COANNULAR SUPERSONIC EJECTOR NOZZLES

by

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The nozzles discussed in this papaer are associated with the transonic and supersonic propulsion work that is performed by the Aerodynamics Analysis Section at Lewis Research Center. There are two aspects of these nozzles which are different from most of the other nozzles discussed at this workshop: most of the flow field within the nozzle is supersonic, except for the initial secondary flow region; and the secondary mass flow is typically about five percent of the primary or core flow.

The original analysis for two stream ejectors was developed and programmed by Anderson, References 1 and 2. Two types of ejector nozzles were discussed in those references; a contoured shroud with no centerbody, and a cylindrical or contoured shroud with a conical plug centerbody. Schematics of these nozzles are shown in Figure 1. In the nozzle in 1a, the flow expansion is controlled by the shape of the shroud contour. In the nozzle in 1b, where the shroud is cylindrical, the expansion is controlled by the shape of the centerbody plug. The core flow is assumed to be inviscid and is treated with the method of characteristics. The secondary flow is treated one-dimensionally so that both the subsonic and supersonic portions can be analyzed in a rapid manner.

The analysis has two features to improve the accuracy of the performance calculations. A special calculation is made to get as realistic a sonic line as possible for this geometry, using an analysis developed by Brown, Reference 3. In addition, the mixing between the secondary and core flows is treated to account for entrainment of the secondary flow into core. Both of these phenomena directly affect the pressure distribution on the shroud and therefore the thrust that the nozzle produces. Figure 2 shows the importance of using a realistic sonic line and a mixing analysis. At the top is the nozzle efficiency, in the middle is the stream thrust, and at the bottom the ratio of secondary total pressure to core total pressure. All are plotted as a function of the ratio secondary to core corrected weight flow. The curves are the results from the analysis with various combinations of sonic lines and mixing. The symbols are data from an experiment at Lewis Research Center (Reference 4). The curve that is closest to the data is the analysis that includes both a realistic sonic line and mixing. The curve furthest from the data uses a uniform sonic line and no mixing.

There are two secondary flow regimes. For low secondary mass flow ratio, less than four percent of the core flow, the secondary stream is entirely mixed with the core, and the core flow impinges on the shroud and is recompressed. For secondary mass flow ratios greater than four percent the secondary flow accelerates and becomes supersonic, but maintains its identity as a separate layer along the shroud. These two regimes are illustrated in Figure 3.

The analysis assumes that at some point in the nozzle the entire flow is supersonic. The flow field is therefore independent of the exit pressure. Since the secondary total pressure ratio and mass flow ratio are not independent, the secondary mass flow ratio is taken as known and iterative calculations are made on the secondary total pressure ratio until a consistent value is obtained.

Recently, a number of ejector nozzles with two separate core streams have been proposed, particularly in connection with variable cycle engine designs. They consist of a core flow surrounded by a fan flow which is itself surrounded by a secondary cooling flow along the shroud surface. Figure 4 shows schematics of two typical designs, with 4a having a conical splitter between the core and fan flow and 4b having an isentropic splitter. Both have conical plug centerbodies.

In the updated analysis the fan and secondary flow interaction are treated as before. The core flow is assumed to be supersonic so that the method of characteristics can be used. The boundary between the fan and the core flows is determined by matching the static pressure across the interface. Typically, at the end of the splitter plate neither the static pressure nor the flow angle of the two streams will match, so that a shock wave will propagate into one or both streams. These shocks are not treated explicitly but as a compression wave in the method of characteristics. The effects of mixing of the fan and core streams is not included in the analysis.

Figure 5 is a visualization of the flow field in a typical three stream nozzle. The secondary flow occupies the gap near the shroud. The secondary mass flow ratio is four precent. In this plot a symbol is plotted at each grid point in the characteristic net, which highlights the expansion and compression regions. Note the end of the splitter, where a compression occurs in the fan flow and an expansion in the core flow due to a mismatch in the static pressure at this point.

Figure 6 is a similar plot for a three stream nozzle with an isentropic splitter. The matching of core and fan flows at the end of the splitter is much better, at least for this set of conditions.

