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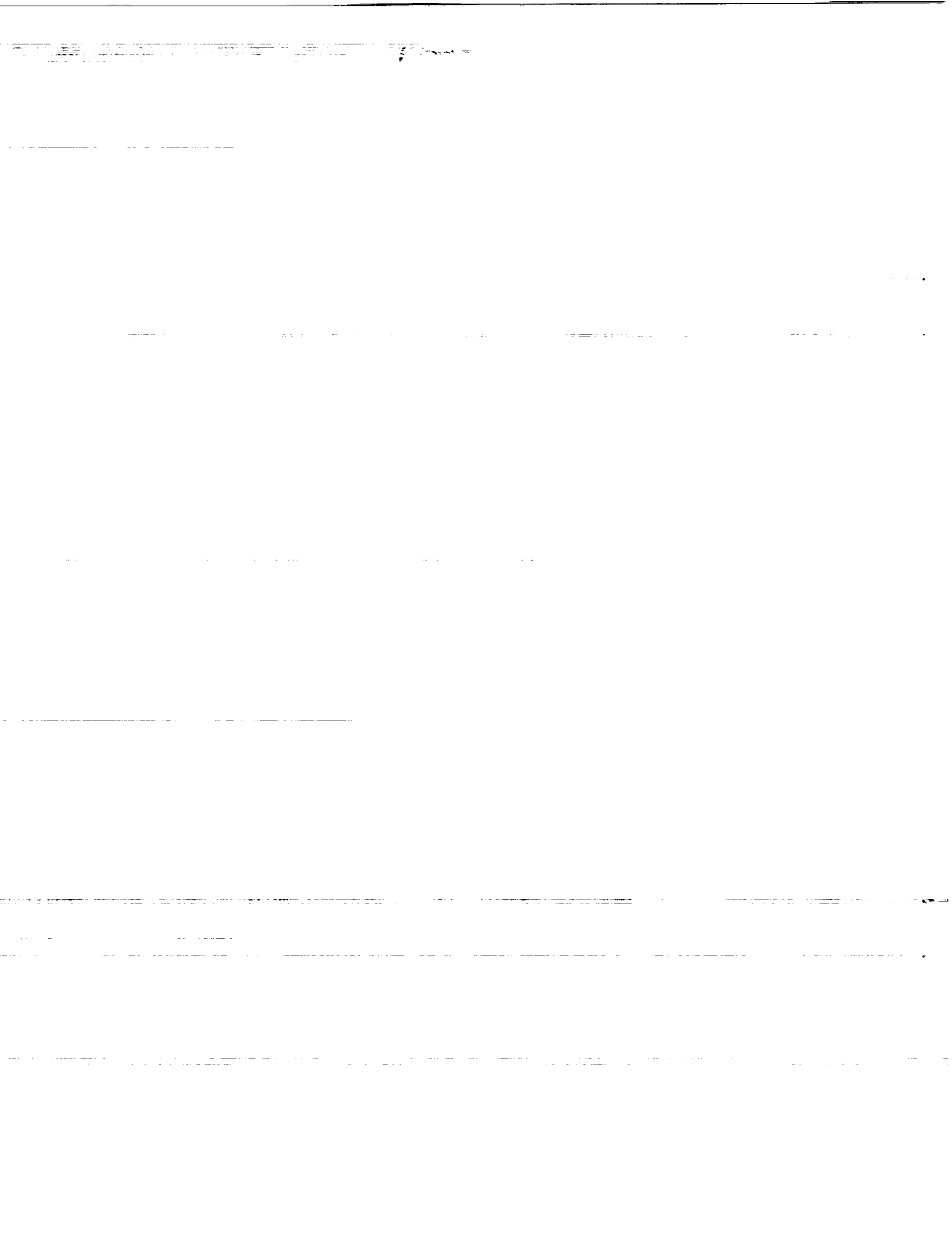
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Abstract

The near-field of the screech noise source structure of an under-expanded supersonic rectangular jet was studied in detail. A miniature probe microphone was used along with a reference microphone to determine the amplitude and phase of the sound pressure near and in the high speed flow field. The transverse structure of the unsteady pressure field was investigated by moving the probe microphone sufficiently far into the jet so that pressure fall-off was observed. Five islands of high sound pressure level have been distinguished which may be associated with the actual local sources of sound production. These sources of screech noise are closely associated with the jet shock structure as would be expected, with the peak region of noise level being found slightly downstream of each of the five observed shocks. The third and fourth noise sources have the highest levels and are about equal in strength. All of the apparent noise sources have their peak levels in the subsonic flow region. Strong cancellations in the acoustic field are observed in the downstream and sideline directions which may account for the predominant upstream propagation of the fundamental tone noise.

Introduction

A research program is underway at NASA Lewis to use unsteady aerodynamic

excitation to cause enhanced mixing of supersonic flow streams. It is intended that the excitation source be a natural source such as a screech tone or some other induced acoustic resonance which feeds on the steady flow energy and produces a very high amplitude acoustic field at the nozzle lip. A first step in this research is to thoroughly investigate the fundamental screech tone acoustic near field. This information will be used to combine several elements to produce a mutually beneficial interaction and enhanced mixing of a multi-element mixer-ejector. The key issues involved in this program concern the excitation source such as natural or induced screech, the mixing of supersonic flow from rectangular nozzles, and the interaction of multiple jets. Excellent models have been developed on some overall properties of screech noise, such as the Strouhal frequency and the directivity. Powell¹ modeled the two-dimensional supersonic jet recognizing that the source of the screech tone involved the interaction of the flow disturbances with the multiple shock structure producing an acoustic feedback to the nozzle lip which closes the loop. Tam² advanced the model to include the rectangular jet which is of interest in this paper. Other examples of flow self-excitation which might be considered are the "whistler nozzle" discovered by Hill and Greene^{3,4} and studied by Hasan and Hussain,⁵ and the flip-flop jet nozzle studied by Viets.⁶ The benefits of enhanced mixing due to the unsteady

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excitation by screech tones for a single round supersonic jet has been presented by Glass⁷ and for a single rectangular jet by Krothapalli, et al.⁸ For single element ejectors, mixing enhancement due to screech excitation has been shown by Quinn⁹ and Hsia et al.,¹⁰ by forced jet deflection due to cyclic blowing by Binder and Didelle,¹¹ and by a flip-flop nozzle by Viets.¹² A multi-element ejector was tested by Chandrasekhara et al.,¹³ but they claim that for their configuration no mixing enhancement due to acoustic interaction was observed. The potential for strong acoustic interaction between two jets has been demonstrated experimentally by Seiner et al.^{14,15} and Wlezien.¹⁶ Twin supersonic jet instability theory has been developed by Morris.¹⁷ Excellent recent review publications by Seiner¹⁸ and Tam¹⁹ provide a broader discussion of the acoustics of supersonic jets.

