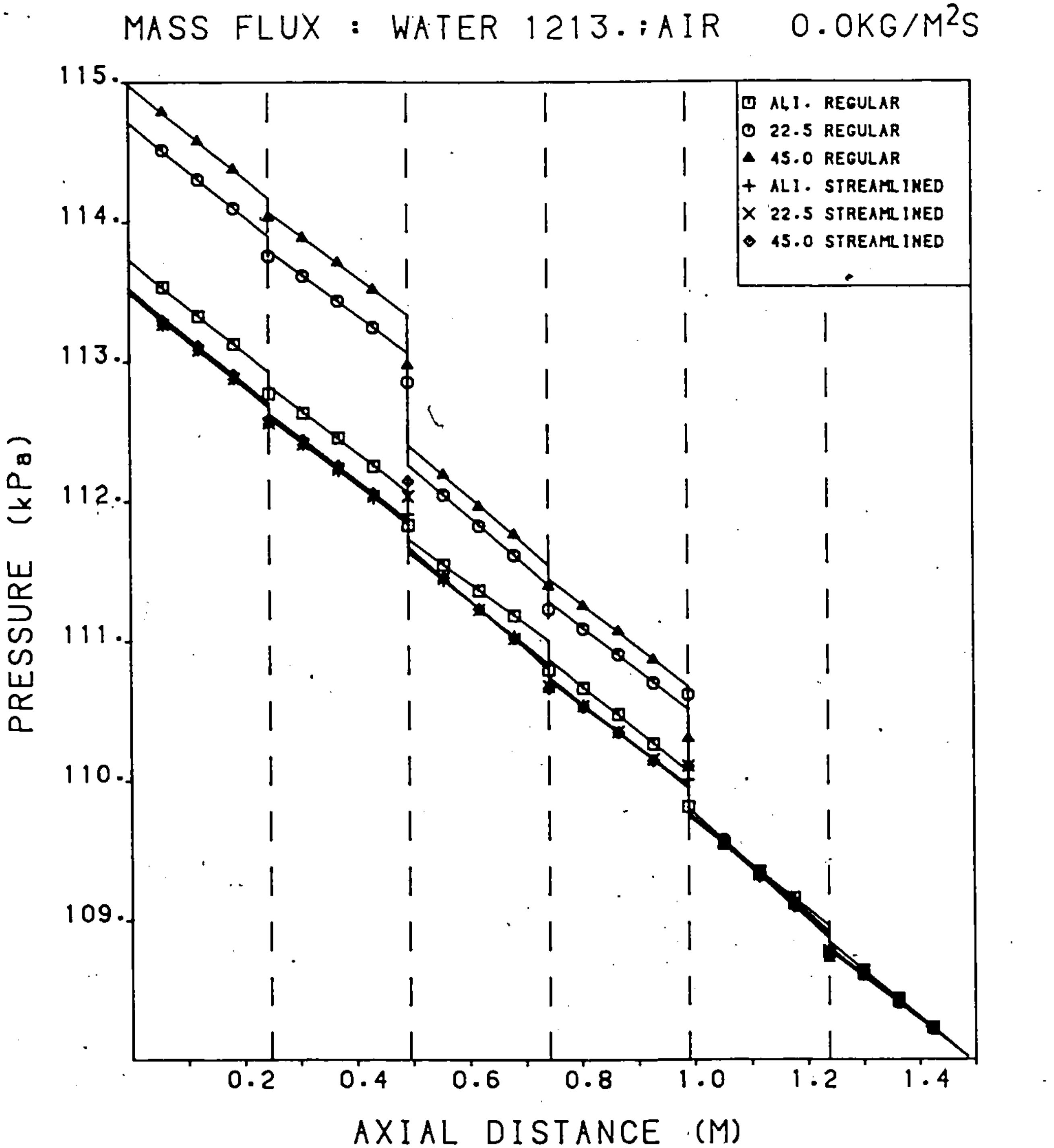


Figure H.8: Single-phase Pressure Distributions with a 1213 kg/m^{2}s Liquid Mass Flux

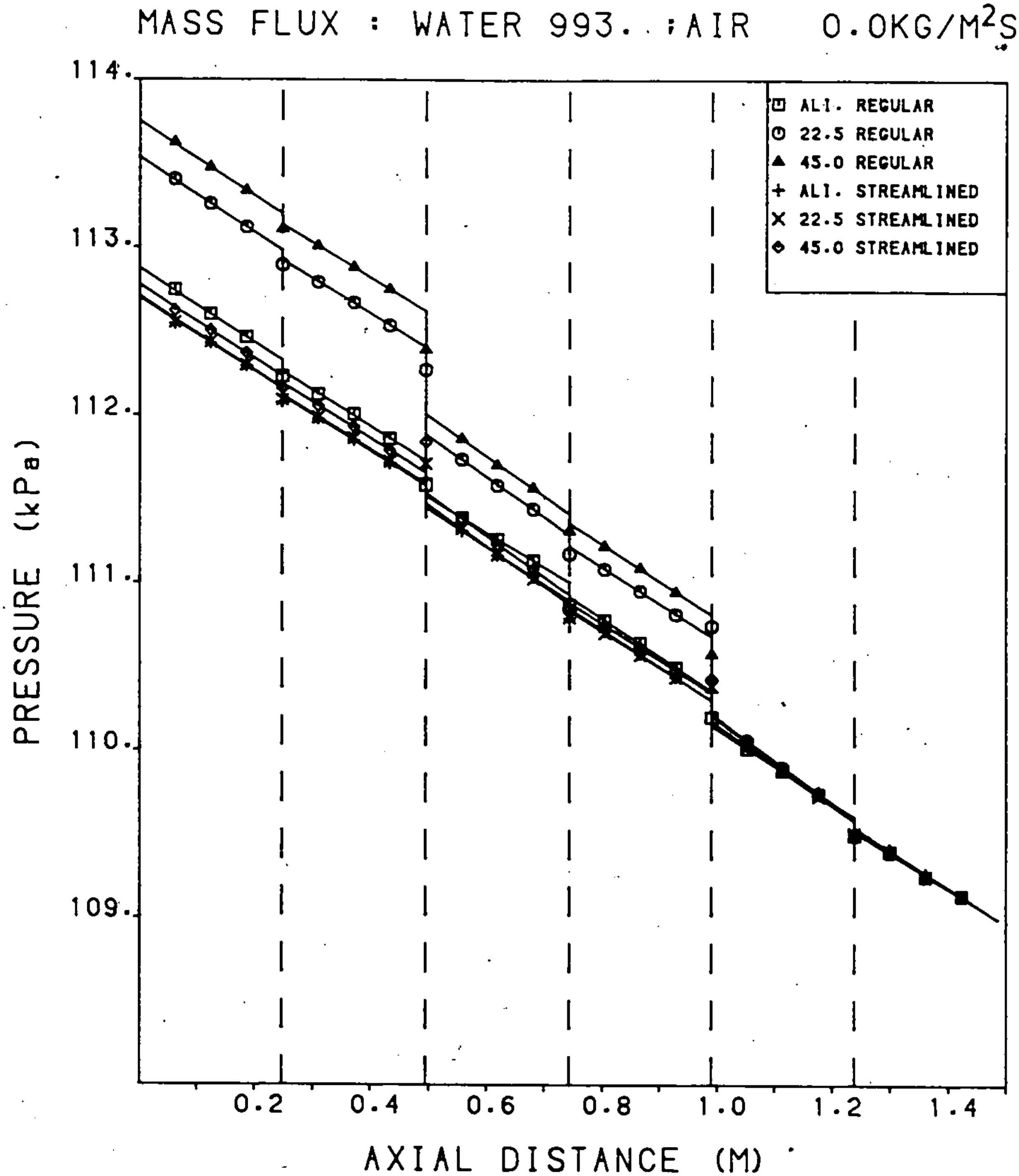


Figure H.9: Single-phase Pressure Distributions with a 993 kg/m^2s Liquid Mass Flux

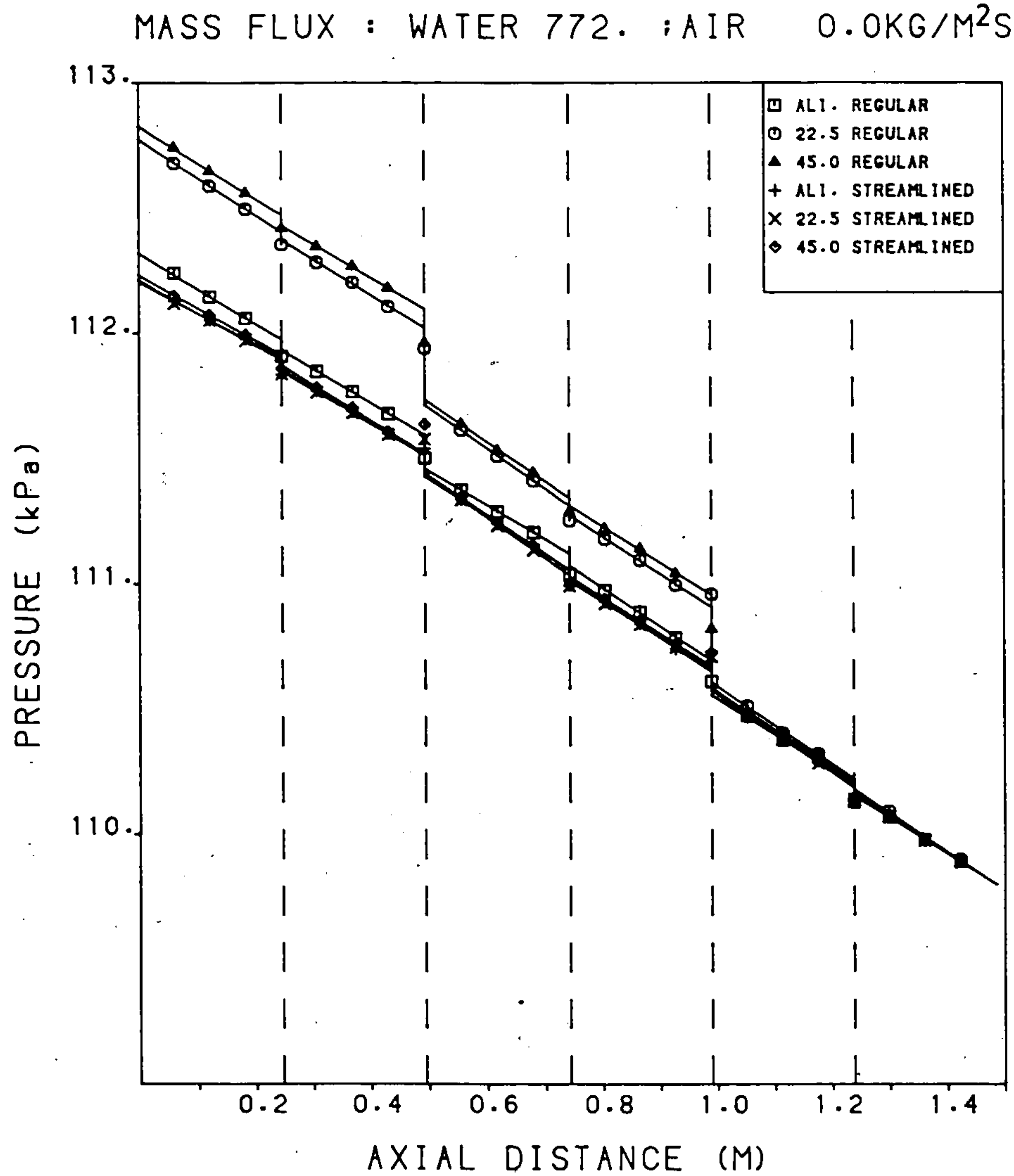


Figure H.10: Single-phase Pressure Distributions with a 772 kg/m²s Liquid Mass Flux

Appendix I

TWO-PHASE PRESSURE DISTRIBUTIONS

FOR VARIOUS BUNDLE ARRANGEMENTS IN EXPERIMENT B

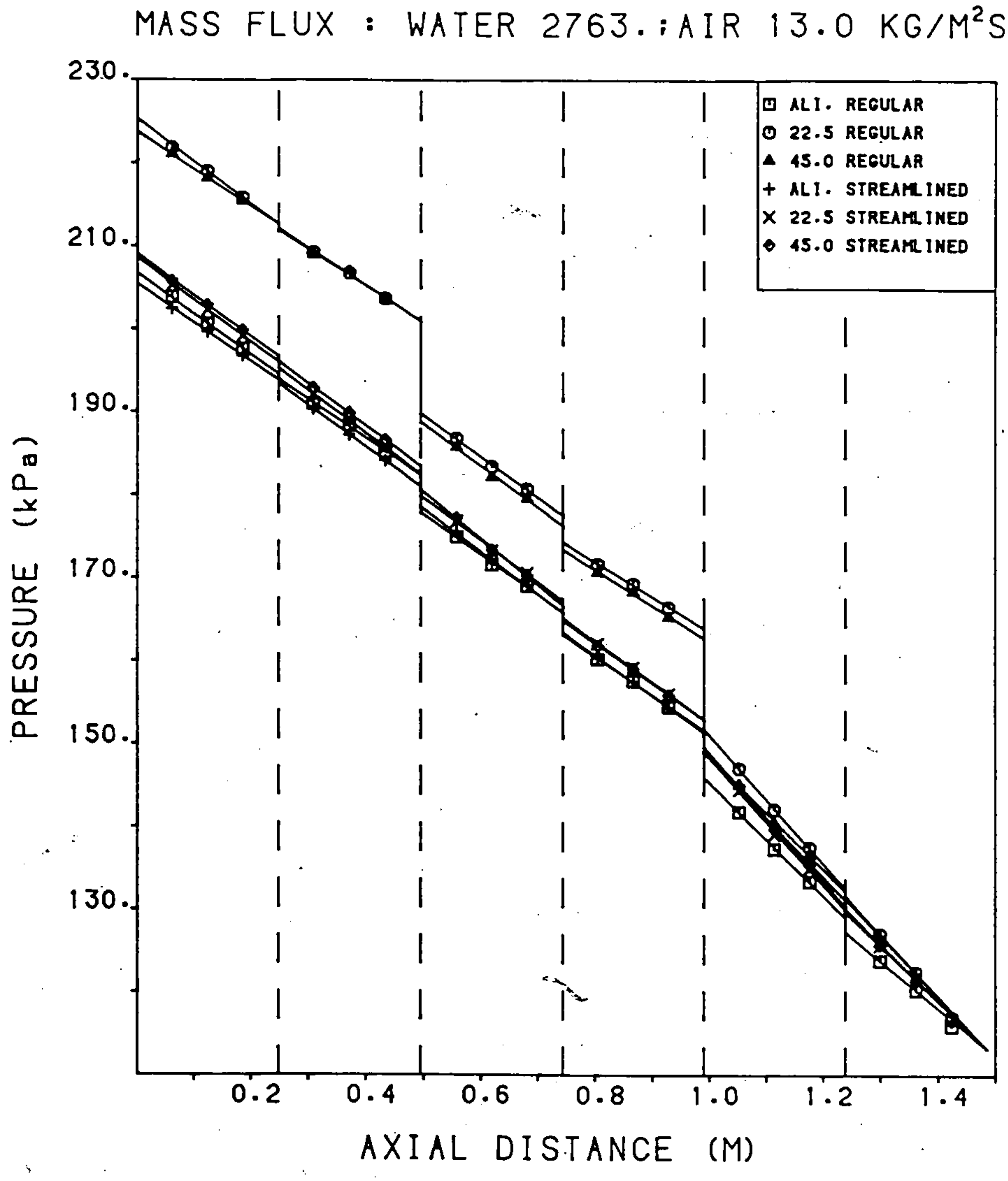


Figure I.1: Two-phase Pressure Distributions with 2763 kg/m s Liquid Mass Flux and 13 kg/m²s Air Mass Flux

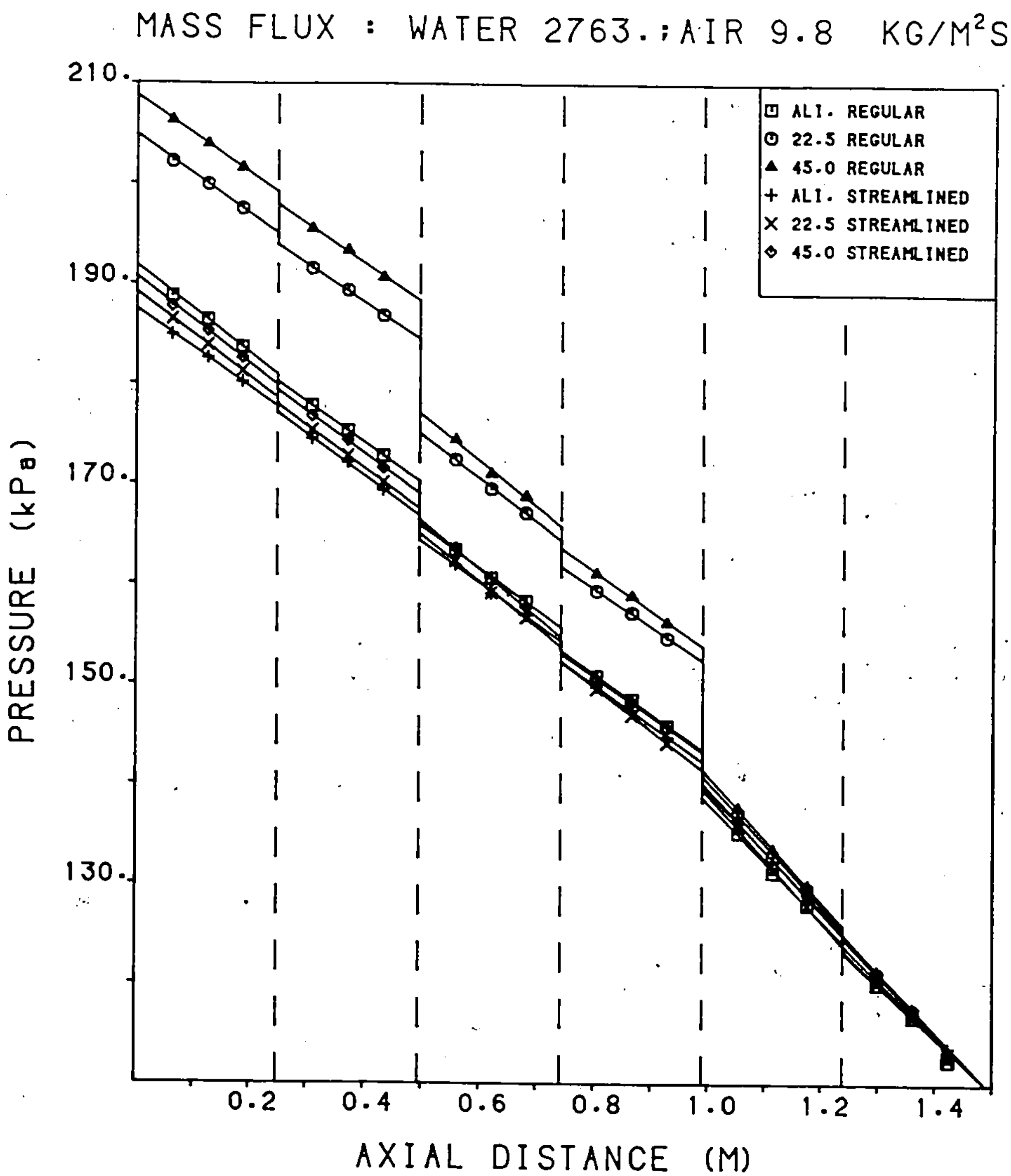


Figure I.2: Two-phase Pressure Distributions with 2763 kg/m s Liquid Mass Flux and 9.8 kg/m²s Air Mass Flux

