Axisymmetric Supersonic Turbulent Base Pressures

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Abstract

RECENT studies of recompression of two-dimensional turbulent free shear layer reattachment and its subsequent redevelopment[2,3] with supersonic external freestreams have demonstrated the importance of the pressure difference across the shear layer within these flow regions. It can easily be shown that the factor $(p_w/p_e - 1)$ is of the order of $M_e^2\,\delta/R$ where $(p_w - p_e)$ is the difference of pressure across the shear layer of thickness δ, M_e is the local freestream Mach number and R is the radius of streamline curvature of the adjacent freestream. For turbulent supersonic base flows, base pressure is relatively low, so that this pressure difference is usually not small during recompression, reattachment, and redevelopment. It was shown that by linking the dividing streamline velocity with its velocity profile slope and taking into consideration the pressure difference across the shear layer, the recompression process can be calculated up to the point of reattachment. Moreover, by interpreting the flow redevelopment downstream of flow reattachment as a process of relaxation of this pressure difference $(p_w - p_e)$, it has been shown that the asymptotic state (corresponding to the original approaching flow condition) serves as a saddle point singularity for the system of equations describing the viscous flow redevelopment which, in turn, provides the closure condition for the Chapman-Korst model[4,5] of base pressures. Nevertheless, this mathematically asymptotic state is practically reached a short distance downstream of the point of reattachment.

The extension of this analysis to the axisymmetric flow past a backward facing step is reported here. The effect of the axisymmetric geometry as well as the sting radius ratio is well borne out from these calculations.

Contents

The methods of analysis and calculations for various flow components of expansion around the corner, turbulent jet mixing, recompression, reattachment, and redevelopment, including the external inviscid flow from the method of characteristics, follow the same basic ideas as discussed in Refs. 2 and 3 and are reported in detail in Ref. 1. It is found that the axisymmetric problem requires a much more complicated formulation than the corresponding two-dimensional problem. It should be pointed out, however, that in the study of flow redevelopment after reattachment, as a process of relaxation of the pressure difference across the viscous layer, it is natural to expect that the fully relaxed state $(p_w - p_e)$ occurs when the streamline at the edge of viscous layer runs parallel to the lower horizontal wall—a state of vanishing streamline curvature. This state assumes an invariably higher static pressure than that of the approaching flow and is a well known phenomenon of "overshoot"—a specific behavior of axisymmetric flow. It is again observed from our analysis that this state is a saddle point singularity for the syste of differential equations describing the viscous flow redevelopment. Figure 1 shows the schematic diagram of the flowfield. Figure 2 shows the typical calculated results in the pressure distribution within the separated flow region. It is clearly observed that the fully relaxed state has indeed a higher

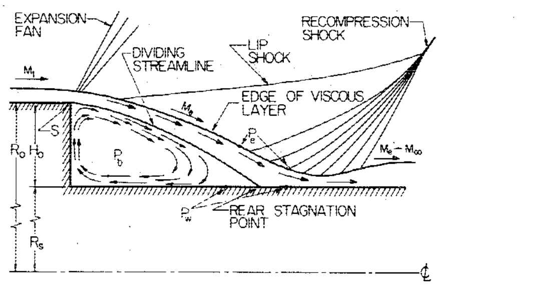

Fig. 1 Axisymmetric supersonic flow over a downstream-facing step.

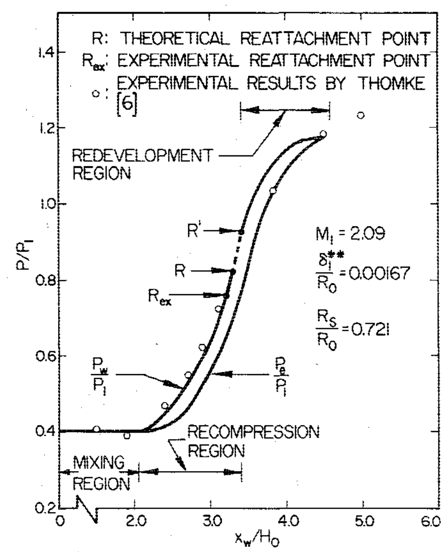

Fig. 2 Comparison of experimental and calculated wall pressure distributions.

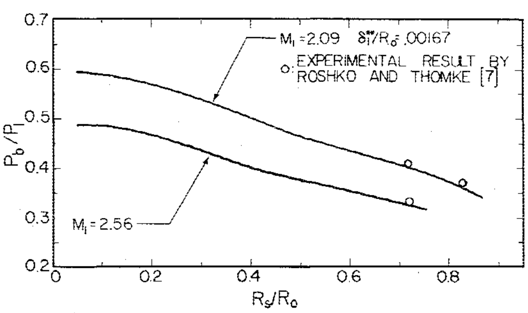

Fig. 3 Effect of sting radius on base pressure.

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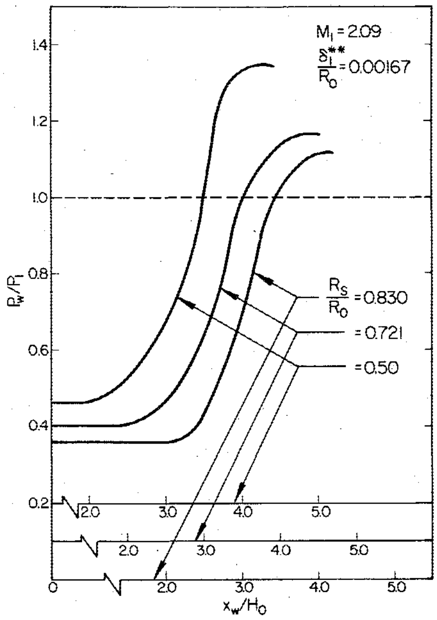

Fig. 4 Effect of sting radius on wall pressure distribution.

pressure than that of the approaching flow. Figure 3 shows the base pressure as influenced by the sting radius ratio. Experimental results by Thomke[6] and Roshko and Thomke[7] are included in Figs. 2 and 3 for comparison purposes. Results for other approaching flow Mach numbers and results demonstrating Reynolds number influence are reported in Ref. 1. Figure 4 shows the amount of static pressure overshoot for different sting radius ratios. It is clearly illustrated that a smaller sting radius ratio results in a larger overshoot.

From the results of these calculations, it is obvious that the interpretation of flow redevelopment as a process of relaxation of the pressure difference across the viscous layer is very useful. In addition, more detailed calculations of these complicated flow processes result in a better appreciation of the physical events and mechanisms governing these flows.

Acknowledgment

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