The above discussion provides an overall though brief background of the research program of which this study is a small part. Of immediate interest here is the very near acoustic field and hopefully the source characterization of the screech tone produced by an underexpanded supersonic rectangular jet. Several attempts have been made to locate the source location of the screech tone in a supersonic jet, the most relevant to the current study being the series of papers of Westley and Woolley.²⁰⁻²⁴ They mapped out the near field pressure amplitude and phase of a supersonic round jet screeching in both the symmetric and spinning modes of hydrodynamic instability. They observed a very complex near field pattern of pressure with maxima clearly associated with the series of shocks in the flow. Phase measurements showed the waves near the jet boundary to be moving downstream as might be expected of hydrodynamic waves. Farther from the jet boundary the waves appear to be originating from the third and fourth shock cells implying that these are the dominant sources of the screech tone. No fall-off in the tone amplitude was observed with the maximum pressure being observed at the maximum insertion toward the jet boundary. This is in contrast to the

present study in which a peak in unsteady pressure level was observed outside of the jet boundary which appears to define the transverse as well as the axial location of the dominant noise source. The reason for this considerable difference is not fully understood. The obvious differences between the two studies are that the previous research was conducted in a round jet and with a relatively larger (6.35 mm) microphone apparently positioned normal to the jet axis while the current study is done in a high aspect ratio rectangular jet with a 2 mm probe microphone pointing downstream (30° to the jet axis).

The new amplitude and phase data for the convergent rectangular nozzle ($H = 7.37$ mm, $L = 71$ mm) with a fully expanded Mach number of $M_{ex} = 1.44$ are presented. Several aspects of the acoustic and hydrodynamic fields will be discussed including some potential sources of error and misinterpretation of the data.

Experimental Procedure

The experimental set-up including the rectangular nozzle, the two microphones, and the coordinate system orientation are shown in Fig. 1. The nozzle exit has a rectangular geometry with dimensions of 7.37 and 71 mm (aspect ratio = 9.64) with the major axis in the vertical (Z) direction. The nozzle transitions smoothly to a circular cross-section of 51 mm diameter in an axial length of 15 cm. Dimensions are internal to the nozzle. The 6.35 mm reference microphone was mounted at $Z = 0$ with minimal clearance to the nozzle wall and slightly behind the nozzle lip. There was some upward orientation (in the X-Z plane) of the microphone tip as shown to avoid interference with the nozzle cylindrical section. The traversing microphone was also 6.35 mm with a 2 mm probe tube mounted in place of the wind-screen. This microphone was placed in the X-Y plane, orientated at 30° to the X-axis, and was moved in the X-Y plane using a precision three-dimensional probe traversing mechanism. A flow control feed-back loop was used to maintain constant

flow which was essential for this experiment due to the sensitivity of the screech phase to flow conditions. Data were recorded only when the plenum total pressure, of about 331 kPa (48 psia), could be maintained to less than 690 Pa (0.1 psi) deviation.

A typical microphone traverse was as follows. The probe tip was located at $Y = -45.7$ mm and a Y traverse was begun with X held constant. The probe was moved toward the jet in increments of 5.59 mm, decreasing to 2.54 mm steps, and then to 1.27 mm steps until $Y = -3.81$ mm was reached. For the last few stations for which the probe tip was in the high velocity flow, the probe was quickly thrust in to the proper coordinate, the data were obtained, and the probe was then quickly moved out of the flow. This was done to minimize the possibility of damage to the microphone and to prevent a calibration change of the probe due to a steady temperature reduction. When the traverse was completed, the probe was returned to $Y = -45.7$ mm and this data point was repeated as a check for data consistency. The amplitude of the transfer function usually repeated to within 0.3 dB and the phase to within 5° . The probe was then advanced 2.54 mm in the X direction and the procedure repeated until $X = 116.8$ mm was reached.

The acoustic data were analyzed using a two channel B&K spectrum analyzer in the transfer function mode. A calibration transfer function was stored in memory and was applied to measurements in the equalized transfer function mode to automatically account for the difference in response due to the probe tube. At each microphone probe position the spectral measurement band was centered upon the screech fundamental and the screech frequency, reference microphone (channel A) power level, and the equalized transfer function amplitude and phase between channels A and B (probe microphone) were recorded. All spectral information were then recorded on a floppy disk for further future analysis as needed. The relative phase

of the probe microphone pressure relative to the reference microphone is the transfer function phase as read. The amplitude is obtained by adding the channel A amplitude level to the equalized transfer function level, both measured in decibels.

It is believed that the method of pressure measurement using a very small diameter downstream pointing microphone probe in a high speed flow is without precedent. This procedure had to be used to obtain the fine spatial resolution needed within this relatively small jet. The downstream orientation of the probe was chosen to minimize the steady pressure magnitude at the microphone diaphragm. The response to acoustic pressure was not the issue but the question was how does the probe respond to the jet velocity fluctuations due to the coherent structures in the jet as the probe is moved into the jet. Fuchs²⁵ has reported pressure measurements within a high speed flow, but his technique used a standard microphone with an attached bullet nose pointing straight up into the flow. This is now a standard method but the large bullet nose does not allow the spatial resolution needed in this study. A calibration of the probe microphone was thus required. An unsteady jet flow was generated using a flip-flop nozzle as discussed by Viets.⁶ The microphone probe and a hot wire anemometer were placed in the oscillating flow at the same immersion (y coordinate, Fig. 1) at the same axial station and very close together in the vertical direction. The two instruments were thus exposed to nearly the same flow velocity in this nearly two-dimensional unsteady flow. The unsteady pressure and velocity spectra were observed over a range of average Mach number (0 to 0.5). The data at the fundamental oscillation frequency was found to be adequately correlated by the equation,

$$p = \rho u^2 \quad (1)$$

between the velocity fluctuation u and the pressure fluctuation p where ρ is the average density. Equation (1) will be used in a

later section (Hydrodynamic Pressure Effect) to estimate the pressure measured by the probe as it is moved into the high speed jet with its unsteady flow due to the jet coherent structure.