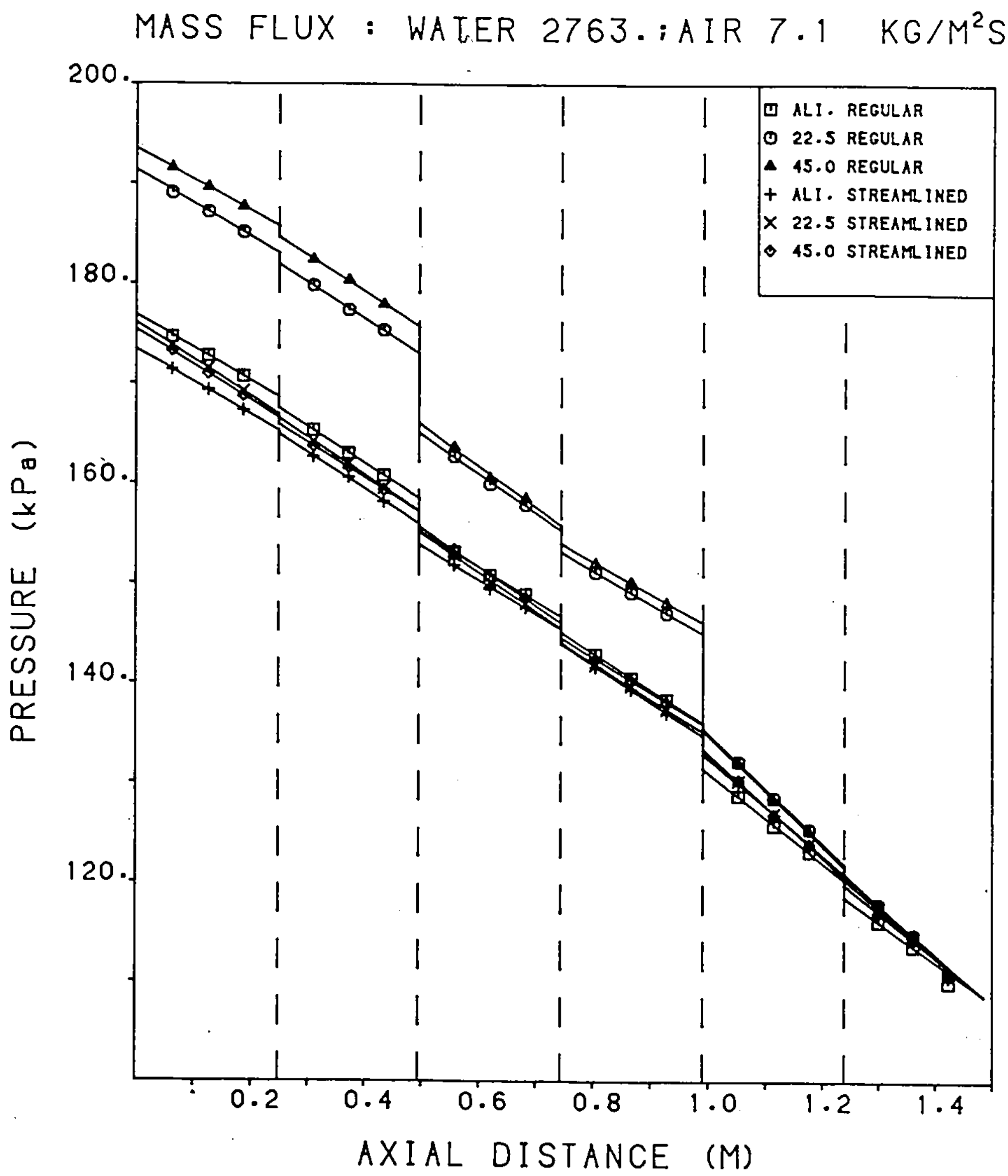


Figure I.3: Two-phase Pressure Distributions with 2763 kg/m s Liquid Mass Flux and 7.1 kg/m²s Air Mass Flux

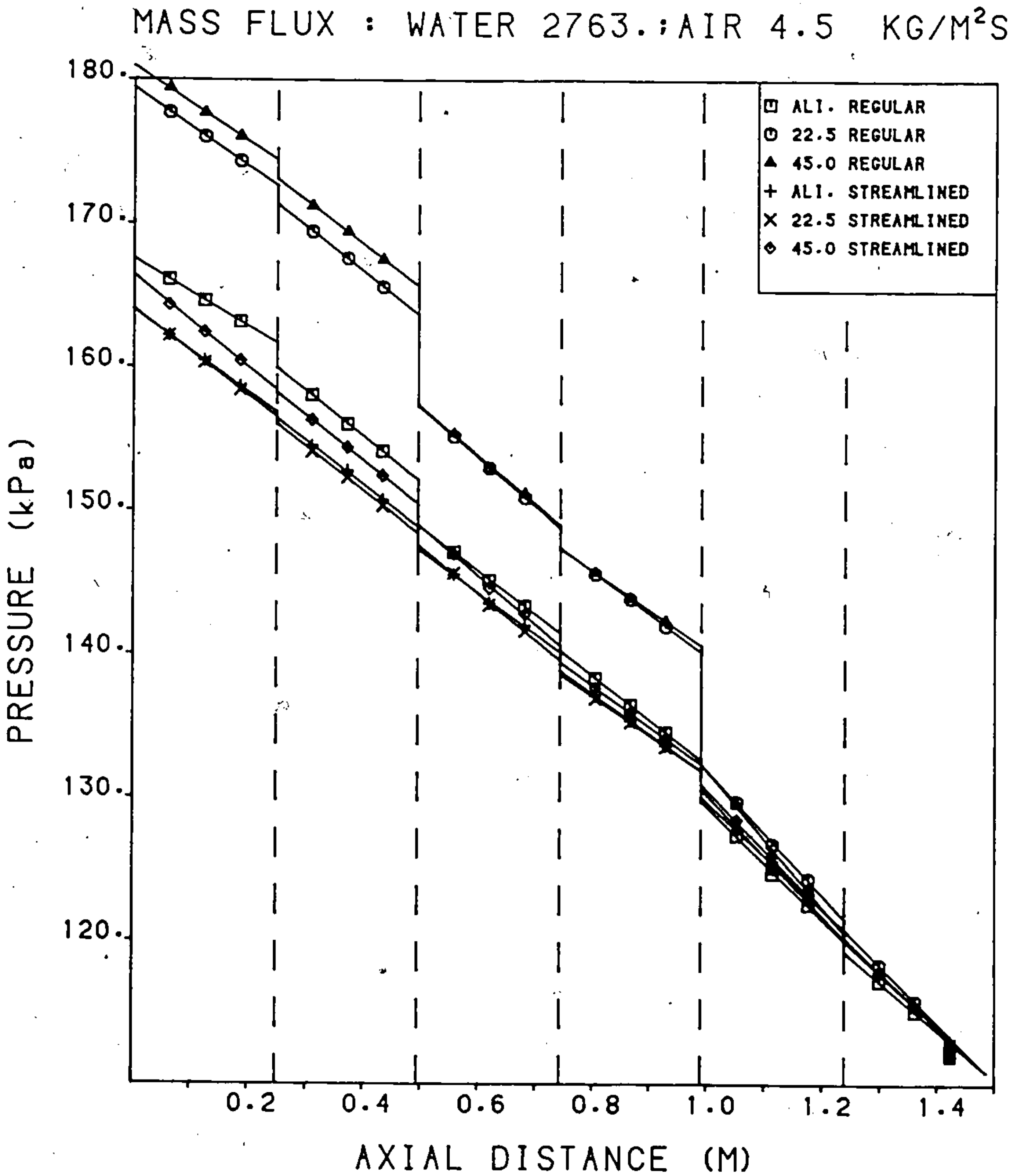


Figure I.4: Two-phase Pressure Distributions with 2763 kg/m s Liquid Mass Flux and 4.5 kg/m²s Air Mass Flux

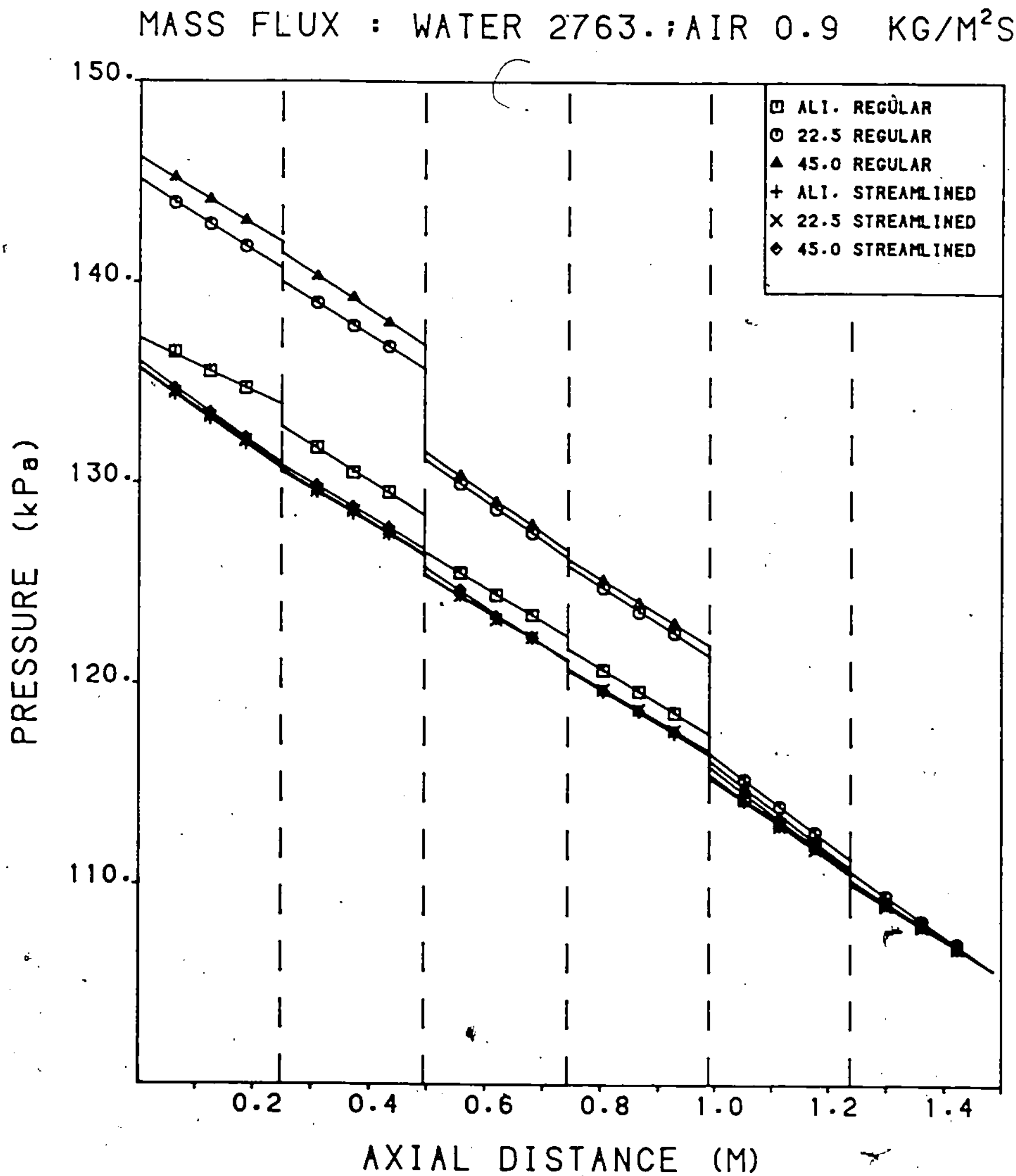


Figure I.5: Two-phase Pressure Distributions with 2763 kg/m s Liquid Mass Flux and 0.9 kg/m^2s Air Mass Flux

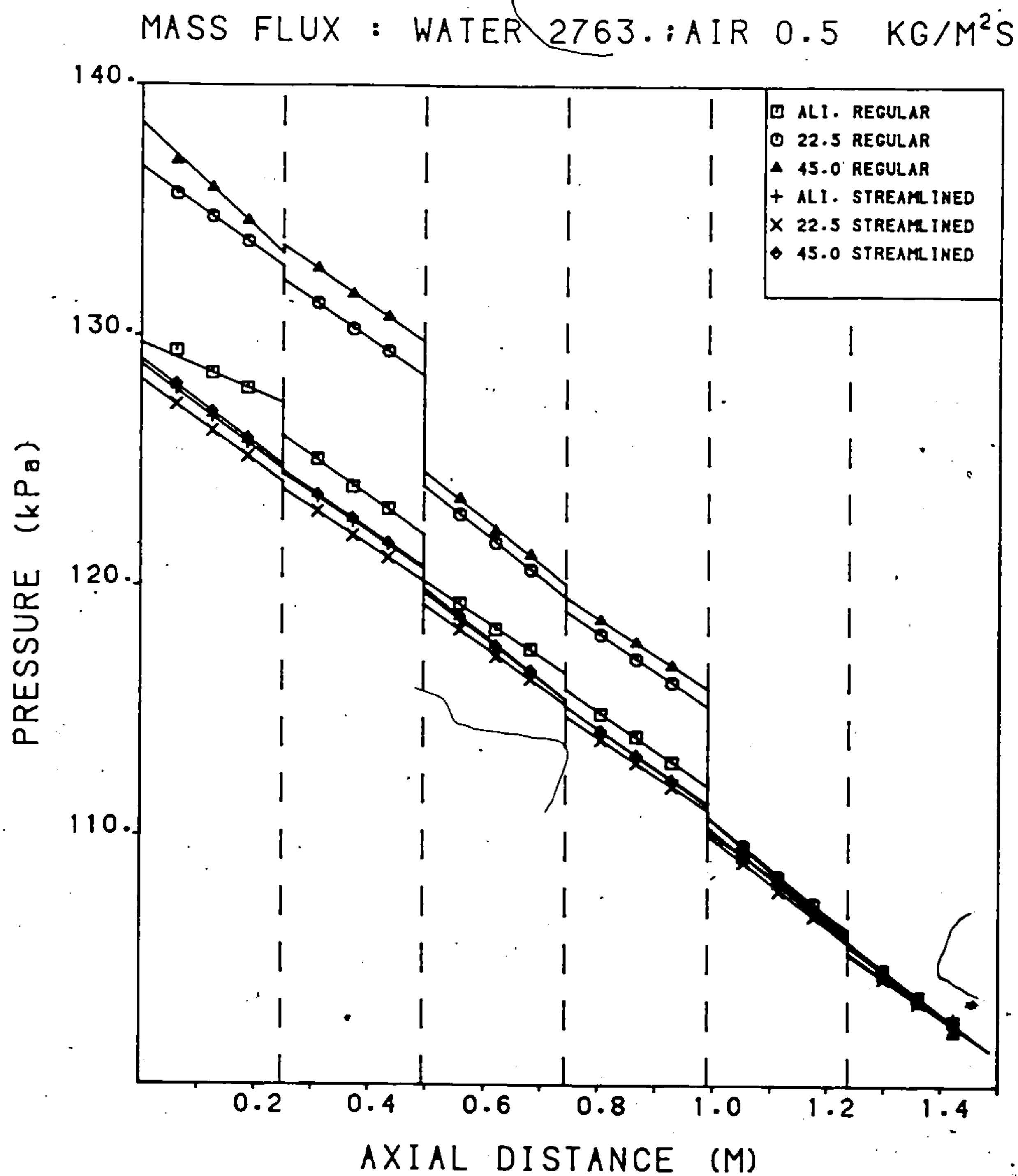


Figure I.6: Two-phase Pressure Distributions with 2763 kg/m s Liquid Mass Flux and 0.5 kg/m²s Air Mass Flux

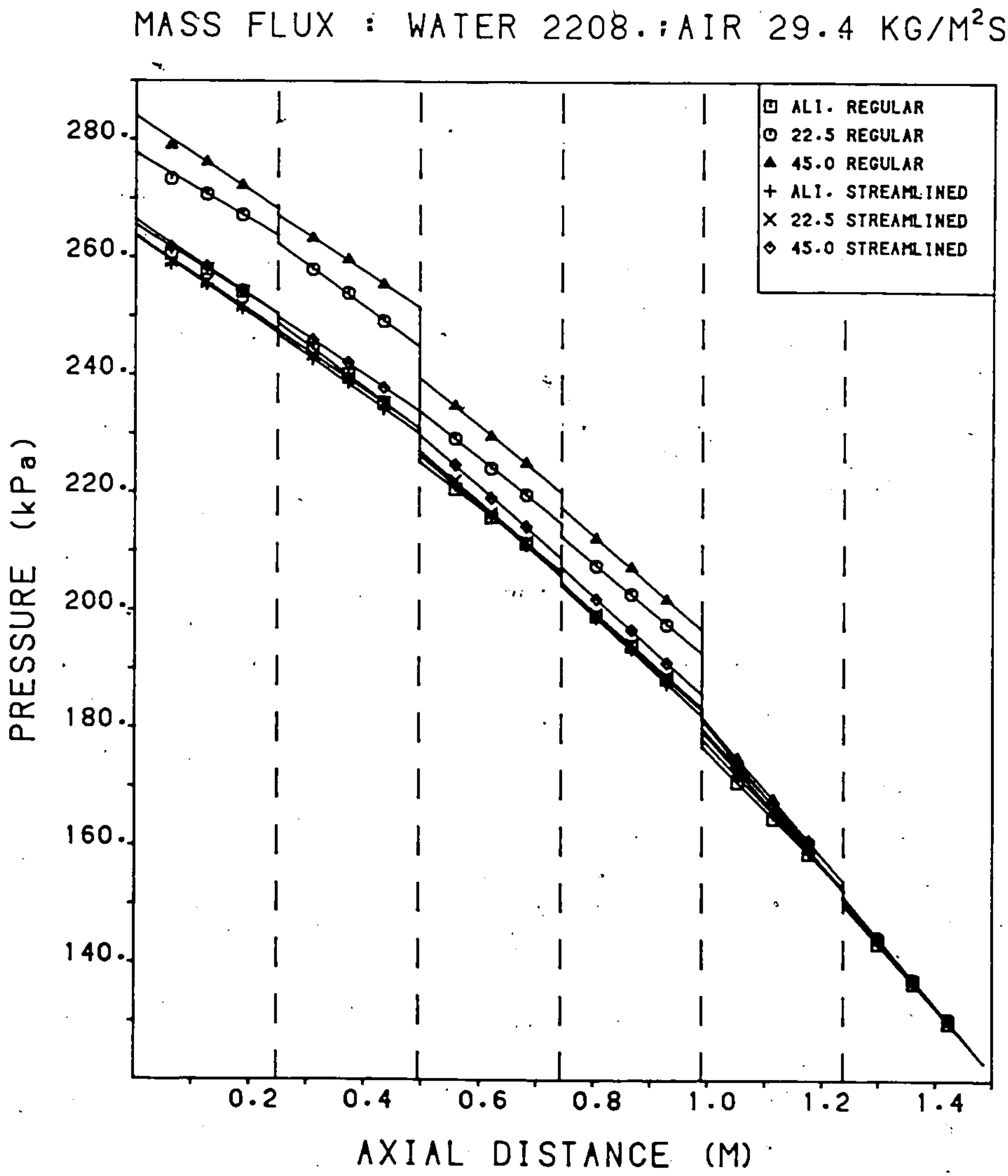


Figure I.7: Two-phase Pressure Distributions with 2208 kg/m s Liquid Mass Flux and 29.4 kg/m²s Air Mass Flux

