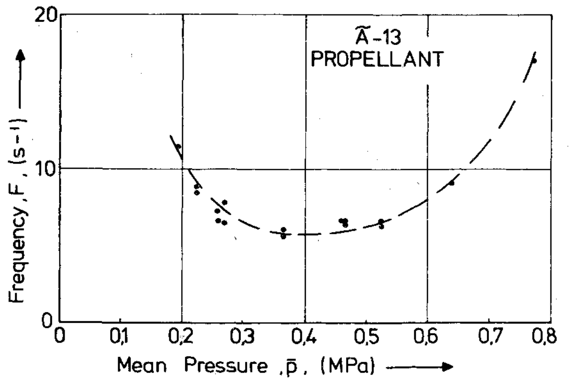

Fig. 2 Nonlinear correlation between mean pressure and frequency for L^* oscillations. (Data from Kumar and McNamara.[6])

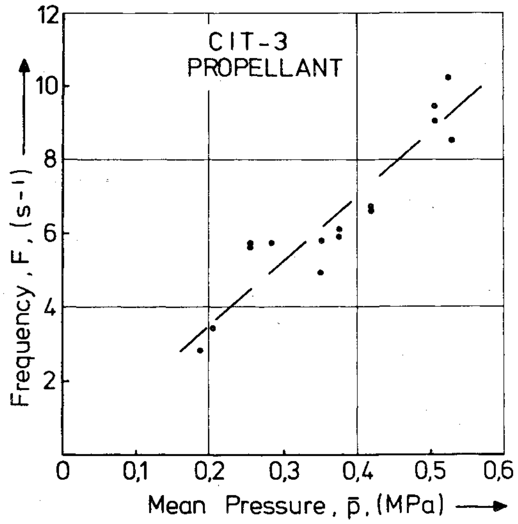

Fig. 3 Linear correlation between mean pressure and frequency for L^* oscillations. (Data from Kumar and McNamara.[6])

similar to that shown in Fig. 2 for a composite propellant may be the missing link between the low- and medium-pressure data in Fig. 1, which applies for a double base propellant.

Data from experiments with CIT-3 propellant, shown in Fig. 3, yield a linear relation between $\bar{p}$ and F, with $dF/d\bar{p} \approx 2\times 10^{-6}$ m·sec·kg^{-1}. The difference between Ã-13 and CIT-3 formulations is the large oxidizer particle size of the latter (175 μm vs 39.5 μm). In this respect, it should be noted that slight changes in the propellant may seriously affect the results of L^* experiments. For example, data from experiments with NWC A-13[5] do not yield a $\bar{p}-F$ correlation, and oscillation frequencies vary between 20 and 90 sec^{-1}, while experiments with JPL-processed Ã-13 produce a distinct $\bar{p}-F$ correlation, with oscillations varying between 6 and 20 sec^{-1}. The pressure range of experiments with CIT-4 propellant is too small for $\bar{p}-F$ analysis.

Price's remarks[3] about oscillatory combustion in L^* burners and rocket motors are still generally applicable. The newly observed relations between oscillation frequency and mean pressure appear to be much more prevalent than previously noted and may contribute to a better understanding of L^* oscillations.

Conclusions

1) Both double base and composite propellants, which are sensitive to L^* oscillations, may exhibit a distinct $\bar{p}-F$ correlation.

2) For ARP double base propellant, there exist two regions in which L^* oscillations may occur: a low-pressure, high-frequency region and a medium-pressure, low-frequency region. In these regions, the frequency increases linearly with the mean pressure.

3) The pressure-frequency relation of L^* oscillations is not affected by the size of the L^* burner.

4) The oxidizer particle size of composite propellants clearly affects the linear burning rate, the frequency at which the oscillations occur, and the $\bar{p}-F$ correlation.

Acknowledgment

This work is the result of a continuous joint research program with the Technological Laboratory TNO.

References

[1] Yount, R. A. and Angelus, T. A., "Chuffing and Nonacoustic Instability Phenomena in Solid Propellant Rockets," *AIAA Journal*, Vol. 2, July 1964, pp. 1307-1313.

[2] Eisel, J. L., Horton, M. D., Price, E. W., and Rice, D. W., "Preferred Frequency Oscillatory Combustion of Solid Propellants," *AIAA Journal*, Vol. 2, July 1964, pp. 1319-1323.

[3] Price, E. W., "Review of the Combustion Instability Characteristics of Solid Propellants," *AGARD Conference Proceedings No. 1, Advances in Tactical Rocket Propulsion*, S. S. Penner, editor, 1968, Part 1, Chapter 5.

