SUPERSONIC JET MIXING ENHANCEMENT DUE TO NATURAL AND INDUCED SCREECH

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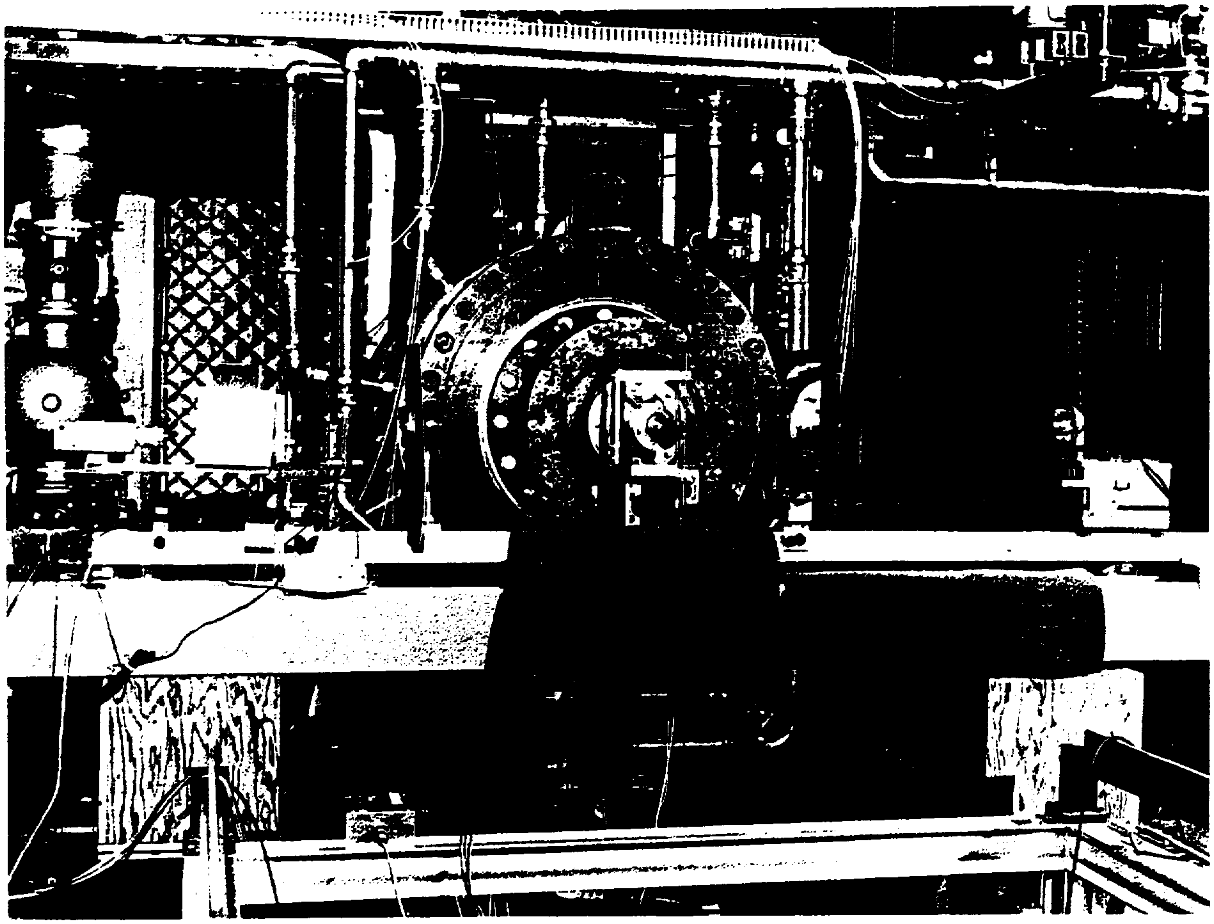
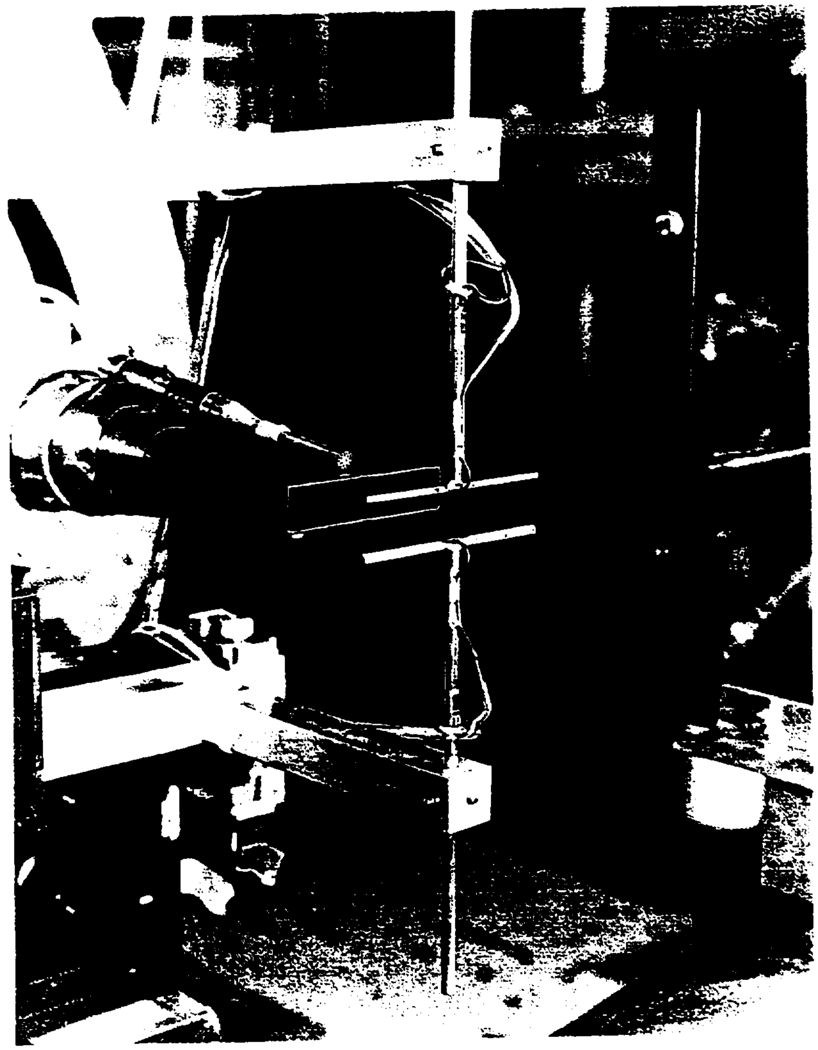
OUTLINE OF PRESENTATION