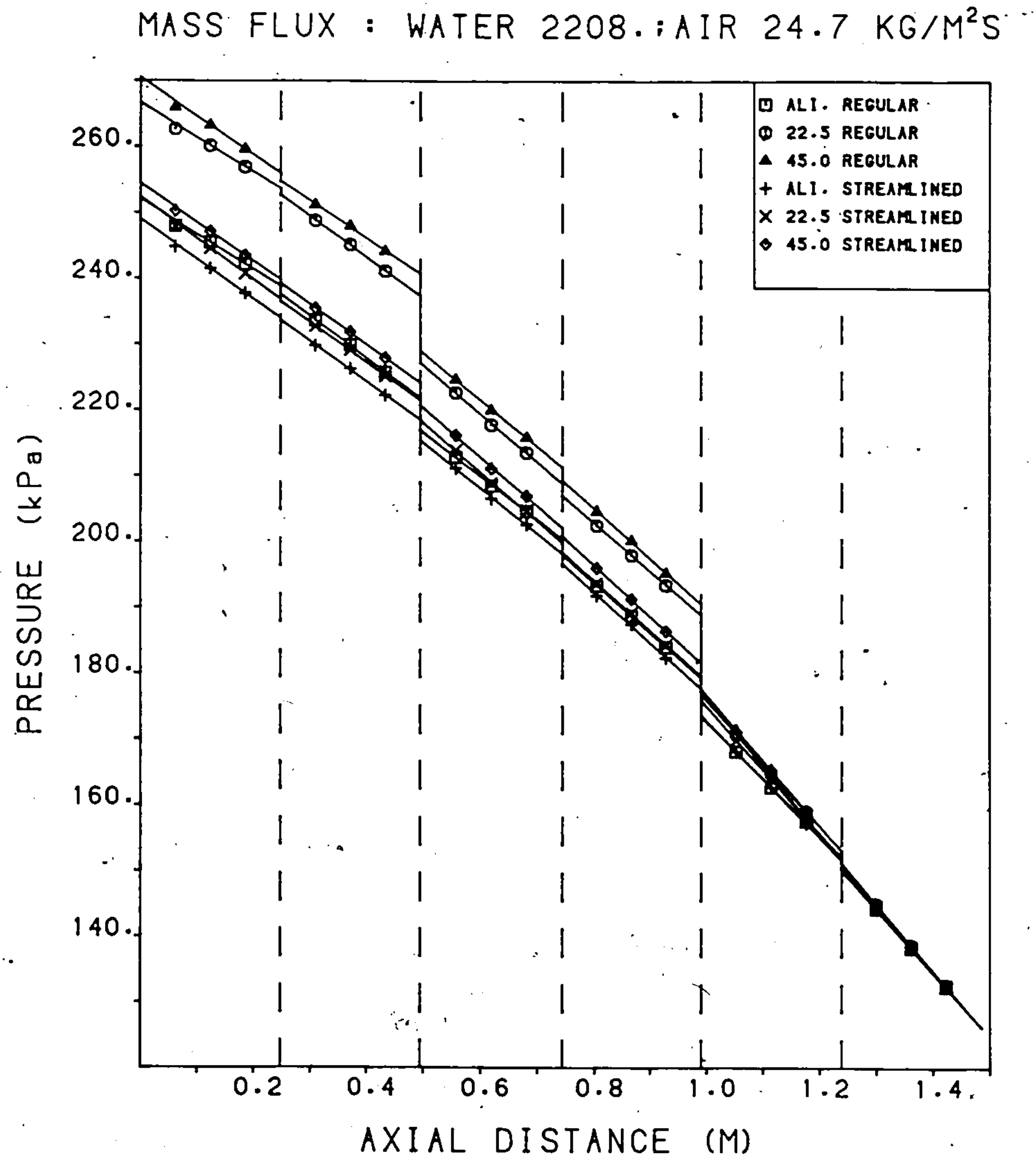


Figure I.8: Two-phase Pressure Distributions with 2208 kg/m s Liquid Mass Flux and 24.7 kg/m^2s Air Mass Flux

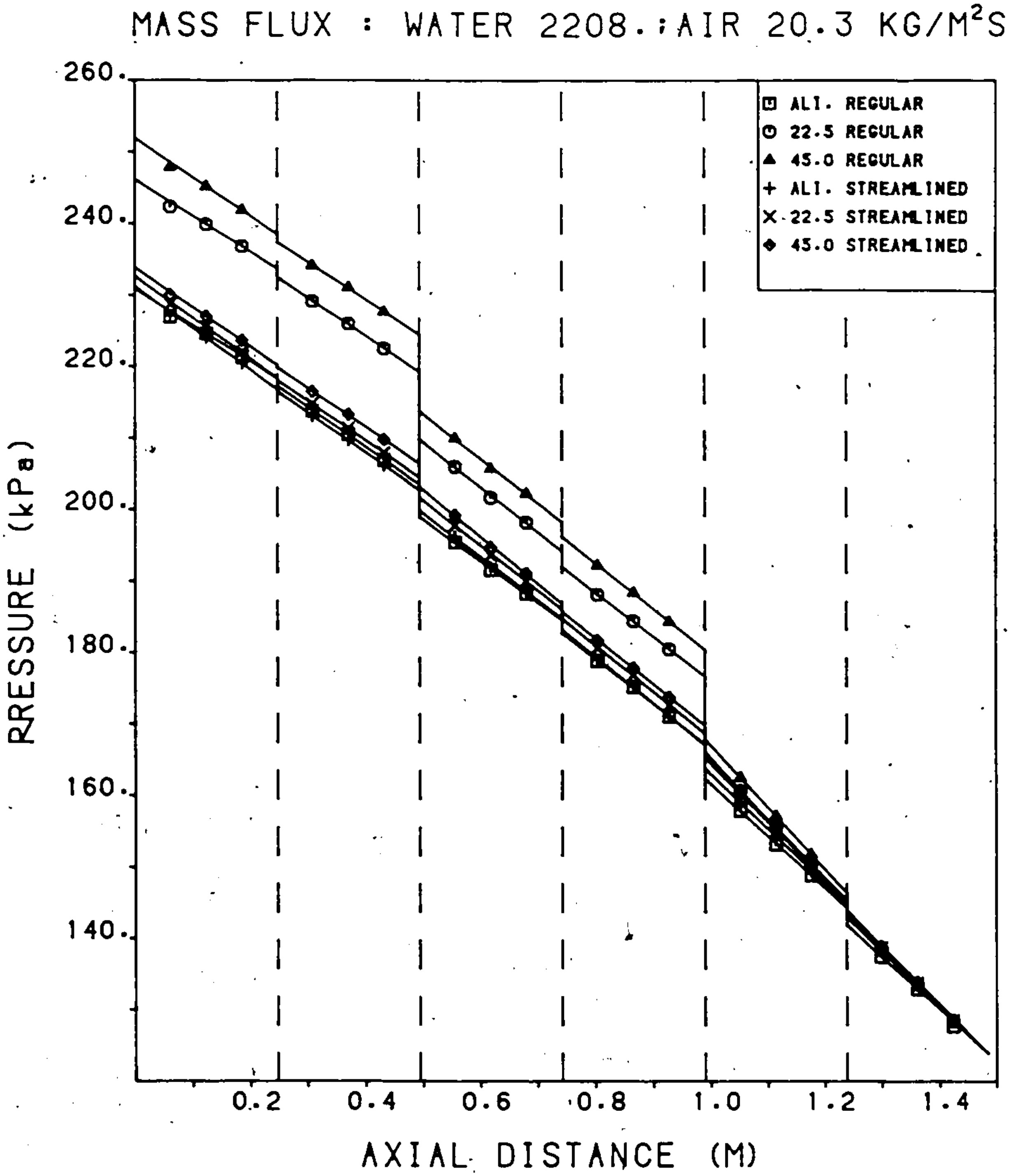


Figure I.9: Two-phase Pressure Distributions with 2208 kg/m s Liquid Mass Flux and 20.3 kg/m²s Air Mass Flux

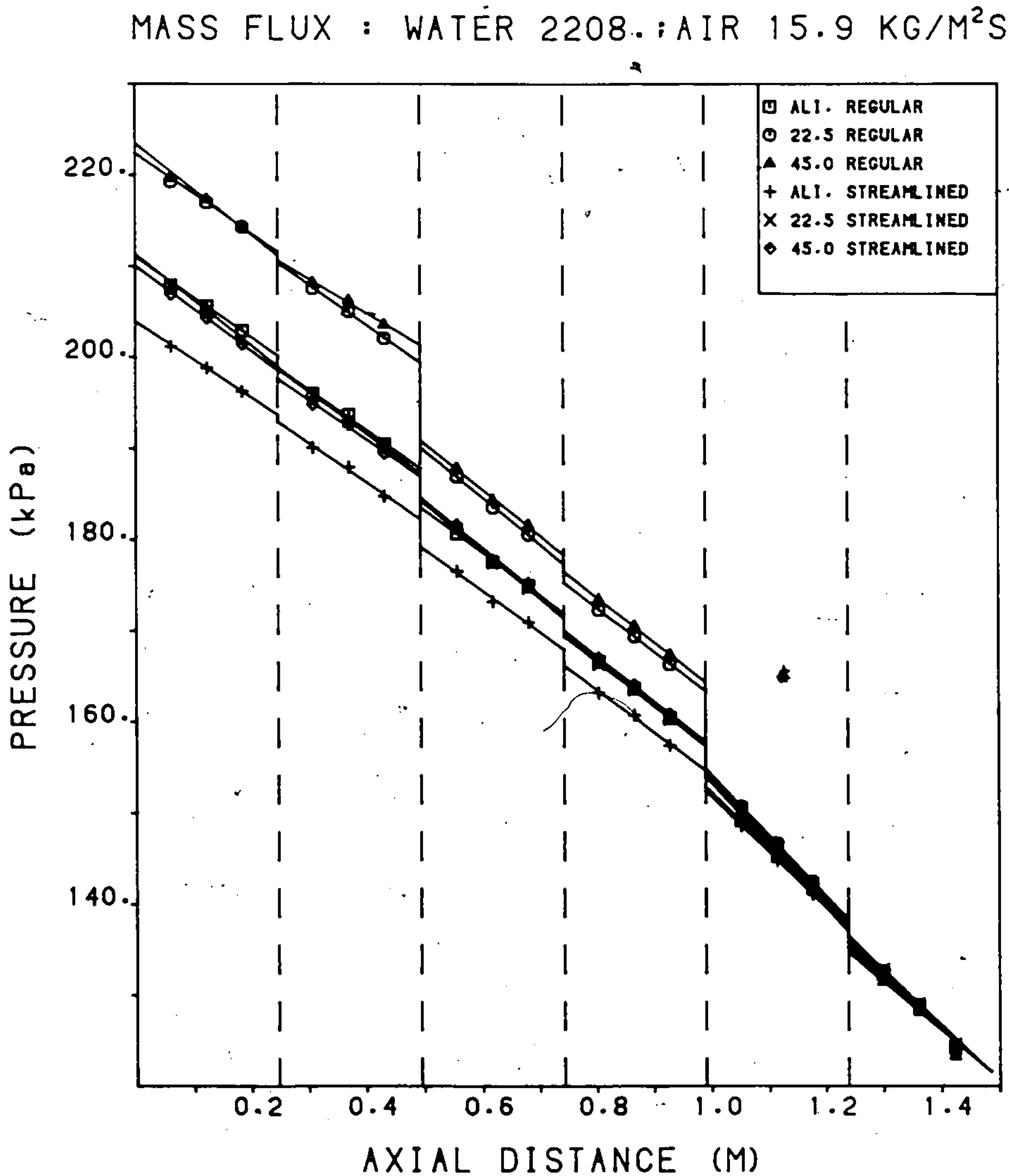


Figure I.10: Two-phase Pressure Distributions with 2208 kg/m s Liquid Mass Flux and 15.9 kg/m²s Air Mass Flux

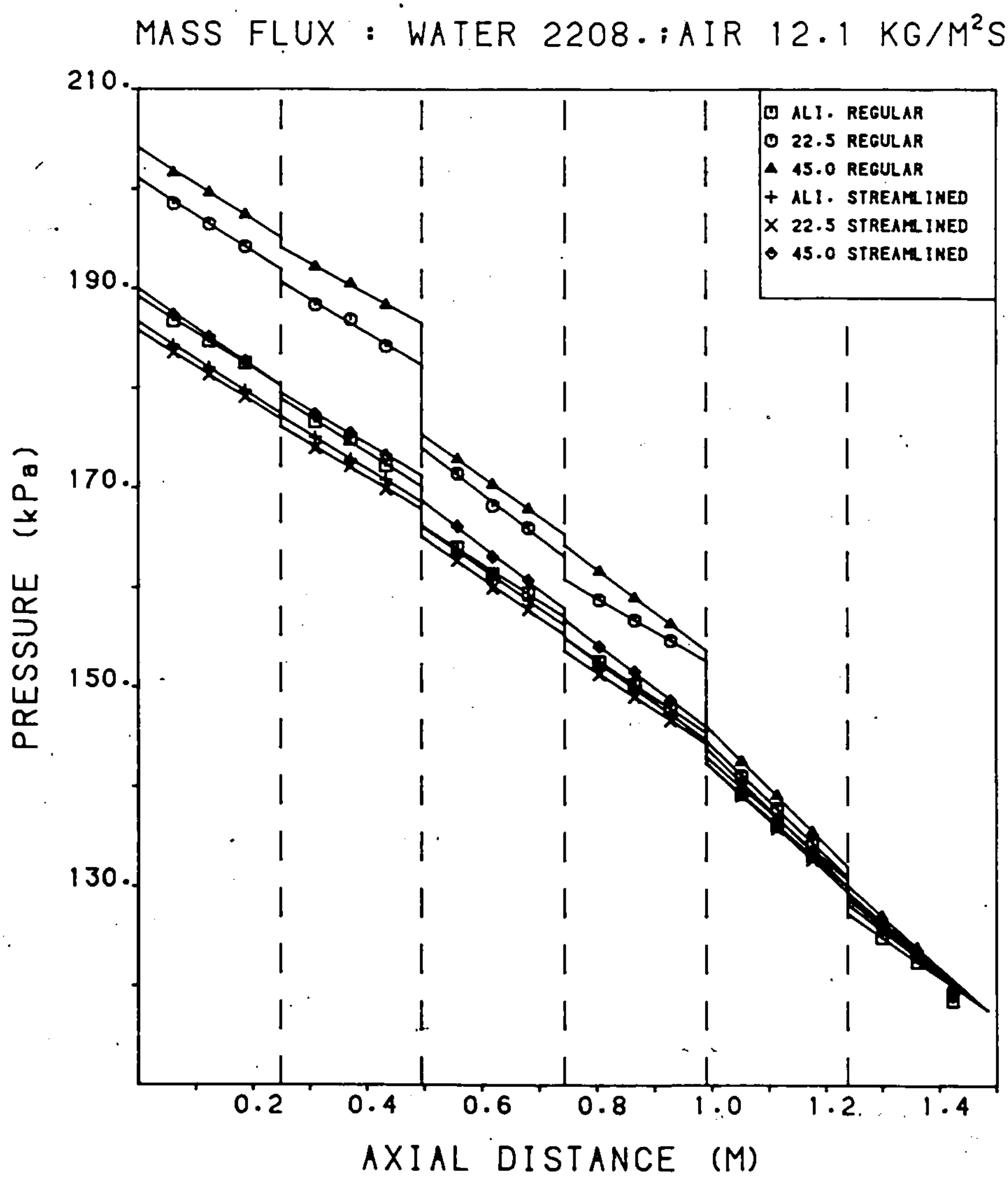


Figure I.11: Two-phase Pressure Distributions with 2208 kg/m s Liquid Mass Flux and 12.1 kg/m²s Air Mass Flux

