Numerical Investigation of Free-molecular Flow around a Circular Cylinder

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INTRODUCTION

Traditional fluid-dynamics treatments are only applicable to gas flows in situations when inter-particle collisions dominate. New and advanced models that have the potential to vastly expand the flow regimes that can be treated efficiently are being developed. One large difficulty in this work is the lack of accurate reference data for validation of the equations. A very accurate set of solutions was generated. It will be used to guide the development of new models as well as to validate their predictive capabilities. In order to achieve this, a new technique to compute solutions describing the complete flow field for free-molecular gas flows at arbitrary velocity passing a cylinder was implemented in a code. The results were also studied in order to assess what effects are most dominant in the flow and in what way the flow characteristics deviate from traditional, collision-dominated flow. Up to now, there has been no good way to create similar reference data. Having reliable free-molecular reference results to use in the development of new models for gas flows will be immensely useful in the research of many other members of the international research community in this field.

METHODOLOGY

To obtain the properties of the gas at each point in space, a statistic approach was used. The probability of a particular particle having a particular velocity is assumed to be given by the Maxwell-Boltzmann distribution function:

$$F = \frac{\rho}{m}\left(\frac{\rho}{2\pi p}\right)^{\frac{3}{2}} e^{-\frac{\rho}{2p}(\vec{v}-\vec{u})^2}$$

All particles arriving at a point directly from infinity are described by this function. Since we have a convex and solid body, we can safely assume that every particle that will hit the cylinder will be reflected only once. The particles leaving the cylinder after a reflection are assumed to also be described by a Maxwell-Boltzmann distribution. However, this time the pressure and density are determined such that the particles leaving the cylinder take the temperature of the cylinder and that there is zero particle flux through the cylinder wall. At each point in the x-y plane, the sum of the two distributions is integrated to find traditional gas properties, such as density, momentum, energy, and heat transfer. A graphical representation of the integration is shown in Figure 1.

