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FINAL REPORT

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ON

CONTROL OF JET NOISE

(NAG-1-1096)

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ABSTRACT

To investigate the possibility of active control of jet noise, knowledge of the noise generation mechanisms in natural jets is essential. Once these mechanisms are determined, active control can be used to manipulate the noise production processes. We investigated the evolution of the flow fields and the acoustic fields of rectangular and circular jets. A predominant flapping mode was found in the supersonic rectangular jets. We hope to

increase the spreading of supersonic jets by active control of the flapping mode found in rectangular supersonic jets. Increased spreading is associated with a faster decrease of the convection speed of the instability waves in high Mach number jets. Once the convection speed of these waves becomes subsonic, noise production by Mach wave emission ceases. In this report, we summarize the accomplishments of the second year contract period.

FACILITY MODIFICATIONS

The computer-controlled low noise valve was further modified to optimize run time and accuracy. Using a nozzle of 2 sq inch exit area, a velocity of M=0.6 can now be maintained for about 40 minutes.

The existing facility includes an aluminum settling chamber. The chamber is not rated for high pressures necessary for supersonic flows. This limitation was overcome by enclosing the settling chamber in a 300-psi pressure tank. The weight (approximately 1 ton) and size of the tank made several modifications of the support system and the pressure lines necessary. The rebuilt facility has been tested for supersonic speeds up to M=1.7.

A forcing system was developed to create a high-frequency, high amplitude perturbation signal. Air jets from a high-pressure reservoir were injected into the primary jet at the nozzle lip. The flow rates of the secondary jets were frequency modulated by a fast spinning perforated disk which opened and closed the inlet to the supply lines of the jets. Up to four jets can be modulated with a fixed phase reference between the jets. The forcing system was successfully applied to subsonic and supersonic jets.

A shadowgraph system was built and installed to visualize supersonic jet flows. The shadowgraph images were documented on video tape and photographic plates.

EXPERIMENTAL RESULTS

Detailed velocity and pressure measurements were conducted in a circular and rectangular jet with an aspect ratio of 3:1 at subsonic speeds. In addition, active control was applied to a rectangular supersonic jet with a design Mach number of M=1.5. Results of our investigation were reported at the DGLR/AIAA Meeting in Aachen, West Germany (Schreck, Ho, and Sarmiento 1992). Important findings are summarized here.

Jet Spreading

Asymmetric nozzles are known to increase the entrainment of ambient fluid due to self-induction. Measurements conducted in our laboratory in an elliptical jet indicated that the mass entrainment is dependent on the exit velocity of the jet. The additional mass entrainment due to self induction decreases with increasing exit velocity. Since jet mixing and jet noise are interrelated, we studied the effect of the exit velocity on the spreading of a rectangular jet of an aspect ratio of 3:1 at subsonic speeds. We found that the shear layer growth in the minor axis plane decreases with increasing Mach number until about M=0.3. Conversely, the shear layer in the major axis plane increases. For higher speeds, the shear layer growth approaches an asymptotic state, i. e. the spread rate in both planes is almost constant. The spreading in the rectangular jet is larger than that in a circular jet in the whole subsonic velocity range.

Acoustic Far Field

A 1" microphone was placed 54 jet diameters away from the jet. Sound measurements were taken at angles of 20 to 90 degrees off axis. It was found that major differences in the radiation of circular and rectangular jets only existed at low Mach numbers (M<0.3). At these velocities, vortex merging contributed substantially to the noise generation. In the rectangular jet, vortex merging was suppressed in the major axis plane resulting in a lower SPL than in the minor axis plane and in the circular jet. In the minor axis plane, noise generated by vortex merging was of similar magnitude as that in the circular jet. At higher speeds (0.3<M<0.9), the boundary layer in the nozzle became turbulent. Consequently, vortex merging occurred less frequently and the jet column instabilities emerged as the major noise source. In this case, no significant difference in the noise radiation patterns of the two jets were found.

Supersonic Jet

A rectangular supersonic nozzle was designed for ideal expansion at M=1.5. The nozzle has an inlet area of 2.25" x 2.25" and an outlet of 2.25" x 0.75". The geometry of the CD nozzle was computed by the method of characteristics for 2-dimensional flows. Schlieren photography revealed that shock cell structures were always present in the jet. This was not surprising since the three-dimensionality of the nozzle and boundary layer effects were neglected. At off-design conditions, large structures of a sinuous or flapping mode were observed in the minor axis plane of the jet. These structures were associated with a discrete screech tone. The self-excitation of the structures by screech increased the spreading of the jet dramatically. When the feed-back loop of the screech tone was enhanced by a large nozzle lip, the length of the potential core could be reduced to about 4 minor axis diameters at velocities of M=1.2 to M=1.3. This observation is important with respect to the generation of noise by Mach wave emission. These instability waves only produce noise as long as the their convection speed is supersonic. The rapid decay of the centerline velocity of the excited jet indicates that the supersonic instability waves reach subsonic speeds earlier, i. e. noise production is reduced.

Active Control

The forcing system described above was mounted on the rectangular nozzle. Air was injected alternatively along the major axis nozzle lip to excite the flapping mode of the jet. Excitation of the jet at M=0.6 and a frequency of 2kHz (St=0.3) increased the broad band turbulence mixing noise. Excitation of the supersonic jet had little effect on the development of the jet. This was due to the large amplitudes necessary to perturb the jet. In order to still force the supersonic jet, a new approach was taken. A two-dimensional diffusor was placed downstream of the jet. Low pressure regions formed between the jet column and the diverging walls. These low pressure regions exerted a lateral force on the jet,, which in connection with the secondary jets, can be used to deflect the jet. We tested several configurations to optimize the design of the diffusor section. Plates with a length of 2 1/2 minor axis diameters mounted at an angle of about 10 degrees worked well. When longer plates were used, the jet attached firmly to one wall and showed a pronounced bi-stable behavior. Besides the configuration of the side walls, the stability of the jet was very sensitive to the pressure ratio. In the case of an overexpanded jet ($M<1.5$), the jet detached prematurely from the wall of diverging sections of the CD nozzle. This premature detachment increased size and strength of the low pressure regions and promoted jet destabilization. With the support of the diffusor, the secondary jets deflected the primary jet by about 5 degrees. When the secondary jets were frequency modulated with a phase difference of 180 degrees between the jets, the primary jet was forced into a flapping mode.

PUBLICATIONS

S. Schreck, C.M. Ho, R. S. Sarmiento, "Noise Radiated from Axisymmetric and Asymmetric Jets", AIAA paper No. 92-02-044, 1992.