



# Flow Measurements and Multiple Pure Tone Noise From a Forward Swept Fan

Donald S. Weir  
Honeywell International, Inc., Engines, Systems & Services,  
Phoenix, Arizona

Gary G. Podboy  
Glenn Research Center, Cleveland, Ohio

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Donald S. Weir  
Honeywell International, Inc., Engines, Systems & Services,  
Phoenix, Arizona

Gary G. Podboy  
Glenn Research Center, Cleveland, Ohio

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Donald S. Weir  
Honeywell Engines, Systems, and Services  
Phoenix, Arizona 85072

Gary G. Podboy  
National Aeronautics and Space Administration  
Glenn Research Center  
Cleveland, Ohio 44135

## Abstract

A forward-swept fan, designated the Quiet High Speed Fan (QHSF), was tested in the NASA Glenn 9- by 15-foot Low Speed Wind Tunnel to investigate its noise reduction relative to a baseline fan of the same aerodynamic performance. The objective of the Quiet High Speed Fan was a 6-dB reduction in the Effective Perceived Noise Level relative to the baseline fan at the takeoff condition. The intent of the Quiet High Speed Fan design was to provide both a multiple pure tone noise reduction from the forward sweep of the fan rotor and a rotor-stator interaction blade passing tone noise reduction from a leaned stator. The tunnel noise data indicated that the Quiet High Speed Fan was quieter than the baseline fan for a significant portion of the operating line and was 6 dB quieter near the takeoff condition. Although reductions in the multiple pure tones were observed, the vast majority of the EPNdB reduction was a result of the reduction in the blade passing tone and its harmonics.

Laser Doppler Velocimetry (LDV) and shroud unsteady pressure measurement data were obtained upstream of the QHSF and baseline rotors to improve the understanding of the shocks which propagate upstream of the two fans when they are operated at high speeds. The flow phenomena that produce multiple pure tone noise is discussed and compared to measurements of the fan acoustic inlet modes and the far field noise signature of the fan.

## Introduction

### Background

The NASA Advanced Subsonic Technology program recently completed a noise reduction element to provide the technology to meet increasingly restrictive airport noise regulations and anticipated noise standards.

As part of this effort a forward swept fan was designed and fabricated by Honeywell Engines, Systems, and Services for the purpose of reducing the noise of supersonic tip speed fans. This 22-inch diameter fan, designated the Quiet High Speed Fan (QHSF), was tested in the NASA Glenn 9- by 15-foot Low Speed Wind Tunnel to investigate its noise reduction characteristics. In addition, a model of an existing conventional fan was also tested to provide a noise baseline (refs. 1 to 3).

In this study, flow field measurements in front of the fan, unsteady pressure measurements on the fan shroud, measurements of the acoustic modes in the inlet duct, and measurements of the far field noise are compared. This unique set of data provides an opportunity to increase the understanding of the mechanisms of multiple pure tone noise generation.

## Test Configuration

### Test Model

Figure 1 shows the 22-inch diameter turbofan model installed in the test section of the NASA Glenn 9- by 15-foot Wind Tunnel. The test was conducted using two different inlets installed upstream of the fan. The flight inlet, shown in figure 1, was installed during the acoustic testing, while a bellmouth inlet was installed during the LDV surveys. The flow field measurement studies were conducted with both the QHSF and baseline fan design.

Table 1 shows some of the design parameters of the two fans used in this test program. The baseline fan has a damperless, moderately aft swept rotor and aft swept stator vanes. The baseline fan had several low noise features in its original design. Blade /vane ratio, rotor-stator spacing and vane sweep were chosen to achieve minimum noise levels from this fan. A photograph of this baseline fan model is shown in

figure 3(a) with the fan case removed so both the rotor and stator vanes are visible.

The Quiet High Speed Fan was designed to have the same aerodynamic performance as that of the baseline fan but with reduced noise. The acoustic objective of the QHSF was a 6-dB reduction in the Effective Perceived Noise relative to the baseline fan at the takeoff condition. The noise reduction was planned to consist of reductions in multiple pure tone noise and rotor-stator interaction noise.



Figure 1.—QHSF 22 in. Rig Showing the Far Field Measurement Configuration with the Traversing Microphone (from ref. 5).

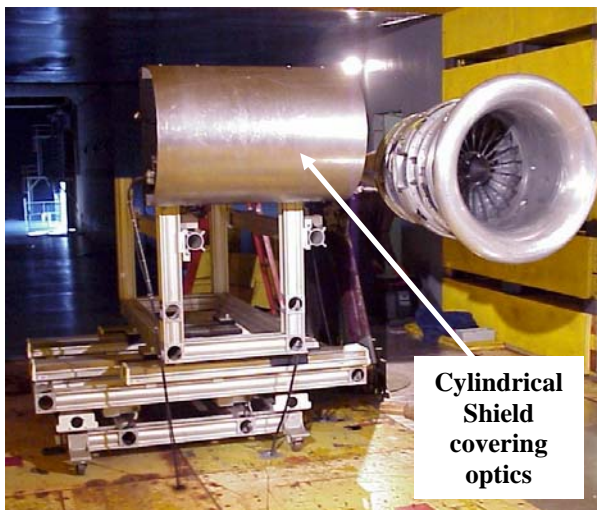


Figure 2.—LDV System Hardware Installed in the NASA Glenn 9- by 15-foot Wind Tunnel with the Rig in the Bellmouth Configuration (from ref. 4).

The multiple pure tone noise is generally attributed to pressure disturbances from the shock structure on the rotor blade. The QHSF incorporates forward sweep on the rotor to reduce the relative velocity component normal to the blade leading edge to subsonic levels. The intent of this sweep is to eliminate the formation of the inlet shock and achieve a multiple pure tone noise reduction. The goal of the rotor blade design was also to contain the remaining shock structure within the blade passages so the shocks would not propagate out the inlet. The forward swept rotor design was not able to achieve this goal at all radial positions at all fan speeds but the goal was achieved over a wide range of positions and speeds. A photograph of the QHSF is shown in figure 3(b).

A significant fan noise source results from the interaction of the rotor wake with the stator leading edge. If the trace speed of the rotor wake passing over the stator leading edge is supersonic, significant noise can be generated. To minimize the trace speed the fan should be designed so the wake intersects the stator leading edge as close to perpendicular as possible. The baseline fan stator vanes are aft swept but basically radial and had significant trace speeds. To minimize the trace speed and reduce the interaction noise, the QHSF stator vanes have been designed with lean in the direction of rotation. The lean increases near the outer shroud to a maximum of 30 degrees at the tip. The stator lean is visible in figure 3(b). The lean results in a near orthogonal intersection between the rotor wake and the stator vane leading edge in the outer span region. This lean reduces the wake trace speed and thus the predicted rotor-stator interaction noise. Reference 2 gives a more complete description of the Quiet High Speed Fan and provides considerably more acoustic design detail.

Table 1.—QHSF and Baseline Fan Design Parameters.

Number of blades	22
Number of vanes	52
Fan diameter	22 in.
Corrected tip speed	1474 ft/s
Corrected fan weight flow	98.9 lbm/s
Stage pressure ratio	1.82
Bypass ratio	3.83
Fan hub-to-tip radius ratio	0.35



(a) Baseline Fan



(b) Quiet High Speed Fan

Figure 3.—The Baseline Fan and QHSF as installed in the 9- by 15-foot Tunnel is shown with the fan cases removed.