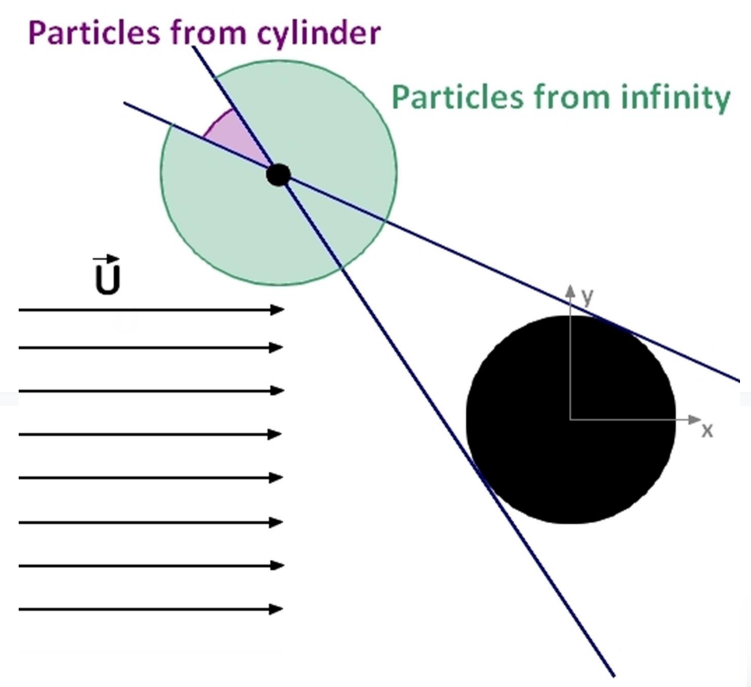

Figure 1 : Graphical representation

RESULTS

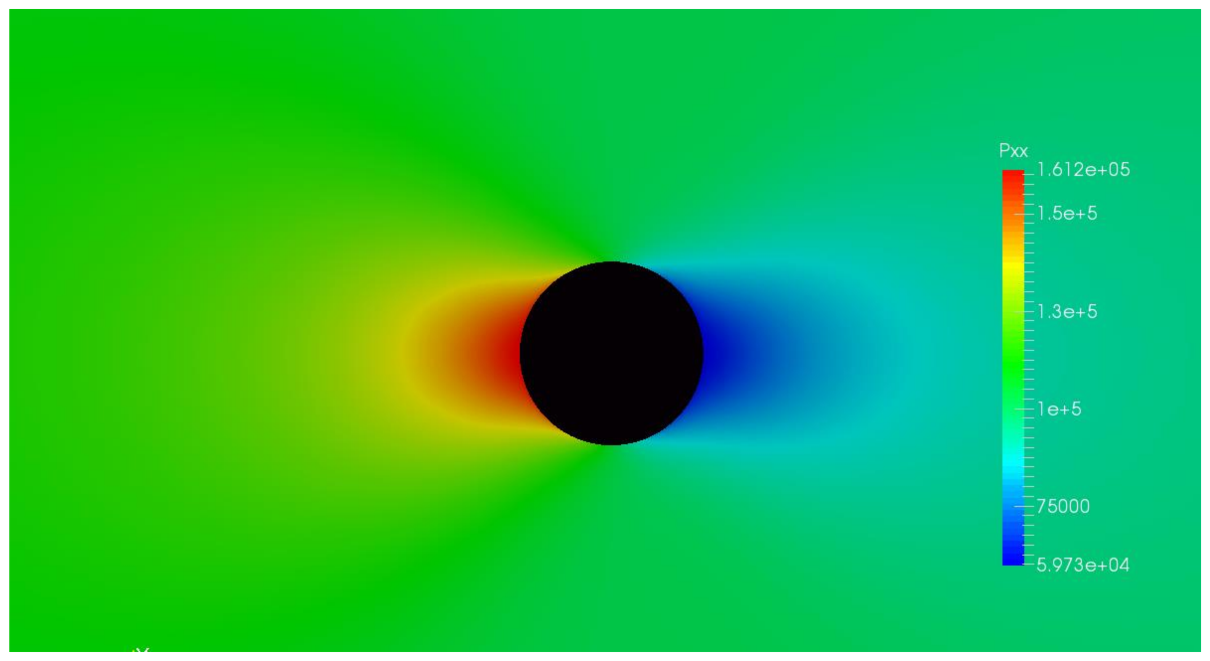

Figure 2: Pressure in the x-direction

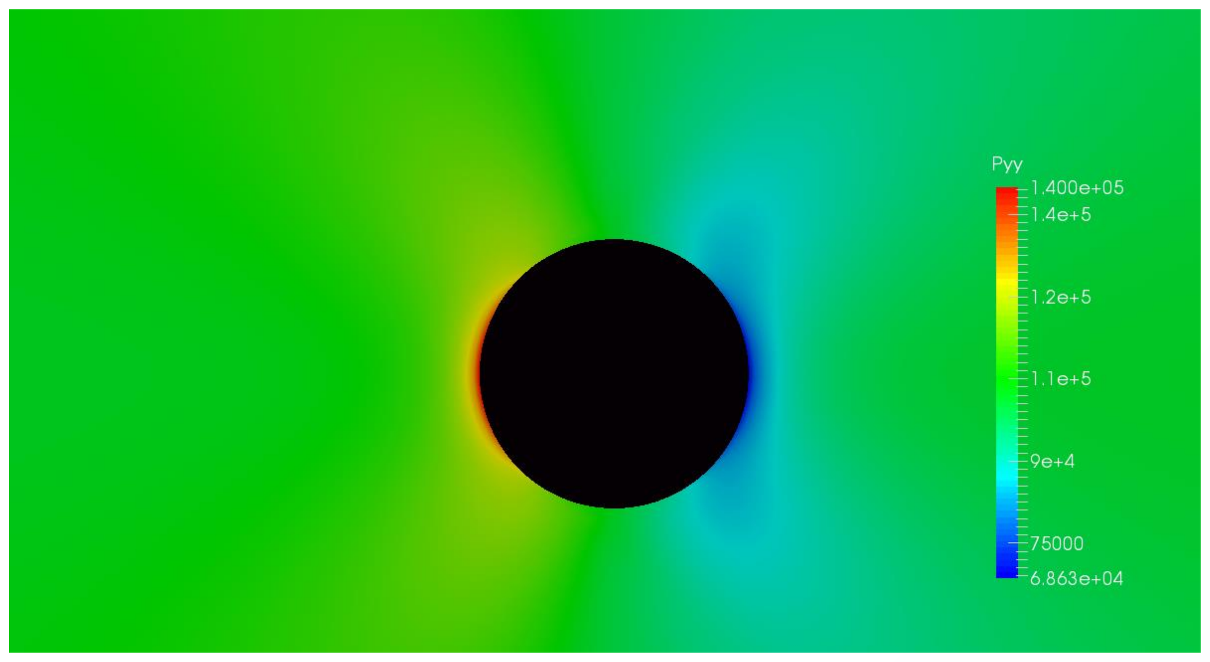

Figure 3: Pressure in the y-direction

Figure 2 and Figure 3 show the pressure in both x- and y-direction. This goes against a common assumption that the pressure on a body is the same in all directions. In fact, since we are not in a state close to equilibrium, we see that this assumption is not valid.

