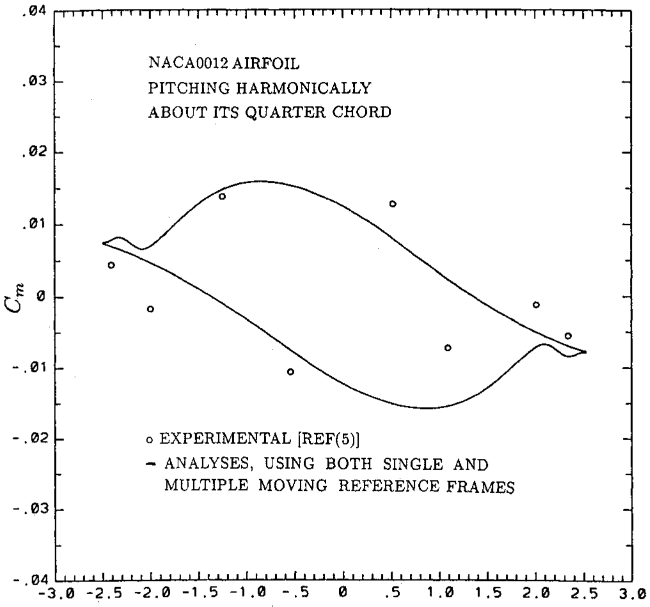

Fig. 3 C_m, pitching-moment coefficient variation during third cycle of sinusoidal pitching motion.

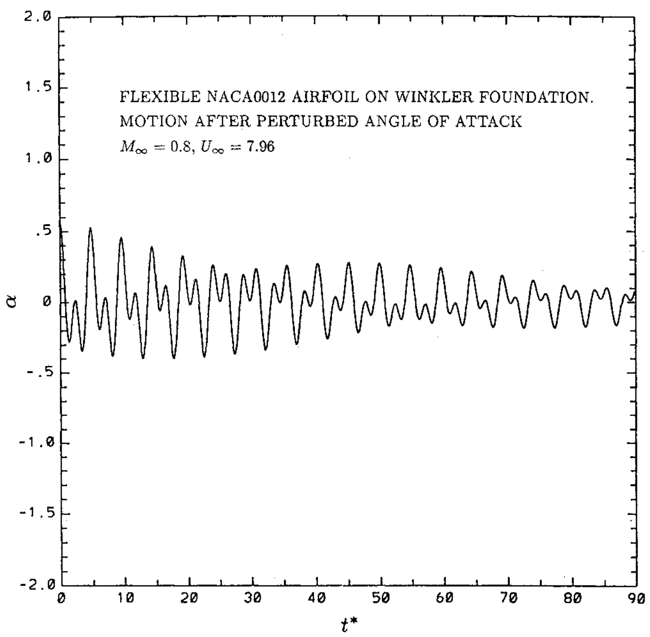

Fig. 4 Aeroelastic response of an infinite wing-like flexible structure.

The computed variations of the pitching-moment coefficient during the third cycle are depicted in Fig. 3. The solutions using one and multiple moving frames of reference are identical and overplot in the figure. More important, the results are shown to be in good agreement with the experimental data of Landon.[5]

Application

Next we consider the transient aeroelastic response of a wing-like structure in transonic flow. The structure is assumed to be indefinitely long so that a two-dimensional analysis can be performed. It includes a thin aluminum skin (Young modulus $E = 1.3 \times 10^7$) that is stiffened with three vertical and parallel rigid shear panels. An NACA0012 cross section is considered. This wing-like structure is assumed to rest on a Winkler-type foundation. The surface of the structure is discretized using two-node hermitian beam elements. Multiple moving frames of reference are invoked to follow the motion and track the deformation of the structural skin. The structure is placed in a flow at Mach number $M_\infty = 0.8$. The imposed velocity is $U_\infty = 7.96$. The angle of attack is slightly perturbed from an initial position and the response of the structure is computed. Figure 4 reports the variation of the angle of attack in time.

Future Work

The extension of this work to the three-dimensional case is in progress. The resulting code will be applied to the investigation of three-dimensional wing-body configurations. Benchmarks with alternative approaches will also be performed.