The two microphones were also calibrated for acoustic measurement. A piston-phone was used with each microphone mounted with a standard wind screen to set the amplifier gain of each channel. The wind screen on the microphone in channel B was then replaced by the 2 mm probe. The tips of both microphones were then mounted close together and at equal distance from an acoustic driver. A white noise spectrum was then applied to the acoustic driver through an amplifier and the spectral analysis of the two microphone signals was made. The transfer function between the two channels was put into memory for use in the equalized transfer function mode. In this mode the transfer function is compared to that in memory and the deviation is displayed as the relevant signal. In this mode the standing wave problems in the probe tube are automatically eliminated. The equalized transfer function of the above set-up now shows an amplitude of unity and zero phase. The two microphones were then moved around together in the field of the acoustic driver to insure that the original calibration position was not contaminated by any reflections and standing wave patterns. The amplitude and phase of the equalized transfer function during this movement remained at nearly unity and zero respectively.

Results

The data presented here represent a detailed spatial analysis of the unsteady pressure amplitude and phase measured in the plane of symmetry (X-Y plane in Fig. 1) of a 7.37- by 71-mm rectangular nozzle with a constant fully expanded Mach number of 1.44. The data will be presented in three ways to emphasize different aspects of the data. First, and overall view of the unsteady pressure field will be presented to look at the gross proper-

ties within the total field of measurement. Next a more detailed set of data on the unsteady pressure and phase will be presented to sift out some important aspects of the screech noise sources. Finally, sources of potential measurement problems are discussed.

The terminology unsteady pressure is used here instead of sound pressure level because the variation in pressure measured is not all acoustic but has a hydrodynamic component when the probe microphone enters the region influenced by the flow field. In fact standing wave patterns can occur involving the hydrodynamic and acoustic pressures, as reported by Moore²⁶ and Tam and Morris,²⁷ when the two pressures are of comparable amplitude. The microphone probe will produce an unsteady pressure response due to an axial flow perturbation according to Eq. (1) discussed previously.

Overall Unsteady Pressure Field Data

Contours of equal sound pressure level for the screech fundamental at 7700 Hz are shown in Fig. 2 for the entire range surveyed in the X-Y plane for $Z = 0$. Contour level values have been omitted to avoid cluttering the figure. Relevant information on levels will be covered shortly. The overall impression of the complexity of the acoustic field should be observed from this figure. Five larger islands of contours are apparent as are several smaller somewhat concentric regions between the large islands and also very near the jet itself. Recall that the jet starts axially at $X/H = 0$, and transversely at $Y/H = -0.5$ and flows from left to right. Grouping of contours are also seen toward the sideline and in the downstream direction. The full range of sound pressure levels observed (135 to 167 dB) are plotted in Fig. 2.

The axial locations of the first five shocks are also shown in Fig. 2. The shock locations were measured using a focusing Schlieren system. In spite of the large aspect ratio of this jet, 9.64, considerable

three-dimensional effects were observed in the shocks, especially for higher numbered shocks. The shock positions shown were measured at the jet center, $Z = 0$, thus in the same plane as that of the other measurements shown.

When only the high amplitude sound pressure level contours (163 to 167 dB) are plotted, a much clearer picture of the physical phenomena emerge as shown in Fig. 3. These high levels must come from local sources or local reinforcement of waves from these sources. It appears that there are five fairly strong, quite evenly spaced sound sources near the jet. The nearly even spacing of these sound sources is due to their association with the shock structure whose spacing is also shown in Fig. 3. It is seen that the peaks lie just downstream of the shocks and are probably due to the large coherent structure related to the jet instability mode passing through and perturbing the shocks. The dominant instability mode for this jet at this Mach number (1.44) is the jet flapping mode since the screech phase difference is 180° on the two sides of the nozzle at $X = 0$.

The lower end of the sound pressure level contours in Fig. 2 is shown with finer decibel increments in Fig. 4. This portrayal of the contours gives accent to the negative interferences or cancellations, the depth of which are indicated by the contour spacing. One strong and several modest cancellations occur in between the noise sources. Several strong cancellations occur at the jet interface where very strong interactions (reflection, refraction) with the supersonic flow may be occurring. In the lower right hand corner of Fig. 4 a strong cancellation occurs near the sideline and a more modest cancellation occurs downstream. These near-field cancellations (sideline and downstream) may be responsible for the dominant upstream directivity of the screech fundamental tone.

An interesting perspective of the screech tone near-field distribution can be seen in the three-dimensional surface plot of Fig. 5. The five source regions can easily be seen with a

reinforcement occurring between the first and second cells. The sideline and downstream cancellations can also be clearly seen. The dominance of the third and fourth source cells can also be visualized.

From the same perspective as Fig. 5, the jet flow total pressure can be visualized in Fig. 6. Note, however, that the transverse axis coordinates have different scales between the two figures. This data is the raw total pressure measured by the total pressure probe, uncorrected for losses across the bow shock, and is often denoted as p_{t2} . The peaks in the noise source strength of Fig. 5 are seen to track along with the total pressure peaks of Fig. 6. This is true because both the total pressure peaks and the unsteady pressure peaks track with the shock structure. The total pressure peaks were found to lie 2 mm ($\Delta X/H = 0.27$) downstream from the shocks. Another interesting feature of Fig. 6 is that the expansion and contraction of the jet can be visualized in the expansion wave and shock regions. Since the jet is underexpanded, the flow first undergoes an expansion with a drop in pressure to the first valley and an obvious lateral expansion of the jet. The jet then contracts laterally as the first shock is reached near the first peak (excluding the peak at the origin). This process then repeats with the first five expansions visible with the scales used here.