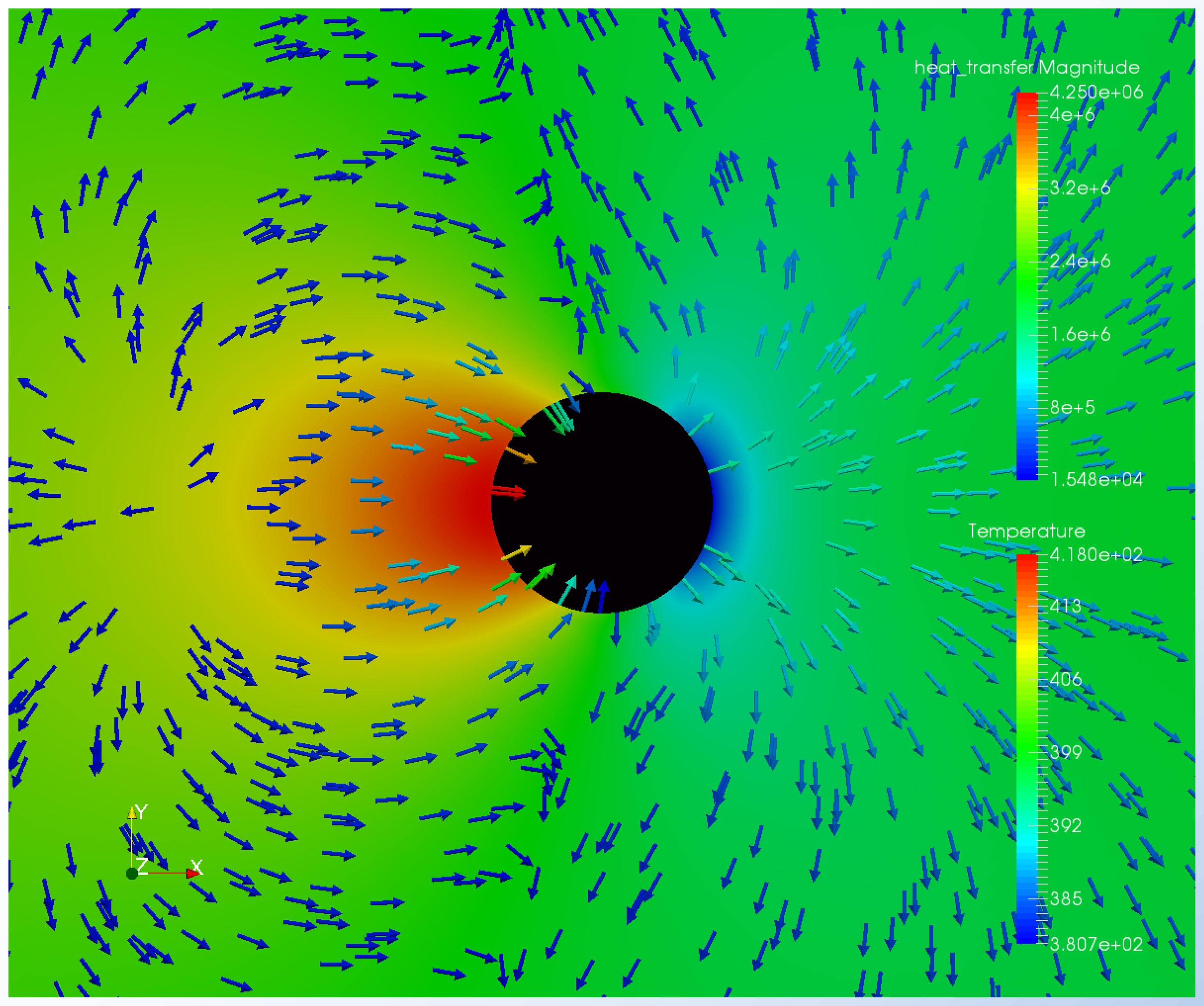

Figure 4 : Heat transfer

RESULTS (CNT'D)

In Figure 4, we see that the heat transfer (represented by the arrows) is going from a cold region to a hotter region. Again, this goes against was most scientists and engineers believe. The laws of equilibrium thermodynamics state that the heat goes from a hot region to a colder region until a thermal equilibrium is reached, but this assumption is only true for a state close to equilibrium. This aspect is the most controversial in this field because not all the different models agree on it.