- REVIEW OF EXPERIMENTAL APPARATUS
- EFFECT OF NATURAL SCREECH ON JET MIXING
  - CONVERGING NOZZLE, UNDEREXPANDED JET
  - CONVERGING-DIVERGING NOZZLE, DESIGN PRESSURE
- EFFECT OF INDUCED SCREECH ON JET MIXING
  - PRODUCED BY PADDLES IN SHEAR LAYERS
  - SIMILAR TO EDGE TONES
  - CONVERGING-DIVERGING NOZZLE, DESIGN PRESSURE
- EFFECT OF PADDLES ON NEAR-FIELD JET NOISE
- CONCLUDING REMARKS

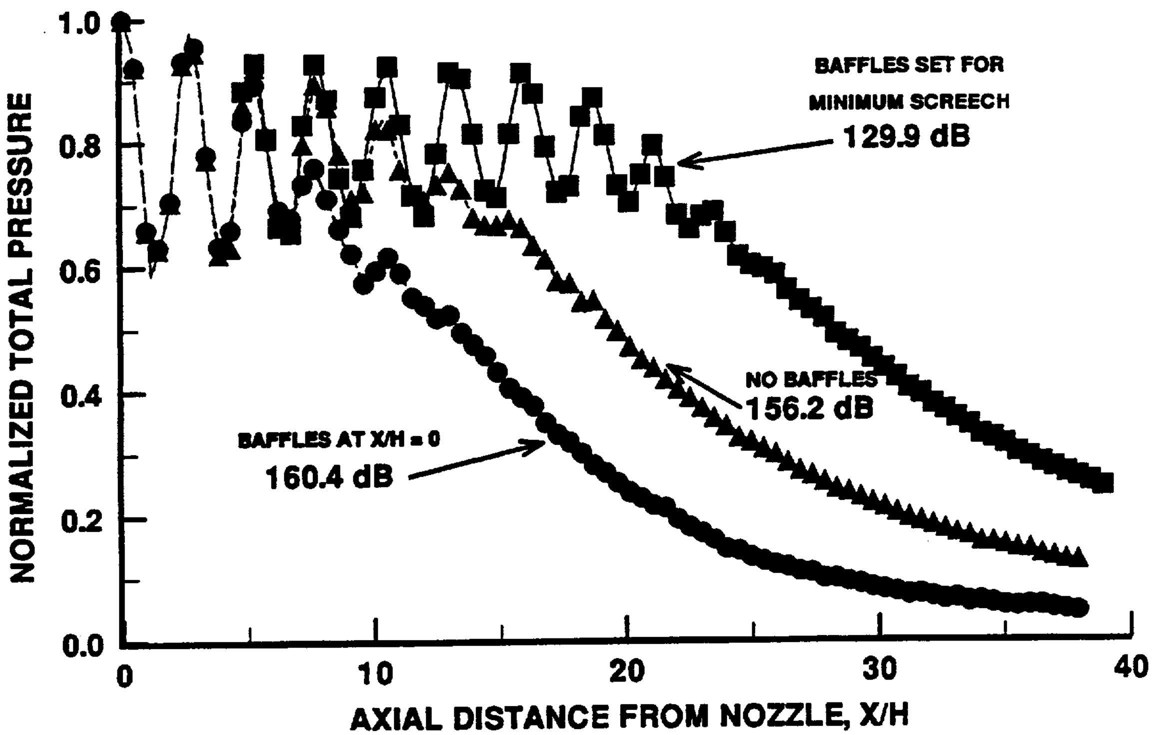


The 30 inch diameter plenum chamber that delivers high pressure air to the rectangular nozzle is seen in the center of the figure. The details of the structure around the nozzle will be shown shortly. At the lower part of the figure is the optical beam that supports the strobed Schlieren system. The strobe on the far right provides the synchronized short duration flash. The next object is the Fresnel lens with a two dimensional grid. A lens focuses the grid onto an image grid which is a reduced print of the two dimensional grid. Refraction of the light by density gradients in the vicinity of the nozzle cause misalignment of the two grids producing lightened and darkened areas on a frosted glass which is viewed by the video camera.