#### *Laser Doppler Velocimetry System*

Flow field measurements were made with the laser Doppler velocimetry (LDV) system at NASA Glenn (ref. 4). Part of the LDV system is positioned inside the test section of the wind tunnel. Figure 2 shows a photograph of the LDV traverse system located on the side of a turbofan model. The traverse was used to move the LDV probe volume radially and axially relative to the model. The LDV optics are located behind the cylindrical shield shown in the photo. This shield was installed to keep the tunnel flow from striking the optics.

Figure 4 shows a photograph taken with the cylindrical shield removed. In this photo the fiber optic cables used to deliver the laser beams into the tunnel, the transmitting optics used to direct the beams into the model, and one set of receiving optics can be seen. The LDV system is a four-beam, two-color, backscatter system which allows the measurement of two components of velocity simultaneously. Two green beams were used to measure the axial component of

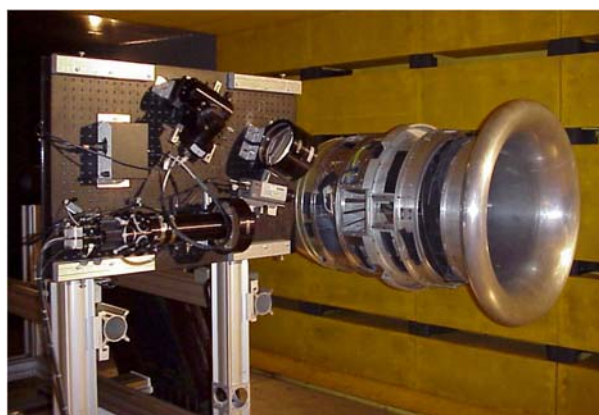


Figure 4.—LDV Measurement System Installed in the 9- by 15-foot Wind Tunnel (from ref. 4).

velocity, while two blue beams allowed the measurement of tangential component.

#### *Shroud Unsteady Pressure Measurements*

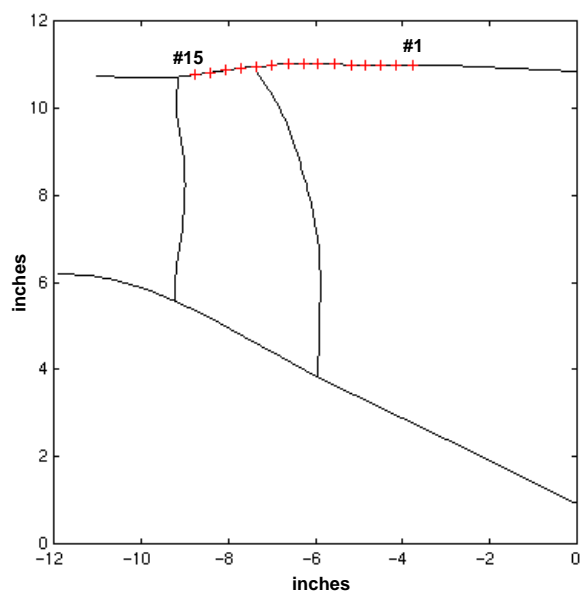
Fifteen unsteady pressure transducers were mounted in the fan shroud at axial positions over and in front of each fan. The purpose of these transducers was to measure the shock characteristics in front of the fan. The data were recorded for multiple rotor revolutions and then averaged to produce the static pressure pattern for each blade passage. The locations of the transducers for each fan are shown in figure 5.

#### *Far Field Acoustic Data*

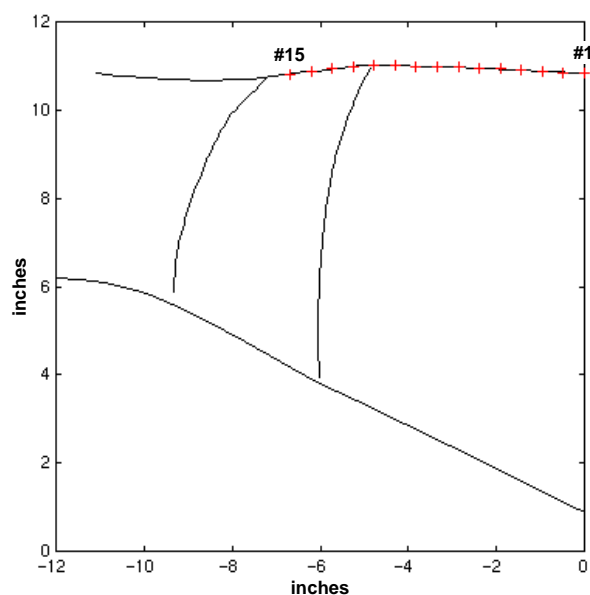
Far field acoustic data were obtained for both fans in the NASA Glenn 9- by 15-foot Low Speed Wind Tunnel (ref. 5). Two basic configurations were tested for each fan. In the first configuration the fans were tested in an open test section configuration. Acoustic data were obtained with 3 fixed microphones and 1 traversing microphone. The tunnel was operated at a through flow Mach number of 0.1. A photograph of the QHSF in the test section is shown in figure 1. Acoustic treatment is visible on the wall.

In the second configuration, a wall was erected from floor to ceiling in the tunnel to block the noise from the fan exit from reaching the forward traverse positions. This enabled the inlet noise to be measured without contamination from the aft noise. The wall was located 6 inches from the fan nacelle. The fixed microphones were removed and only the traversing microphone was present for this tunnel configuration. The multiple pure tone data used in this study was taken in this second configuration.





(a) Baseline Fan



(b) Quiet High Speed Fan

Figure 5.—Pressure Sensors were mounted on the Shroud Wall to measure the Shock Positions.

#### Acoustic Mode Measurements

A continuously rotating microphone technique as presented in reference 6 was used. The mode measurement system installed on the inlet is shown in figure 6. The rotating rake uses a control system slaved to the fan shaft to rotate at exactly  $1/200^{\text{th}}$  of the fan speed as if it were geared to the fan shaft. In the rotating frame of reference, each spinning circumferential mode order is Doppler shifted inversely

proportional to its spin rate. Thus, each circumferential order is separated by 0.005 shaft orders in frequency. The radial order is determined by a least squares curve fit to the measured complex radial profile, using the basis functions from the hard wall boundary condition of the Bessel's equation of all radial orders that might be expected. In order to resolve the highest radial order that can propagate in the inlet, at 2BPF, 14 radial measurements were used. These microphone signals are brought across the rotating frame by FM telemetry.

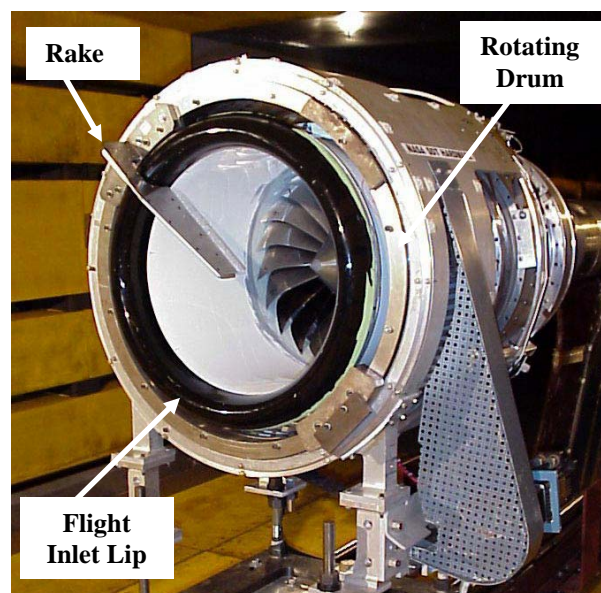


Figure 6.—QHSF 22 in. Rig Showing the Rotating Rake Measurement System (from ref. 6).

