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THE IMPACT OF THE UNDERWEDGE-SURFACE ANGLE ON THE AERODYNAMIC SURFACE QUANTITIES OF A SHARP LEADING EDGE IN HYPERSONIC FLOW

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Abstract
The problem of hypersonic low density flow over flat plates and wedges aligned with the flow has been extensively investigated experimentally and theoretically. Experimental and theoretical works on these shapes have been concentrated primarily on the analysis of the flowfield structure by considering the leading edges as being Şaerodynamically-sharpŤ, and with a finite bevel angle in the case of plates. The reason for that is because all the experimental work has suffered with the problem of assessing the influence of the tip thickness and the underwedge-surface angle on the measurements of the aerodynamic surface quantities, since it is not possible to investigate experimentally the special case of zero-tip thickness with zero-degree or finite underwedge-surface angle. Physically, some of the molecules that collide with the frontal face, or with the underwedge surface or on the top of the flat plate are emitted in an upstream direction. These refle cted molecules collide with the incoming freestream molecules, thereby altering the flow about the idealized flat plate or sharp-edged wedge. Furthermore, experimental difficulty arises from the complication of installing pressure taps very close to the nose of the leading edge. In low-density flows, the true pressure on a surface can be significantly different from that measured in orifice cavities or pressure holes, because of the increase in the effect of molecule-surface collisions, the so-called orifice effect. A critical study providing information on maximum allowable tip thickness or underwedge-surface angle for a given flow pattern has not received considerable attention. Such information is important when a comparison is to be made between experimental results in the immediate vicinity of the leading edge and the theoretical results, which generally assume a zero-thickness leading edge. In this scenario, Santos (Santos, 2001) has investigated the sensitivity of the flowfield structure and the aerodynamic surface quantities to leading-edge thickness variations for a flat plate in a low-density hypersonic flow. The range of Knudsen number, based on the tip thickness, covered from the transitional flow regime to the free molecular flow regime. Nevertheless, the effect of the underwedge-surface angle was not investigated. In an effort to obtain further insight into the nature of the flowfield structure of sharp leading edge under hypersonic transitional flow conditions, the present work will extend the previous analysis (Santos, 2001) by investigating closer the underwedge-surface angle effects. In this fashion, a parametric study is performed on a flat plate in order to assess the impact on the aerodynamic surface quantities (on the top surface) due to variations on the underwedge-surface angle. The flow past to the sharp leading edges will be examined by means of the Direct Simulation Monte Carlo (DSMC) method. Nowadays, the DSMC method has been recognized as an extremely powerful technique capable of predicting an almost unlimited variety of rarefied flowfields in the regimes where neither the Navier-Stokes nor the free molecular approaches are appropriate. In the present account, a procedure based on the physics of the particles will be employed. In this respect, the flowfield is assumed to consist of three distinct classes of molecules: those molecules from the freestream that have not been affected by the presence of the leading edge are denoted as class I molecules; those molecules that, at some time in their past history, have struck and been reflected from the body surface are denoted as class II molecules; and finally, those molecules that have been indirectly affected by the presence of the body are defined as class III molecules. The simulations pointed out that the pressure, skin friction and the heat flux increased on the upper surface of the flat plate with the underwedge-surface angle rise. It was found that pressure was more affected than the heat flux with increasing the underwedge-surface angle. It was also found that, molecules on the lower side of the flat plate, i.e., molecules below the stagnation line, affected the flowfield on the upper side of the plate. Due to the procedure adopted, it is possible not only to identify those molecules but also to quantify the contribution of each one of the molecular classes to the surface quantity rise. Results indicated that, with the size of the models being tested in hypersonic tunnels, large effects on surface quantities due to either leading-edge thickness or the underwedge-surface angle are possible even with models whose leading edges are generally considered as being aerodynamically sharp.

Keywords: DSMC, Hypersonic Flow, Sharp-Leading Edge

References

[1] Santos, W. F. N., 2001, "Rarefied hypersonic flow past the sharp/blunt leading edge of a flat plate", in 2nd International Conference on Computational Heat and Mass Transfer, Rio de Janeiro, Brasil.