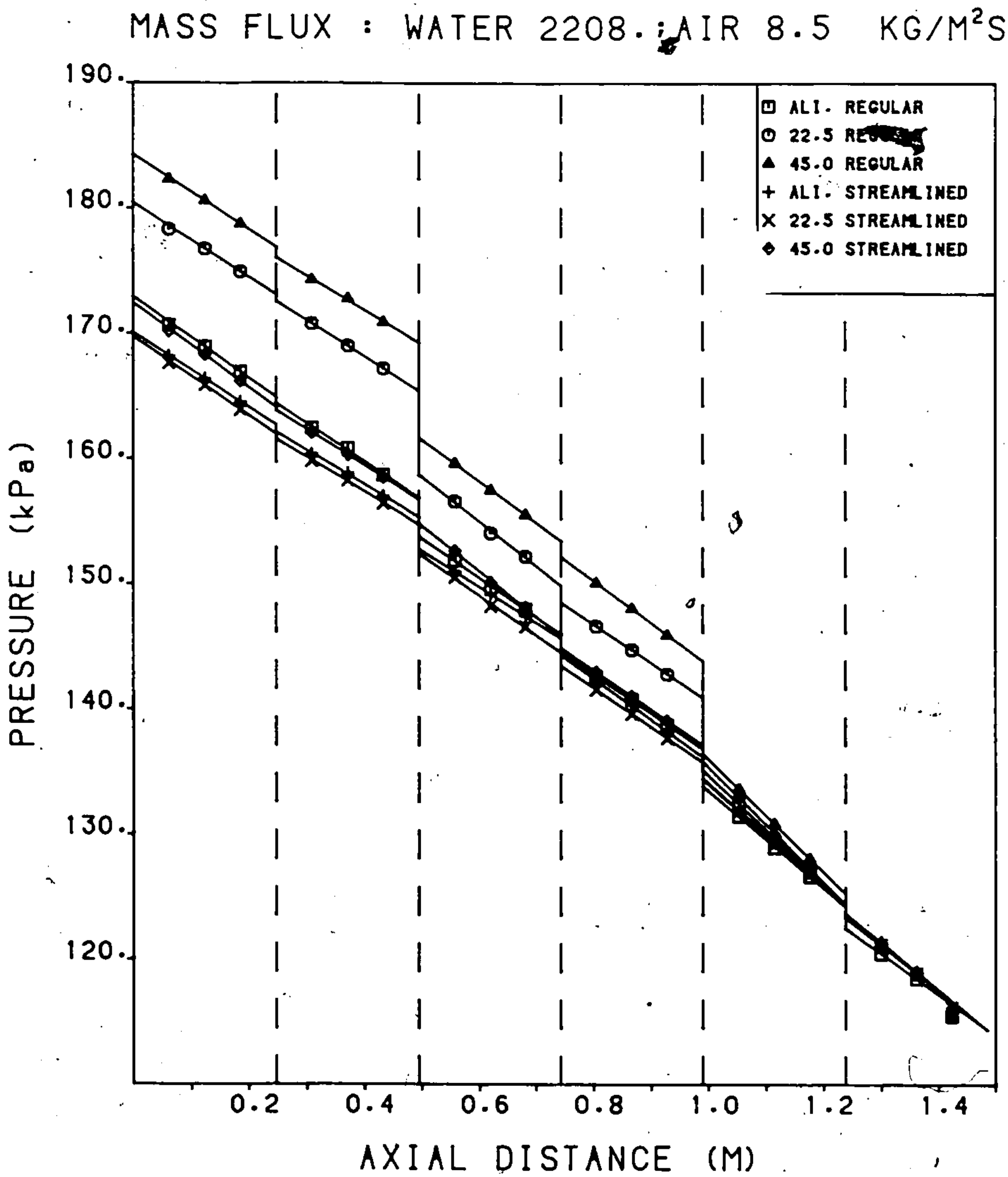


Figure I.12: Two-phase Pressure Distributions with 2208 kg/m s Liquid Mass Flux and 8.5 kg/m²s Air Mass Flux

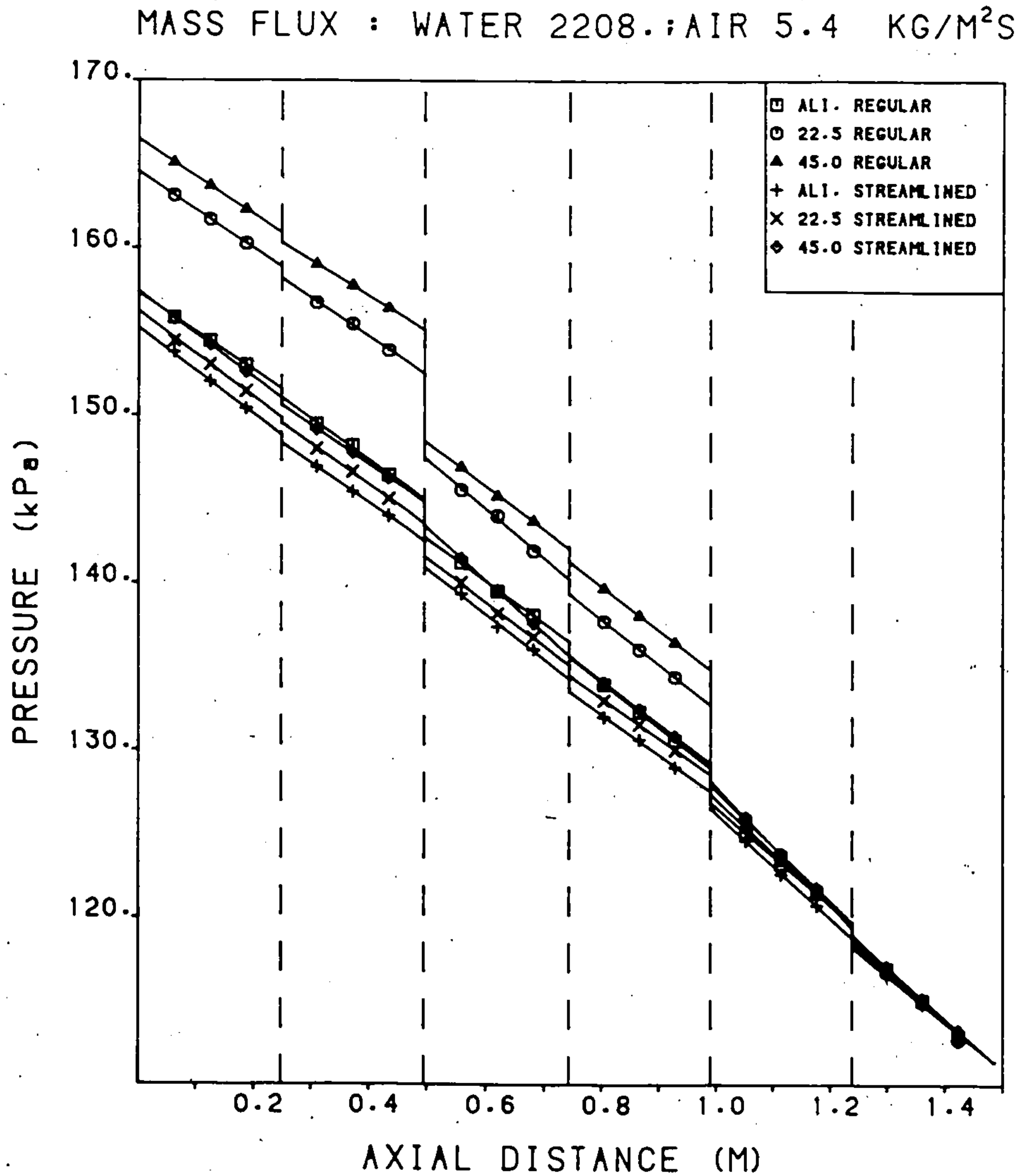


Figure I.13: Two-phase Pressure Distributions with 2208 kg/m s Liquid Mass Flux and 5.4 kg/m^{2}s Air Mass Flux

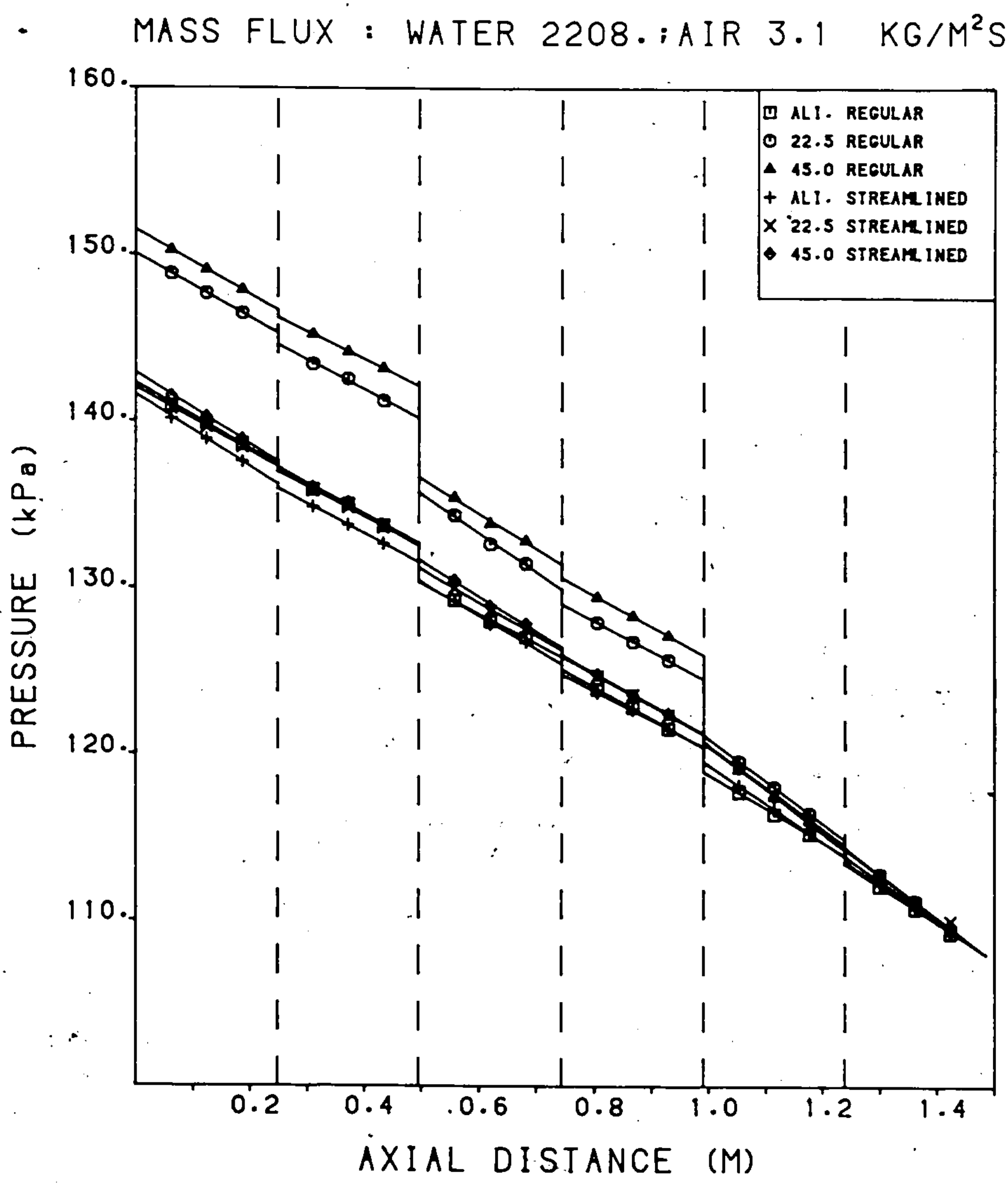


Figure I.14: Two-phase Pressure Distributions with 2208 kg/m s Liquid Mass Flux and 3.1 kg/m²s Air Mass Flux

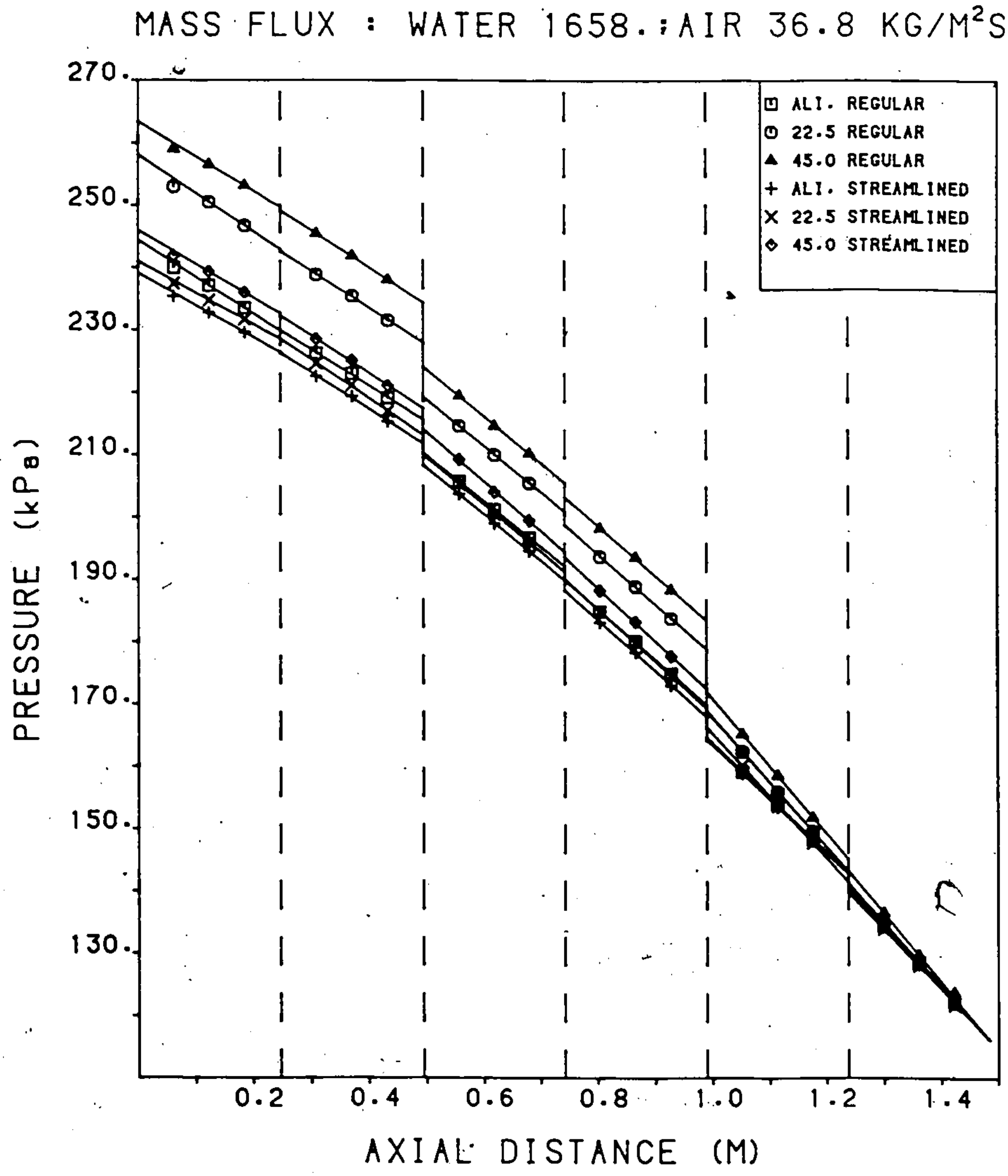


Figure I.15: Two-phase Pressure Distributions with 1658 kg/m s Liquid Mass Flux and 36.8 kg/m^{2}s Air Mass Flux

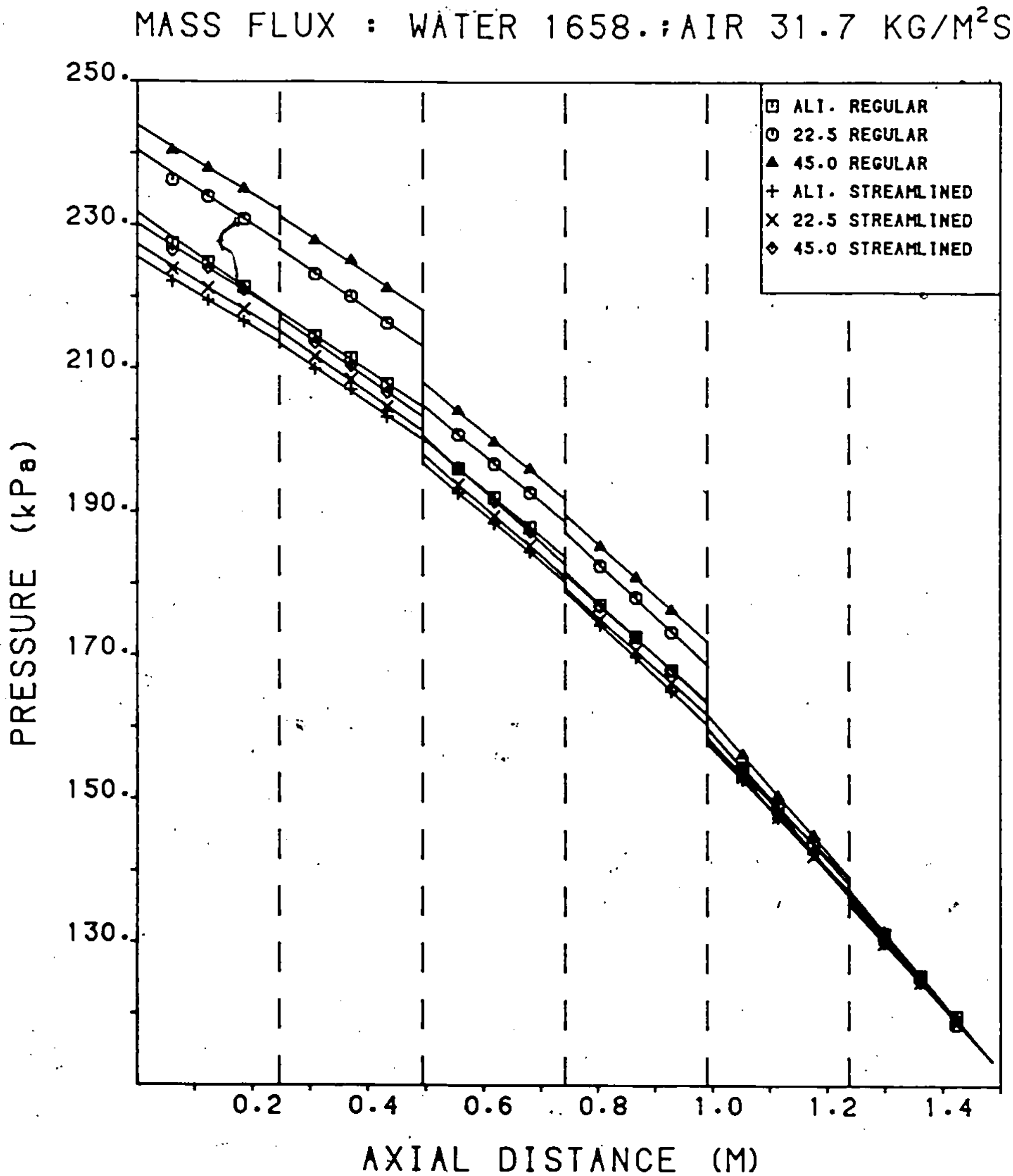


Figure I.16: Two-phase Pressure Distributions with 1658 kg/m s Liquid Mass Flux and 31.7 kg/m²s Air Mass Flux