The rectangular CD nozzle is seen with a 0.25 inch microphone attached to measure the screech amplitude at the nozzle lip. Mounted downstream from the nozzle are the paddles which induce the screech. The jet is dominated by the flapping mode of instability and as the jet impinges upon a paddle the pressure increases. The paddle acts as an acoustic source sending sound back to the nozzle lip. The flow emerging from the nozzle is excited by this pressure wave causing the flapping instability which closes the feedback loop. The paddles are mounted on a three-dimensional movement so that paddle position can be adjusted for maximum screech feedback and mixing enhancement. The first experimental results which will be shown use a set of baffles mounted similarly to the paddles of this figure. However, the baffles are extensive surfaces which block the acoustic feedback from the shock cells to the nozzle lip while allowing the supersonic jet to pass through. Using baffles reduce screech and mixing while paddles induce screech and increase jet mixing.

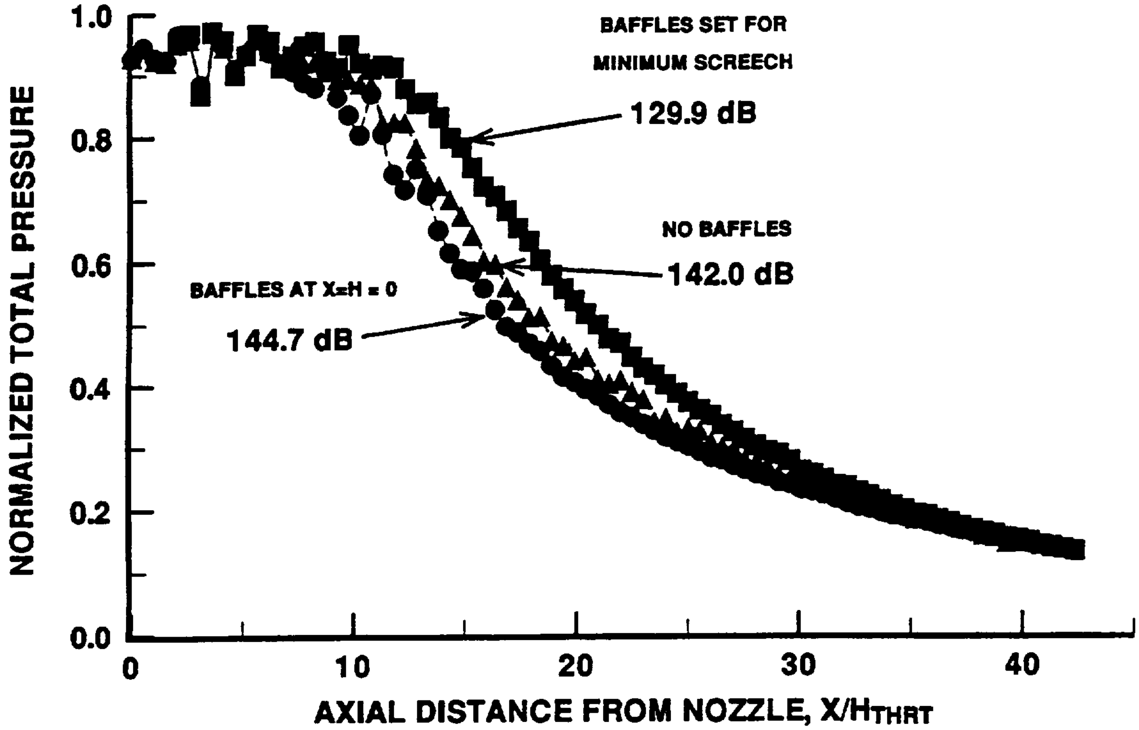
EFFECT OF SCREECH LEVEL ON MIXING OF UNDEREXPANDED JET
CONVERGENT RECTANGULAR NOZZLE, ASPECT RATIO = 4.97, M_{exp} = 1.55



Three sets of normalized total pressure data are shown here as a function of the axial distance from the nozzle exit normalized by the small nozzle exit dimension. This total pressure data is the raw pressure as measured by a total pressure tube without correction for local static pressure or drop over the tube bow shock. This is a converging nozzle run underexpanded and the total pressure oscillations with axial distance show the presence of strong shocks in the jet flow. The middle curve shows the data for the bare jet. The screech level at the nozzle lip is seen to be 156.2 dB, and the potential core length is about 10 as expected. When the baffles are used to eliminate the screech feedback path, the screech is reduced to 129.9 dB. The potential core is increased to 20 showing a dramatic reduction in jet mixing. The lower curve is the result of parking the baffles at X/H = 0. The screech is seen to increase to 160.4 dB and the potential core reduce to about 5 indicating an increase in mixing over the bare jet.