[4] Strand, L. D., "Summary of a Study of the Low-Pressure Combustion of Solid Propellants," Jet Propulsion Laboratory California Institute of Technology, Pasadena, Calif., Tech. Rept. 32-1242, April 15, 1968.

[5] Schöyer, H. F. R., "Report on Low-Frequency Oscillatory Combustion Experiments," Daniel and Florence Guggenheim Jet Propulsion Center, California Institute of Technology, Pasadena, Calif., Feb. 1971.

[6] Kumar, R. N. and McNamara, R. P., "Some Experiments Related to L-Star Instability in Rocket Motors," Daniel and Florence Guggenheim Jet Propulsion Center, California Institute of Technology, Pasadena, Calif., March 1973.

[7] De Boer, R. S., Schöyer, H. F. R., and Wolff, H., "Results of L^* Instability Experiments with Double Base Rocket Propellants II," Delft University of Technology, Dept. of Aerospace Engineering/Technological Laboratory TNO, Delft/Rijswijk, The Netherlands (to be published).

[8] De Boer, R. S. and Schöyer, H. F. R., "Results of L^*-Instability Experiments with Double Base Rocket Propellants," Delft University of Technology, Dept. of Aerospace Engineering/Technological Laboratory TNO, Rept. LR-224/TL R 3050-I, Delft/Rijswijk, The Netherlands, Dec. 1976.

Surface Pressure Fluctuation Generated by a Jet Impinging on a Curved Plate

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Introduction

THIS work deals with a turbulent jet impinging on a solid boundary. The study of this problem is motivated by the use of the blown flap in STOL airplanes. Experiments related

Presented as Paper 77-114 at the AIAA 15th Aerospace Sciences Meeting, Los Angeles, Calif., Jan. 24-26, 1977; submitted March 9, 1977; revision received June 6, 1977.

Index categories: Structural Design (including Loads); Aeroacoustics.

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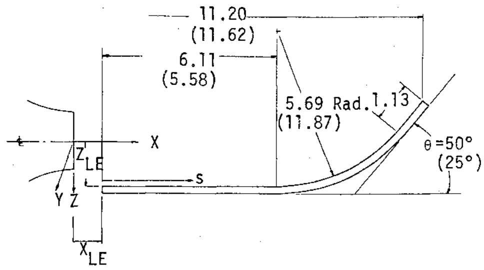

Fig. 1 Geometry of 50° (25°) curved plate.

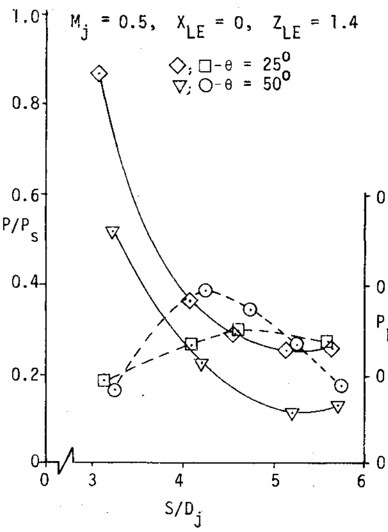

Fig. 2 Spatial distribution of rms level of pressure fluctuations, P---, P/P_s—.

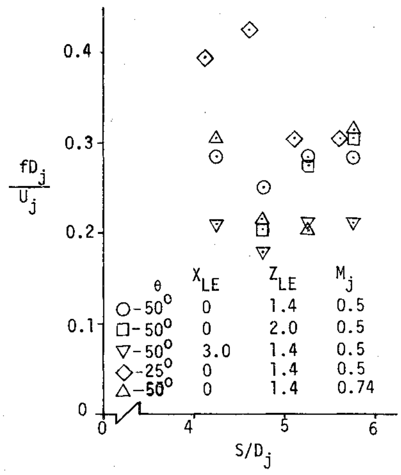

Fig. 3 Spatial distribution of Strouhal numbers.

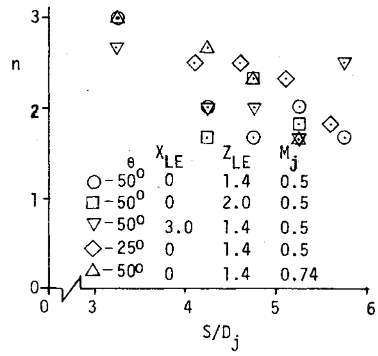

Fig. 4 Spatial distribution of roll-off exponents.

to these topics have been reported by various authors.[1-4] Most of the results were for impingement on a flat plate or a straight trailing portion of a curved plate. The present work deals with impingement on the curved section of curved plates, eliminating the complicated geometry of the wing and flap model while retaining the curvature effect lost with the flat plate.

