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Correlation Technique for Predicting Attached Turbulent Boundary-Layer/Flap Interaction Pressures

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Abstract

THE method of Lees-Reeves-Klineberg has been successful for rapidly predicting a large class of interacting laminar flows. Hunter and Reeves[1] extended the laminar work and presented a method for calculating the two-dimensional flow separation and reattachment of a turbulent boundary layer caused by a compression corner. In this work, which is a summary of Ref. 2, a further extension is made to supersonic turbulent flows over adiabatic two-dimensional compression corners where the turning angle is such that the flow remains attached. The importance of the problem coupled with the success of the moment method for similar flows strongly suggests its development for applications where rapid calculations are essential.

Contents

The flow of a two-dimensional supersonic turbulent boundary layer over an adiabatic compression corner is studied. The range of compression angles is restricted to those for which the flow remains attached to the surface. The moment method is used to determine the solution with the pressure distribution as the primary quantity of interest. The equations governing the solution for this problem have been set forth by previous authors[1,3] and are used in a similar form. Since the method is an integral one, a family of profiles is needed to complete the formulation. Reference 3 used a combination of experimental values, existing analytical solutions, and a power law profile in the limit $\theta/\delta^* \to 1$ to obtain the necessary family. These profile results are also used here.

The outer edge boundary condition coupling the viscous and inviscid flow regions can be either a Prandtl-Meyer or tangent wedge relation. Because of the fullness of the turbulent profiles and the existence of shock waves deep within the layer, the tangent wedge relation was found more useful and was used in obtaining Figs. 1-3.

The angles considered in this study are relatively small. Therefore, the flow, which starts out supercritical, remains so, and a fully supercritical interaction results. A typical calculation of such a case is shown in Fig. 1 along with the data of Roshko and Thomke.[4] This is for an $M=5$, $Re_\delta = 0.38 \times 10^6$, $\alpha = 13$ deg compression. The agreement is very poor.

What can be seen from this figure, which is typical of all other cases run, is that two things are lacking in the analysis. The first is the very sharp rise exhibited by the data at the corner. This rise can be likened to the theoretical rise in pressure which is supposed to occur at a supercritical-subcritical jump and at first was thought to be evidence of one. The other problem with the calculated results is that the pressure rises too slowly. An examination of the equations revealed that they have only one length scale—the displacement thickness δ^*.

The results obtained based solely on the theory as presented are of no particular value. In order to make the method useful, a means of improving the results had to be found. In light of what has just been said, it is clear that this was done with the aid of a jump as well as a change in length scale. In so

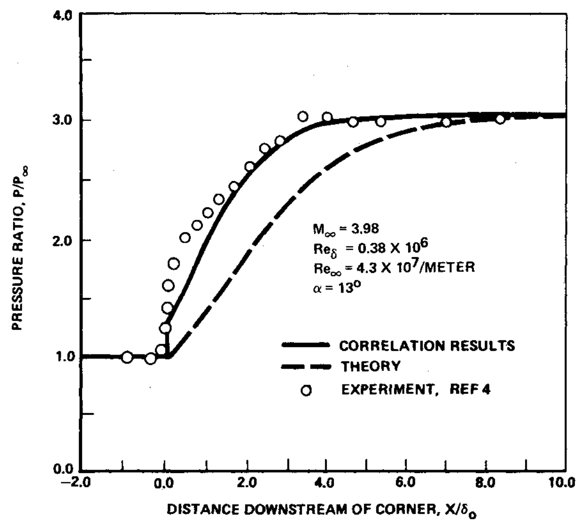

Fig. 1 Typical compression corner pressure distribution for attached flow.

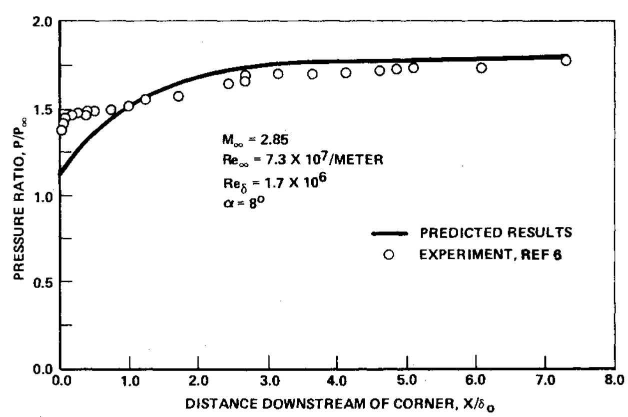

Fig. 2 Comparison of correlation model pressure rise with data.