Detailed Unsteady Pressure Amplitude and Phase

The unsteady pressure amplitude and phase are shown in Figs. 7, 8 and 9 for three different ranges of the axial variable. The phase data presented in Figs. 7 to 9 are subject to a certain amount of interpretation. The raw phase analysis provides data between -180° and 180° with abrupt jumps in phase as one of these limits is exceeded. Careful analysis is required to determine the proper quadrant for this phase data over the entire field of measurement. Continuous phase data is to be expected away from the sources at the outer boundary of the measurements. Jumps

in phase might be accepted near sources of noise and might even be expected across flow discontinuities such as shocks. The phase data has been cross-plotted to approach apparent discontinuities in an asymptotic manner to confirm that the jump in phase was indeed physical. The corrections to the raw data, where made, only amounted to the addition of 360° to the phase. The authors offer the interpretation of the phase data as their best judgment of the correct phase but it is possible that this may be in error.

The amplitude and phase data for the screech tone in the region nearest the nozzle lip are shown in Figs. 7(a) and (b). The first island of high amplitude contours is seen at $X/H \approx 3$ and $Y/H \approx -1$ in Fig. 7(a). These high amplitudes are seen just downstream of the first shock, as can also be said about the other four apparent noise sources and the other four shocks seen in Figs. 8(a) and 9(a). Strong cancellations can be seen in the near vicinity of the second through the fifth shocks. Near the jet boundary, just upstream of the first shock, a very strong cancellation is seen and the phase data of Fig. 7(b) are reminiscent of a strong refraction with the sharply curved wave-fronts. Recall that this is just the region that the jet expands out to retract again at the shock.

In spite of this strong cancellation just upstream of the first shock, between all of the noise sources and the nozzle lip, the sound pressure level is seen to recover to a high value near the lip itself. In Fig. 7(a), the 160 dB contour is seen just downstream of the lip, near $X/H = 0$ and $Y/H = -0.5$. In fact right at the lip a level of 159 dB was measured. This strong reinforcement closes the feedback loop causing the screech instability and tone and can only come from the superposition of multiple sources as discussed by Powell.¹

If a claim is made that these very distinct islands of high unsteady pressure are indeed the source regions, it would be most satisfying if the phase data showed a distinct

pattern of outward radiating wave fronts. There is a hint of this as seen in the phase plots of Figs. 7(b) to 9(b) but the phase seems to be clouded by the sensitivity to multiple source additions, reflections from the supersonic shear layer, and contamination from the hydrodynamic flow field. If these high pressure islands are not the source regions, then it must be explained how these nearly symmetrical mounds are formed by sources more embedded in the flow region.

Some additional observations can be made regarding the phase plots of Figs. 7(b) to 9(b). Very abrupt phase increases are observed just upstream of Shocks 2, 3, and 4. However a very large phase decrease occurs just downstream of Shock 5. This is somewhat troublesome but this interpretation of the phase quadrants was the only one that provided smooth phase change away from the shocks and sources as mentioned earlier. A very interesting observation can be made regarding the phase very near to the jet between Shocks 4 and 5. The constant phase lines are nearly parallel to the jet interface, slightly diverging downstream, which is exactly what might be expected from an oscillating displacement of the entire jet in this region. This behavior is most likely due to the flapping instability of the jet which has grown sufficiently at these downstream distances to dominate the hydrodynamic pressure in between the shocks. Right at the shocks, the shock oscillation probably dominates the unsteady pressure.

Although a sixth shock was not visible from the Schlieren picture, the axial total pressure traverse did show a ripple indicating some disturbance at $X/H \approx 13.5$. The phase plot in Fig. 9(b) indicates that there is indeed some perturbation at this position even though it is too weak to detect in the magnitude plot of Fig. 9(a). This again points out the extreme sensitivity of the phase relative to the magnitude detection of an event.

The forward radiating sound, as represented by the constant phase contours in the

lower left-hand corner of Fig. 7(b), are very smooth and regular with a spacing nearly that expected of far-field radiation. It should be recalled however, that the wave-fronts from several sources are still coalescing here since the measurements are in the near-field with the total measurement field extending only one wavelength transversely and about six wavelengths axially.

Another interesting phenomenon can be seen from the constant phase contours at the far right side of Fig. 9(b), the contours from -40° to 40° . It is seen that near the jet the contours are closely spaced with the spacing increasing away from the jet. This phenomenon is of course just the transition from a hydrodynamic wave near the jet, with a lower phase velocity governed by the subsonic mixing layer flow, to the acoustic wave farther from the jet with its higher phase velocity. Note the phase ripple as the pressure transitions from one phenomenon to the other.

For those who may want to work further with this data, the following information is provided. The five observable shocks were measured to occur at $X/H = 2.08, 4.38, 6.62, 8.71, \text{ and } 11.11$. The peaks of the five islands of maximum unsteady pressure were located at $X/H \approx 3.07, 5.21, 6.93, 9.34, \text{ and } 11.49$, and $-Y/H \approx 1.06, 1.40, 1.69, 1.87, \text{ and } 2.35$. The peak unsteady pressure levels were 166.2, 166.0, 167.3, 166.9, and 164 dB.

Possible Sources of Error in the Pressure Measurements

Since the phenomenon of the fall-off in unsteady pressure as the jet flow field is approached has apparently not been previously reported, it is natural to inquire as to whether this observation is truly physical or just due to some measurement error. Two possible errors that might occur when a microphone probe, with the orientation used in this experiment, is inserted into a high speed flow will be discussed. The first is that the microphone sensitivity is reduced due to a reduction in static pressure on the diaphragm when it is

not vented to the other side of the diaphragm. The second is that the unsteady hydrodynamic pressure due to the large scale structure in the jet flow may cause standing wave patterns with the acoustic field which may give the illusion that there is a pressure fall-off. In the following two sections these phenomena will be shown to be incapable of producing the observed pressure fall-off which produces the high amplitude closed pressure contours which are suggestive of the local screech noise sources.