Apparatus and Data Processing

The air jet has a 2-in. nozzle and exhausts into an anechoic room with a low frequency cutoff of 150 Hz. Two different curved plates were built for these experiments, both 30 in. in span (Fig. 1). These plates were instrumented with ⅛-in. Kulite piezoresistive pressure transducers (model XTEL-1-190-25G). The transducer signals were recorded on a Hewlett-Packard 14-channel FM tape recorder (model 3955A). The frequency response for the system comprised of transducers, amplifiers, and the tape recorder extended from 10 Hz to 20 kHz. Static pressures were measured from two rows of 0.02-in. static pressure ports running chordwise on the plates. Symmetry of the jet was established by moving the plate in the Y direction (see Fig. 1), so the ports were first on one side and then the other side of the jet. The data digitized and analyzed with a Hewlett-Packard Fourier analyzer (model 5451B).

Experimental Results

The purpose of this work is to study the effect of parametric variations on the fluctuating pressures. Three categories of parameters are used: the Mach number M, the deflection angle of the plate θ, and the relative position between the jet and the plate X_{LE} and Z_{LE}.

Level of Surface Pressure Fluctuation

For the same Mach number, the maximum fluctuation levels are of the same order for two different plates (Fig. 2). The reason for this may be that, since the pressure fluctuation is related to the fluctuating velocity and the velocity fluctuation has developed to the same state for similar downstream locations on the two plates, the levels of pressure fluctuation are of the same order. The spatial distribution of rms values can be seen to have different patterns for the two plates. This is a result of the two different curvatures, an argument strongly supported by the evidence that the spatial distributions of the rms values normalized by the local mean pressure have the same shape. The difference in magnitude of the normalized profile is due to the large difference in values of mean pressure on the two plates. Both the static pressure and the level of fluctuating pressure can be scaled to the square of the Mach number, M^2.

Spectra

For dynamic loading studies, the spectra are also important. The Strouhal numbers, fD_j/U_j based upon the peak power frequency, are close to 0.3 (Fig. 3) and are not very sensitive to the change of relative position or difference in deflection angles. These simple results provide important basic design information for the response of structures under aeroacoustic excitation. It is interesting to note that since the Strouhal number (0.3) is very close to the most unstable mode of a free jet,[5] the peak pressure fluctuation may be associated with large shedding vortices whose shedding frequencies are not affected by the difference in deflection angles or by small changes in relative positions. This means the peak Strouhal number stays almost constant.

The slope of the high-frequency end of the spectrum is proportional to f^{-n}, where n is a decreasing function of the streamwise distance (Fig. 4). This implies that the flow is still in a developing range. Relatively more high-frequency components are generated at downstream stations, where the roll-off exponent approaches an asymptotic value of 2. The

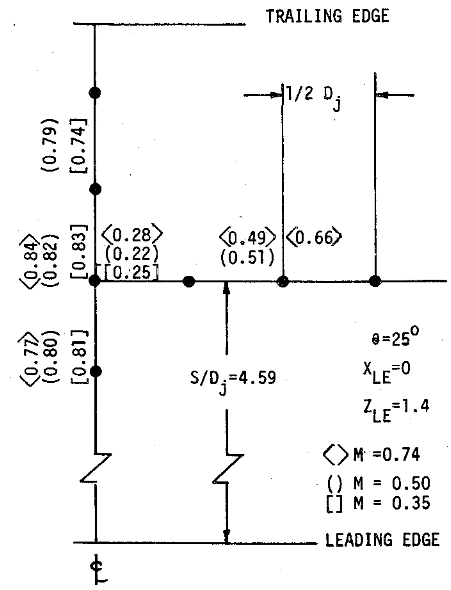

Fig. 5 Spatial distribution of the maximum value of $[C_0(f)]^{1/2}$.