There are several additions that could be made to the program to improve the accuracy of the calculations. Particularly important is a subroutine to generate better initial flow profiles for the sharply angled throat regions in these geometries. There is currently no simple way of producing the sonic line for an annular converging nozzle. Treating the shock waves more exactly and bridging some local subsonic bubbles would also enhance the capabilities of the program.

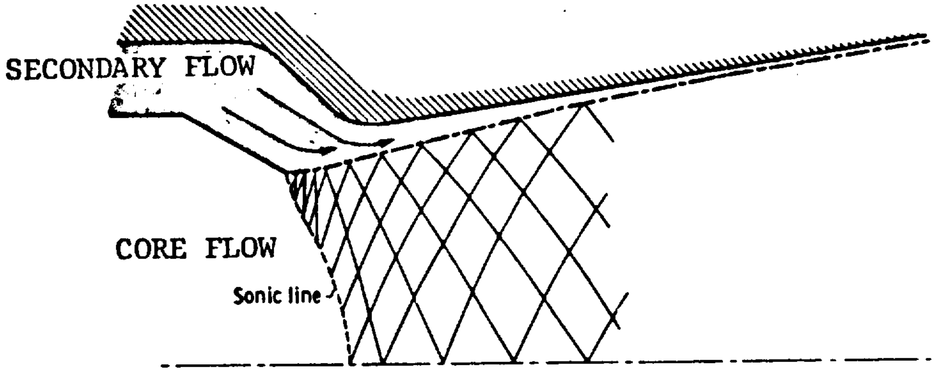
References

1. Anderson, Bernhard H.: Assessment of an Analytical Procedure for Predicting Supersonic Ejector Nozzle Performance. NASA TN D-7601, 1974.

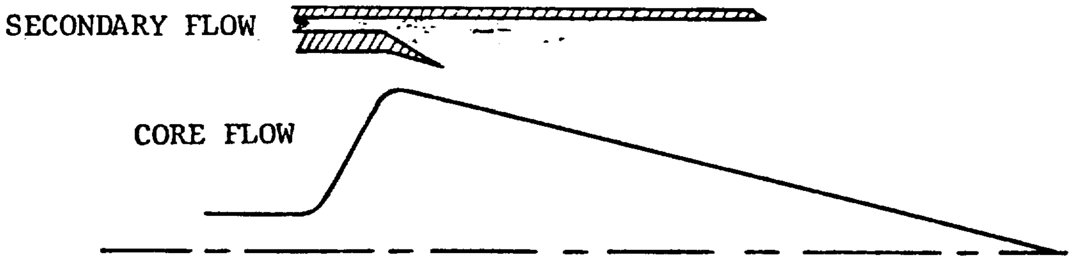
2. Anderson, Bernhard H.: Computer Program for Calculating the Flow Field of Supersonic Ejector Nozzles. NASA TN D-7602, 1974.

3. Brown, Eugene F.: Compressible Flow Through Convergent Conical Nozzles with Emphasis on the Transonic Region. Ph.D. Thesis, University of Illinois, 1968.

4. Shrewsbury, George D., and Jones, John R.: Static Performance of an Auxiliary Inlet Ejector Nozzle for Supersonic Cruise Aircraft. NASA TMX-1653, 1968.



(a) Contoured shroud two-stream ejector.



(b) Conical plug two-stream ejector.

Figure 1.- Schematic of typical two-stream ejector nozzles.