EFFECT OF SCREECH ON MIXING OF PROPERLY EXPANDED JET

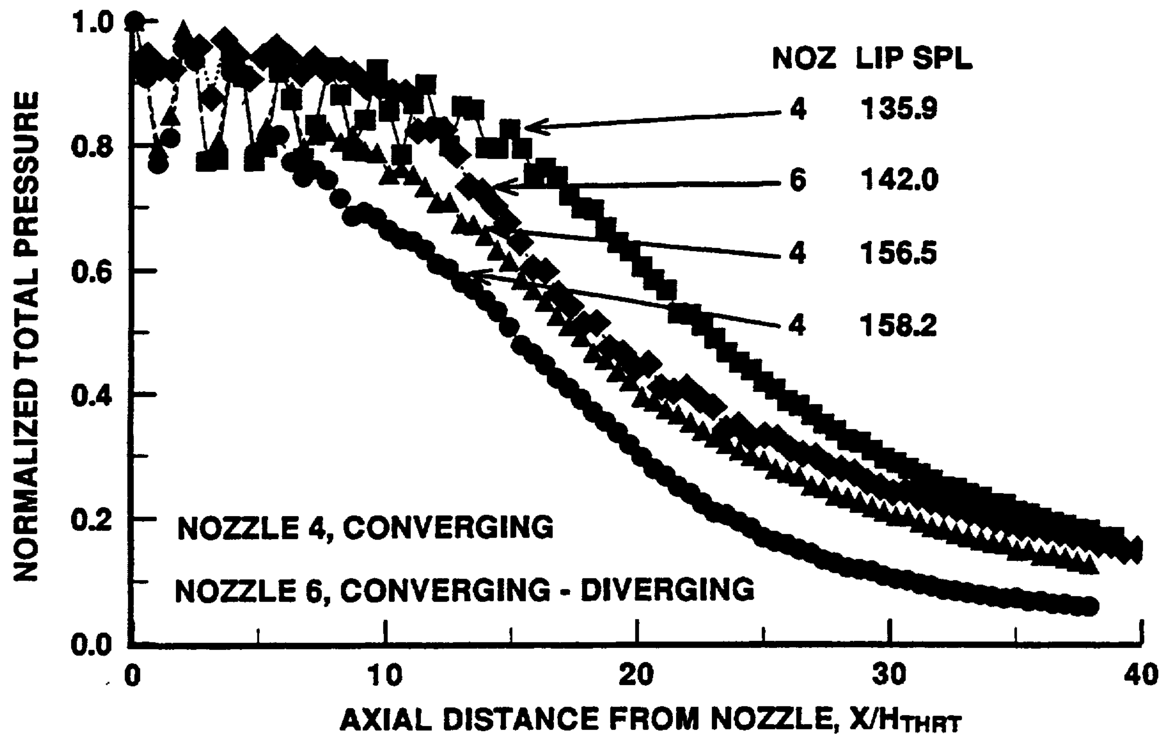
CONVERGING-DIVERGING NOZZLE, ASPECT RATIO = 4.82, M_{exp} = 1.39



This figure shows the results of repeating the previous experiment with a properly expanded flow from a converging-diverging rectangular nozzle. The results are qualitatively the same but with much reduced screech levels and effect on jet mixing. There is about a 15 dB level difference between the extreme curves with only a modest change in mixing.

EFFECT OF SCREECH ON MIXING - COMPARE TWO NOZZLES

CONVERGING AND CONVERGING-DIVERGING, $M_{exp} = 1.4$



The centerline total pressure is shown for the converging-diverging nozzle (#6) operated at design pressure and also for the converging nozzle (#4) operated underexpanded both at a Mach number of 1.4. Nozzle #4 is seen to be somewhat less sensitive to screech level than at a 1.55 Mach number from a previous figure, but also the screech level variation is less (22 dB) than that of the previous figure (30 dB). The most interesting point to be made here is that the bare jet from the CD nozzle mixes almost as well as that of the converging nozzle although the screech level is much lower (142 and 156.5 dB).

INDUCED INSTABILITY OF SUPERSONIC JET

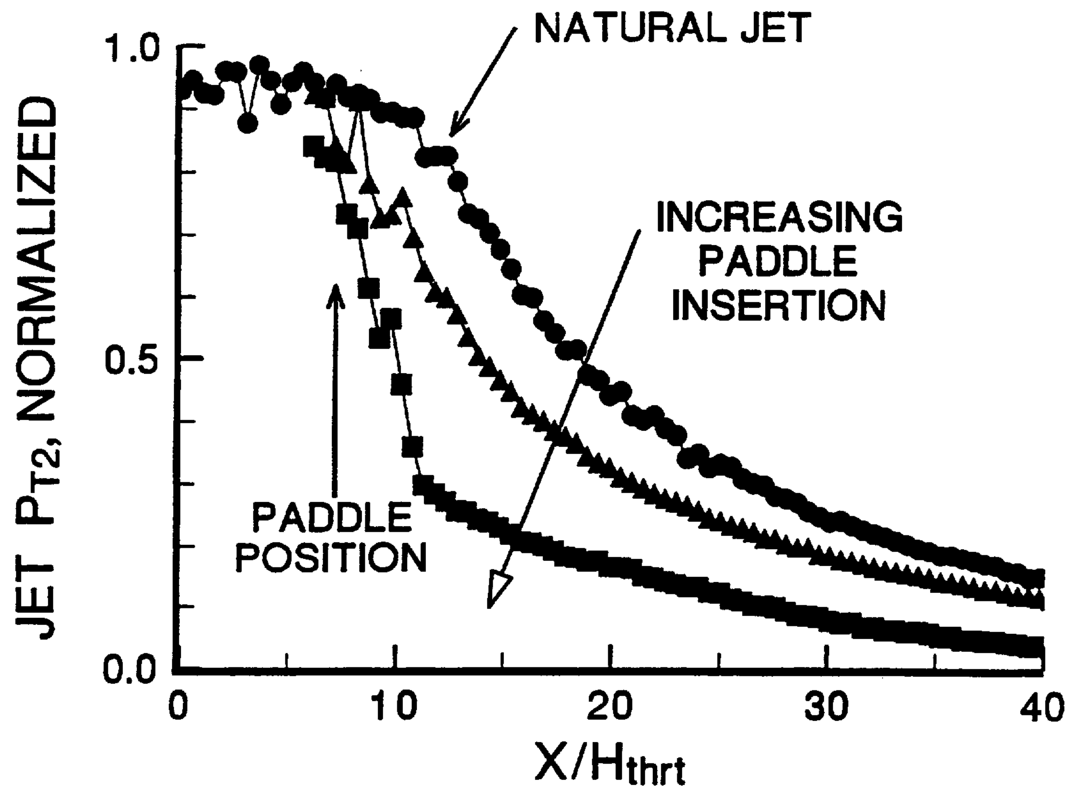
a. Natural jet

b. Induced flapping instability
paddles at X/H_{exit}=7.1 8

Induced instability of supersonic jet (M=1.4), Schlieren photographs, converging-diverging nozzle, design pressure

