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The Effect of Inflow Velocity Profiles on the Performance of Supersonic Ejector Nozzles

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THE EFFECT OF INFLOW VELOCITY PROFILES ON THE PERFORMANCE OF SUPERSONIC EJECTOR NOZZLES

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INTRODUCTION

The design of supersonic nozzles is becoming increasingly complex as conflicting requirements for low noise, higher efficiency, and wider operating range are driving the designer toward more variable geometry and multiple stream flows. Analysis techniques must be modified and expanded to take into account these additional complexities and still retain the rapid computational rate necessary for optimization and design studies. A nozzle analysis must handle more flow streams, more complex geometries, and more hightly distorted initial profiles. This paper discusses some modifications to a method for calculating the performance characteristics of supersonic ejector nozzles and demonstrates the improvement in results the modifications provide.

BACKGROUND

In references 1 and 2 a method is presented for analyzing the flow field in an axisymmetric ejector nozzle having a supersonic core and a subsonic secondary flow. The core flow is treated with the method of characteristics, the secondary flow with a one-dimensional analysis, and the mixing of the two streams with a semi-empirical relation (ref. 3). For a conical choked core nozzle a sonic line initial profile is obtained using the method of reference 4. This code is used as a design and optimization procedure and takes about 2 minutes of CPU time on an IBM 360.

It is demonstrated in reference 2 that the shape of the initial profile can have a significant effect on performance.

Comparison between flows with uniform profiles and flows with the more realistic profiles predicted by the method of reference 4 show differences of about 1 percent in nozzle efficiency. Comparisons with data show that the results based on the realistic profiles are in much better agreement with experiment.

MODIFICATIONS TO ANALYSIS

In response to the requirements of newer supersonic nozzle designs, the method of reference 1 has been extended to analyze two separate concentric supersonic core streams. The streams are assumed to be separated by a slip line and no mixing of the two core streams is considered. The mixing of the outer core stream with the secondary flow is retained. In this geometry the outer core throat is no longer a conical convergent nozzle, and the initial profiles based on reference 3 are no longer valid. If a central plug is present neither core throat may be conical. The significant radial component of velocity in the throat regions implies that a uniform initial profile is probably not appropriate.

A transonic time-dependent analysis by M. Cline (ref. 5) was used to generate realistic initial profiles for the outer stream of these configurations. This analysis was applied to the outer core stream in the immediate neighborhood of the throat, including a short region downstream of the lip. A constant pressure boundary condition was used at the slip line. The use of this procedure for initial profiles produces a significant change in the nozzle performance and a better comparison with experimental data.

RESULTS

Figure 1 shows the two axisymmetric geometries discussed in this paper. The shroud contour and the outer fan stream nozzle lip are identical for both geometries. Case I has an isentropic splitter between the fan and core flows, a short core plug and internal supersonic expansion in the central core stream passage. Case II has a conical splitter and a larger diameter, longer plug. The splitter between the two core flows is assumed to be very thin. The central core flow is choked at the end of the splitter.

The flow fields produced by two different initial profiles in the outer core stream were analyzed for each geometry. One profile had a uniform Mach number along a straight line. The flow angle varied linearly between the two solid boundaries to match the tangency condition. The second initial profile was obtained by applying the transonic analysis of reference 5 in the throat region of the outer core flow. A line with supersonic velocities was chosen from this solution as the initial profile. The central core flow was assumed to have a uniform initial profile.

A comparison of the Mach 1.01 lines from each profile are shown in figures 2(a) and (b). In each case it is clear that the straight line profiles are not a very good approximation to the more realistic result from the transonic analysis. In figure 2(a) note the overexpansion on the splitter due to its upstream curvature. The transonic solutions also indicate a more complex flow angle variation than the simple linear change for the uniform profile.

Comparison of the performance parameters for each initial profile are shown in figures 3(a) and (b). The gross thrust coefficient (the computed thrust divided by the sum of the ideal thrust of the two core flows) is plotted as a function of secondary mass flow ratio (secondary mass flow divided by total mass flow). The thrust coefficients are presented along with some unpublished experimental data on these geometries taken at Lewis Research Center. The values of gross thrust coefficient above 1.0 are the result of neglecting the secondary mass flow in the ideal thrust computation.

The more realistic initial profiles from the analysis of reference 5 reduce the thrust coefficients by about 1 1/2 percent. The reduction brings the value in better agreement with the experimental data. Similar conclusions can be observed for both configurations.

CONCLUSIONS

The initial profile for a nozzle flow can significantly affect nozzle performance. Particular care should be used in those cases with large radial velocity components and wall curvature near the nozzle exits. Special efforts to obtain realistic initial profiles for analytical work will greatly improve the validity of the results.