Pressure Sensitivity of the Microphone

The microphone used in this experiment was a Larson Davis number 2530 with a stated static pressure sensitivity loss of $\leq -0.001 \text{ dB/mbar}$. This microphone is vented through the preamplifier so that any static pressure produced by the probe unit will be felt across the diaphragm. First it must be estimated how the pressure in the probe responds to the steady flow. Then the steady flow velocity experienced by the probe as it is traversed around the unsteady peaks will be shown.

From any published drag coefficient correlations for cylinders in cross-flow or spheres in a high Reynolds number flow, such as in Bird et al.,²⁸ a static pressure deficit on the leeward side can be estimated. If the assumption is made that one-third of the drag is due to this pressure deficit then this relative vacuum is estimated to be one-fifth of the magnitude of the total pressure. This appears to agree roughly with some limited data taken with a steady pressure transducer connected to a 2 mm tube and inserted into the high speed flow in the same manner as with the microphone probe. Great precision is not required here since it will be shown that the static pressure is not even close to being a problem.

The steady flow velocity contours, calculated from the steady total pressure measurements shown in Fig. 6, are shown superimposed on the unsteady pressure con

tours in Fig. 10, which are acoustic pressure contours at least away from the jet. The 100 m/s velocity contour is seen to lie well toward the jet from the measured acoustic peak. Using the relation discussed in the paragraph above, the static pressure on the diaphragm is estimated to be 12 mbar. Using the microphone data above, the sensitivity loss is thus less than 0.01 dB which is insignificant. Along the 200 m/s contour the microphone sensitivity loss is estimated to be less than 0.05 dB, again insignificant. The 200 m/s velocity contour is seen to be far from any of the peak measured unsteady pressures and thus the steady flow can not cause the fall-off in sound pressure level due to an unvented static pressure on the microphone diaphragm.

Hydrodynamic Pressure Effect

When the microphone probe is inserted into the region influenced by the flow, an unsteady pressure is developed due to the unsteady flow passing over the probe tube. The probe tube has been calibrated for this effect and the result was given as Eq. (1). This unsteady hydrodynamic pressure can interact with the acoustic pressure if the two are of similar magnitude to form standing wave patterns, as discussed by Moore²⁶ and Tam and Morris,²⁷ which may give an illusion of pressure fall-off. A key point is that the two pressures must be similar in magnitude.

Estimated hydrodynamic pressure contours are shown superimposed on the measured acoustic pressure contours in Fig. 11. A local turbulence level of 30 percent was used to convert the measured steady flow to an unsteady velocity, and then Eq. (1) was used to convert this to unsteady pressure. It is seen that the hydrodynamic pressure levels do not even come close to the acoustic pressure levels in the vicinity of the peak acoustic pressures. The hydrodynamic pressure can thus have no influence on the unsteady pressure in the vicinity of the peak. Of course as the shear layer is more closely approached, the

unsteady pressure is seen to be completely dominated by the flow induced pressure fluctuations. Several examples of the dominance of the hydrodynamic pressure have been pointed out in the previous discussions earlier in this paper.

Concluding Remarks

Data is presented showing the near-field noise structure of the fundamental of the natural screech tone of an underexpanded rectangular jet of dimensions 7.37 by 71 mm, aspect ratio 9.64, flowing at 1.44 Mach number. The data were obtained using a 2 mm probe attached to the microphone. This allowed very fine spatial resolution and provided some protection for the microphone since the probe tube pointed downstream at 30° to the jet axis. Thus the probe could be inserted very close to and in fact into the jet flow. Some of the more important observations from the data are:

1. Five distinct islands of maximum noise level formed by closed contours have been observed. This observation is apparently unique in that the noise level is seen to decrease from the peak toward the jet axis. This measurement is made possible by the fine spatial resolution of the probe and the ability to move the probe into the flow and maintain accuracy.
2. The five islands or mountains of peak noise are located just downstream of the five observable shocks.
3. The peaks are all located well out of the supersonic flow, in fact in quite low velocity subsonic flow.
4. The peaks are real and they are acoustic. Possible extraneous causes of the acoustic pressure roll-off, such as microphone static pressure problems or influence by the unsteady hydrodynamic pressure field, have definitely been ruled out.

5. The pressure peaks are believed to be closely associated with or in fact may be the screech noise sources.

6. Several strong cancellations and reinforcements are observed between these apparent noise sources. The observed cancellations observed may be responsible for the dominant upstream propagation of the screech tone.

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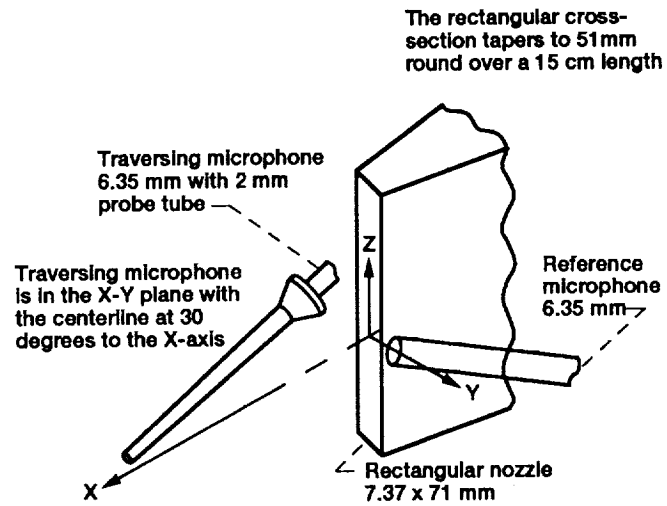


Fig. 1. Coordinates and layout of experiment.