#### Results

LDV data were obtained upstream of the forward-swept and aft-swept rotors to get a better understanding of the shocks which propagate upstream of the two fans when they are operated at high speeds. If the shocks on the different blades were identical then the flow pattern upstream of the rotor would repeat on a once-per-blade basis, and only acoustic tones at harmonics of the blade passing frequency would be produced from this flow. In practice, however, the shocks on the blades are not identical, and the upstream flow contains features that repeat on a once-per-revolution basis; this irregular pattern creates acoustic tones at harmonics of both the once-per-rev and blade-passing frequencies. The acoustic tones occurring at harmonics of the once-per-rev frequency which are not also multiples of the blade passing frequency are known as multiple pure tones. The LDV data were acquired in order to get a better understanding of the flow phenomena that produce this multiple pure tone noise.

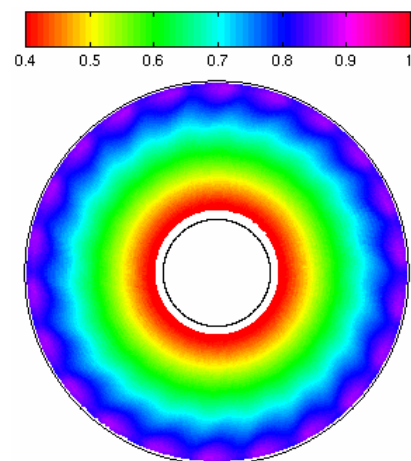


The shocks which exist upstream of the fan create disturbances in the upstream pressure field which, in turn, create noise. To use the LDV data to explain the noise, it is necessary to make some assumptions regarding how the pressure and velocity are related. In the discussion that follows it is assumed that the amplitude of the disturbances in the measured velocity field are proportional to those in the pressure field. Since the exact relationship between velocity and pressure is not known, it is not possible to make quantitative estimates of the noise based solely on these velocity measurements. Nevertheless, it is thought that these data can be used to determine qualitatively how the noise changes as the flow upstream of the rotor changes.

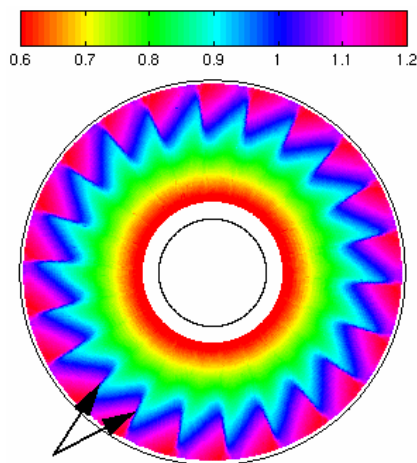
### *QHSF Evaluation*

Figure 7 shows contour plots of the phase locked-average relative Mach number computed from the LDV data obtained at an axial station upstream of the QHSF. The figure shows contours corresponding to the rotor operating at tip relative Mach numbers of 0.817, 1.074, and 1.189, respectively. The view depicted is from downstream of the flow, looking upstream with the fan rotating clockwise. A comparison of the subsonic (a) and supersonic (b and c) tip speed data reveals that the flow upstream of the rotor is much more uniform when the fan is operating at subsonic speeds. At low speed, the flow exhibits a smooth, sinusoidal-like variation in the circumferential direction. In contrast, the two supersonic tip speeds show a sawtooth-like variation in the flow. The steep gradients in the flow associated with this sawtooth pattern result from the shocks on the blades propagating upstream to this axial location. The circumferential and radial locations at which some of the steepest gradients occur are highlighted on the two supersonic tip speed data plots. Note that the steepest gradient occurs inboard of the tip. This suggests that either the shocks occurring at the tip are weaker than those occurring further inboard, or the tip shocks are swallowed inside the blade passages and, therefore, do not propagate upstream of the rotor. In either case, these results suggest that the tip leading edge sweep is providing a desired result - the relatively uniform flow upstream of the tip would be expected to generate less tone noise than the strong shocks found further inboard.

Another way to view these variations is to look at line plots of the relative Mach number distributions across the rotor revolution. Figure 8 shows the radial and axial locations of the surveys. Figure 9 presents the distributions measured for three speeds. The dashed lines overlaid on top of the contour plots presented at the top represent the radial measurement location corresponding to the line plots. Based on these line plots, (not all of which are provided here; see ref. 7 for a complete description) the following observations can be made:

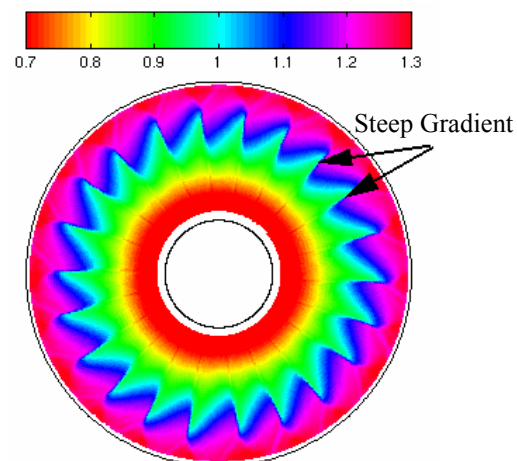


(a) Tip Relative Mach Number = 0.817



Steep Gradient

(b) Tip Relative Mach Number = 1.074



(c) Tip Relative Mach Number = 1.189

Figure 7.—Relative Mach Number Contours Measured Upstream of the QHSF at Three Different Tip Speeds.

- 1) The subsonic tip speed data (red) show the sinusoidal circumferential variation in the flow.
- 2) Proceeding inboard from the outermost radius, strong shocks are not seen in the mid-speed data (black) until about 90% span.
- 3) At mid-speed, the shocks are strongest from about 85 to 75% span; they then decrease in strength further inboard.
- 4) At the highest speed, strong shocks aren't seen until about 80% span; they reach their max strength at about 75% span, remain at about this strength through 65% span, and then decrease further inboard.
- 5) The subsonic tip speed data show less blade-to-blade variations than the supersonic tip speed data.

More information regarding the blade-to-blade variations in the flow can be seen from a frequency spectrum analysis of the relative Mach number distributions. Performing a Fourier Transform of the data generated the autospectra of the Mach number distribution. The autospectra for each of the three speeds is shown in figure 9, with the low-speed data in red, mid-speed in black, and high-speed in blue. The autospectra are plotted vs. shaft order over a range spanning from  $m = 1$  to  $m = 22$ ;  $m = 1$  corresponds to the rotor once-per-rev frequency;  $m = 22$  represents the blade passing frequency of the 22-bladed rotor. The low-speed data were shifted slightly to the left and the high-speed data were shifted slightly to the right of the corresponding  $m$  order for better visibility. For each speed, there is a strong correlation between the size of the spike occurring at  $m = 22$  and the amplitude of the corresponding relative Mach number "wave."