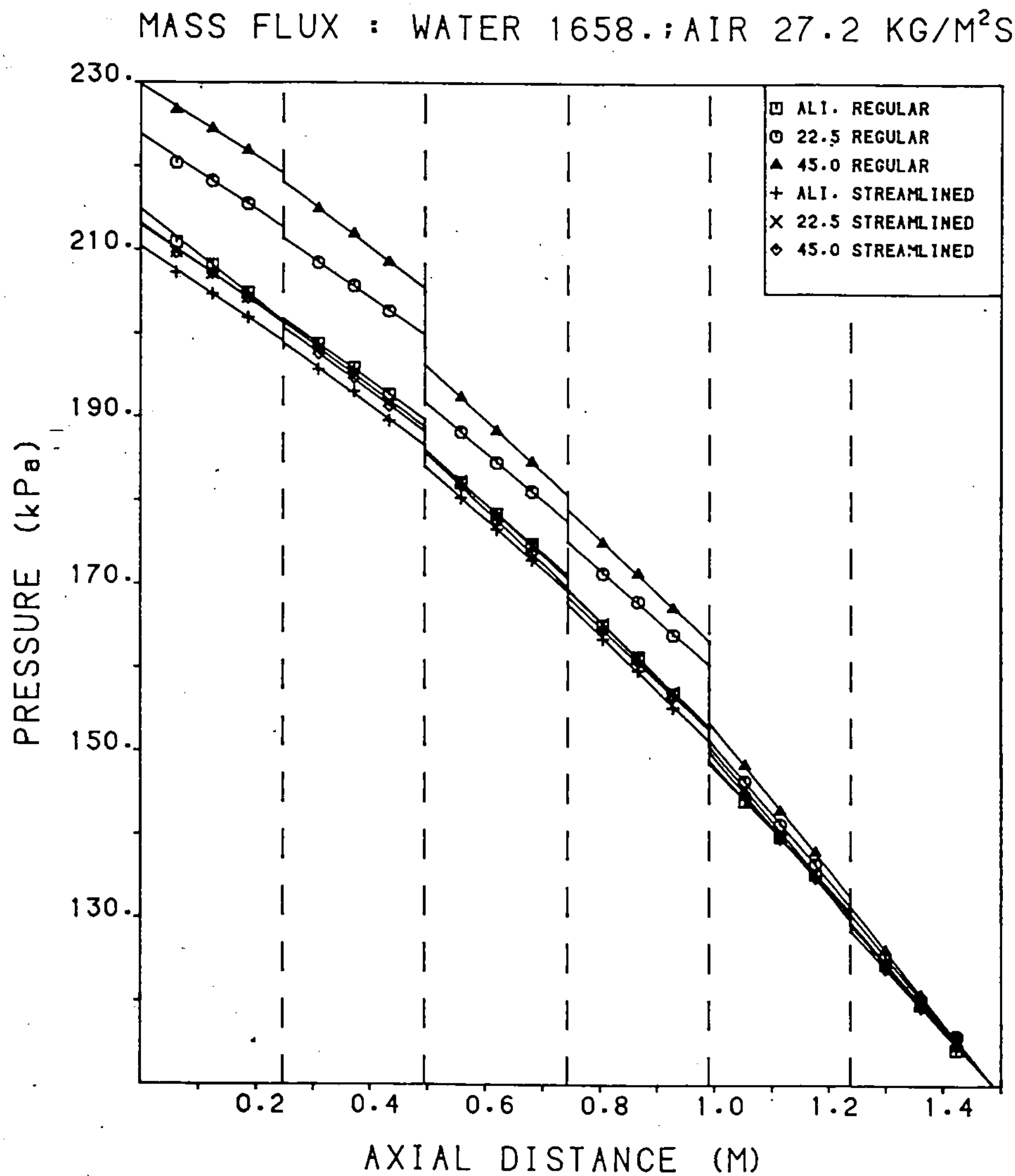


Figure I.17: Two-phase Pressure Distributions with 1658 kg/m s Liquid Mass Flux and 27.2 kg/m^2s Air Mass Flux

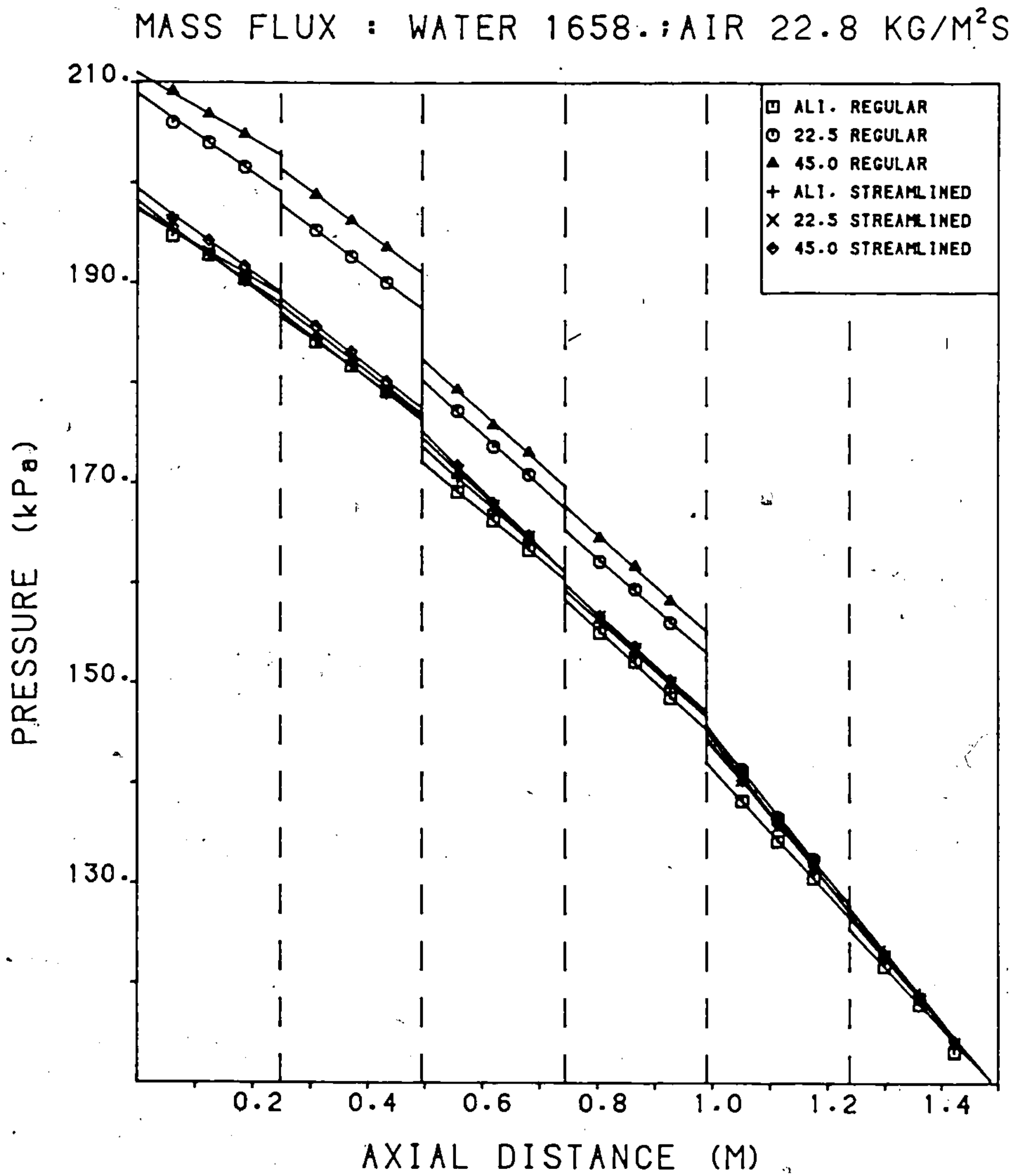


Figure I.18: Two-phase Pressure Distributions with 1658 kg/m s Liquid Mass Flux and 22.8 kg/m²s Air Mass Flux

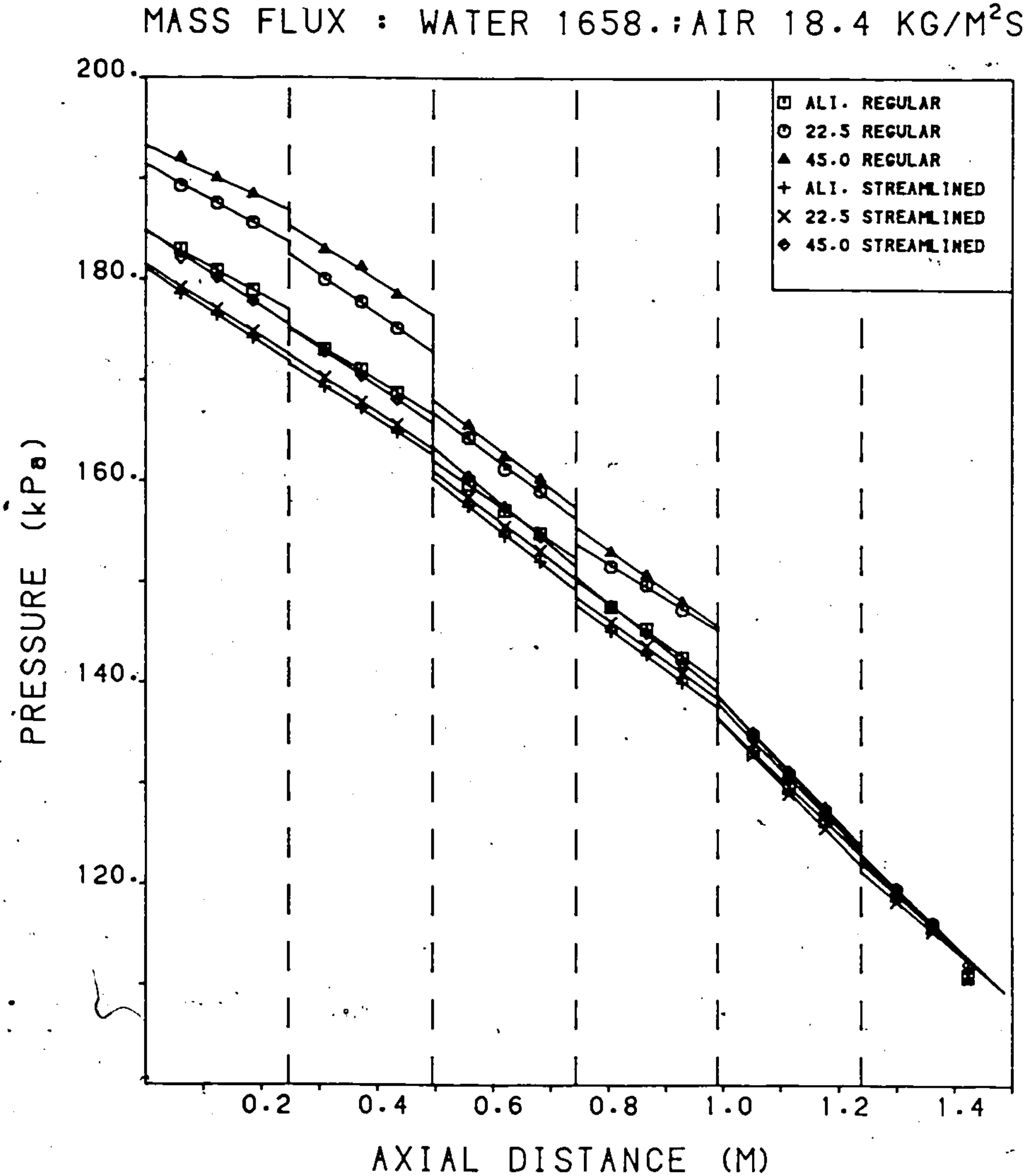


Figure I.19: Two-phase Pressure Distributions with 1658 kg/m s Liquid Mass Flux and 18.4 kg/m²s Air Mass Flux

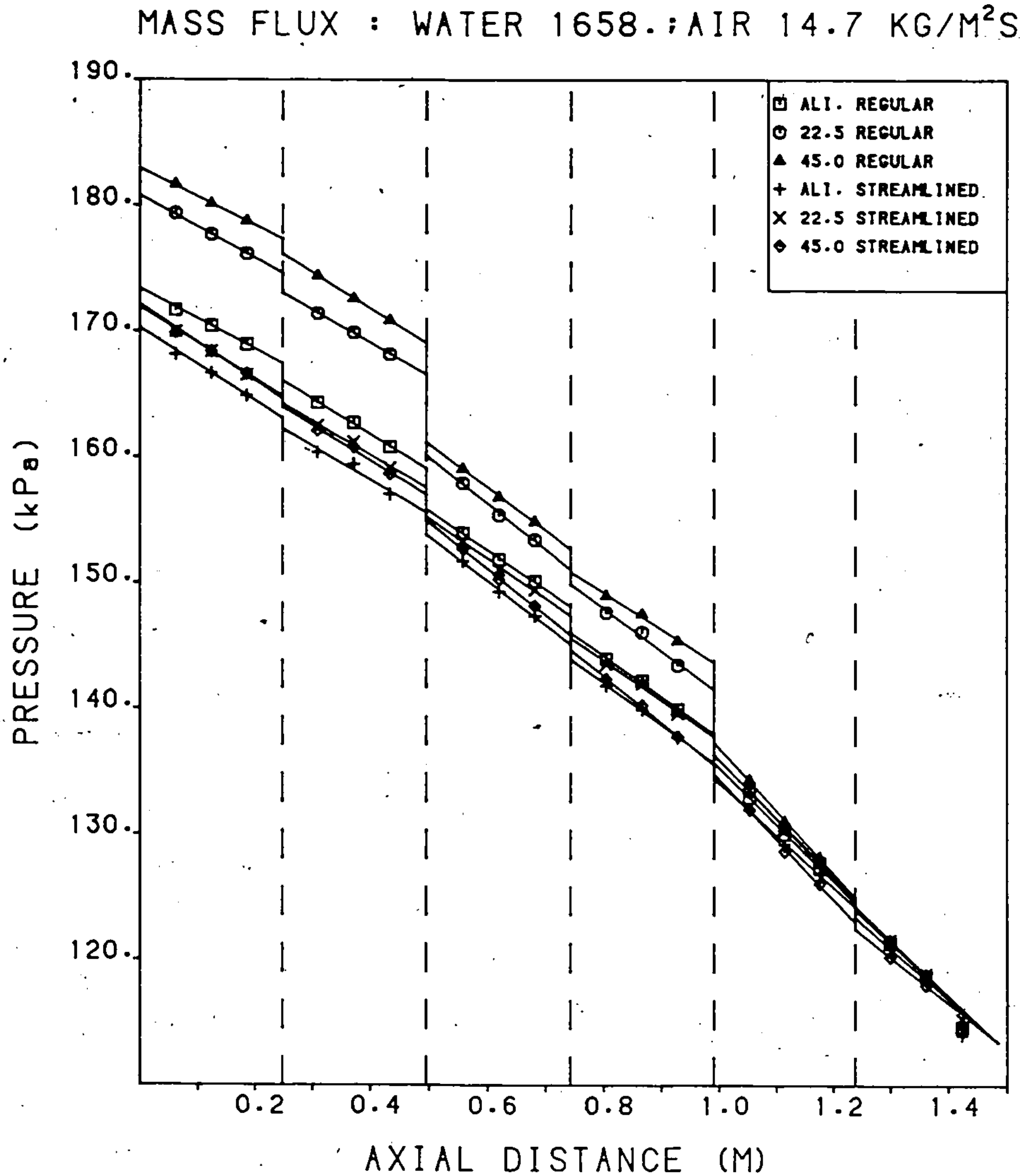


Figure I.20: Two-phase Pressure Distributions with 1658 kg/m s Liquid Mass Flux and 14.7 kg/m^{2}s Air Mass Flux

Appendix J

EXPERIMENTAL RESULTS OF EXPERIMENT A

FOR SINGLE-PHASE FLOW

Table J.1: Single-phase Flow Results for 25% Obstructions

	CENTRAL	PERIPHERAL	HORIZONTAL SEGMENT	VERTICAL SEGMENT	TOP SEGMENT	BOTTOM SEGMENT
REYNOLDS NO.	11518	11518	11518	11518	11518	11518
UP FRIC.LOSS (KPA/M)	0.219	0.221	0.217	0.214	0.221	0.221
DN FRIC.LOSS (KPA/M)	0.216	0.220	0.213	0.223	0.223	0.221
LOCAL LOSS (KPA)	0.141	0.048	0.152	0.152	0.092	0.103
UP FRIC.FACT	0.032	0.032	0.031	0.031	0.032	0.032
DN FRIC.FACT	0.031	0.032	0.031	0.032	0.032	0.032
UP LOSS.COEF	1.249	1.260	1.235	1.222	1.260	1.260
DN LOSS.COEF	1.233	1.253	1.215	1.272	1.274	1.259
OB LOSS.COEF	0.806	0.274	0.864	0.865	0.524	0.589

Table J.2: Single-phase Flow Results for 40% OBstructions

	CENTRAL	PERIPHERAL	HORIZONTAL SEGMENT	VERTICAL SEGMENT	TOP SEGMENT	BOTTOM SEGMENT
REYNOLDS NO.	11518	11518	11518	11518	11518	11518
UP FRIC.LOSS (KPA/M)	0.223	0.222	0.222	0.213	0.219	0.224
DN FRIC.LOSS (KPA/M)	0.201	0.225	0.220	0.217	0.225	0.225
LOCAL LOSS (KPA)	0.421	0.239	0.454	0.456	0.346	0.346
UP FRIC.FACT	0.032	0.032	0.032	0.031	0.032	0.032
DN FRIC.FACT	0.029	0.033	0.032	0.032	0.033	0.033
UP LOSS.COEF	1.271	1.265	1.266	1.215	1.249	1.279
DN LOSS.COEF	1.145	1.282	1.257	1.241	1.285	1.282
OB LOSS.COEF	2.402	1.366	2.588	2.611	1.975	1.972