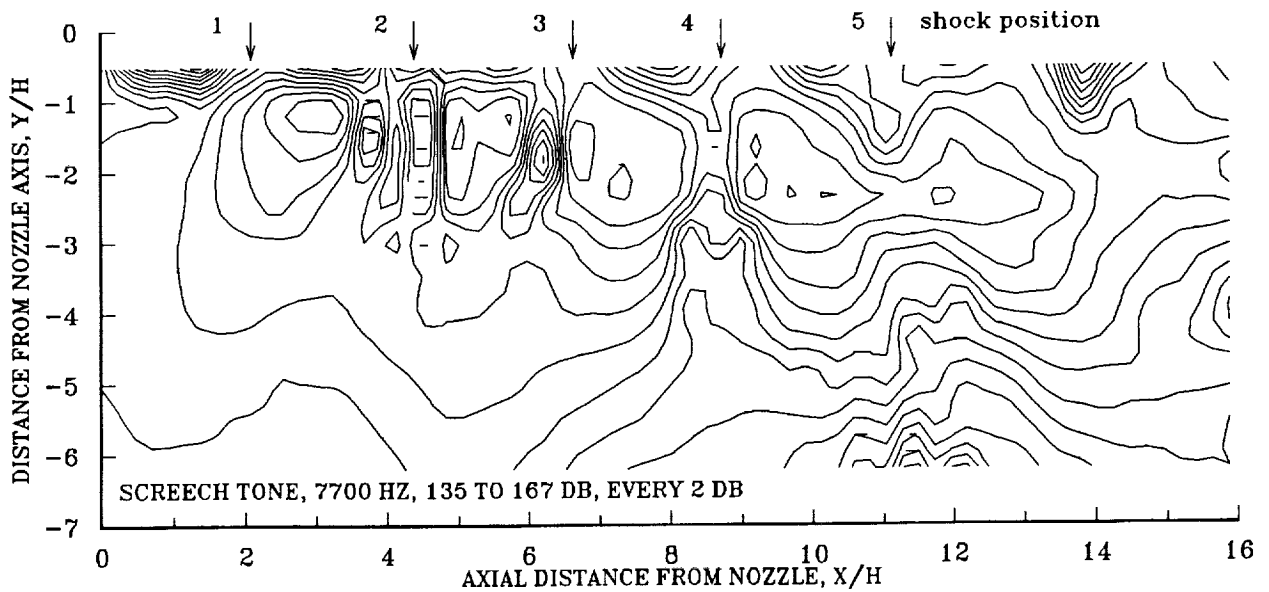


Fig. 2. Unsteady Pressure Level Contours in the X-Y Plane
Rectangular Nozzle, 7.37x71 mm, $M_{ex} = 1.44$

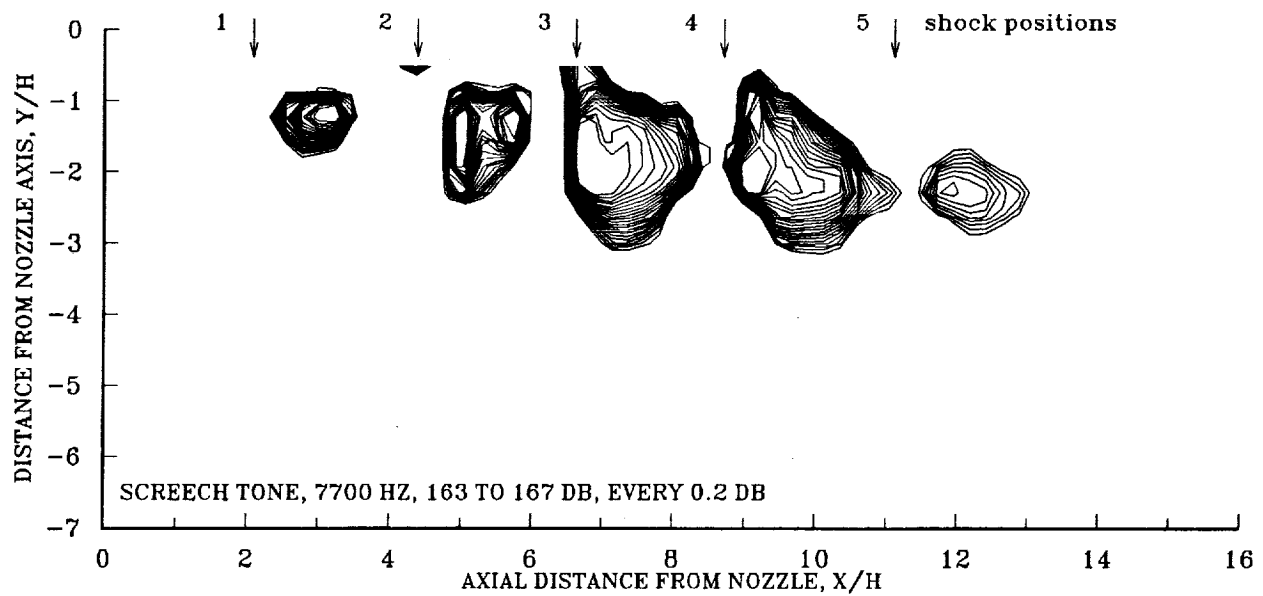


Fig. 3. High Amplitude Unsteady Pressure Level Contours in the X-Y Plane
Rectangular Nozzle, 7.37x71 mm, $M_{ex} = 1.44$