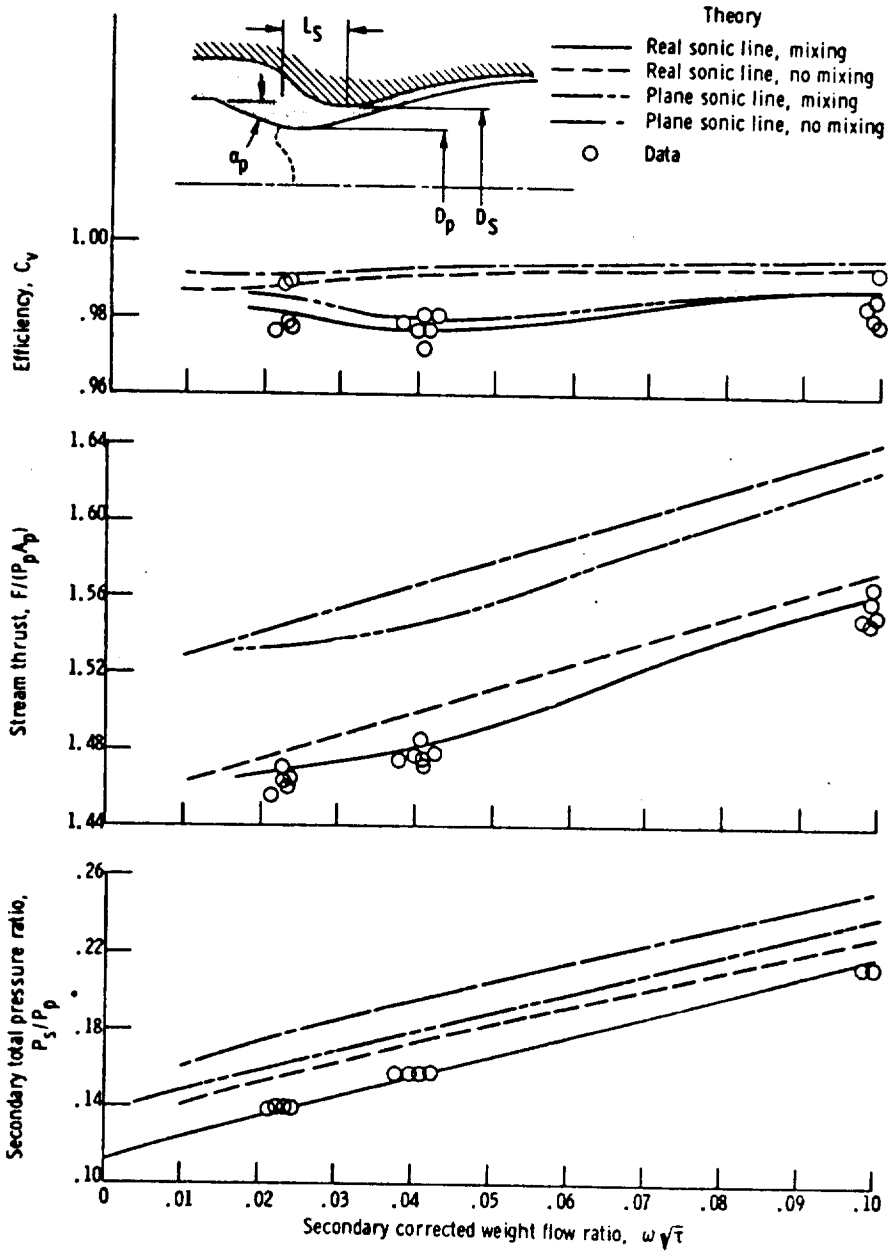
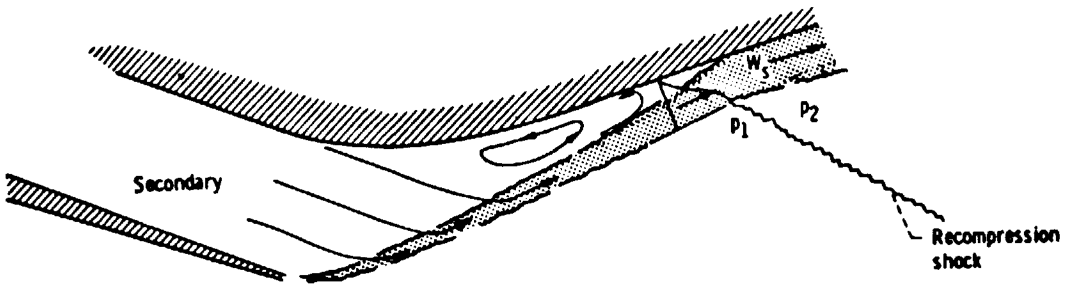
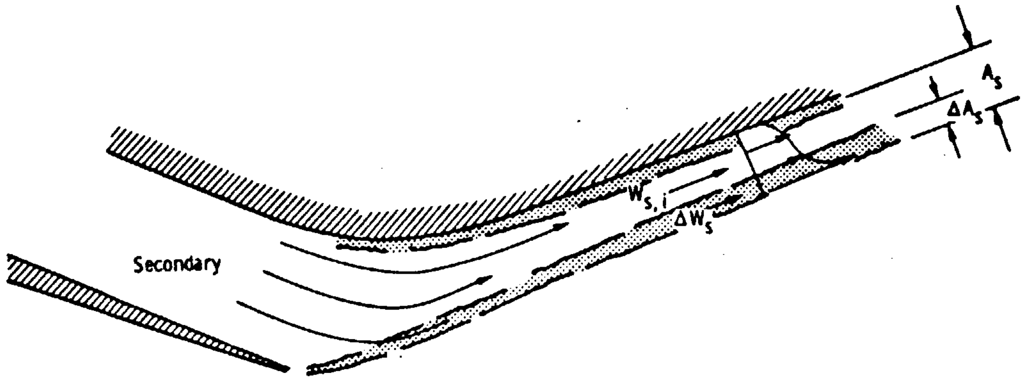