Appendix K

EXPERIMENTAL RESULTS OF EXPERIMENT A

FOR TWO-PHASE FLOW

Table K.1: Two-phase Flow Results for the 25% Obstructions

MASS FLUX (KG/M.M.S) WATER	MASS FLUX (KG/M.M.S) AIR	QUALITY X	PRESSURE LOSS FRICTION (KPA/M) UPSTREAM	PRESSURE LOSS FRICTION (KPA/M) DOWNSTREAM	PRESSURE LOSS LOCAL (KPA) OBSTRUCTION	TWO-PHASE MULTIPLIER FRICTION UPSTREAM	TWO-PHASE MULTIPLIER FRICTION DOWNSTREAM	TWO-PHASE MULTIPLIER LOCAL OBSTRUCTION
25% CENTRAL OBSTRUCTION								
592.1	126.2	17.6	7.70	8.19	5.38	23.42	25.30	31.78
592.1	103.6	14.9	6.78	7.19	4.40	21.98	23.67	27.70
592.1	82.6	12.2	5.97	6.52	3.28	20.59	22.84	21.92
592.1	63.6	9.7	4.89	5.41	2.44	17.87	20.07	17.26
592.1	43.8	6.9	4.25	4.41	1.38	16.51	17.40	10.42
592.1	27.1	4.4	3.48	3.35	1.33	14.25	13.93	10.53
25% PERIPHERAL OBSTRUCTION								
592.1	125.7	17.5	7.89	6.72	4.27	25.34	21.64	34.57
592.1	103.2	14.8	6.94	5.96	3.64	24.39	20.47	31.39
592.1	82.2	12.2	5.94	5.06	3.18	22.19	18.46	29.23
592.1	63.6	9.7	5.20	4.30	2.44	20.56	16.62	23.68
592.1	43.8	6.9	4.23	3.61	2.02	17.76	14.84	20.90
592.1	27.1	4.4	3.52	2.55	1.16	15.60	11.03	12.65
25% HORIZONTAL CENTRAL SEGMENT OBSTRUCTION								
592.1	125.7	17.5	7.63	8.34	4.78	22.07	26.12	20.32
592.1	103.6	14.9	6.80	7.17	4.08	20.92	23.89	18.44
592.1	82.2	12.2	5.84	6.20	3.06	19.15	22.02	14.75
592.1	63.9	9.7	4.87	5.23	2.12	16.84	19.61	10.78
592.1	43.8	6.9	4.30	4.33	1.65	15.86	17.27	8.94
592.1	27.1	4.4	3.11	3.10	1.06	12.10	13.03	6.05
25% VERTICAL CENTRAL SEGMENT OBSTRUCTION								
592.1	125.7	17.5	7.68	8.13	4.87	24.14	25.23	24.01
592.1	103.2	14.8	6.83	7.20	4.15	22.88	23.80	21.81
592.1	82.2	12.2	5.78	6.21	3.58	20.59	21.83	19.97
592.1	63.9	9.7	5.68	5.32	2.74	21.37	19.76	16.14
592.1	43.4	6.8	4.56	4.29	2.12	18.27	16.99	13.31
592.1	27.3	4.4	3.45	2.58	1.35	14.55	10.74	8.93
25% BOTTOM PERIPHERAL SEGMENT OBSTRUCTION								
592.1	125.5	17.5	7.60	7.80	5.32	25.71	24.41	31.78
592.1	103.2	14.8	6.67	7.08	5.20	24.04	23.60	33.11
592.1	83.8	12.4	6.03	6.36	4.72	22.99	22.43	31.76
592.1	63.9	9.7	4.94	5.43	4.28	20.00	20.32	30.61
592.1	43.8	6.9	4.24	4.48	3.30	18.26	17.85	25.11
592.1	27.3	4.4	2.99	2.75	2.23	13.59	11.53	17.91
25% TOP PERIPHERAL SEGMENT OBSTRUCTION								
592.1	125.3	17.5	7.83	6.88	3.34	25.50	21.68	18.54
592.1	103.2	14.8	6.87	6.06	2.80	23.81	20.30	16.50
592.1	82.2	12.2	5.75	5.22	2.42	21.20	18.61	15.17
592.1	63.9	9.7	5.04	4.59	1.77	19.61	17.29	11.74
592.1	43.8	6.9	4.48	4.14	1.47	18.59	16.61	10.39
592.1	27.1	4.4	3.33	3.61	1.21	14.54	15.27	[illegible]

Table K.2: Two-phase Flow Results for the 40% Obstructions

MASS FLUX (KG/M.M.S) WATER	MASS FLUX (KG/M.M.S) AIR	QUALITY X	PRESSURE LOSS FRICTION (KPA/M) UPSTREAM	PRESSURE LOSS FRICTION (KPA/M) DOWNSTREAM	PRESSURE LOSS LOCAL (KPA) OBSTRUCTION	TWO-PHASE MULTIPLIER FRICTION UPSTREAM	TWO-PHASE MULTIPLIER FRICTION DOWNSTREAM	TWO-PHASE MULTIPLIER LOCAL OBSTRUCTION
			40% CENTRAL OBSTRUCTION					
592.1	127.1	17.7	7.51	8.08	14.44	20.04	23.09	27.31
592.1	104.5	15.0	6.59	7.20	11.86	18.74	21.92	23.91
592.1	83.0	12.3	5.70	6.45	8.97	17.25	20.93	19.26
592.1	64.3	9.8	4.92	5.50	6.33	15.76	18.87	14.37
592.1	44.4	7.0	4.39	4.54	4.02	14.96	16.56	9.71
592.1	27.3	4.4	3.69	3.41	2.77	13.25	13.15	7.05
			40% PERIPHERAL OBSTRUCTION					
592.1	126.5	17.6	7.62	6.71	12.42	23.06	20.42	35.22
592.1	103.6	14.9	6.72	5.98	11.10	21.71	19.42	33.57
592.1	82.6	12.2	5.75	4.98	9.29	19.76	17.19	29.86
592.1	63.9	9.7	4.65	4.14	7.61	17.63	15.11	25.90
592.1	44.1	6.9	4.38	3.37	5.43	16.93	13.09	19.65
592.1	27.3	4.4	3.56	2.74	3.33	14.52	11.24	12.70
			40% HORIZONTAL CENTRAL SEGMENT OBSTRUCTION					
592.1	127.1	17.7	7.75	7.82	13.71	24.24	23.13	21.97
592.1	104.5	15.0	6.81	6.74	11.59	22.68	21.25	19.79
592.1	83.0	12.3	5.86	5.63	8.80	20.79	18.89	16.01
592.1	63.8	9.7	4.95	4.63	6.37	18.60	16.47	12.28
592.1	43.8	6.9	4.51	4.06	4.02	18.03	15.38	8.25
592.1	27.3	4.4	3.28	2.68	2.87	13.87	10.69	6.20
			40% VERTICAL CENTRAL SEGMENT OBSTRUCTION					
592.1	126.7	17.6	7.84	8.12	12.84	22.99	23.57	21.26
592.1	104.5	15.0	6.88	7.24	11.45	21.47	22.37	20.19
592.1	83.4	12.3	5.78	6.31	9.27	19.17	20.73	17.38
592.1	63.9	9.7	4.83	5.35	7.69	17.00	18.66	15.29
592.1	44.1	6.9	4.38	4.19	5.21	16.40	15.54	11.02
592.1	27.3	4.4	3.47	3.40	3.64	13.70	13.30	8.12
			40% BOTTOM PERIPHERAL OBSTRUCTION					
592.1	127.1	17.7	7.66	8.19	13.78	22.91	24.65	28.51
592.1	104.1	14.9	6.69	7.51	12.28	21.33	24.12	27.11
592.1	83.4	12.3	5.77	6.51	10.86	19.55	22.19	25.47
592.1	64.7	9.8	4.91	5.91	8.97	17.62	21.33	22.25
592.1	44.2	6.9	4.23	4.15	6.93	16.17	15.96	18.33
592.1	27.3	4.4	3.11	2.75	4.67	12.53	11.15	13.04
			40% TOP PERIPHERAL SEGMENT OBSTRUCTION					
592.1	126.7	17.6	7.73	7.61	11.14	25.18	23.81	19.59
592.1	104.5	15.0	6.89	6.53	9.48	23.87	21.73	17.74
592.1	83.8	12.4	5.95	5.37	7.84	21.90	18.99	15.58
592.1	63.8	9.7	5.05	4.77	5.97	19.74	17.89	12.59
592.1	44.2	6.9	4.77	4.02	4.40	19.80	16.04	9.87
592.1	27.6	4.4	3.13	2.47	3.24	13.72	[illegible]	[illegible]

Appendix L

EXPERIMENTAL RESULTS OF EXPERIMENT B

FOR SINGLE-PHASE FLOW

Table L.1: Single-phase Flow Results for Various Bundle Configurations (Aligned Regular Bundles)

• ALIGNED REGULAR BUNDLES (290781)

ASS FLUX KG/M.M.S) WATER	PRESSURE LOSS (KPA/M) FRICTION	LOCAL (KPA) JUNCTION	LOCAL (KPA) SPACERS	TOTAL	LOSS COEFFICIENT (K) FRICTION	JUNCTION	SPACERS	TOTAL	FRICTION FACTOR
3313.3	17.86	2.65	0.89	24.69	1.6037	0.4812	0.1617	2.2467	0.0242
3036.8	15.18	2.26	0.74	21.00	1.6228	0.4879	0.1604	2.2710	0.0245
2760.0	12.67	1.79	0.58	17.24	1.6389	0.4677	0.1507	2.2573	0.0247
2483.8	10.49	1.46	0.50	14.26	1.6752	0.4695	0.1611	2.3058	0.0253
2207.6	8.51	1.15	0.40	11.50	1.7210	0.4695	0.1623	2.3528	0.0260
1931.5	6.75	0.88	0.31	9.04	1.7837	0.4709	0.1638	2.4184	0.0269
1655.5	5.23	0.65	0.23	6.92	1.8789	0.4741	0.1678	2.5209	0.0283
1380.3	4.03	0.46	0.15	5.19	2.0840	0.4846	0.1599	2.7284	0.0314
1104.2	2.72	0.29	0.10	3.46	2.1992	0.4729	0.1654	2.8375	0.0332
828.1	1.66	0.16	0.07	2.08	2.3823	0.4709	0.1895	3.0426	0.0359

ALIGNED REGULAR BUNDLES (300781)

ASS FLUX KG/M.M.S) WATER	PRESSURE LOSS (KPA/M) FRICTION	LOCAL (KPA) JUNCTION	LOCAL (KPA) SPACERS	TOTAL	LOSS COEFFICIENT (K) FRICTION	JUNCTION	SPACERS	TOTAL	FRICTION FACTOR
3035.3	15.11	2.11	0.71	20.57	1.6153	0.4568	0.1539	2.2260	0.0244
2759.0	12.74	1.76	0.59	17.25	1.6487	0.4600	0.1542	2.2629	0.0249
2483.0	10.49	1.40	0.48	14.09	1.6755	0.4531	0.1537	2.2822	0.0253
2208.9	8.49	1.10	0.38	11.31	1.7167	0.4480	0.1539	2.3187	0.0259
1930.9	6.67	0.85	0.31	8.88	1.7613	0.4519	0.1631	2.3762	0.0266
1655.0	5.21	0.63	0.23	6.86	1.8732	0.4593	0.1682	2.5008	0.0283
1434.2	4.19	0.49	0.18	5.47	2.0051	0.4759	0.1727	2.6537	0.0303
1213.5	3.13	0.35	0.13	4.02	2.0926	0.4680	0.1725	2.7331	0.0316
992.8	2.15	0.22	0.08	2.73	2.1513	0.4483	0.1712	2.7707	0.0325
772.1	1.42	0.14	0.05	1.79	2.3459	0.4686	0.1819	2.9964	0.0354

ALIGNED REGULAR BUNDLES (050881)

ASS FLUX KG/M.M.S) WATER	PRESSURE LOSS (KPA/M) FRICTION	LOCAL (KPA) JUNCTION	LOCAL (KPA) SPACERS	TOTAL	LOSS COEFFICIENT (K) FRICTION	JUNCTION	SPACERS	TOTAL	FRICTION FACTOR
3036.6	15.06	2.01	0.74	20.40	1.6121	0.4339	0.1602	2.2061	0.0243
2760.2	12.69	1.67	0.62	17.11	1.6409	0.4367	0.1616	2.2392	0.0248
2483.8	10.38	1.33	0.50	13.92	1.6581	0.4305	0.1614	2.2500	0.0250
2207.7	8.44	1.05	0.40	11.21	1.7053	0.4277	0.1615	2.2945	0.0257
1931.6	6.62	0.80	0.31	8.77	1.7476	0.4289	0.1674	2.3440	0.0264
1655.5	5.25	0.63	0.24	6.88	1.8882	0.4548	0.1713	2.5143	0.0285
1434.7	4.16	0.48	0.18	5.43	1.9921	0.4650	0.1789	2.6360	0.0301
1213.9	3.17	0.33	0.12	4.03	2.1170	0.4466	0.1681	2.7317	0.0319
993.1	2.16	0.21	0.09	2.72	2.1525	0.4293	0.1764	2.7582	0.0325
772.4	1.43	0.14	0.05	1.79	2.3561	0.4586	0.1782	2.9949	0.0356

ble L.2: Single-phase Flow Results for Various Bundle Configurations (22.5° Misaligned Regular Bundles)

• 22.5 DEG. MISALIGNED REGULAR BUNDLES (300781)

MASS FLUX (KG/M.M.S) WATER	(KPA/M) FRICTION	PRESSURE LOSS LOCAL (KPA) JUNCTION	SPACERS	TOTAL	LOSS COEFFICIENT (K) FRICTION	JUNCTION	SPACERS	TOTAL	FRICTION FACTOR
3311.3	18.96	5.43	0.78	31.10	1.7032	0.9848	0.1417	2.8298	0.0257
3028.6	16.15	4.64	0.70	26.59	1.7311	1.0041	0.1506	2.8857	0.0261
2758.8	13.58	3.80	0.54	22.06	1.7575	0.9925	0.1402	2.8902	0.0265
2482.8	11.30	3.06	0.46	18.17	1.8053	0.9866	0.1473	2.9392	0.0272
2206.8	9.07	2.38	0.36	14.41	1.8339	0.9711	0.1467	2.9517	0.0277
1930.8	7.14	1.81	0.28	11.22	1.8856	0.9682	0.1471	3.0009	0.0284
1654.8	5.55	1.38	0.22	8.66	1.9970	0.9991	0.1584	3.1544	0.0301
1379.0	4.18	0.98	0.15	6.37	2.1857	1.0273	0.1542	3.3472	0.0327
1103.1	2.79	0.60	0.08	4.11	2.2539	0.9803	0.1341	3.3683	0.0340
827.3	1.73	0.35	0.05	2.49	2.4867	1.0066	0.1540	3.6473	0.0375

22.5 DEG. MISALIGNED REGULAR BUNDLES (300781)

MASS FLUX (KG/M.M.S) WATER	(KPA/M) FRICTION	PRESSURE LOSS LOCAL (KPA) JUNCTION	SPACERS	TOTAL	LOSS COEFFICIENT (K) FRICTION	JUNCTION	SPACERS	TOTAL	FRICTION FACTOR
3036.5	16.48	4.62	0.70	26.89	1.7616	0.9968	0.1510	2.9094	0.0266
2781.0	13.85	3.78	0.52	22.28	1.7908	0.9898	0.1359	2.9165	0.0270
2485.7	11.29	3.01	0.45	18.07	1.8019	0.9690	0.1439	2.9148	0.0272
2209.9	9.20	2.38	0.35	14.55	1.8580	0.9708	0.1446	2.9735	0.0280
1933.6	7.30	1.82	0.27	11.38	1.9246	0.9704	0.1434	3.0383	0.0290
1657.3	5.64	1.36	0.20	8.69	2.0245	0.9882	0.1478	3.1606	0.0305
1380.9	4.16	0.96	0.13	6.28	2.1525	1.0015	0.1408	3.2946	0.0325
1104.7	2.78	0.60	0.08	4.11	2.2525	0.9752	0.1360	3.3637	0.0340
938.9	2.14	0.43	0.06	3.09	2.3974	0.9775	0.1319	3.5068	0.0362
773.2	1.56	0.29	0.04	2.20	2.5773	0.9751	0.1255	3.6780	0.0389

22.5 DEG. MISALIGNED REGULAR BUNDLES (040881)

MASS FLUX (KG/M.M.S) WATER	(KPA/M) FRICTION	PRESSURE LOSS LOCAL (KPA) JUNCTION	SPACERS	TOTAL	LOSS COEFFICIENT (K) FRICTION	JUNCTION	SPACERS	TOTAL	FRICTION FACTOR
3032.5	16.42	4.79	0.65	27.08	1.7576	1.0356	0.1409	2.9340	0.0265
2756.5	13.71	3.83	0.55	22.32	1.7759	1.0026	0.1449	2.9234	0.0268
2480.8	11.25	3.04	0.44	18.08	1.7996	0.9831	0.1425	2.9253	0.0272
2204.8	9.15	2.42	0.35	14.57	1.8523	0.9877	0.1433	2.9834	0.0279
1929.1	7.15	1.85	0.29	11.37	1.8904	0.9879	0.1565	3.0349	0.0285
1653.4	5.64	1.40	0.21	8.79	2.0300	1.0193	0.1495	3.1988	0.0306
1432.8	4.48	1.08	0.18	6.90	2.1481	1.0447	0.1538	3.3466	0.0324
1212.3	3.35	0.78	0.11	5.03	2.2414	1.0238	0.1438	3.4090	0.0338
991.8	2.31	0.49	0.07	3.40	2.3054	0.9957	0.1452	3.4463	0.0346
771.4	1.55	0.31	0.04	2.21	2.5572	1.0199	0.1348	3.7119	0.0386

ble L.3: Single-phase Flow Results for Various Bundle Configurations (45° Misaligned Regular Bundles)

• 45.0 DEG. MISALIGNED REGULAR BUNDLES (240781)

SS FLUX (G/M.M.S) WATER	(KPA/M) FRICTION	PRESSURE LOSS LOCAL (KPA) JUNCTION	SPACERS	TOTAL	LOSS COEFFICIENT (K) FRICTION	JUNCTION	SPACERS	TOTAL	FRICTION FACTOR
3313.2	19.70	6.33	0.58	33.41	1.7690	1.1478	0.1056	3.0224	0.0267
3038.8	16.78	5.34	0.55	28.50	1.7926	1.1514	0.1183	3.0633	0.0270
2782.0	14.29	4.40	0.45	23.85	1.8469	1.1492	0.1167	3.1128	0.0279
2464.5	11.57	3.55	0.36	19.34	1.8479	1.1439	0.1175	3.1093	0.0279
2211.0	9.58	2.79	0.30	15.70	1.9345	1.1359	0.1212	3.1916	0.0292
1935.0	7.43	2.13	0.23	12.09	1.9581	1.1353	0.1225	3.2159	0.0295
1658.7	5.83	1.59	0.17	8.42	2.1269	1.1557	0.1232	3.4058	0.0321
1382.5	4.38	1.14	0.13	6.87	2.2812	1.1844	0.1308	3.5764	0.0341
1105.9	2.86	0.71	0.08	4.52	2.3870	1.1626	0.1304	3.6800	0.0360
829.4	1.83	0.40	0.05	2.70	2.6250	1.1509	0.1375	3.9133	0.0396

45.0 DEG. MISALIGNED REGULAR BUNDLES (030781)

SS FLUX (G/M.M.S) WATER	(KPA/M) FRICTION	PRESSURE LOSS LOCAL (KPA) JUNCTION	SPACERS	TOTAL	LOSS COEFFICIENT (K) FRICTION	JUNCTION	SPACERS	TOTAL	FRICTION FACTOR
3037.1	18.47	5.76	0.63	29.06	1.7605	1.2437	0.1357	3.1399	0.0266
2760.2	13.74	4.73	0.51	24.04	1.7776	1.2351	0.1335	3.1462	0.0268
2406.6	10.28	3.41	0.37	17.72	1.7512	1.1716	0.1274	3.0502	0.0264
2207.7	8.14	2.97	0.32	15.61	1.8471	1.2146	0.1299	3.1916	0.0279
1931.6	7.32	2.30	0.25	12.33	1.9333	1.2283	0.1311	3.2937	0.0292
1655.5	5.65	1.71	0.18	9.37	2.0309	1.2435	0.1327	3.4072	0.0306
1434.7	4.44	1.32	0.15	7.31	2.1245	1.2775	0.1403	3.5423	0.0321
1213.9	3.32	0.93	0.10	5.32	2.2160	1.2558	0.1297	3.6015	0.0334
993.1	2.28	0.60	0.06	3.58	2.2787	1.2102	0.1270	3.6159	0.0344
772.4	1.53	0.37	0.04	2.32	2.5180	1.2365	0.1328	3.8872	0.0380

