Viscous Interaction of Sonic Transverse Jets with Supersonic External Flows

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Nomenclature

A = amplification factor, T/T_v
b = slot width
C_d = slot discharge coefficient
L = distance between leading edge and slot axis
M_{1e} = freestream Mach number
P_{01} = freestream stagnation pressure
P_{0j} = jet stagnation pressure
T = sum of interaction force and jet thrust
T_v = vacuum jet thrust

Theme

PRESENTS the results of an analytical study of a two-dimensional flowfield alteration by a surface jet, when the boundary layer is turbulent. Of particular interest are the upstream boundary-layer separation distance and the "amplification factor." Results compare favorably with experimental data. A new correlation parameter has been proposed, and an empirical equation for the amplification factor is given, for edge Mach numbers between 2 and 5.

Content

Analytical solutions of viscous jet-interaction have been lacking. A few have been given based on control volume approaches. The present study offers a new solution which is based on the system approach, i.e., the flowfield is divided into several elements of widely different characteristics; solutions were obtained for each element with its own governing equations and boundary conditions, and finally the individual solutions were patched together to give an over-all solution.

The proposed flow model is shown in Fig. 1. A sonic jet is issued perpendicularly into a supersonic freestream. Assumptions include the following: 1) the flow is two-dimensional; 2) the surface is adiabatic; 3) a fully-developed turbulent boundary layer exists upstream of the secondary jet; 4) no mixing between the freestream and the secondary jet until sufficiently downstream; 5) contribution to the interaction force from the downstream side is negligible; and 6) the flow obeys the ideal gas law.

Methods of solution can be stated as follows:

1) Mager's free, shock-separated turbulent boundary layer model,[1] along with the method of Reshotko and Tucker, was used to determine the property changes across the separation region.

2) Korst's mixing theory[2] was used to trace the development of the shear layer and the dividing streamline, up to the interaction shock.

3) The pressure behind the jet strong shock was assumed to be equal to the reattachment pressure calculated from the above methods and assuming that the dividing streamline first passes through a normal shock and then stagnates isentropically onto the jet boundary.

4) The penetration height was determined based on the assumption that the jet flow had expanded isentropically from the calculated pressure behind the jet strong shock to freestream static pressure (see Fig. 1).

The calculated results are shown in Figs. 2 and 3, which show fairly good agreement with the experimental data of Spaid and Zukoski.[3] In Fig. 3 a new correlating parameter for the amplifi-

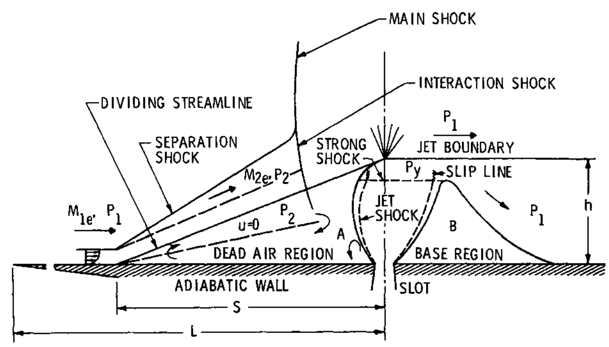

Fig. 1 Theoretical jet interaction flow model.

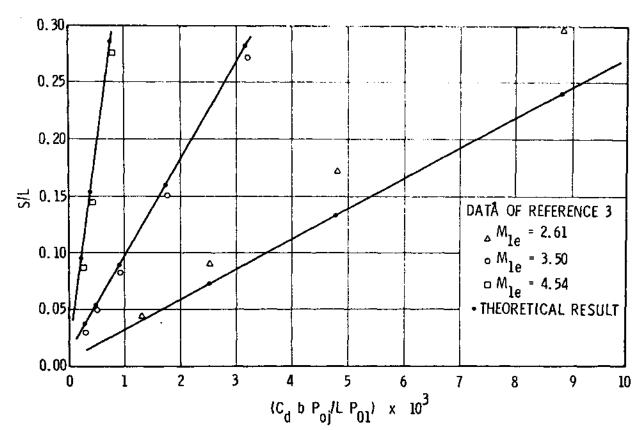

Fig. 2 Separation distance in front of the secondary jet.

Received May 24, 1971; synoptic received September 10, 1971; revision received February 7, 1972. Full paper (authors' Rept. No. JI-001) available from National Technical Information Service, Springfield, Va. 22151, as N72-14299 at the standard price (available upon request).

Index category: Jets, Wakes, and Viscid-Inviscid Flow Interactions.

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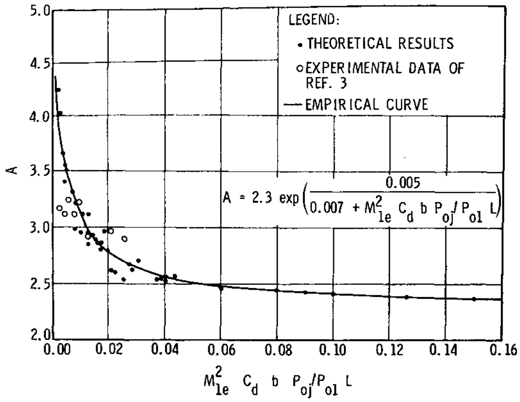

Fig. 3 Amplification factor.

cation factor was proposed. The theoretical data points were obtained by varying M_{1e}, P_{0j}/P_{01}, $C_d b$, and L. As Fig. 3 shows, there is some scattering of the theoretical data points, indicating that the proposed correlating parameter is not "final." However, since the amount of scattering is fairly small, it is reasonable to assume that the correct correlating parameter is likely to be close to the proposed one, perhaps within a fraction of power of a certain variable or a group of variables. A more detailed discussion can be found in Ref. 4. The amplification factor can be represented by the empirical equation

$$A = 2.3 \exp\left(\frac{0.005}{0.007 + M_{1e}{}^2 C_d b P_{0j}/P_{01} L}\right) \tag{1}$$

The present methods are valid for $2 < M_{1e} < 5$, approximately.

References

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