If the flows upstream of the blades were identical, then only this BPF spike would be visible in the spectrum plots. As the blade-to-blade variations in the flow increase, so do the levels of the sub-BPF spikes. The average level of these spikes can be thought of as a measure of the blade-to-blade variations in the flow. As before, this figure indicates that the blade-to-blade variations increase with rotor speed.

The relative levels of the BPF vs. sub-BPF spectra are shown more concisely in figure 10. This figure provides two radial distributions for each speed - one distribution shows the BPF spectrum level; the other distribution corresponds to the level determined by computing the logarithmic sum of the 21 sub-BPF spikes measured at each radial location. The plots indicate a general increase in both the BPF and sub-BPF levels with increasing rotor speed. In the tip region, the BPF level at high-speed is actually lower than that measured at mid-speed. It is interesting to note, however, that the sub-BPF levels measured in the tip region show a similar, but not dramatic, decrease as the rotor speed is increased. Thus, these results show that swallowing the shocks reduces the amplitude of the disturbance propagating upstream of the rotor, but not the blade-to-blade variations in the flow. This does not mean, however, that swallowing the shocks does not help to reduce the blade-to-blade variations relative to what they would be if the shocks were not swallowed.

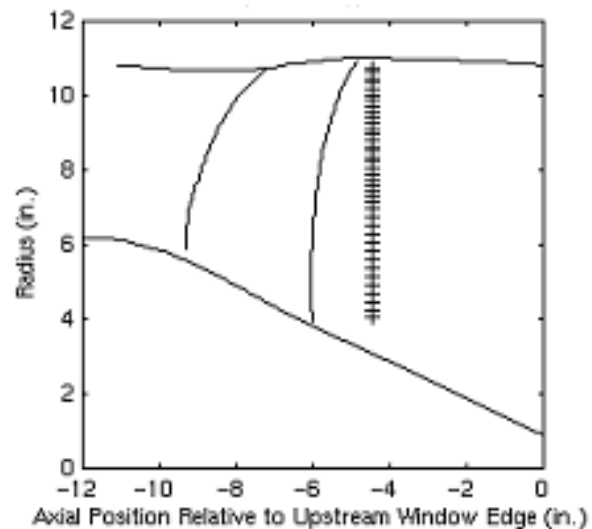


Figure 8.—Measurement Positions for the LDV Radial Surveys of the QHSF Flowfield.

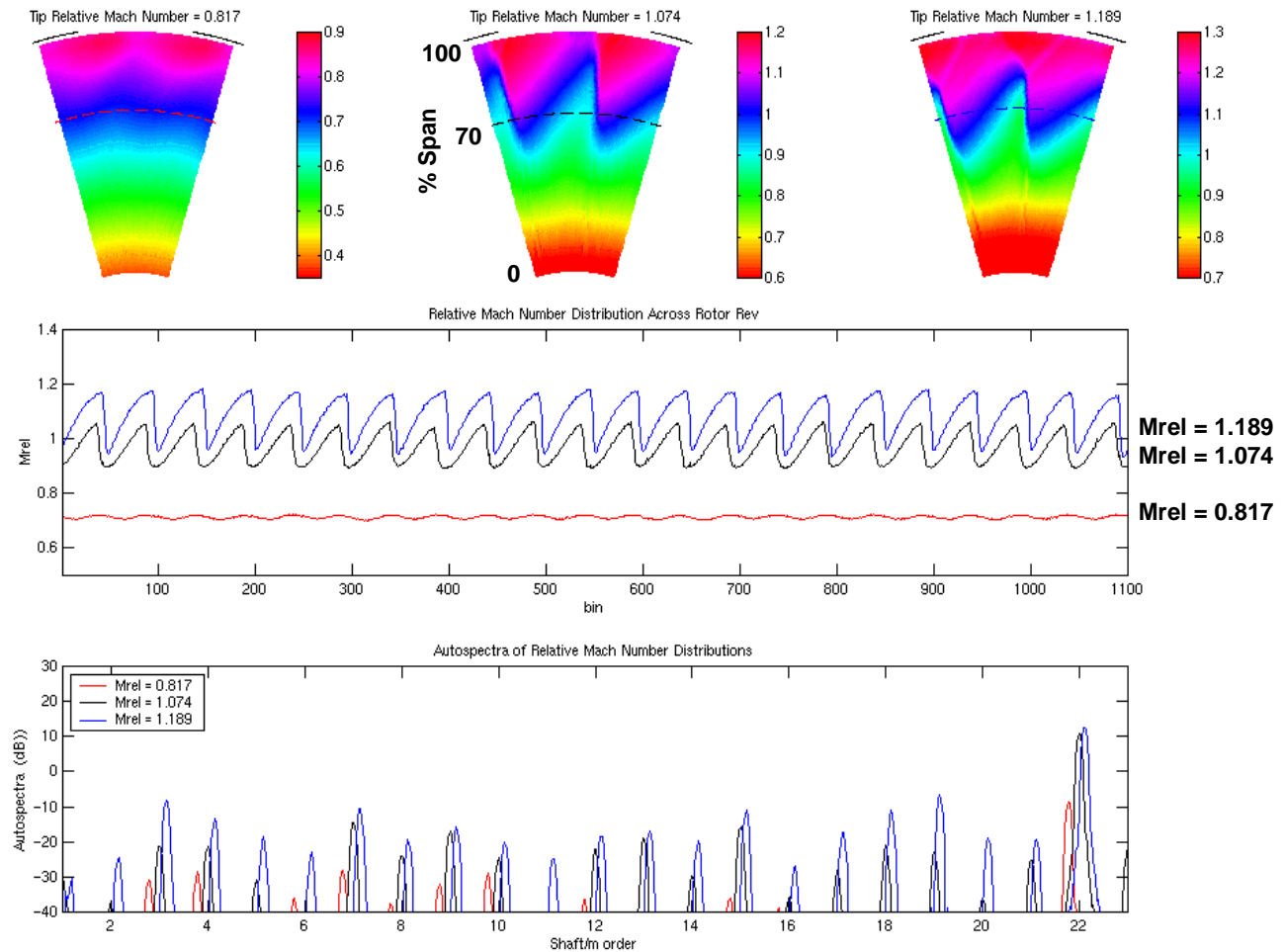


Figure 9.—Plots of the Tip Relative Mach Number at a Fixed Radial Position for Three Different Rotor Speeds for the QHSF Show the Blade to Blade Variation of the Shock Characteristics.

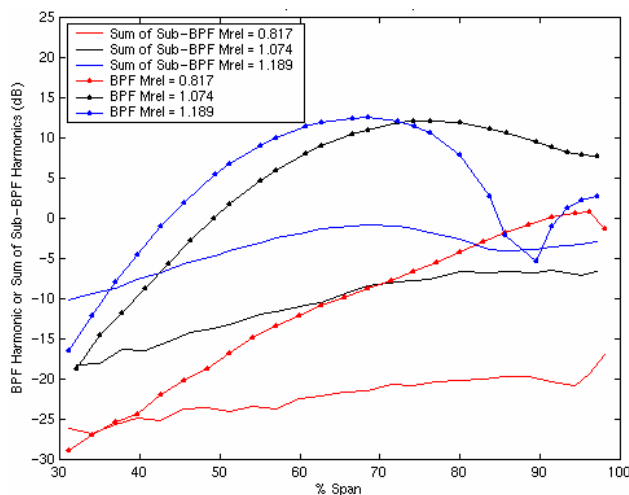


Figure 10.—Relative Levels of the Shaft Order modes Show the Potential Contribution of Mach Number Variations to the Production of Multiple Pure Tone Noise.