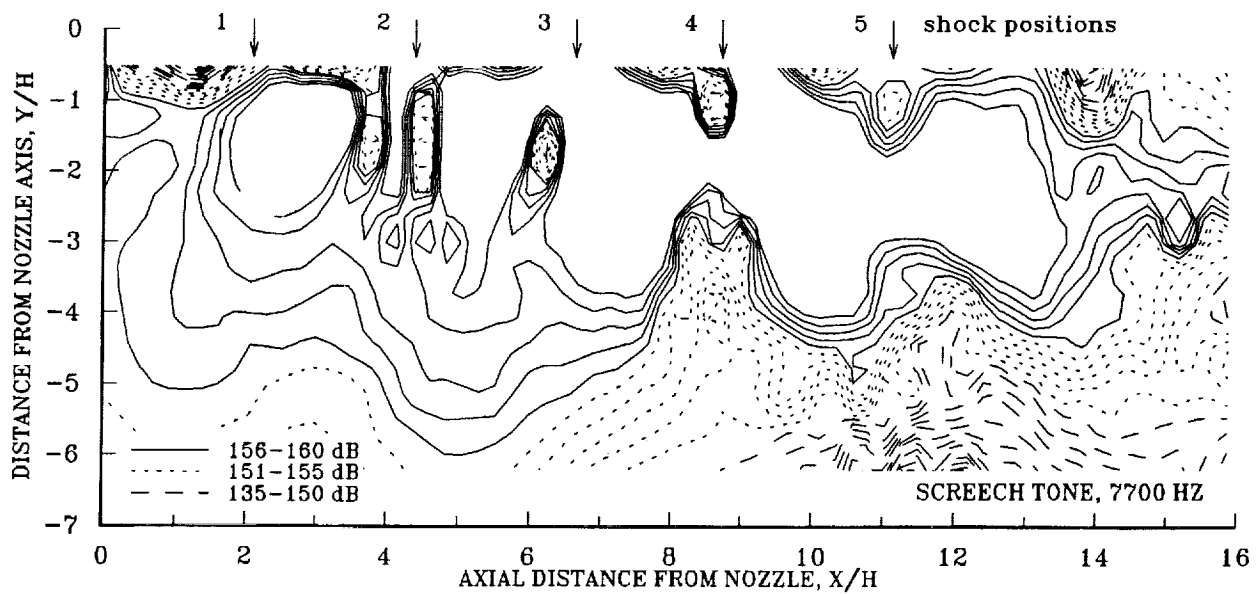


Fig. 4. Lower Amplitude Unsteady Pressure Level Contours in the X-Y Plane
Rectangular Nozzle, 7.37x71 mm, $M_{ex} = 1.44$

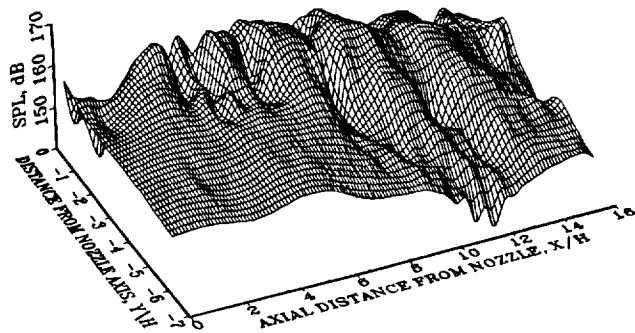


Fig. 5. Screech Unsteady Pressure Level, $f = 7700$ Hz
Rectangular Nozzle, 7.37×71 mm, $M_{ex} = 1.44$

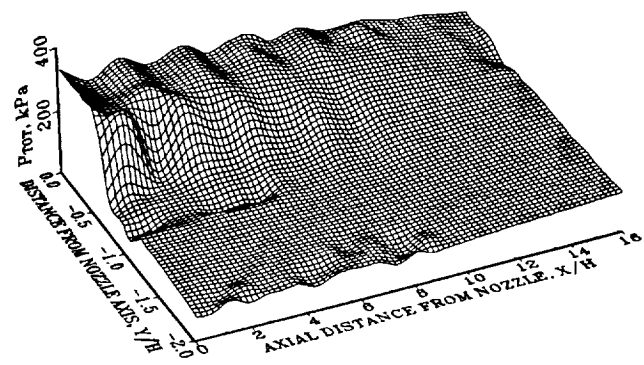
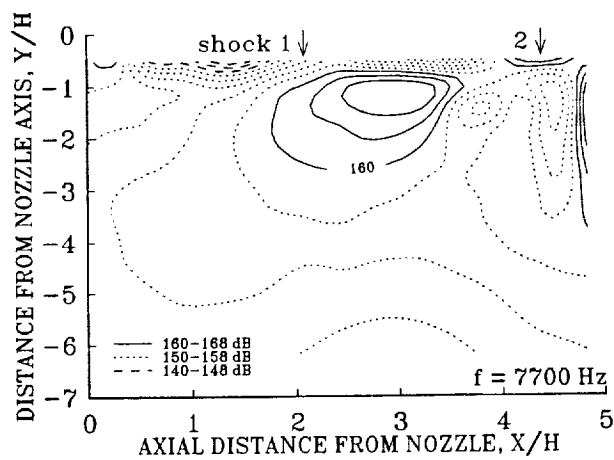
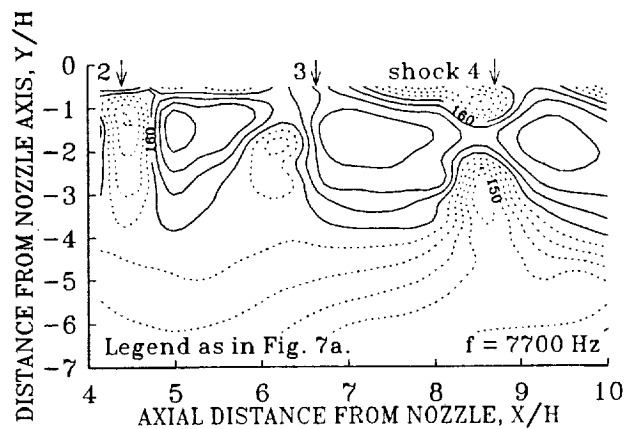


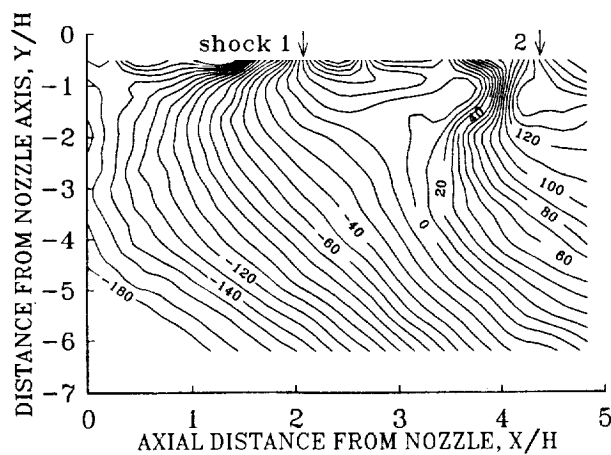
Fig. 6. Steady Flow Total Pressure, $M_{ex} = 1.44$
Rectangular Nozzle, 7.37×71 mm