The discussion returns to the use of paddles to induce screech. This figure shows Schlieren photographs of the natural jet and the jet with paddles in place to produce maximum induced screech. Both are for the properly expanded flow at 1.4 Mach number for a converging-diverging rectangular nozzle. With the paddles in place the jet is seen to have a large amplitude flapping instability produced by the acoustic feedback from the paddles to the nozzle lip. The instability wavelength is seen to be comparable to the jet dimension so a large increase in mixing can occur.

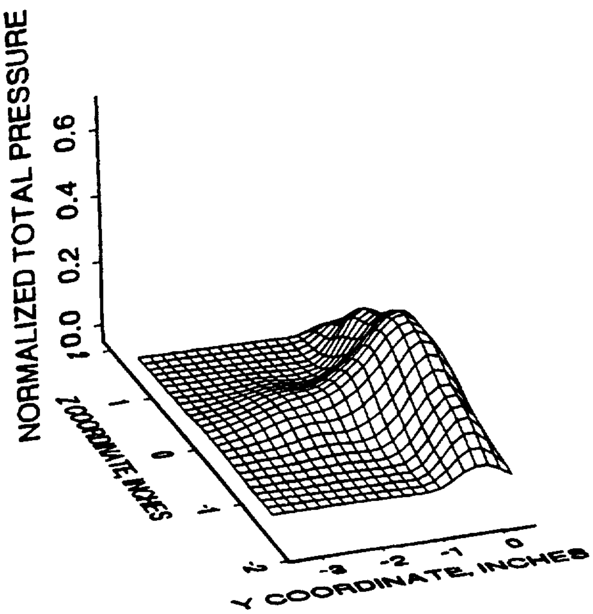
MIXING INCREASE - INDUCED SCREECH



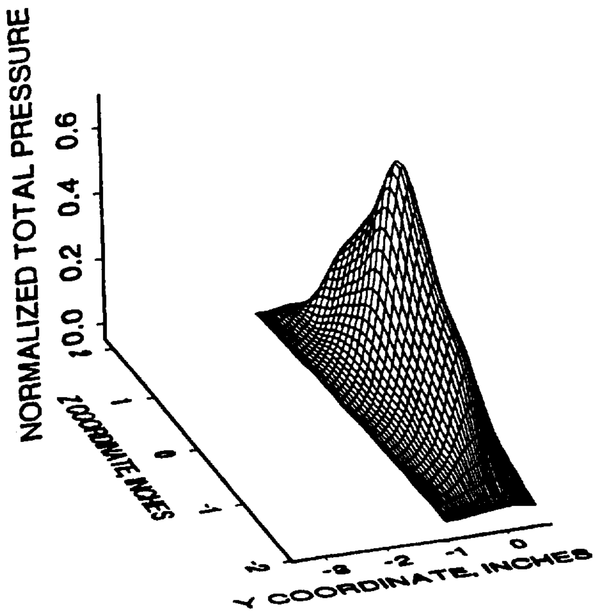
The increased mixing due to the induced screech caused by the paddles is shown as measured by the jet centerline total pressure. The jet is again the properly expanded flow from the rectangular converging-diverging nozzle operating at 1.4 Mach number. Note that the total pressure oscillations, due to shock structure in the jet, are very small compared to previous figures for underexpanded jets. As the paddles are inserted further into the flow, the centerline total pressure drops dramatically. The drop in total pressure starts upstream of the paddles since the flapping oscillations are large there.