Figure 2.- Influence of sonic line and mixing process on performance of a convergent-divergent contoured flap ejector. Shroud shoulder diameter ratio, D_S/D_O, 1.37; spacing ratio, L_S/D_p, 0.5; primary nozzle lip angle, α_p, 27°; Reynolds number, Re, 3.3×10^6; ratio of primary total pressure to free-stream static pressure, P_p/p_0, 27.

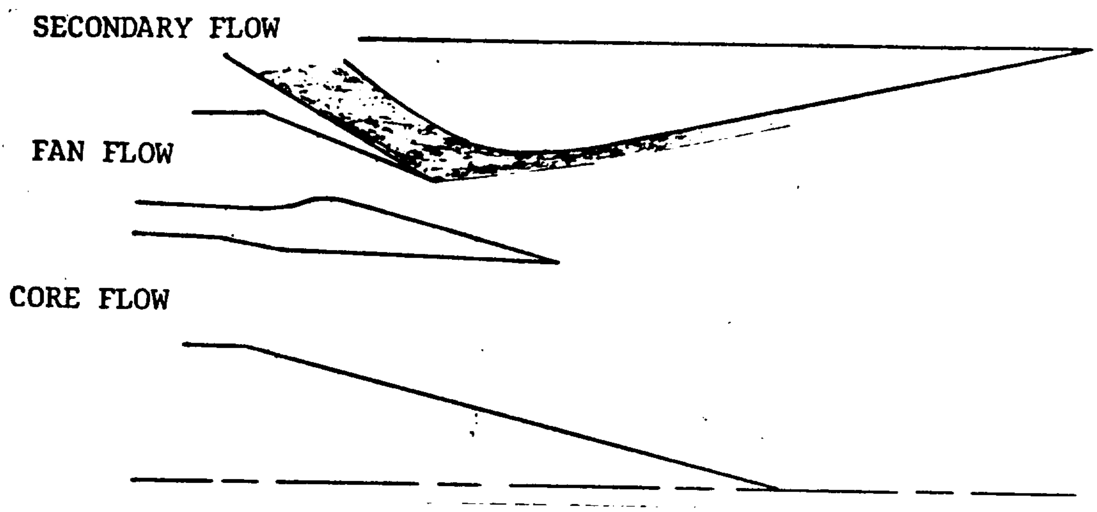


(a) Low secondary flow.

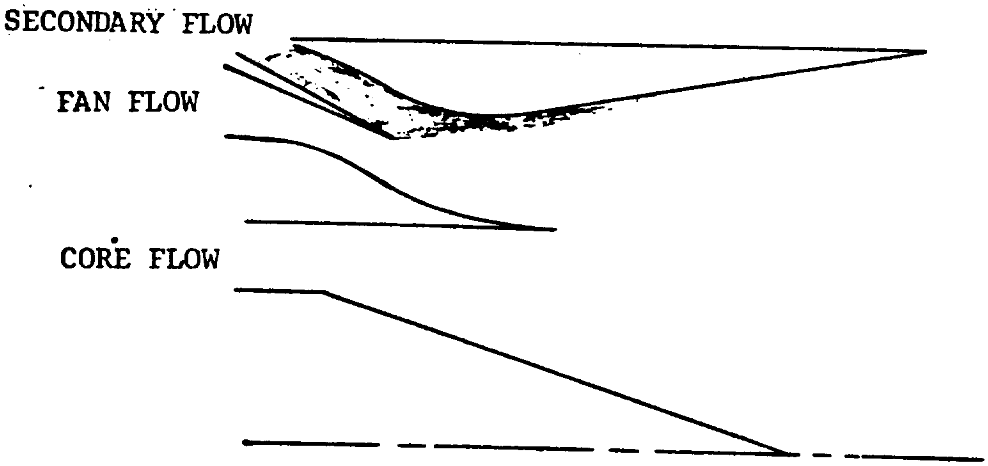


(b) High secondary flow.