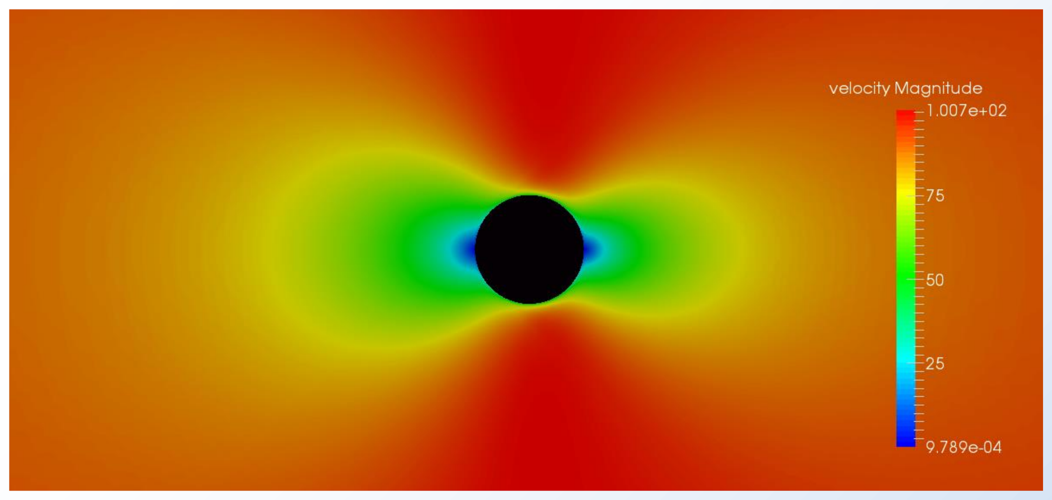

Figure 5: Velocity

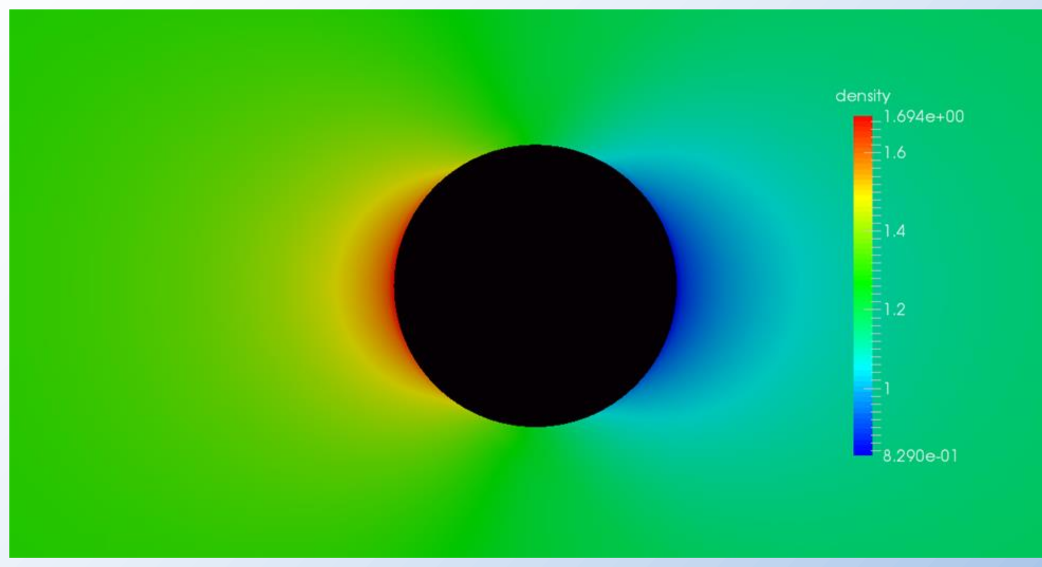

Figure 6: Density

Figures 5 and 6 show the velocity and the density around the cylinder respectively. These results were expected.

CONCLUSION

In conclusion, for this specific case where the inter-particle collisions do not occur, the flow characteristics deviate from traditional flows. Principles that are commonly used across scientific fields, such as the laws of equilibrium thermodynamics, are not applicable, mostly because the state is not close to equilibrium. Further verification would be required to validate these results but we have confidence that they are exact and represent what truly happens.

ACKNOWLEDGEMENT

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HEAT TRANSFER FROM COLD TO HOT?