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Jet Mixing Enhancement by Hydrodynamic Excitation

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Introduction

IT is well established that acoustic excitation can increase mixing in jets. Previous work[1] (and references cited therein) has produced notable improvements in understanding the mixing of unheated jets at high and low speeds and of heated jets at low speed. At high Mach numbers, the mixing of heated jets was not significantly improved by acoustic excitation. One of these studies suggests that higher excitation levels may be needed to control high Mach number jets at high temperatures.

The excitation frequency must fall within a preferred range to be effective. The preferred frequency f is defined by a Strouhal number fD/U based on jet diameter D and velocity U. The preferred Strouhal number range of 0.2–0.5 is shown in Ref. 2.

The model consisted of a coannular jet system with provisions for holding rings in the secondary (annular or outer) flow stream as shown in Fig. 1. The primary nozzle is 7.5 cm (2.95 in.) in diameter and the secondary nozzle is 11 cm (4.32

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in.) in diameter. The vortex shedding ring is 10.2 cm (4.0 in.) inside diameter and is positioned in the secondary flow midway between the exit of the two nozzles. Two rings were used: one made from 3.2-mm- (⅛-in.-) diam rod and one made from 6.4-mm (¼-in.) rod. For convenience, the rings will be identified by the rod diameter. A 6.5-mm- (¼-in.-) diam pitot probe was used for total pressure measurements in the plume. A 12.7-mm- (½-in.-) diam Bruel and Kjaer microphone was placed in the nozzle exit plane at a distance of 122 cm (48 in.) from the nozzle axis for acoustic measurements.

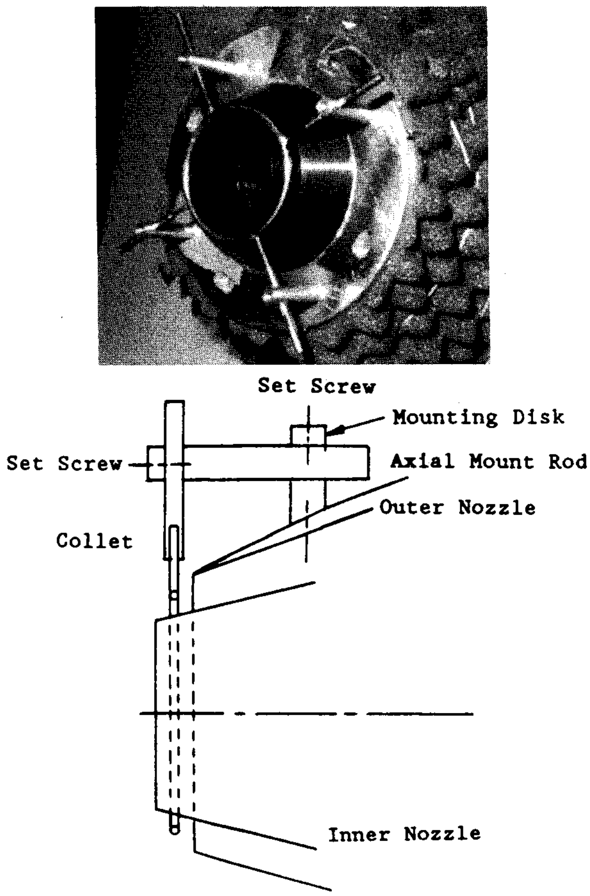

Fig. 1 Coannular nozzle systems with vortex shedding ring.

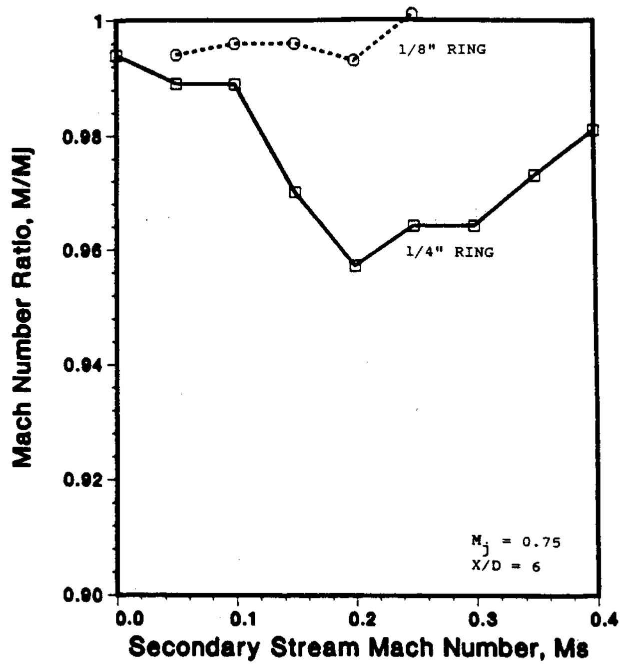

Fig. 2 Effect of ring wire diameter on jet centerline Mach number.