COMPARISON OF TOTAL PRESSURE DISTRIBUTIONS

EFFECT OF PADDLES, PRESSURE PROBE AT X=7 INCHES



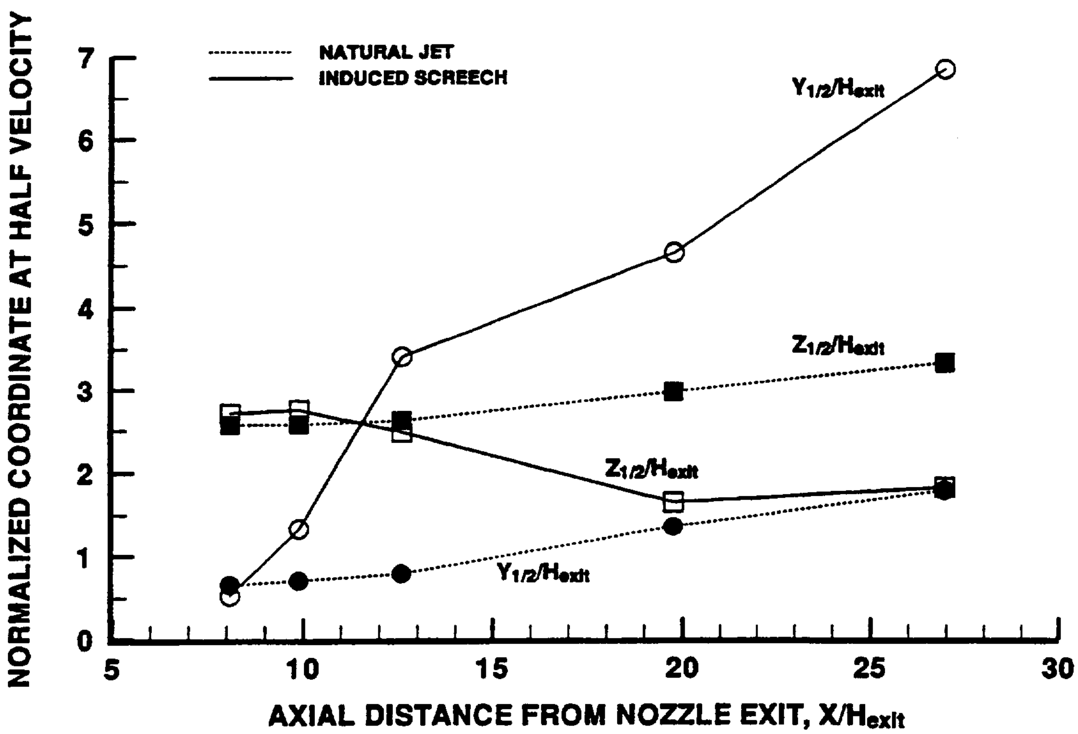
PADDLES AT X=4 INCHES



NO PADDLES

The total pressure distribution in a cross-sectional plane seven inches downstream from the nozzle exit are shown here. Without paddles the pressure distribution is seen to have a high peak on the axis and to have mixed very little in the direction of the nozzle small dimension (Y coordinate). With paddles located four inches from the nozzle, the mixing is seen to be dramatically increased with the centerline pressure reduced and a large amount of flow being pushed out in the Y direction due to the flapping instability.