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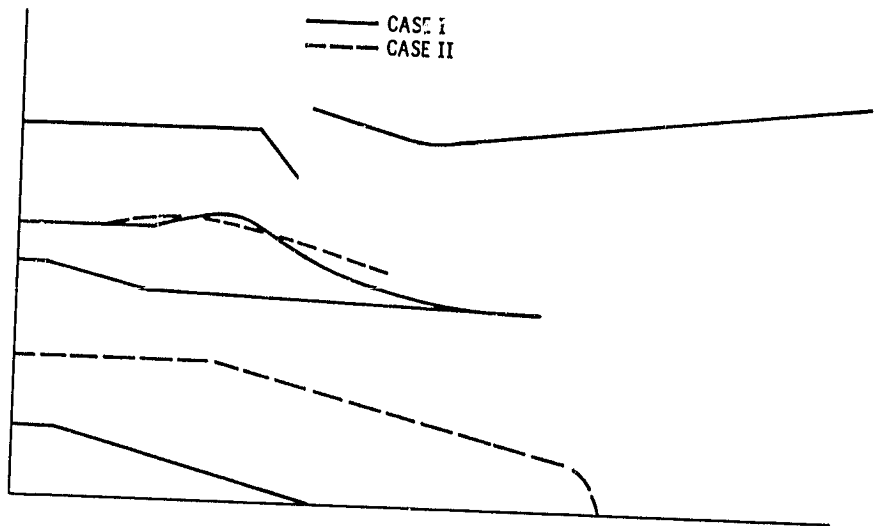
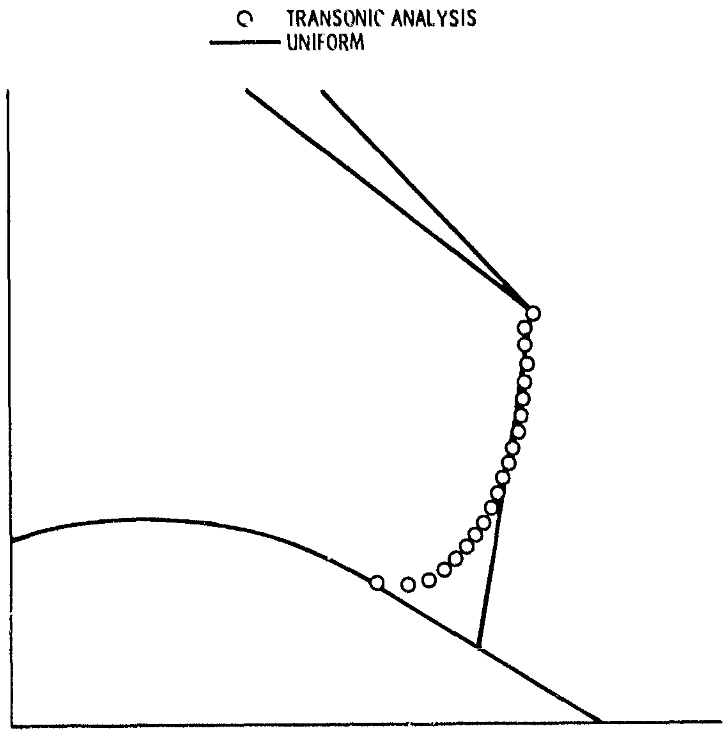
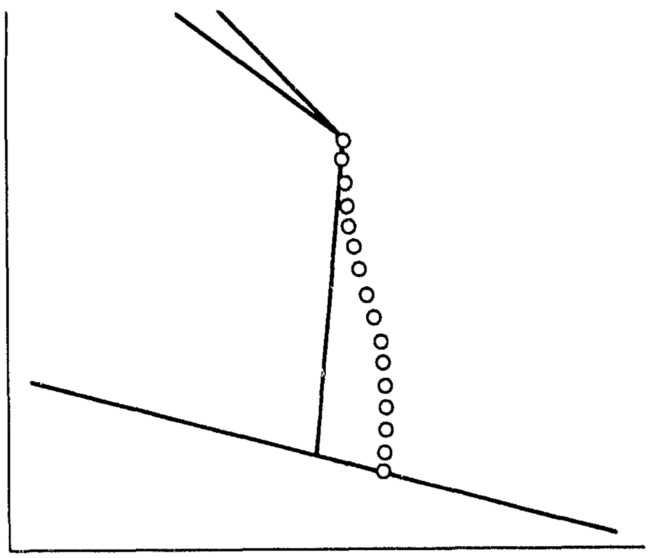


Figure 1. - Ejector geometry.

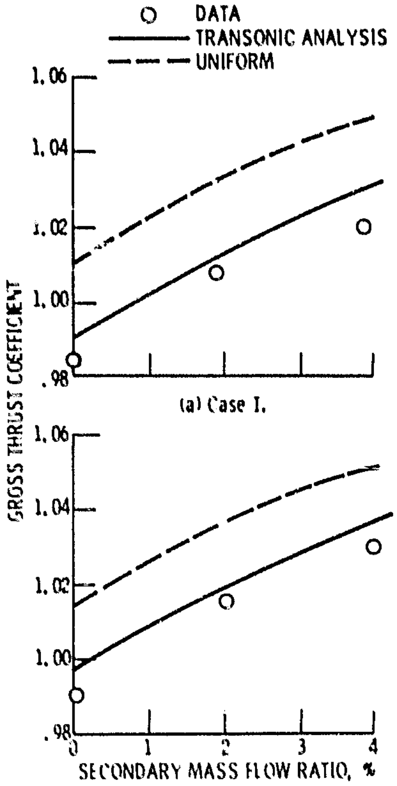


(a) Case I.



(b) Case II.

Figure 2. - Initial profiles.



(b) Case II.

Figure 3. - Performance.