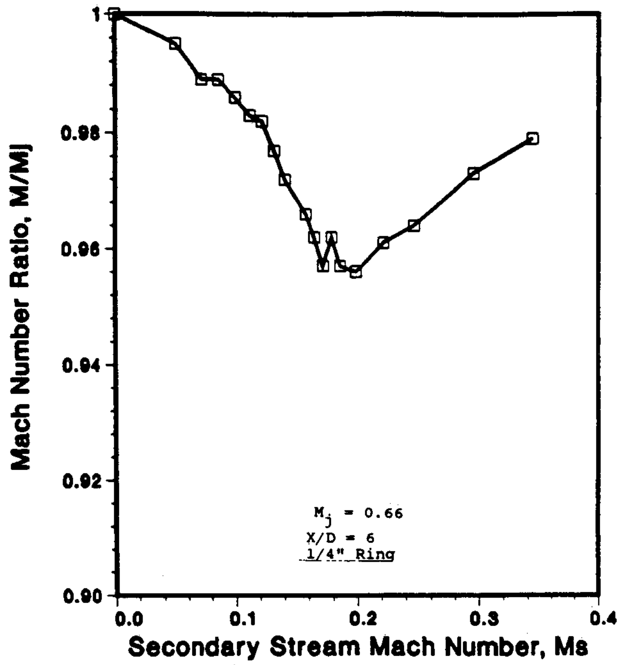

Fig. 3 Effect of secondary stream Mach number on centerline Mach number.

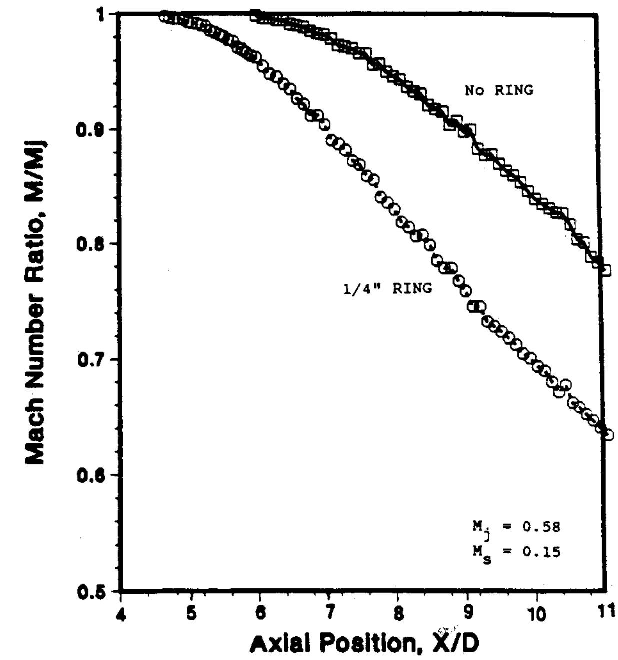

Fig. 4 Effect of hydrodynamic excitation on jet centerline Mach number profile.

Test Results

The flow data is presented in terms of the ratio of local Mach number to primary jet exit Mach number. Frequency data is presented in terms of Strouhal number using nozzle diameter D and primary jet exit velocity U_1 or ring rod diameter d and secondary exit velocity U_2 as appropriate. The 3.2-mm (⅛-in.) ring did not produce a significant increase in mixing at any Strouhal number up to 0.4.

The 6.4-mm (¼-in.) ring did produce significant mixing as shown in Fig. 2. Vortex shedding from a rod is characterized by a nominal Strouhal number fd/U_2 of 0.2. In the case of the 3.2-mm (⅛-in.) ring, the required velocity appears to have been so low that the shedding did not produce enough energy to excite the primary jet.