Figure 3.- Schematic of typical secondary flow regimes.



(a) Conical splitter three-stream ejector.



(b) Isentropic splitter three-stream ejector.

Figure 4.- Schematic of typical three-stream ejector nozzle.

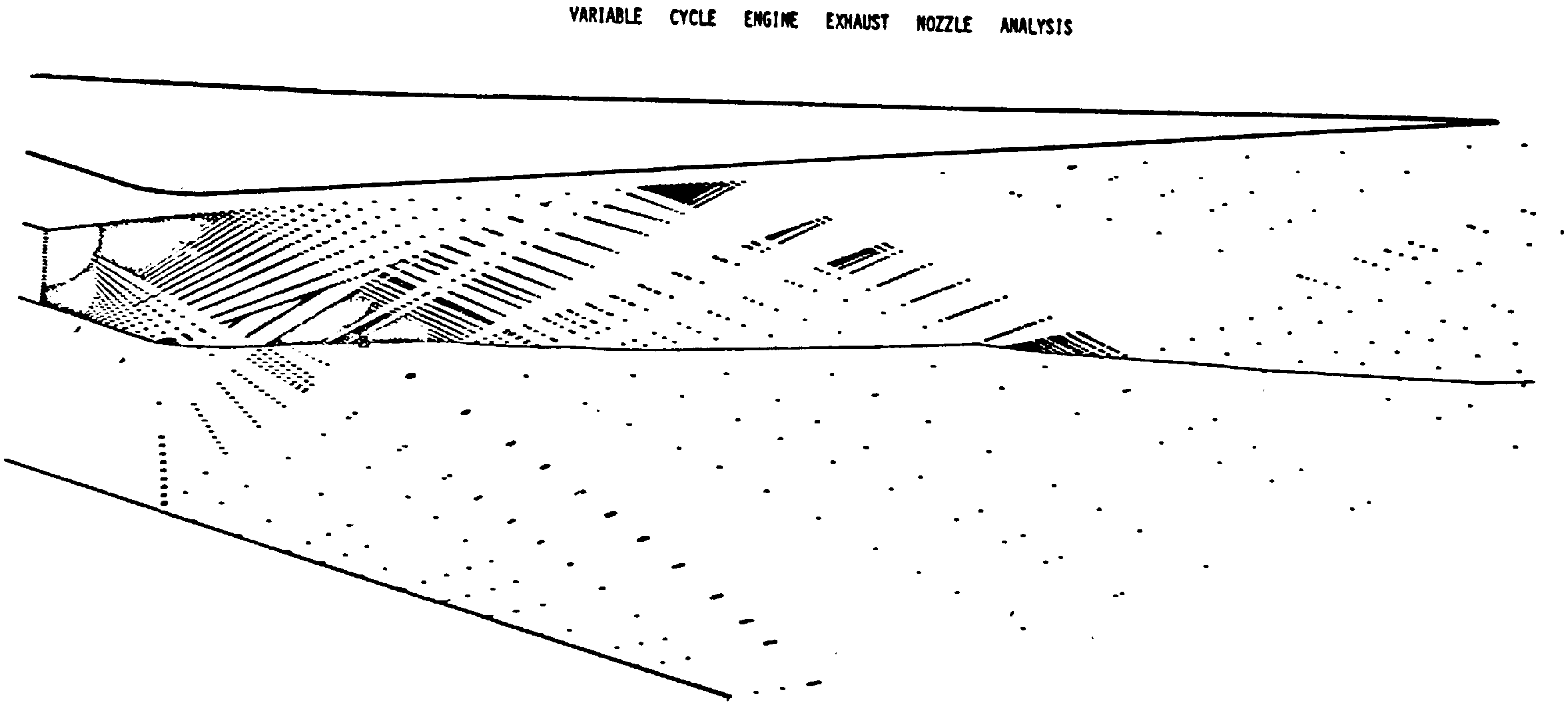


Figure 5.- Flow visualization for three-stream ejector nozzle with conical splitter.