Analysis of the LDV data that were acquired at the locations in figure 11 shows the variation of the flow disturbances upstream of the fan. Figure 12 shows the flow field measured upstream of the forward-swept fan operating at the highest LDV test speed (1328 ft/sec tip speed). Two relative tip Mach number contour plots are presented on each figure at the two radial positions. The view provided is from outside looking in such that the rotor blades would be to the left of the contour plots. These blades would rotate downward in this view, and the axial flow would be right-to-left.

More details of the flows measured at these two radial locations can be seen from the circumferential distributions of relative Mach number; and the autospectra computed from these relative Mach number distributions. The axial location corresponding to the data is indicated by the black

vertical lines overlaid on top of the two contour plots presented at the top of the slide. There is a significant difference in how the perturbation evolves at the two different radial locations. Apparently, this evolution depends upon whether or not the shock occurring at a given radial location is swallowed inside the blade passage. At the outer radial location, where the shock is swallowed, the amplitude of the flow disturbance starts out relatively low near the blade and remains practically constant with increasing distance upstream of the rotor. In contrast, at the inner radial location, where a strong upstream propagating shock exists, the amplitude of the flow disturbance is much higher near the blade but rapidly decreases to approximately the same level as that measured at the outer radial location. Once the amplitude decays to this lower level, it remains relatively constant as the distance upstream of the rotor increases.

Figure 13 shows the axial distributions of the BPF (lines with symbols) and the logarithmically summed sub-BPF (without symbols) spectrum levels measured at these two radial locations. The data suggest that the amplitude of the disturbance upstream of a rotor does not decay exponentially when the shock occurring at that radius is swallowed inside the blade passage. It is also apparent from this figure that the line plots representing the sub-BPF levels mimic the behavior of the corresponding BPF distributions, albeit at a significantly lower level.

At the inner radial location, both the BPF and sub-BPF levels are decreasing with distance upstream of the rotor; in contrast, at the outer location both are increasing slightly. If the outer location data were extrapolated further upstream, both the BPF and sub-BPF levels at that radius would be higher than those measured inboard. If this trend were to continue out to the inlet throat, then it would be reasonable to expect the outer portion of the blade to create more noise than the inner portion. This is interesting since it would mean that that part of the blade which does not have a strong shock propagating upstream of it would actually be creating more noise than that part which does. This result does not mean that there is no benefit to sweeping the blades forward, since if the shock was not swallowed, there would probably be even higher spectrum levels and more noise created by the blade tips.

The measured unsteady pressures from the shroud pressure transducers presented in figure 14 confirm the results from the LDV measurements at  $r = 10.6$  in.

Figure 15 shows the results of the measurements of the fan acoustic modes in the duct. The data are for the same supersonic tip speed conditions as the LDV data presented above. Shaft orders from 1 to 22 are presented, although the order 22 is the BPF tone, it is included for reference. Figure 16 shows the corresponding far field data at a directivity angle of 50 degrees where multiple pure tone noise is expected to dominate.

In figure 15(a) there is no significant acoustic energy below shaft order 13. At this fan tip speed (1.074), the lower modes do not propagate. It is interesting to note that multiple pure tone noise seems to be dominant in shaft orders 13 to 15 and 18 to 19. These same shaft orders have significant amplitude in the black autospectra in figure 9. The far field noise data in figure 16(a) show significant multiple pure tone noise at shaft orders of 11, 15, and 19, in good agreement with the modal and LDV data.

The same level of agreement is seen for the higher tip Mach number case. In figure 15(b) there is no significant acoustic energy below shaft order 4. The multiple pure tone noise seems to be dominant in shaft orders 4, 7, 9, 13, and 19. These same shaft orders have significant amplitude in the autospectra in figure 9 and 12. The far field noise data in figure 16(b) show significant multiple pure tone noise at the same shaft orders, in good agreement with the modal and LDV data.

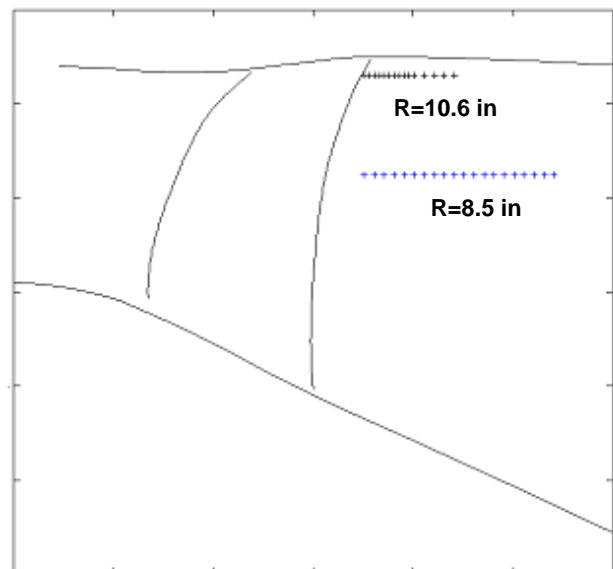


Figure 11.—Measurement Positions for the LDV Axial Surveys of the QHSF Flowfield.