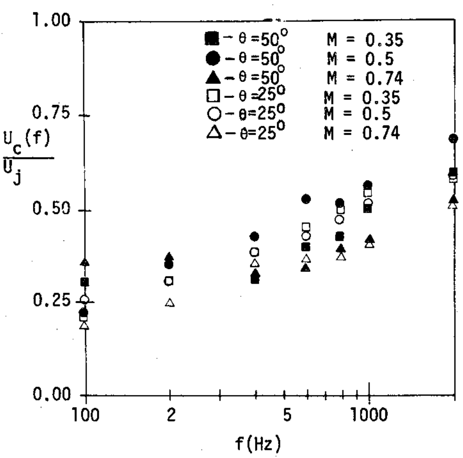

Fig. 6 Narrow-band convection speed for $X_{LE} = 0, Z_{LE} = 1.4$.

roll-off exponents do not vary appreciably with Mach number, deflection angle, or the relative positions of the jet and plate. This is because the changes in geometry or deflection angle mostly affect the structure of the large-scale shedding vortices and not the high-frequency end of the spectrum that governs the roll-off exponent.

Coherence

The square root of coherence is the narrow-band correlation coefficient between two spatial points. In this experiment, the bandwidth is 20 Hz. The maximum coherence usually occurs near the frequency corresponding to the Strouhal number 0.3. This implies that the maximum coherence is mostly due to the large-scale coherent structure. A two-dimensional diagram is used to represent the coherence function on the curved plates (Fig. 5). The number given is the maximum of the square root of coherence between two adjacent points. The maximum coherence does not vary significantly with the variation of Mach number.

Narrow-Band Convection Speed

In a turbulent shear flow, the convection speed of velocity fluctuations is not constant for eddies with different wavelengths. The convection speeds of the pressure fluctuations are also a function of the wavelength.[6,7] The narrow-band convection speed $U_c(f) = 2\pi f \Delta s / \alpha$ is calculated from the phase α of the cross spectrum. The convection speed increases from 0.2 U_j at low frequency to 0.6 U_j at high frequency, and is the same for the two plates (Fig. 6). The fact that the convection velocity increases with frequency agrees with measurements of velocity fluctuations in free jet.[6] Preisser and Block[8] reported that the high-frequency pressure fluctuations convect slower than low-frequency pressure fluctuations. Their conclusion is based on measurements made with transducers at a large spatial separation. However, transducers separated by a large distance have a low pass spatial filter effect. The high-frequency phase difference measured at large separation can be misleading.

Conclusion

An experimental study of a jet impinging on a curved surface was performed. A major finding is that variations in most of the measured properties can be explained by the presence of large coherent structures. The parametric variations do not significantly affect the shedding frequency of the coherent structures, but do affect their development.

Acknowledgments

This work was performed at the University of Southern California and was supported by a subcontract with McDonnell-Douglas Corporation, the prime contractor in Air Force contract number F 33615-75-C-3057 awarded by the Air Force Flight Dynamics Laboratory.

References

[1] Strong, D.R., Siddon, T.E., and Chu, W.T., "Pressure Fluctuations on a Flat Plate with Oblique Jet Impingement," NASA CR-839, 1967.

[2] Donaldson, C. duP. and Snedeker, R.S., "A Study of Free Jet Impingement," Part 1," *Journal of Fluid Mechanics,* Vol. 45, Jan. 1971, p. 281; and with Margolis, D.P., "Part 2:" *Journal of Fluid Mechanics,* Vol. 45, Feb. 1971, p. 477.

[3] Yu, J.C., Reddy, N.N., and Whitesides, J.L. Jr., "Noise and Flow Characteristics of an Externally Blown Flap," *Proceedings of Second Interagency Symposium on University Research in Transportation Noise,* Vol. 1, 1974, p. 219.

[4] Foss, J.F. and Kleis, S.J., "Mean Flow Characteristics for the Oblique Impingement of an Axisymmetric Jet," *AIAA Journal,* Vol. 14, June 1976, p. 705.

[5] Crow, S.C. and Champagne, F.H., "Orderly Structure in Jet Turbulence," *Journal of Fluid Mechanics,* Vol. 48, Aug. 1971, p. 547.

[6] Wills, J.A.B., "On Convection Velocities in Turbulent Shear Flows," *Journal of Fluid Mechanics,* Vol. 20, Nov. 1964, p. 417.

[7] Ho, C.M. and Kovasznay, L.S.G., "Acoustic Shadowgraph," *The Physics of Fluids,* Vol. 19, Aug. 1976, p. 1118.

[8] Preisser, J.S. and Block, P.J.W., "An Experimental Study of the Aeroacoustics of a Subsonic Jet Impinging Normal to a Large Rigid Surface," AIAA Paper 76-520, 1976.

On Wall Friction in MHD Channel Flows

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Nomenclature

A = channel cross-sectional area
a_l = turbulence correlation coefficient in Eq. (16), see Ref. 4
B = magnetic field

Received March 1, 1977; revision received June 13, 1977.
Index category: Plasma Dynamics and MHD.
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