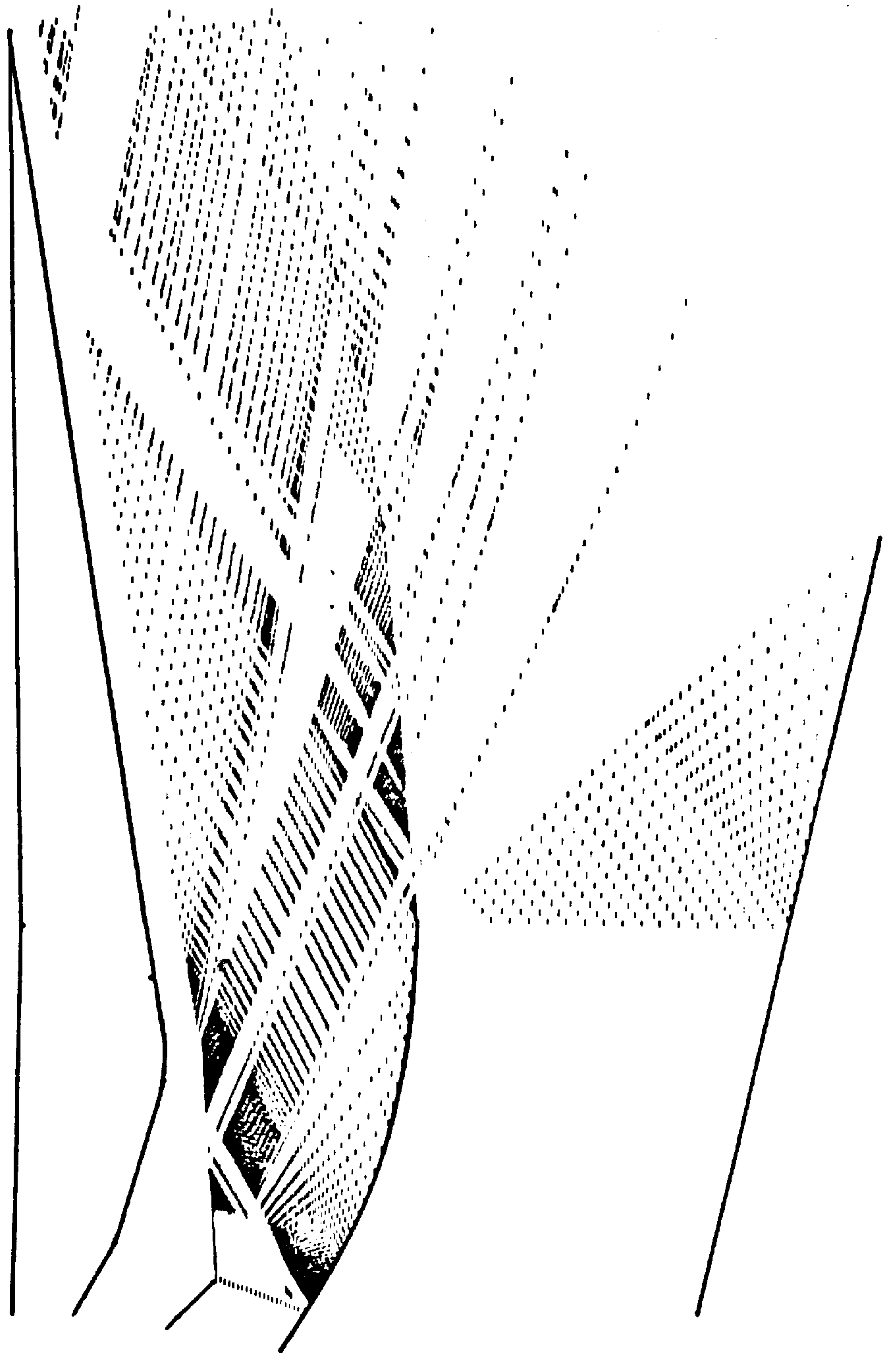


Figure 6.- Flow visualization for three-stream ejector nozzle with isentropic splitter.