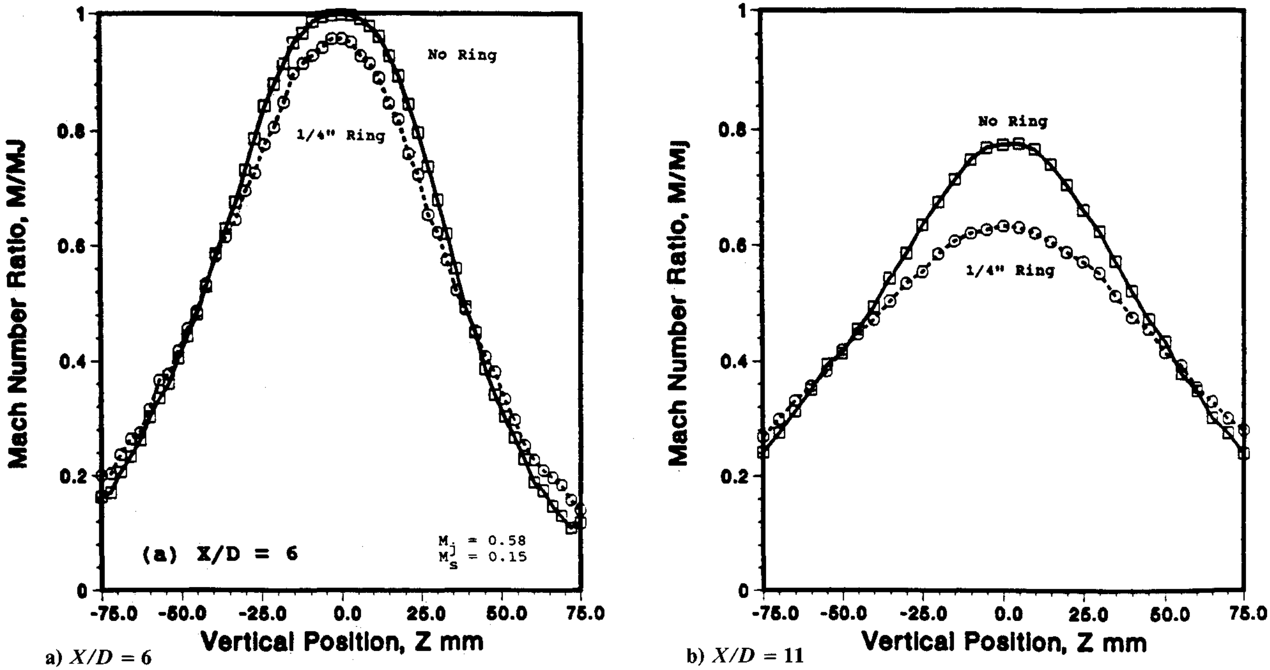

Fig. 5 Effect of hydrodynamic excitation on jet velocity profiles.

The test condition $M_2 = 0.18$ and $fd/U_2 = 0.17$ produced maximum mixing in the $M_1 = 0.66$ primary jet as shown in Fig. 3. The corresponding Strouhal number fD/U_1 for the primary jet is 0.47. As shown in Ref. 2, this agrees very well with previous data for the preferred excitation frequency of circular jets.

The decay of the jet centerline Mach number ratio with and without the ring illustrates the enhanced mixing produced by the vortex shedding from the ring. As shown in Fig. 4, the ring produced significantly faster mixing of the jet. The enhanced mixing of the jet has reduced the potential core length from 6 to 4½ jet diameters. At 11 jet diameters from the nozzle exit, the centerline Mach number ratio with the ring is 18% lower than that without the ring. Typical transverse velocity profiles are shown for $X/D = 6$ and 11 in Fig. 5. The increased mixing rate is shown by the increasing gap between the peak velocities and the ring and no-ring velocity profiles with increasing distance from the nozzle exit plane.

Conclusions and Recommendations

This proof-of-concept study has shown that hydrodynamic excitation by controlled vortex shedding can significantly enhance the mixing of a jet with its environment. There appears to be a threshold energy level for excitation to occur as has been suggested in other studies. A study to identify the parameters that effect the threshold and to quantify their effects should be made.

The use of a passive source of the excitation energy should be demonstrated, and the drag associated with the excitation source should be quantified. Application to rectangular jets would be especially useful.

Acknowledgment

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