45.0 DEG. MISALIGNED REGULAR BUNDLES (060881)

SS FLUX (G/M.M.S) WATER	(KPA/M) FRICTION	PRESSURE LOSS LOCAL (KPA) JUNCTION	SPACERS	TOTAL	LOSS COEFFICIENT (K) FRICTION	JUNCTION	SPACERS	TOTAL	FRICTION FACTOR
3035.2	16.59	5.75	0.59	29.00	1.7685	1.2417	0.1281	3.1383	0.0287
2758.9	13.79	4.67	0.47	23.88	1.7843	1.2201	0.1235	3.1279	0.0269
2482.9	11.46	3.76	0.38	19.58	1.8315	1.2139	0.1218	3.1672	0.0276
2206.8	9.28	2.97	0.30	15.72	1.8774	1.2141	0.1241	3.2156	0.0283
1930.8	7.30	2.27	0.24	12.22	1.9288	1.2111	0.1266	3.2666	0.0291
1654.9	5.66	1.70	0.18	8.33	2.0352	1.2323	0.1284	3.3959	0.0307
1434.1	4.48	1.30	0.13	7.28	2.1452	1.2584	0.1280	3.5307	0.0324
1213.4	3.31	0.92	0.10	5.30	2.2156	1.2435	0.1289	3.5890	0.0334
992.7	2.33	0.61	0.06	3.62	2.3230	1.2216	0.1162	3.6608	0.0350
772.1	1.50	0.37	0.04	2.29	2.4829	1.2265	0.1264	3.8358	0.0375

able L.4: Single-phase Flow Results for Various Bundle Configurations (Aligned Streamlined Bundles)

• ALIGNED STREAMLINED BUNDLES (240781)

SS FLUX G/M.M.S) WATER	PRESSURE LOSS (KPA/M) FRICTION	PRESSURE LOSS LOCAL (KPA) JUNCTION	PRESSURE LOSS LOCAL (KPA) SPACERS	TOTAL	LOSS COEFFICIENT (K) FRICTION	LOSS COEFFICIENT (K) JUNCTION	LOSS COEFFICIENT (K) SPACERS	TOTAL	FRICTION FACTOR
3316.5	18.91	1.24	0.62	22.47	1.6963	0.2238	0.1121	2.0324	0.0256
3039.6	16.45	1.09	0.52	19.50	1.7569	0.2356	0.1126	2.1050	0.0265
2763.0	13.67	0.91	0.46	16.27	1.7661	0.2380	0.1190	2.1231	0.0266
2486.4	11.12	0.75	0.35	13.22	1.7750	0.2428	0.1135	2.1313	0.0268
2209.9	9.02	0.61	0.29	10.73	1.8217	0.2492	0.1198	2.1908	0.0275
1931.0	7.15	0.44	0.20	8.34	1.8891	0.2369	0.1077	2.2337	0.0285
1655.3	5.28	0.40	0.20	6.42	1.8981	0.2930	0.1437	2.3358	0.0287
1378.3	4.08	0.26	0.12	4.78	2.1111	0.2718	0.1247	2.5075	0.0318
1104.5	2.79	0.16	0.08	3.23	2.2527	0.2632	0.1242	2.6400	0.0340
828.3	1.74	0.10	0.04	1.88	2.5064	0.2930	0.1042	2.9035	0.0378

• ALIGNED STREAMLINED BUNDLES (280781)

SS FLUX G/M.M.S) WATER	PRESSURE LOSS (KPA/M) FRICTION	PRESSURE LOSS LOCAL (KPA) JUNCTION	PRESSURE LOSS LOCAL (KPA) SPACERS	TOTAL	LOSS COEFFICIENT (K) FRICTION	LOSS COEFFICIENT (K) JUNCTION	LOSS COEFFICIENT (K) SPACERS	TOTAL	FRICTION FACTOR
3316.5	18.91	1.24	0.62	22.47	1.6963	0.2239	0.1121	2.0324	0.0256
3037.1	16.27	1.02	0.45	19.00	1.7385	0.2201	0.0981	2.0567	0.0262
2760.9	13.60	0.86	0.38	15.89	1.7588	0.2239	0.0987	2.0813	0.0265
2484.9	11.14	0.70	0.32	13.03	1.7782	0.2270	0.1024	2.1077	0.0268
2209.0	9.03	0.57	0.26	10.58	1.8237	0.2331	0.1072	2.1640	0.0275
1933.3	7.19	0.47	0.19	8.42	1.8977	0.2530	0.1027	2.2535	0.0286
1657.1	5.55	0.37	0.15	6.48	1.9943	0.2655	0.1068	2.3666	0.0301
1380.9	4.23	0.25	0.10	4.87	2.1863	0.2604	0.1092	2.5558	0.0330
1104.6	2.82	0.16	0.07	3.24	2.2797	0.2690	0.1110	2.6597	0.0344
828.4	1.81	0.08	0.06	1.99	2.5941	0.2417	0.1794	3.0152	0.0391

ALIGNED STREAMLINED BUNDLES (050881)

SS FLUX G/M.M.S) WATER	PRESSURE LOSS (KPA/M) FRICTION	PRESSURE LOSS LOCAL (KPA) JUNCTION	PRESSURE LOSS LOCAL (KPA) SPACERS	TOTAL	LOSS COEFFICIENT (K) FRICTION	LOSS COEFFICIENT (K) JUNCTION	LOSS COEFFICIENT (K) SPACERS	TOTAL	FRICTION FACTOR
3034.9	16.08	0.97	0.48	18.77	1.7201	0.2087	0.1041	2.0329	0.0260
2758.7	13.49	0.81	0.41	15.76	1.7461	0.2125	0.1062	2.0647	0.0263
2482.7	10.93	0.65	0.32	12.74	1.7470	0.2101	0.1037	2.0608	0.0264
2206.7	8.82	0.57	0.28	10.40	1.7832	0.2339	0.1141	2.1312	0.0269
1930.7	7.06	0.43	0.20	8.23	1.8658	0.2273	0.1088	2.2020	0.0281
1654.7	5.46	0.33	0.16	6.36	1.9644	0.2407	0.1146	2.3198	0.0296
1433.9	4.37	0.26	0.12	5.07	2.0916	0.2496	0.1184	2.4596	0.0316
1213.2	3.28	0.19	0.08	3.76	2.1948	0.2509	0.1088	2.5545	0.0331
992.6	2.24	0.13	0.08	2.63	2.2405	0.2621	0.1558	2.6583	0.0338
772.0	1.55	0.06	0.02	1.70	2.5552	0.2164	0.0767	2.6463	0.0386

able L.5: Single-phase Flow Results for Various Bundle Configurations (Aligned Streamlined Bundles)

ALIGNED STREAMLINED BUNDLES (060881)

ASS FLUX KG/M.M.S) WATER	(KPA/M) FRICTION	PRESSURE LOSS LOCAL (KPA) JUNCTION	SPACERS	TOTAL	LOSS COEFFICIENT (K) FRICTION	JUNCTION	SPACERS	TOTAL	FRICTION FACTOR
3037.0	16.29	1.00	0.46	18.99	1.7413	0.2157	0.0990	2.0559	0.0263
2760.7	13.52	0.83	0.37	15.75	1.7484	0.2188	0.0978	2.0630	0.0264
2484.4	11.18	0.69	0.30	13.00	1.7852	0.2218	0.0967	2.1037	0.0269
2208.2	9.05	0.56	0.25	10.54	1.8295	0.2275	0.1009	2.1579	0.0276
1932.0	7.14	0.44	0.20	8.31	1.8839	0.2356	0.1041	2.2236	0.0284
1655.9	5.51	0.36	0.15	6.42	1.9786	0.2581	0.1059	2.3426	0.0299
1435.1	4.32	0.30	0.12	5.09	2.0663	0.2878	0.1206	2.4746	0.0312
1214.4	3.30	0.19	0.08	3.80	2.2019	0.2604	0.1111	2.5734	0.0332
993.4	2.23	0.13	0.05	2.57	2.2289	0.2695	0.1099	2.6082	0.0338
772.6	1.47	0.09	0.04	1.71	2.4227	0.3044	0.1334	2.8605	0.0366

ALIGNED STREAMLINED BUNDLES (070881)

ASS FLUX KG/M.M.S) WATER	(KPA/M) FRICTION	PRESSURE LOSS LOCAL (KPA) JUNCTION	SPACERS	TOTAL	LOSS COEFFICIENT (K) FRICTION	JUNCTION	SPACERS	TOTAL	FRICTION FACTOR
3037.4	16.14	1.02	0.47	18.90	1.7248	0.2201	0.1020	2.0469	0.0260
2761.0	13.49	0.85	0.39	15.78	1.7446	0.2213	0.1031	2.0691	0.0263
2484.7	11.11	0.69	0.33	12.99	1.7733	0.2241	0.1049	2.1023	0.0268
2208.5	8.98	0.56	0.26	10.49	1.8153	0.2277	0.1065	2.1496	0.0274
1932.3	7.03	0.43	0.21	8.21	1.8544	0.2314	0.1102	2.1960	0.0280
1656.1	5.43	0.34	0.16	6.38	1.9522	0.2492	0.1176	2.3190	0.0295
1435.2	4.31	0.27	0.13	5.03	2.0614	0.2582	0.1227	2.4424	0.0311
1214.3	3.23	0.19	0.09	3.75	2.1572	0.2626	0.1221	2.5419	0.0325
993.4	2.25	0.13	0.07	2.62	2.2504	0.2546	0.1462	2.6512	0.0340
772.6	1.48	0.08	0.04	1.69	2.4389	0.2668	0.1297	2.8354	0.0368

ALIGNED STREAMLINED BUNDLES (070881)

ASS FLUX KG/M.M.S) WATER	(KPA/M) FRICTION	PRESSURE LOSS LOCAL (KPA) JUNCTION	SPACERS	TOTAL	LOSS COEFFICIENT (K) FRICTION	JUNCTION	SPACERS	TOTAL	FRICTION FACTOR
1655.8	5.45	0.35	0.16	6.41	1.9603	0.2575	0.1197	2.3375	0.0298
1545.3	4.66	0.30	0.14	5.69	2.0088	0.2524	0.1193	2.3785	0.0303
1434.9	4.28	0.27	0.13	5.00	2.0458	0.2580	0.1233	2.4271	0.0309
1324.4	3.78	0.23	0.12	4.43	2.1215	0.2631	0.1327	2.5172	0.0320
1214.0	3.20	0.20	0.10	3.74	2.1380	0.2640	0.1311	2.5330	0.0323
1103.6	2.71	0.16	0.07	3.14	2.1923	0.2618	0.1192	2.5734	0.0331
993.2	2.24	0.13	0.06	2.58	2.2372	0.2524	0.1182	2.6077	0.0338
882.8	1.83	0.11	0.05	2.12	2.3172	0.2711	0.1278	2.7160	0.0350
772.4	1.44	0.08	0.04	1.66	2.3745	0.2636	0.1393	2.7774	0.0358
662.0	1.13	0.06	0.03	1.30	2.5440	0.2654	0.1519	2.9613	0.0384

ble L.6: Single-phase Flow Results for Various Bundle Configurations (22.5° Misaligned Streamlined Bundles

22.5 DEG. MISALIGNED STREAMLINED BUNDLES (290781)

ASS FLUX KG/M.M.S) WATER	PRESSURE LOSS (KPA/M) FRICTION	PRESSURE LOSS LOCAL (KPA) JUNCTION	PRESSURE LOSS LOCAL (KPA) SPACERS	TOTAL	LOSS COEFFICIENT (K) FRICTION	LOSS COEFFICIENT (K) JUNCTION	LOSS COEFFICIENT (K) SPACERS	LOSS COEFFICIENT (K) TOTAL	FRICTION FACTOR
3311.3	19.41	1.14	0.53	22.58	1.7444	0.2067	0.0969	2.0481	0.0263
3034.6	16.57	0.96	0.45	19.20	1.7720	0.2077	0.0966	2.0764	0.0267
2758.3	13.74	0.82	0.38	15.99	1.7791	0.2156	0.0998	2.0944	0.0268
2482.3	11.[illegible]	0.70	0.31	13.14	1.7959	0.2254	0.0997	2.1211	0.0271
2206.3	9.[illegible]	0.55	0.25	10.63	1.8491	0.2254	0.1005	2.1750	0.0279
1930.3	7.21	0.43	0.19	8.36	1.9054	0.2294	0.1014	2.2361	0.0287
1654.3	5.64	0.34	0.14	6.53	2.0296	0.2484	0.1014	2.3793	0.0306
1323.5	4.16	0.25	0.10	4.82	2.3395	0.2833	0.1189	2.7418	0.0353
1102.8	2.82	0.17	0.07	3.25	2.2803	0.2703	0.1157	2.6663	0.0344
827.0	1.70	0.10	0.04	1.96	2.4383	0.3024	0.1246	2.8664	0.0368

22.5 DEG. MISALIGNED STREAMLINED BUNDLES (040881)

SS FLUX G/M.M.S) WATER	PRESSURE LOSS (KPA/M) FRICTION	PRESSURE LOSS LOCAL (KPA) JUNCTION	PRESSURE LOSS LOCAL (KPA) SPACERS	TOTAL	LOSS COEFFICIENT (K) FRICTION	LOSS COEFFICIENT (K) JUNCTION	LOSS COEFFICIENT (K) SPACERS	LOSS COEFFICIENT (K) TOTAL	FRICTION FACTOR
3039.9	16.70	1.07	0.45	19.56	1.7835	0.2318	0.0964	2.1117	0.0269
2763.2	13.91	0.89	0.37	16.27	1.7976	0.2328	0.0970	2.1272	0.0271
2486.6	11.33	0.72	0.30	13.26	1.8082	0.2336	0.0977	2.1395	0.0273
2210.0	9.15	0.59	0.24	10.70	1.8472	0.2401	0.0998	2.1870	0.0279
1933.6	7.17	0.46	0.19	8.38	1.8922	0.2452	0.0990	2.2365	0.0285
1657.2	5.67	0.37	0.15	6.62	2.0345	0.2701	0.1052	2.4099	0.0307
1436.2	4.50	0.28	0.11	5.24	2.1526	0.2738	0.1065	2.5329	0.0325
1215.1	3.39	0.20	0.08	3.91	2.2666	0.2730	0.1096	2.6491	0.0342
994.1	2.31	0.14	0.05	2.67	2.3020	0.2808	0.1079	2.6906	0.0347
773.2	1.52	0.10	0.04	1.76	2.5056	0.3232	0.1166	2.9454	0.0378

22.5 DEG. MISALIGNED STREAMLINED BUNDLES (050881)

SS FLUX G/M.M.S) WATER	PRESSURE LOSS (KPA/M) FRICTION	PRESSURE LOSS LOCAL (KPA) JUNCTION	PRESSURE LOSS LOCAL (KPA) SPACERS	TOTAL	LOSS COEFFICIENT (K) FRICTION	LOSS COEFFICIENT (K) JUNCTION	LOSS COEFFICIENT (K) SPACERS	LOSS COEFFICIENT (K) TOTAL	FRICTION FACTOR
3033.9	16.68	0.97	0.39	19.23	1.7847	0.2107	0.0848	2.0802	0.0269
2757.9	13.80	0.83	0.34	15.97	1.7860	0.2175	0.0878	2.0914	0.0269
2481.9	11.33	0.66	0.26	13.04	1.8116	0.2131	0.0842	2.1089	0.0273
2206.0	9.24	0.54	0.21	10.64	1.8689	0.2222	0.0878	2.1788	0.0282
1930.1	7.25	0.43	0.16	8.33	1.9171	0.2273	0.0866	2.2310	0.0289
1654.3	5.61	0.34	0.13	6.47	2.0176	0.2482	0.0937	2.3594	0.0304
1433.5	4.49	0.26	0.10	5.15	2.1518	0.2555	0.0930	2.5002	0.0325
1213.0	3.35	0.20	0.06	3.81	2.2402	0.2644	0.0838	2.5884	0.0338
992.3	2.27	0.13	0.05	2.59	2.2726	0.2559	0.0947	2.6232	0.0343
771.8	1.51	0.08	0.03	1.71	2.4873	0.2769	0.0942	2.8584	0.0375

le L.7: Single-phase Flow Results for Various Bundle Configurations (45° Misaligned Streamlined Bundles)

45.0 DEG. MISALIGNED STREAMLINED BUNDLES (280781)

SS FLUX (G/M.M.S) WATER	PRESSURE LOSS (KPA/M) FRICTION	LOCAL (KPA) JUNCTION	LOCAL (KPA) SPACERS	TOTAL	LOSS COEFFICIENT (K) FRICTION	JUNCTION	SPACERS	TOTAL	FRICTION FACTOR
3310.0	19.82	0.98	0.45	22.46	1.7812	0.1773	0.0819	2.0403	0.0269
3037.8	17.10	0.93	0.41	19.58	1.8265	0.2006	0.0889	2.1160	0.0276
2758.6	14.36	0.78	0.34	16.42	1.8586	0.2045	0.0884	2.1515	0.0280
2482.5	11.59	0.63	0.27	13.26	1.8519	0.2048	0.0872	2.1439	0.0279
2208.5	9.36	0.52	0.22	10.74	1.8933	0.2120	0.0915	2.1968	0.0286
1929.2	7.46	0.42	0.17	8.55	1.9723	0.2260	0.0903	2.2886	0.0298
1654.7	5.74	0.33	0.13	6.59	2.0832	0.2417	0.0923	2.3972	0.0311
1380.6	4.30	0.24	0.09	4.91	2.2266	0.2536	0.0936	2.5738	0.0336
1104.4	2.87	0.16	0.06	3.27	2.3167	0.2656	0.0956	2.6779	0.0350
828.2	1.94	0.09	0.03	2.14	2.7934	0.2703	0.0784	3.1421	0.0421

45.0 DEG. MISALIGNED STREAMLINED BUNDLES (040881)

SS FLUX (G/M.M.S) WATER	PRESSURE LOSS (KPA/M) FRICTION	LOCAL (KPA) JUNCTION	LOCAL (KPA) SPACERS	TOTAL	LOSS COEFFICIENT (K) FRICTION	JUNCTION	SPACERS	TOTAL	FRICTION FACTOR
3037.0	16.88	0.98	0.42	19.50	1.8040	0.2118	0.0901	2.1059	0.0272
2760.6	14.21	0.81	0.33	16.32	1.8376	0.2108	0.0868	2.1353	0.0277
2484.2	11.61	0.66	0.27	13.31	1.8532	0.2117	0.0855	2.1504	0.0280
2207.9	9.37	0.53	0.21	10.75	1.8937	0.2175	0.0876	2.1987	0.0286
1931.7	7.32	0.43	0.16	8.40	1.9327	0.2268	0.0877	2.2471	0.0292
1655.6	5.74	0.33	0.13	6.58	2.0614	0.2410	0.0917	2.3941	0.0311
1434.7	4.54	0.26	0.10	5.21	2.1745	0.2537	0.0958	2.5241	0.0328
1213.9	3.41	0.20	0.07	3.90	2.2820	0.2871	0.0924	2.6414	0.0344
993.1	2.35	0.13	0.05	2.67	2.3477	0.2721	0.0931	2.7130	0.0354
772.4	1.52	0.09	0.03	1.72	2.5015	0.2854	0.0942	2.8811	0.0377

45.0 DEG. MISALIGNED STREAMLINED BUNDLES (040881)

SS FLUX (G/M.M.S) WATER	PRESSURE LOSS (KPA/M) FRICTION	LOCAL (KPA) JUNCTION	LOCAL (KPA) SPACERS	TOTAL	LOSS COEFFICIENT (K) FRICTION	JUNCTION	SPACERS	TOTAL	FRICTION FACTOR
3035.8	16.67	0.97	0.41	19.25	1.7823	0.2092	0.0887	2.0802	0.0269
2759.5	14.02	0.80	0.33	16.12	1.8133	0.2099	0.0858	2.1090	0.0274
2483.1	11.54	0.66	0.27	13.28	1.8436	0.2132	0.0884	2.1452	0.0278
2206.8	9.21	0.54	0.22	10.62	1.8618	0.2212	0.0900	2.1731	0.0281
1930.7	7.30	0.42	0.17	8.40	1.9295	0.2259	0.0899	2.2453	0.0291
1654.7	5.66	0.34	0.13	6.53	2.0348	0.2498	0.0965	2.3811	0.0307
1433.9	4.50	0.28	0.10	5.19	2.1559	0.2738	0.0951	2.5247	0.0325
1213.2	3.35	0.19	0.07	3.83	2.2436	0.2582	0.0951	2.5969	0.0338
992.6	2.33	0.13	0.05	2.65	2.3313	0.2621	0.0941	2.6874	0.0352
772.0	1.50	0.09	0.03	1.71	2.4736	0.2970	0.1013	2.8719	0.0373

Appendix M

EXPERIMENTAL RESULTS OF EXPERIMENT B

FOR TWO-PHASE FLOW

TABLE F.1 TWO-PHASE FLOW RESULT WITH A 25. USGPM WATER FLOW RATE.