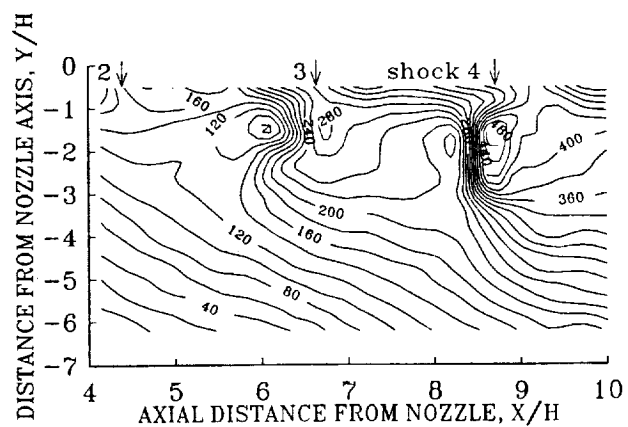
a. amplitude



a. amplitude



b. phase



b. phase

Fig. 7. Amplitude and phase of screech tone
near 7.37×71 mm nozzle, $M_{ex} = 1.44$

Fig. 8. Amplitude and phase of screech tone
downstream of nozzle

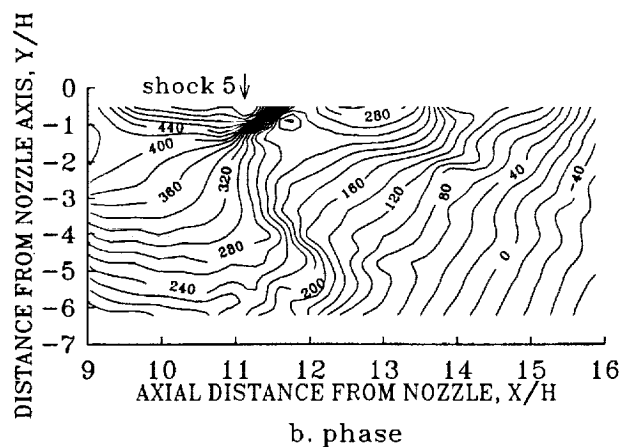
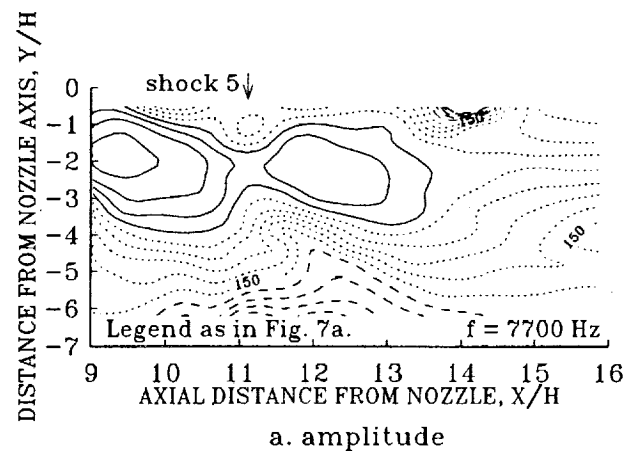


Fig. 9. Amplitude and phase of screech tone farthest downstream from nozzle

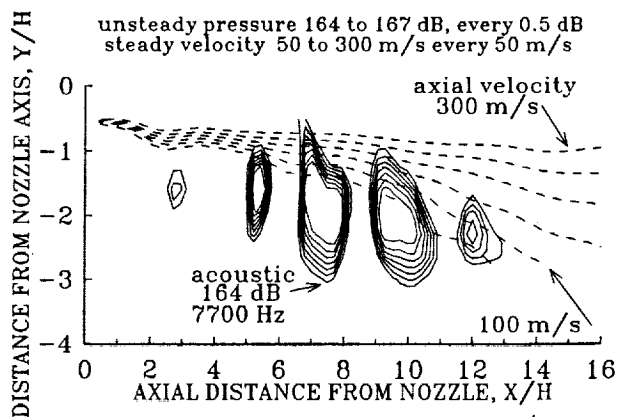


Fig. 10. Overlay of unsteady pressure level and steady flow velocity contours

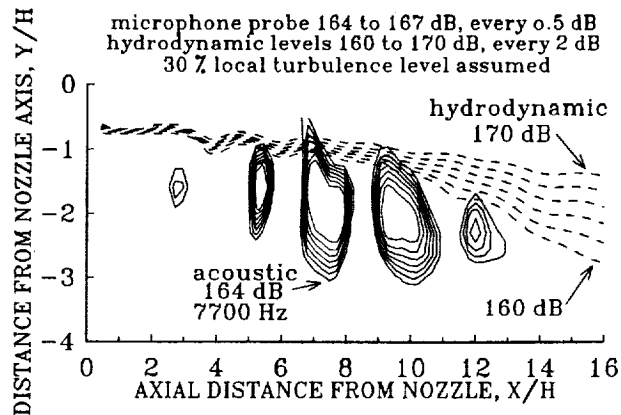


Fig. 11. Microphone probe measurements and calculated unsteady hydrodynamic pressure

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13. ABSTRACT (Maximum 200 words) The near-field of the screech noise source structure of an under-expanded supersonic rectangular jet was studied in detail. A miniature probe microphone was used along with a reference microphone to determine the amplitude and phase of the sound pressure near and in the high speed flow field. The transverse structure of the unsteady pressure field was investigated by moving the probe microphone sufficiently far into the jet so that pressure fall-off was observed. Five islands of high sound pressure level have been distinguished which may be associated with the actual local sources of sound production. These sources of screech noise are closely associated with the jet shock structure as would be expected, with the peak region of noise level being found slightly downstream of each of the five observed shocks. The third and fourth noise sources have the highest levels and are about equal in strength. All of the apparent noise sources have their peak levels in the subsonic flow region. Strong cancellations in the acoustic field are observed in the downstream and sideline directions which may account for the predominant upstream propagation of the fundamental tone noise.				
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