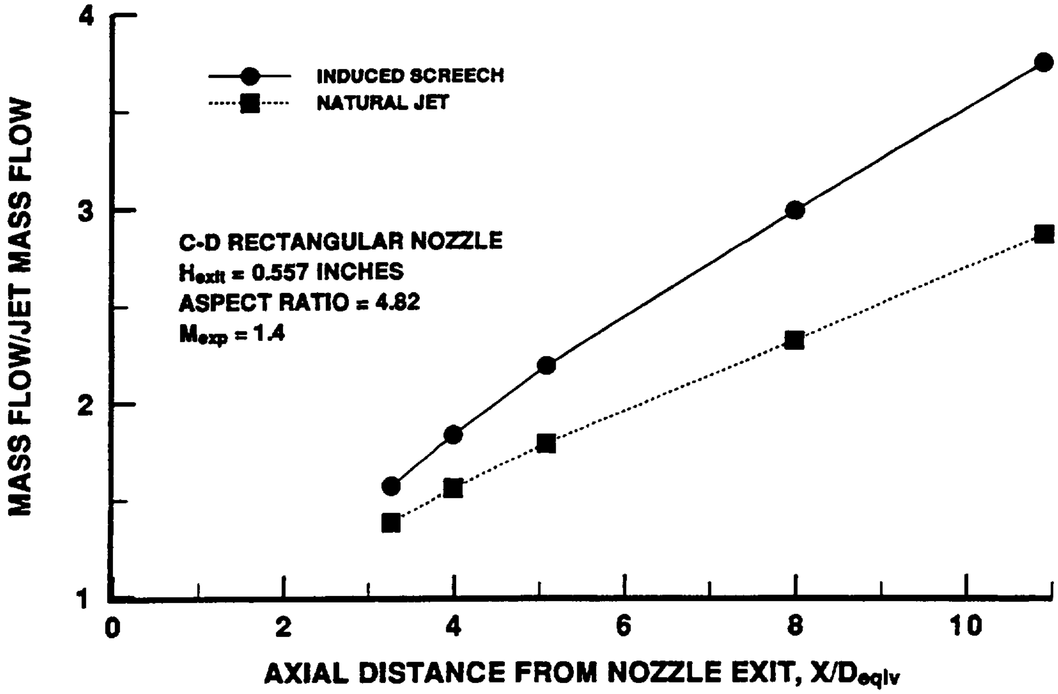
HALF VELOCITY COORDINATES FOR THE NATURAL AND INDUCED SCREECH JETS



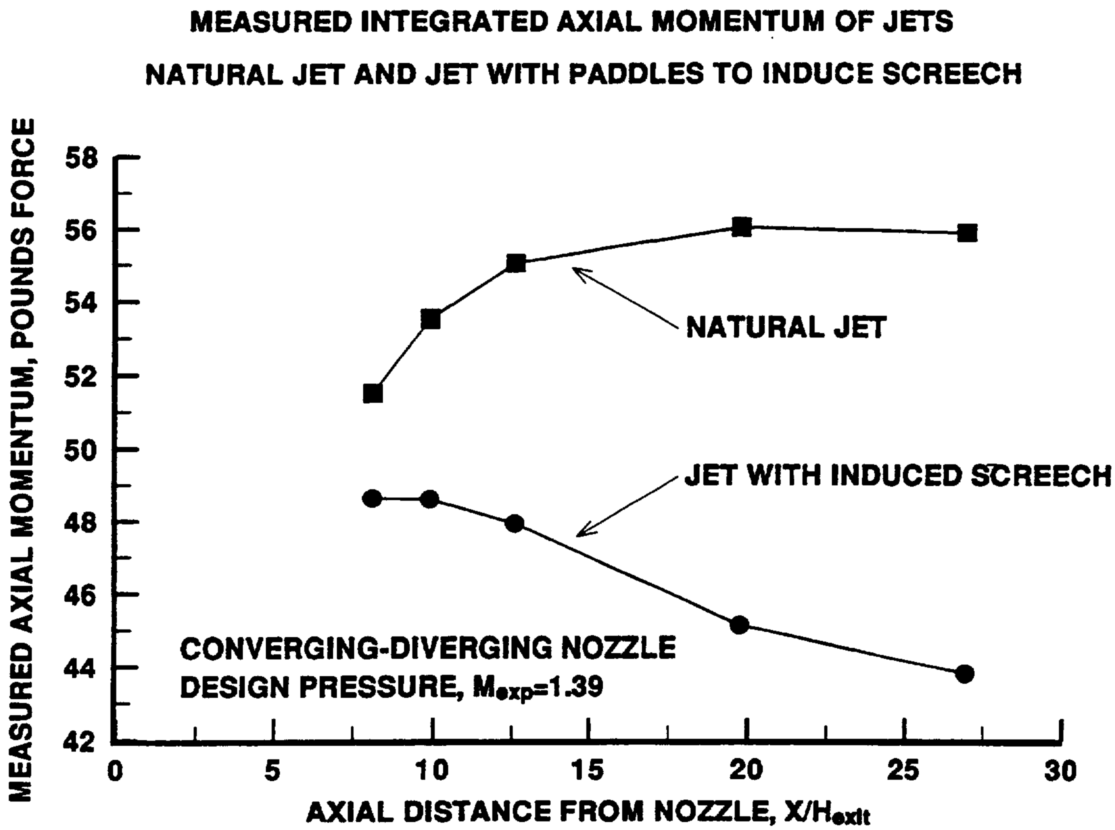
Estimates of the half-velocity coordinates as they develop downstream of the nozzle are shown. These are estimates since the transverse coordinate at 1/4 the centerline total pressure rather than 1/2 the centerline velocity were used. For the natural jet both the Y and Z coordinates are seen to slowly grow as mixing increases with no cross-over occurring. However with induced screech caused by the paddles, the jet Y coordinate is seen to increase drastically due to the flapping and mixing of the jet. An apparent coordinate cross-over occurs, but this is just due to the violent jet flapping in the Y direction and is not coordinate switching as often discussed in connection with low aspect ratio elliptic jets.

COMPARISON OF MEASURED MASS FLOW AT SEVERAL AXIAL STATIONS

NATURAL JET AND JET WITH PADDLES



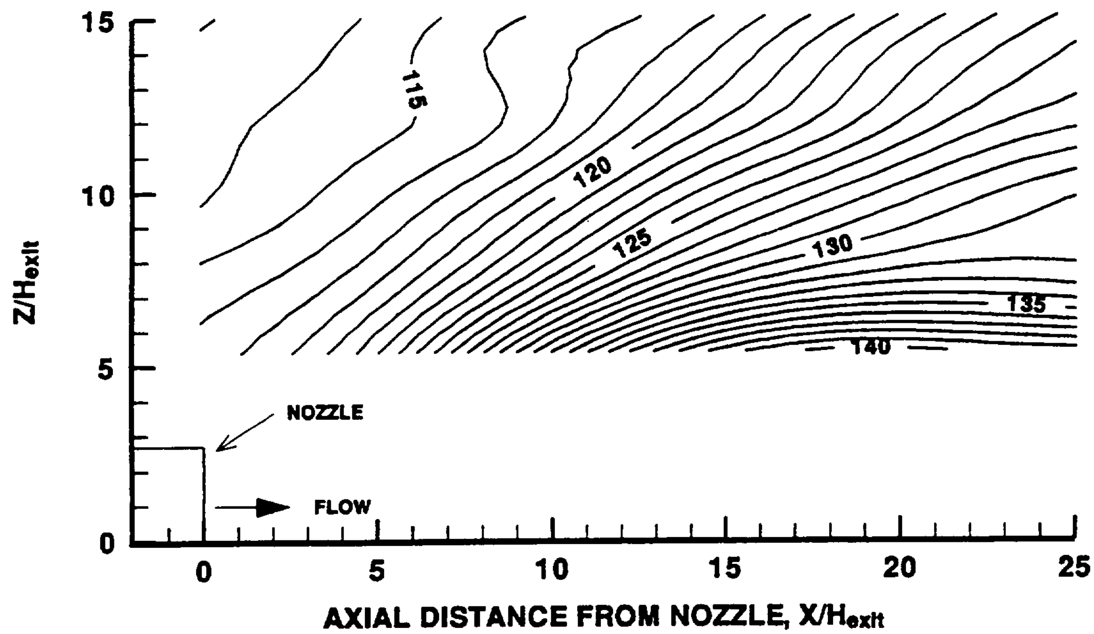
The increase in entrained mass flow due to induced screech is shown in this figure. The mass flow was derived from the total pressure measurements assuming constant static pressure. The entire cross-sectional plane (out to zero total pressure) was included at five axial locations. The equivalent circular nozzle diameter (same area) was used for normalization. At the larger axial distances, the entrained flow is seen to increase by about 48% (total flow by 31%).



The measured axial momentum, as calculated from the total pressure traverses, for the jet with and without paddles is shown here. Again the nozzle is the converging-diverging rectangular nozzle properly expanded at 1.4 Mach number. For the natural jet the momentum trend is as expected. Due to the reduced local static pressure near the nozzle caused by air entrainment, the total pressure and thus the integrated momentum of the jet appears low. As the local static pressure increases to room pressure, the momentum asymptotically approaches a value of 56 pounds force. The ideal thrust of this jet is about 57 pounds force. With induced screech caused by the paddles, there is some momentum loss due to the forces on the paddles, but then there seems to be a continuous drop in momentum well downstream from the paddles perhaps due to the violent mixing in this region. Force data using strain gages on the paddle supports has been taken to clarify the above momentum phenomenon and to measure the paddle drag for trade-off studies.