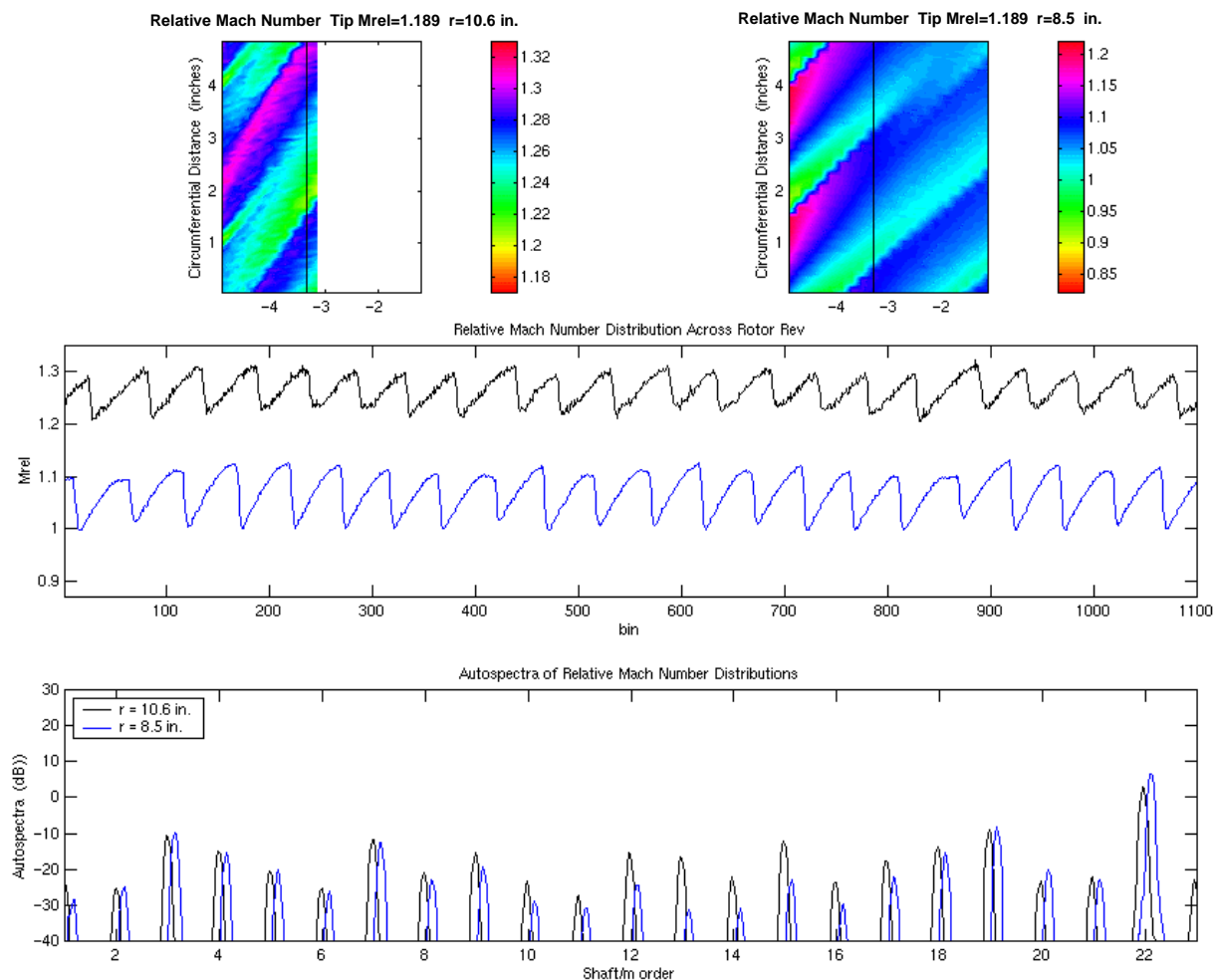


Figure 12.—Plots of the Relative Mach Number at a Fixed Rotor Speed for Two Different Radial Positions for the QHSF Show the Blade to Blade Variation of the Shock Characteristics.

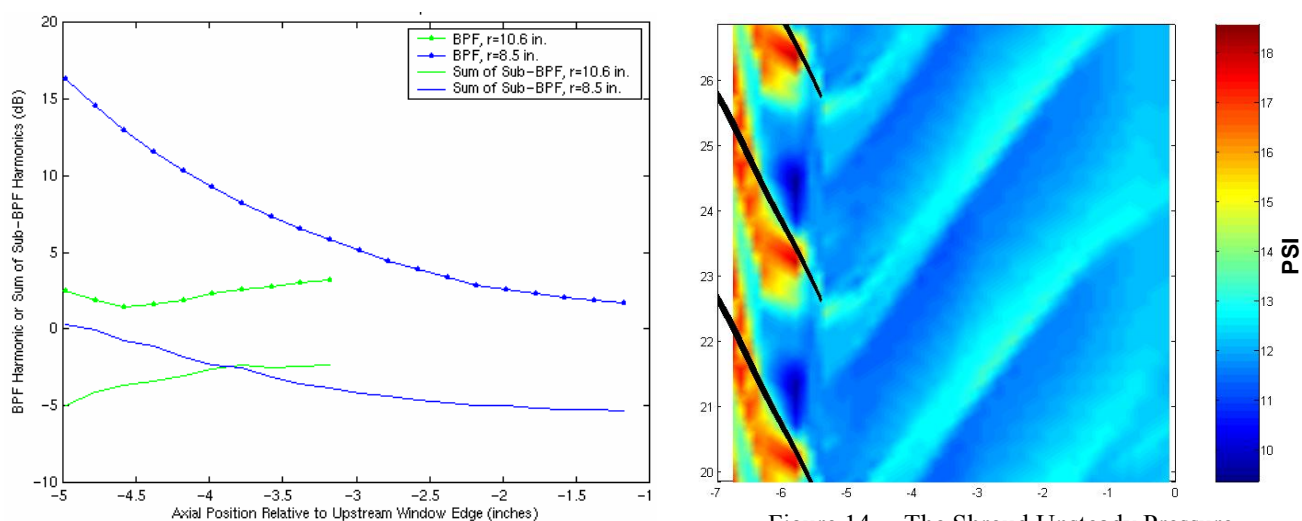
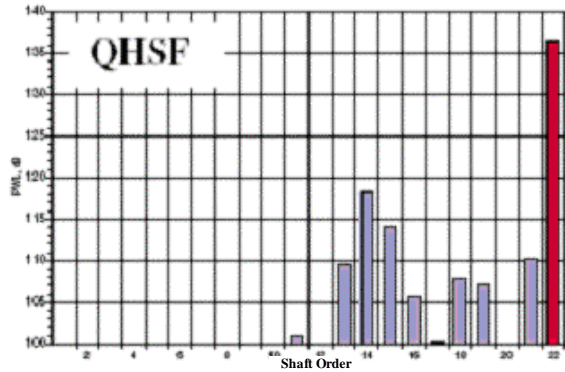
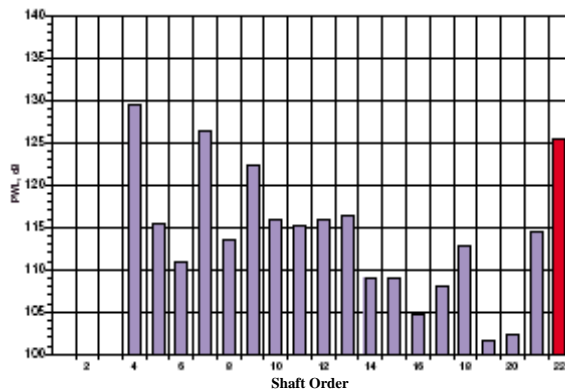


Figure 13.—Relative Levels of the Shaft Order Modes Show the Mach Number Variations in the Axial Direction for the QHSF.

Figure 14.—The Shroud Unsteady Pressure Measurements Show the Same Shock Characteristics as the LDV Data for the QHSF.