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Index categories: Aerodynamics; Jets, Wakes, and Viscid-Inviscid Flow Interactions.

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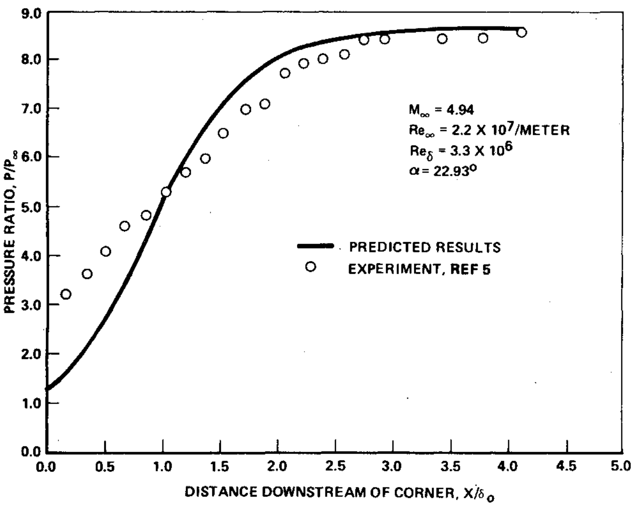

Fig. 3 Comparison of correlation model pressure rise with data.

doing, the method was changed from one resting on a theoretical foundation to a correlation technique.

The jump to be included has to be to supercritical downstream conditions because an integration path to the downstream boundary condition could not be found from a subcritical state. But no convincing argument could be found to determine this supercritical downstream point. After some numerical experimentation, it was found that the jump should be the one for which the solution trajectory in the phase plane comes arbitrarily close to subcritical while still remaining supercritical. This is because in no instance was the pressure rise as large as the data indicated it should be. But the jump could not be made larger because the trajectory would become subcritical and no solution existed. Near this curve whose trajectory lies arbitrarily close to the singularity, small changes in initial conditions produce very small changes in the solution trajectories.

Through numerical experimentation it was found that for a change in length scale a 40% reduction in δ^* yields the best results throughout the supersonic Mach number ranges where data could be found.

Data comparisons of the correlation model including the jump and reduced δ^* are presented in Figs. 1-3. The improvement is evident from the first figure. Instead of lagging behind the data as the theoretical results do, the correlation prediction rises to the level of the data within about one boundary layer thickness of the corner and tracks it downstream. Figures 2 and 3 provide representative samples of other comparisons at two extremes of available data. The first is at a relatively low Mach number and compression angle, and the second is at a high Mach and Reynolds number and compression angle. In both cases there is good agreement within one δ.

An interesting conclusion can be obtained from this work aside from the obvious ones associated with the theoretical and correlation predictions. By varying the size of the term associated with viscosity in the governing differential equations, it is possible to determine the role that viscosity plays in the solution. It was found that these terms can be varied over a very wide range with essentially no effect on the solution. Thus the viscous effect is minor. Aside from viscosity, only the inviscid coupling remains as the forcing function in the equations. This leads to the conclusion that the inviscid-viscous coupling is not only an essential feature of the flow, but it is by far the dominant feature.

Reasonable justification for most of the assumptions that go into the theory can be put forth. Yet the theoretical results, as shown in Fig. 1, do not agree well with the data at all. It is believed, in agreement with previous authors, that the inability of the present formulation to permit shock wave penetration into the boundary layer is the major reason for the theoretical method's failure.

What is finally presented here is a correlation technique. The success of any such technique is proven only by the breadth and accuracy of the data comparisons. The figures given here and in Ref. 2 provide comparisons which give us confidence in the method in the supersonic flow region.

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