NEAR-FIELD NOISE MEASUREMENTS, CD NOZZLE, M_{exp}=1.395

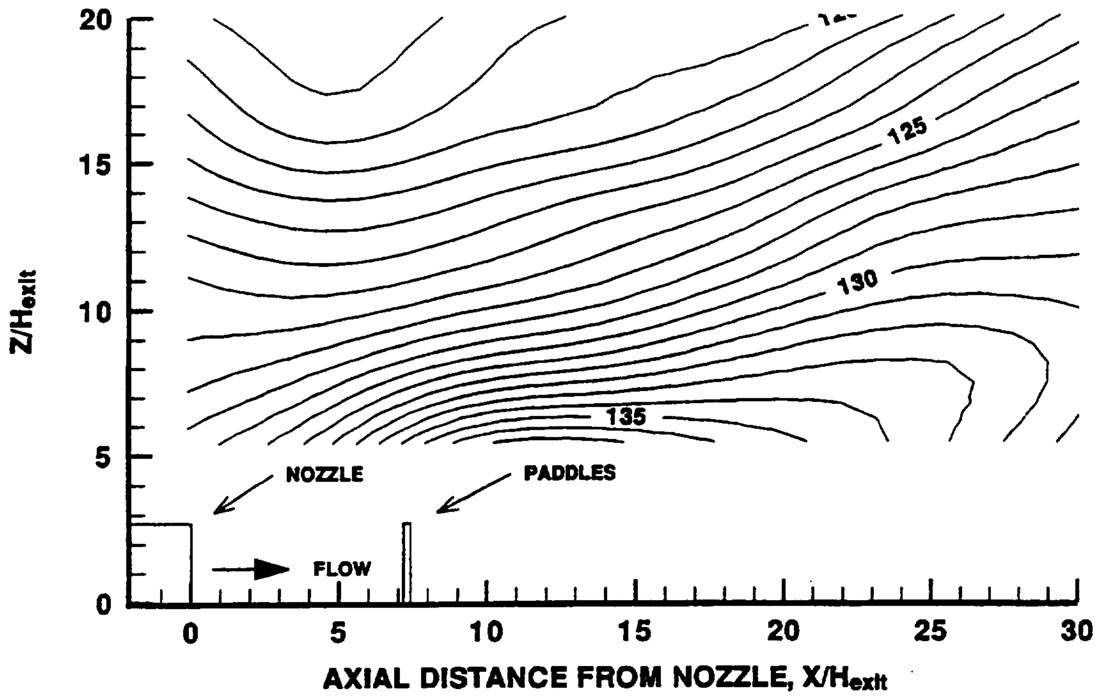
NATURAL JET, 1/3 OCTAVE, F = 2500 HZ



Near-field noise measurements in the Z-X plane are shown in this figure. The Z coordinate is that of the large dimension of the rectangular nozzle. The nozzle is shown in broad-side view in the lower left. This frequency, 2500 Hz, is the 1/3 octave peak in the mixing noise. Near the jet when the constant noise contours run roughly parallel to the jet, the potential of the hydrodynamic field (coherent structures) is being measured. This potential field grows and then decays with axial distance. In this case, for the natural jet, the coherent structures are seen to peak out at a normalized axial distance of about nineteen. The noise field produced by these structures occurs as a lobed pattern of constant noise contours, in this case occurring downstream beyond the range of this graph. This noise field is presented for comparison with the next figure with induced screech due to paddles.

NEAR-FIELD NOISE MEASUREMENTS, CD NOZZLE, M_{exp}=1.395

LONG PADDLES, X_{pad}/H_{exit}=7.18, 1/3 OCTAVE, F=2500 HZ



This is similar to the previous figure except that paddles are included to induce screech. The screech frequency is about double the broadband mixing noise frequency shown by the constant noise contours in this figure. Notice that the hydrodynamic field peaks out at a normalized axial distance of about twelve (nineteen without paddles). The noise radiation field, as seen by the lobe shaped contours, can be seen evolving from the region just downstream from the hydrodynamic field peak. The paddles are thus seen to move the mixing process and the noise radiation evolution up closer to the nozzle exit.

CONCLUDING REMARKS

- THE MIXING OF AN UNDEREXPANDED JET FROM A RECTANGULAR NOZZLE WAS EXTREMELY SENSITIVE TO THE SCREECH TONE AMPLITUDE

- FOR A CONVERGING-DIVERGING NOZZLE OPERATED AT DESIGN PRESSURE
  - –THE MIXING WAS FAIRLY INSENSITIVE TO SCREECH TONE AMPLITUDE
  - –THE MIXING WAS COMPARABLE TO THAT OF AN UNDEREXPANDED JET AT MUCH HIGHER SCREECH TONE EXCITATION AMPLITUDE

- PADDLES CAN BE USED IN THE JET SHEAR LAYERS
  - –A HIGH AMPLITUDE SCREECH TONE CAN BE INDUCED
  - –THE JET MIXING CAN BE DRAMATICALLY INCREASED
  - –DRAG LOSSES MUST BE DOCUMENTED TO ALLOW TRADE-OFF STUDIES

- THE PADDLES MAY HAVE A BENEFICIAL EFFECT ON THE MIXING NOISE-ACOUSTIC TREATMENT INTERACTION (PRELIMINARY)