(a) Tip Relative Mach Number = 1.074

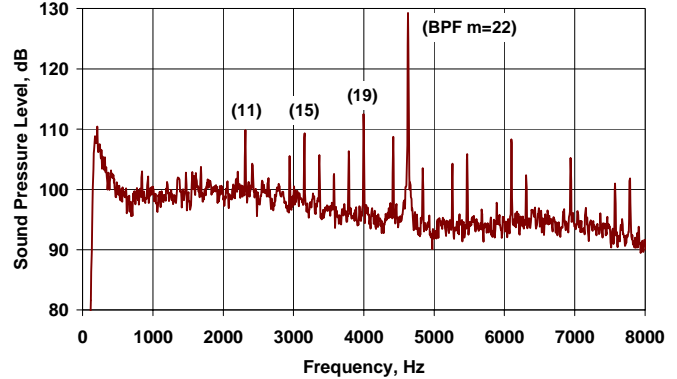


(b) Tip Relative Mach Number = 1.189

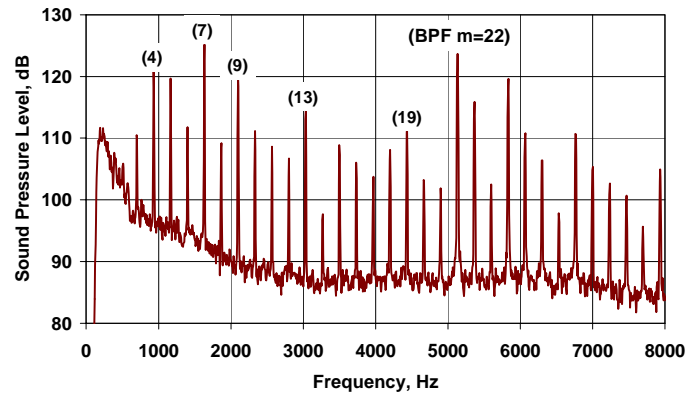
Figure 15.—Modal Measurements of the Inlet Noise of the QHSF Show the Dominant Modes of the Multiple Pure Tone Noise (from ref. 6).

#### Baseline Fan Evaluation

LDV data were also taken on the baseline fan at the higher supersonic tip speed condition. Data were taken at two different axial planes upstream of the rotor as shown in figure 17. The contour plots presented in figure 18 show that the rotor blades generate a significant disturbance in the flow upstream of the blades over the entire blade span. The data measured further upstream indicate that the disturbance generated by the inner part of the blades disappears by the time it reaches this upstream location. Unlike the forward-swept fan, this aft-swept design does not swallow the tip shocks at this speed. The line plots at the center of each slide show circumferential distributions of relative Mach number, while the plots at the bottom show autospectra computed from these distributions.



(a) Tip Relative Mach Number = 1.074



(b) Tip Relative Mach Number = 1.189

Figure 16.—Far Field Measurements of the Inlet Noise of the QHSF Show the Dominant Modes of the Multiple Pure Tone Noise (data from ref. 5).

In the tip region, the relative Mach number distributions resemble the same sawtooth pattern as the QHSF. The shocks are present upstream of the blades down to about midspan. Further inboard, the distributions measured at station 2 resemble an N-shaped pattern. The steep gradients in the flow at these inner radial locations result from the flow adjusting to the leading edges of the blades, not from shocks in the flow. In general, these data are showing that the stronger the shock measured at station 2, the greater the disturbance measured upstream at station 1. They also indicate, however, that if no shock exists at a given radial location on the blade then the strong perturbation in the flow created just upstream of the blade decays very rapidly with distance away from the rotor.



Figure 19 shows the relative levels of the shaft order harmonics for the baseline fan at the higher supersonic tip speed condition. This plot indicates that over much of the span the amplitude of the disturbance measured upstream of the blade at station 2 is about the same regardless of radius. In contrast, the BPF line plot presented for axial station 1 (blue line with symbols) indicates that the amplitude of the disturbance measured at this upstream location varies considerably with radius. The vertical distance between these two BPF distributions at a given radius can be thought of as representing a measure of the decay of the amplitude of the flow disturbance between these two axial locations. The overall trend indicated by the data is that the disturbance upstream of the rotor decays more rapidly with decreasing radius.

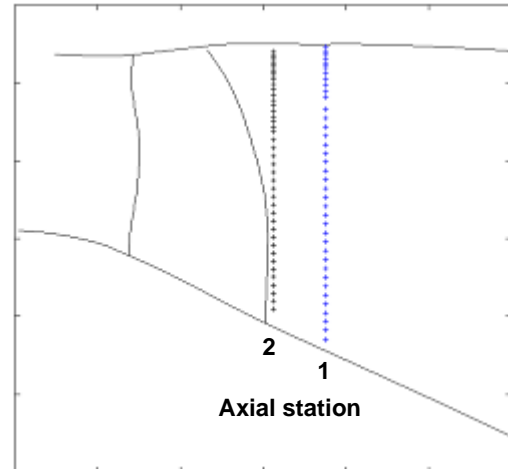


Figure 17.—Measurement Positions for the LDV Radial Surveys of the Baseline Fan Flowfield.

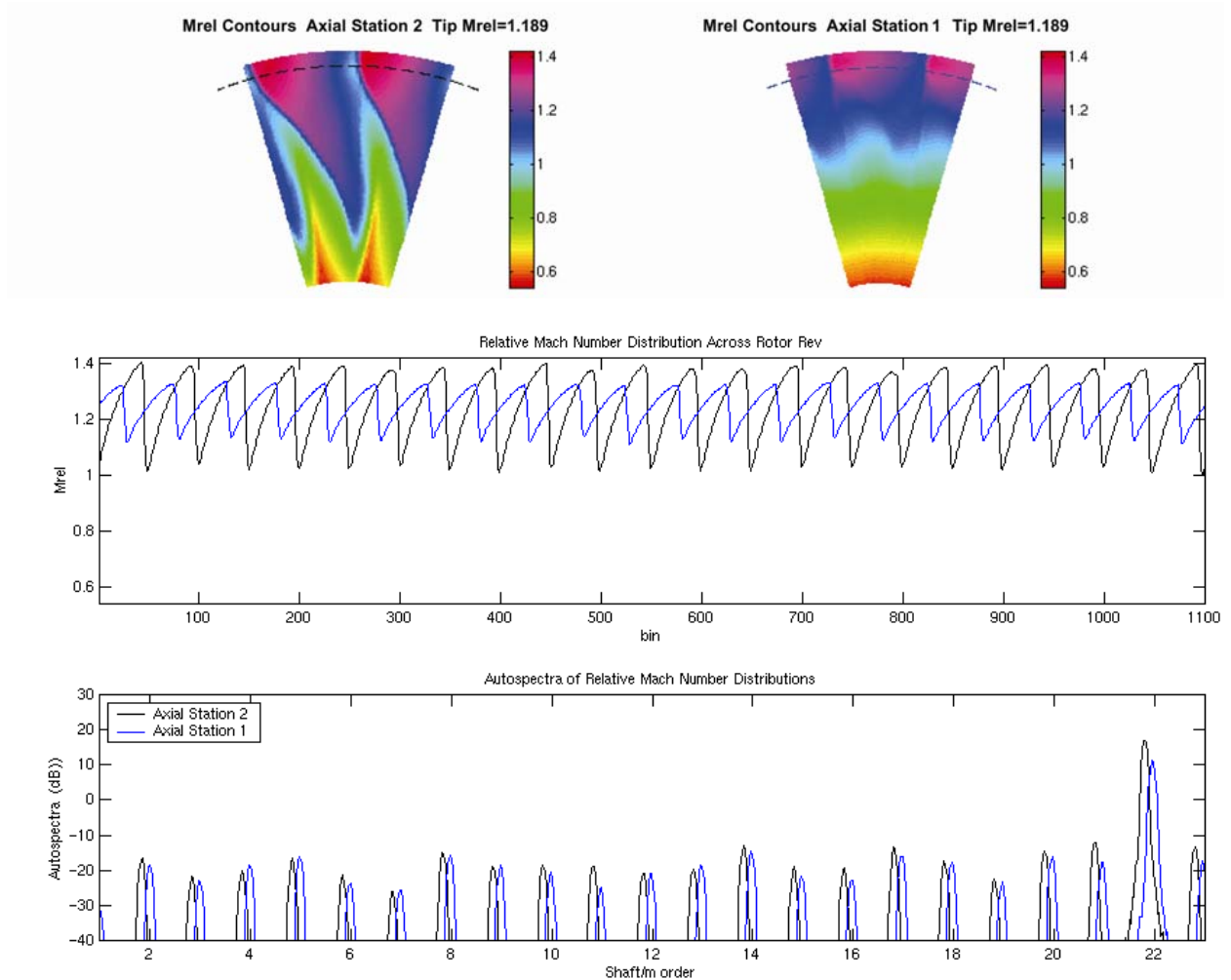


Figure 18.—Plots of the Tip Relative Mach Number at a Fixed Rotor Speed for Two Different Axial Positions for the Baseline Fan Show the Blade to Blade Variation of the Shock Characteristics.