MASS FLUX (KG/M.M.S) WATER	AIR	QUALITY X	PRESSURE LOSS FRICTION (KPA/M)	LOCAL (KPA) JUNCTION	SPACERS	TOTAL	TWO-PHASE MULTIPLIER FRICTION	LOCAL JUNCTION	SPACERS	TOTAL
ALIGNED REGULAR BUNDLES - TWO PHASE (05/08/82)										
2762.8	13.1	0.471	51.64	4.95	2.16	65.48	4.03	2.82	4.11	3.77
2762.8	10.0	0.360	45.31	4.40	1.61	57.19	3.54	2.51	3.06	3.30
2762.8	7.1	0.258	36.95	3.83	1.60	48.39	2.89	2.19	3.06	2.80
2762.8	4.5	0.164	32.15	2.98	0.98	40.48	2.52	1.70	1.88	2.35
2762.8	1.0	0.035	17.33	1.97	0.66	22.39	1.36	1.13	1.26	1.30
2762.8	0.5	0.017	15.78	1.83	0.61	20.36	1.24	1.05	1.16	1.18
22.5 DEG. MISALIGNED REGULAR BUNDLES - TWO PHASE (05/08/82)										
2762.9	13.5	0.487	57.17	11.17	2.02	82.01	4.13	3.18	3.85	3.66
2762.9	10.3	0.371	47.46	10.04	1.66	69.98	3.44	2.87	3.17	3.13
2762.9	7.4	0.266	41.85	8.40	1.52	61.39	3.04	2.41	2.90	2.75
2762.9	4.7	0.169	35.30	6.91	1.04	51.09	2.57	1.98	1.89	2.29
2762.9	1.0	0.037	19.52	4.63	0.51	29.40	1.42	1.33	0.98	1.32
2762.9	0.5	0.017	17.07	4.39	0.55	26.71	1.24	1.26	1.07	1.20
45.0 DEG. MISALIGNED REGULAR BUNDLES - TWO PHASE (05/08/82)										
2763.0	13.5	0.487	54.21	12.32	2.40	82.40	3.85	2.60	4.58	3.41
2763.0	10.4	0.375	48.64	11.31	1.66	73.91	3.46	2.40	3.17	3.07
2763.0	7.5	0.269	42.04	9.89	1.27	64.09	3.00	2.10	2.42	2.66
2763.0	4.7	0.170	35.06	8.05	1.00	53.70	2.51	1.71	1.91	2.24
2763.0	1.0	0.037	18.84	5.47	0.59	30.84	1.35	1.17	1.13	1.29
2763.0	0.5	0.018	16.92	5.15	0.54	28.44	1.21	1.10	1.03	1.19
ALIGNED STREAMLINED BUNDLES - TWO PHASE (06/08/82)										
2763.2	12.8	0.462	57.78	2.38	1.13	63.46	4.22	2.72	3.08	3.94
2763.2	9.7	0.350	47.26	2.41	1.09	52.80	3.46	2.76	2.95	3.29
2763.2	7.0	0.252	39.12	1.90	1.27	45.01	2.87	2.18	3.45	2.81
2763.2	4.4	0.161	31.42	1.70	1.02	36.22	2.31	1.95	2.79	2.26
2763.2	0.9	0.034	17.52	1.05	0.47	20.28	1.29	1.21	1.28	1.27
2763.2	0.5	0.016	16.79	0.96	0.28	18.78	1.24	1.11	0.78	1.18
22.5 DEG. MISALIGNED STREAMLINED BUNDLES - TWO PHASE (06/08/82)										
2763.3	12.9	0.466	57.42	3.23	1.18	65.31	4.12	3.77	3.19	4.02
2763.3	9.8	0.353	48.68	2.17	0.96	54.66	3.50	2.54	2.62	3.38
2763.3	7.0	0.254	41.11	1.90	0.89	46.59	2.96	2.23	2.42	2.88
2763.3	4.4	0.161	33.21	1.05	0.56	36.03	2.40	1.23	1.53	2.23
2763.3	0.9	0.034	17.46	1.12	0.48	20.44	1.26	1.31	1.30	1.27
2763.3	0.5	0.016	15.91	0.98	0.46	18.66	1.15	1.15	1.27	1.16
45.0 DEG. MISALIGNED STREAMLINED BUNDLES - TWO PHASE (08/08/82)										
2763.5	13.0	0.467	58.81	3.03	1.17	66.45	4.10	3.71	3.15	4.04
2763.5	9.8	0.353	48.27	2.77	1.28	55.65	3.38	3.40	3.48	3.39
2763.5	7.1	0.255	40.62	1.93	1.07	46.42	2.85	2.38	2.90	2.84
2763.5	4.5	0.161	34.02	1.42	0.79	37.96	2.39	1.75	2.15	2.32
2763.5	0.9	0.034	18.42	0.81	0.43	20.68	1.30	1.00	1.16	1.27
2763.5	0.5	0.016	16.82	0.85	0.37	19.12	1.19	1.06	1.01	1.17

TABLE F.2 TWO-PHASE FLOW RESULT WITH A 20. USGPM WATER FLOW RATE.

MASS FLUX (KG/M.M.S) WATER	AIR	QUALITY %	PRESSURE LOSS (KPA/M) FRICTION	LOCAL (KPA) JUNCTION	LOCAL (KPA) SPACERS	TOTAL	TWO-PHASE MULTIPLIER FRICTION	LOCAL JUNCTION	LOCAL SPACERS	TOTAL
	ALIGNED REGULAR BUNDLES - TWO PHASE (09/09/82)									
2208.0	29.8	1.330	88.25	5.80	2.35	101.54	10.13	5.14	6.54	8.72
2208.0	24.9	1.112	77.86	5.30	2.23	90.05	8.98	4.72	6.23	7.77
2208.0	20.3	0.908	63.81	4.62	2.08	76.21	7.39	4.13	5.82	6.60
2208.0	16.0	0.717	51.31	4.32	2.13	63.65	5.96	3.88	5.99	5.53
2208.0	12.1	0.544	39.47	3.43	2.34	51.65	4.60	3.09	6.60	4.61
2208.0	8.6	0.388	32.[illegible]	2.96	1.52	41.62	3.77	2.68	4.30	3.84
2208.0	5.5	0.247	26.79	2.12	0.90	32.45	3.14	1.92	2.54	2.85
2208.0	3.1	0.140	19.29	1.89	0.63	23.91	2.27	1.71	1.78	2.10
	22.5 DEG. MISALIGNED REGULAR BUNDLES - TWO PHASE (09/09/82)									
2208.0	30.4	1.357	90.69	11.50	2.36	114.42	9.66	4.68	6.58	7.67
2208.0	25.6	1.144	82.34	10.90	1.91	104.62	8.80	4.46	5.32	7.05
2208.0	21.1	0.944	68.45	9.91	2.11	90.67	7.35	4.07	5.92	6.13
2208.0	16.6	0.744	54.15	8.66	1.99	74.94	5.84	3.57	5.60	5.09
2208.0	12.5	0.562	42.75	7.92	2.09	62.45	4.62	3.28	5.91	4.26
2208.0	8.8	0.395	35.07	6.05	1.16	49.59	3.81	2.51	3.28	3.39
2208.0	5.6	0.252	28.81	4.73	0.92	39.87	3.14	1.97	2.61	2.73
2208.0	3.2	0.144	22.80	3.83	0.68	30.87	2.47	1.80	1.85	2.12
	45.0 DEG. MISALIGNED REGULAR BUNDLES - TWO PHASE (09/09/82)									
2208.0	30.7	1.372	93.84	13.00	2.52	120.74	9.78	4.28	7.00	7.49
2208.0	25.8	1.152	82.48	12.02	2.35	108.17	8.63	3.97	6.58	6.74
2208.0	21.2	0.950	70.57	11.28	2.22	95.57	7.42	3.74	6.22	5.98
2208.0	16.6	0.744	53.02	9.97	2.20	77.38	5.60	3.32	6.19	4.86
2208.0	12.6	0.567	45.78	9.11	1.46	65.83	4.85	3.05	4.12	4.15
2208.0	8.9	0.404	35.87	7.29	1.39	53.13	3.81	2.45	3.93	3.36
2208.0	5.6	0.254	27.57	6.59	0.75	42.00	2.98	2.22	2.14	2.67
2208.0	3.2	0.145	21.61	5.26	0.68	32.96	2.31	1.78	1.94	2.10
	ALIGNED STREAMLINED BUNDLES - TWO PHASE (09/09/82)									
2208.1	29.4	1.314	93.35	3.71	1.61	100.08	10.12	6.21	8.47	9.21
2208.1	24.6	1.100	79.28	3.53	1.59	86.54	8.63	5.93	6.41	8.00
2208.1	20.0	0.897	66.95	3.02	1.71	74.67	7.32	5.10	6.94	6.93
2208.1	15.7	0.707	49.87	2.59	1.84	58.62	5.47	4.39	7.49	5.46
2208.1	11.9	0.535	42.88	2.05	1.26	49.00	4.72	3.49	5.14	4.58
2208.1	8.4	0.381	33.39	2.09	1.08	39.29	3.69	3.57	4.41	3.69
2208.1	5.4	0.243	26.58	1.27	0.63	30.34	2.94	2.17	2.58	2.85
2208.1	3.1	0.138	20.23	0.99	0.47	22.67	2.24	1.69	1.94	2.14
	22.5 DEG. MISALIGNED STREAMLINED BUNDLES - TWO PHASE (09/09/82)									
2208.2	29.4	1.315	93.98	3.85	1.59	101.07	9.97	6.68	6.40	9.24
2208.2	24.7	1.107	82.96	3.35	1.37	89.04	8.84	5.83	5.51	8.17
2208.2	20.1	0.903	69.25	3.08	1.38	76.31	7.41	5.38	5.57	7.03
2208.2	16.0	0.718	54.21	2.94	1.77	62.96	5.82	5.17	7.18	5.82
2208.2	11.9	0.535	41.27	2.35	1.40	48.86	4.45	4.14	5.71	4.54
2208.2	8.5	0.385	33.70	1.81	0.91	38.72	3.64	3.21	3.73	3.61
2208.2	5.4	0.244	27.00	1.54	0.65	31.07	2.93	2.73	2.67	2.90
2208.2	3.1	0.139	21.70	0.88	0.33	23.04	2.36	1.57	1.35	2.16
	45.0 DEG. MISALIGNED STREAMLINED BUNDLES - TWO PHASE (09/09/82)									
2208.3	29.4	1.315	96.71	4.07	1.43	103.43	10.11	7.36	5.74	9.41
2208.3	24.7	1.107	84.71	3.85	1.30	91.64	8.90	7.00	5.23	8.38
2208.3	20.3	0.910	70.81	3.40	1.22	78.02	7.47	6.20	4.84	7.16
2208.3	15.9	0.713	53.94	3.02	1.66	63.31	5.71	5.53	6.78	5.83
2208.3	12.1	0.545	45.21	2.27	1.15	52.22	4.80	4.17	4.69	4.83
2208.3	8.5	0.385	35.99	1.60	0.94	41.11	3.84	2.96	3.83	3.81
2208.3	5.4	0.245	29.78	1.21	0.22	31.87	3.18	2.24	0.89	2.96
2208.3	3.1	0.139	21.98	0.72	0.42	23.75	2.35	1.33	1.73	2.[illegible]

TABLE H.3 TWO-PHASE FLOW RESULT WITH A 15. USGPM WATER FLOW RATE.

MASS FLUX (KG/M.M.S) WATER	AIR	QUALITY %	PRESSURE LOSS (KPA/M) FRICTION	LOCAL (KPA) JUNCTION	LOCAL (KPA) SPACERS	TOTAL	TWO-PHASE MULTIPLIER FRICTION	LOCAL JUNCTION	LOCAL SPACERS	TOTAL
ALIGNED REGULAR BUNDLES -TWO PHASE (05/08/82)										
1658.0	36.9	2.175	82.62	5.24	2.36	94.53	15.12	7.87	10.93	13.13
1658.0	32.1	1.851	76.14	4.68	2.06	85.96	14.01	7.07	9.64	12.01
1658.0	27.3	1.621	66.52	4.02	1.76	76.33	12.31	6.10	8.26	10.72
1658.0	22.7	1.356	54.12	3.92	1.60	64.35	10.07	5.99	7.54	9.09
1658.0	18.7	1.117	45.24	4.02	1.48	56.32	8.46	6.17	7.03	7.99
1658.0	14.8	0.884	36.66	2.76	1.33	44.93	6.89	4.26	6.32	6.41
22.5-DEG. MISALIGNED REGULAR BUNDLES - TWO PHASE (05/08/82)										
1657.9	37.6	2.218	87.38	9.23	2.06	106.38	14.89	6.39	9.53	11.67
1657.9	32.5	1.921	77.45	8.43	1.70	95.44	13.31	5.87	7.94	10.54
1657.9	27.8	1.650	67.86	8.38	1.70	84.56	11.70	5.88	7.97	9.39
1657.9	23.3	1.384	58.15	7.10	1.67	74.94	10.08	5.00	7.89	8.36
1657.9	18.9	1.126	46.71	6.18	1.59	62.31	8.14	4.38	7.55	6.99
1657.9	15.0	0.897	38.51	5.72	1.07	52.33	6.74	4.07	5.12	5.80
45.0 DEG. MISALIGNED REGULAR BUNDLES - TWO PHASE (05/08/82)										
1657.8	38.1	2.247	90.72	10.78	2.10	111.74	15.08	6.09	9.72	11.39
1657.8	32.8	1.942	79.07	9.93	2.01	99.31	13.22	5.64	9.38	10.19
1657.8	28.0	1.663	71.85	9.32	1.46	90.26	12.11	5.33	6.83	9.31
1657.8	23.6	1.404	58.61	8.86	1.43	77.64	9.91	5.09	6.74	8.05
1657.8	19.2	1.144	47.99	7.48	1.44	66.27	8.16	4.32	6.81	6.91
1657.8	15.0	0.897	38.04	7.00	1.28	54.41	6.50	4.06	6.08	5.70
ALIGNED STREAMLINED BUNDLES - TWO PHASE (06/08/82)										
1657.7	36.7	2.167	82.86	3.62	2.04	91.09	14.62	9.40	13.48	13.60
1657.7	31.5	1.866	76.66	2.97	1.34	81.89	13.61	7.75	8.91	12.30
1657.7	27.0	1.605	67.81	2.43	1.27	73.08	12.10	6.37	8.49	11.04
1657.7	22.5	1.341	57.62	2.48	1.15	63.07	10.34	6.54	7.75	9.58
1657.7	18.3	1.092	46.84	1.75	1.02	51.96	8.45	4.65	6.88	7.93
1657.7	14.6	0.874	36.34	1.50	1.03	41.86	6.58	4.00	6.97	6.42
22.5 DEG. MISALIGNED STREAMLINED BUNDLES - TWO PHASE (06/08/82)										
1657.7	36.8	2.171	86.38	3.16	1.45	93.02	14.66	8.60	9.56	13.61
1657.7	31.7	1.875	77.15	3.20	1.45	83.88	13.17	8.76	9.64	12.35
1657.7	27.0	1.604	70.32	2.49	1.04	75.17	12.07	6.86	6.94	11.13
1657.7	22.7	1.356	59.00	2.24	0.98	63.92	10.18	6.30	6.56	9.51
1657.7	18.4	1.095	46.39	2.07	1.21	53.17	8.05	5.75	8.16	7.95
1657.7	14.5	0.866	37.40	1.87	1.11	42.70	6.52	5.23	7.51	6.42
45.0 DEG. MISALIGNED STREAMLINED BUNDLES -TWO PHASE (06/08/82)										
1657.6	36.8	2.171	89.92	3.44	1.50	95.95	15.07	9.73	9.92	13.99
1657.6	31.7	1.875	79.15	3.16	1.47	85.28	13.35	8.97	9.79	12.51
1657.6	27.2	1.615	69.27	2.56	1.22	74.73	11.74	7.32	8.13	11.02
1657.6	22.8	1.354	60.10	2.12	0.87	64.30	10.24	6.07	5.84	9.53
1657.6	18.4	1.100	50.33	1.75	0.80	54.80	8.82	5.06	5.42	8.13
1657.6	14.7	0.878	38.28	1.41	0.86	43.14	6.59	4.08	5.83	6.46