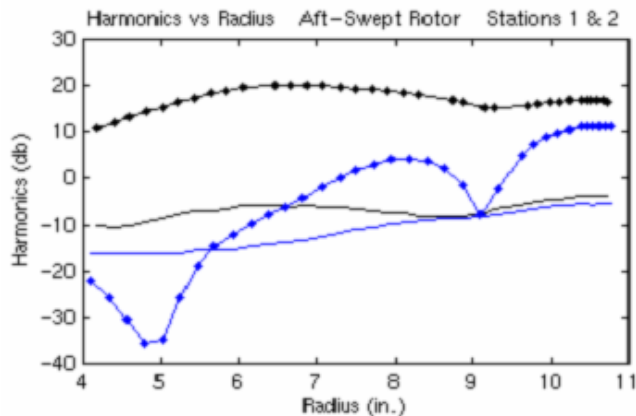


Figure 19.—Relative Levels of the Shaft Order Modes Show the Mach Number Variations in the Radial Direction for the Baseline Fan.

LDV data were acquired upstream of the baseline fan at the locations shown in figure 20. Figure 21 shows the flow field measured upstream of the baseline fan operating at the highest LDV test speed (1328 ft/sec tip speed) at the position closest to the shroud.

The measured unsteady pressures from the shroud pressure transducers presented in figure 22 confirm the results from the LDV measurements at  $r = 10.6$  in.

Figure 23 shows the results of the measurements of the fan acoustic modes in the duct for the baseline fan at a tip relative Mach number of 1.189. Figure 24 shows the corresponding far field data at a directivity angle of 50 degrees where multiple pure tone noise is expected to dominate.

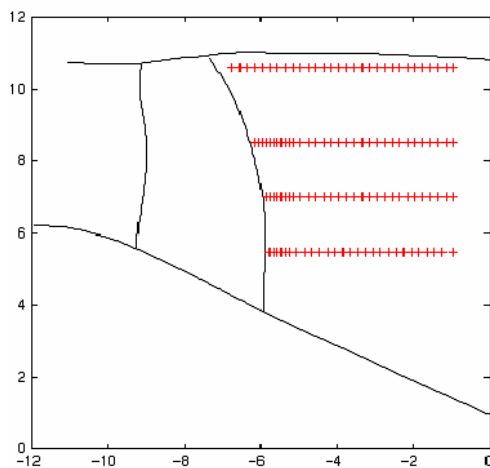


Figure 20.—Measurement Positions for the LDV Axial Surveys of the Baseline Fan Flowfield.

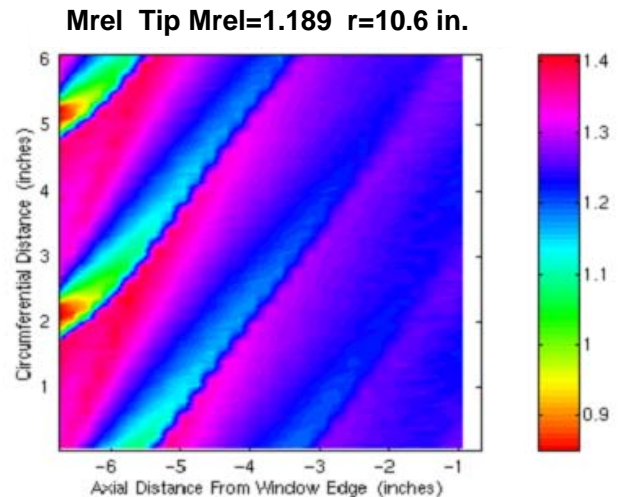


Figure 21.—Plot of the Relative Mach Number at a Fixed Rotor Speed Near the Shroud for the Baseline Fan clearly Show the Shock Propagation Forward of the Blade.

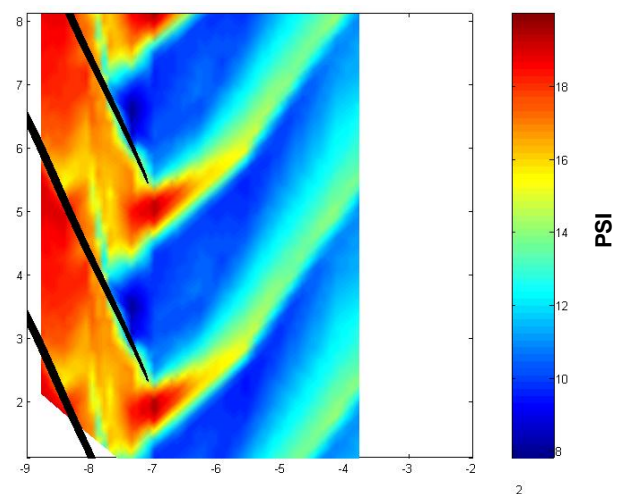


Figure 22.—The Shroud Unsteady Pressure Measurements Show the Same Shock Characteristics as the LDV Data for the Baseline Fan.

In figure 23 there is no significant acoustic energy below shaft order 5. At this fan tip speed, the lower modes do not propagate. It is interesting to note that multiple pure tone noise seems to be dominant in shaft orders 8 to 9 and 13 to 14. These same shaft orders have significant amplitude in autospectra in figure 18. The far field noise data in figure 24 show significant multiple pure tone noise at shaft orders of 8 and 13, in good agreement with the modal and LDV data.

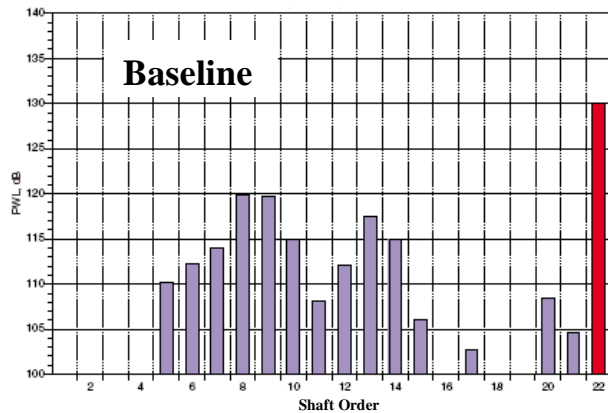


Figure 23.—Modal Measurements of the Inlet Noise of the Baseline Fan Show the Dominant Modes of the Multiple Pure Tone Noise (from ref. 6).

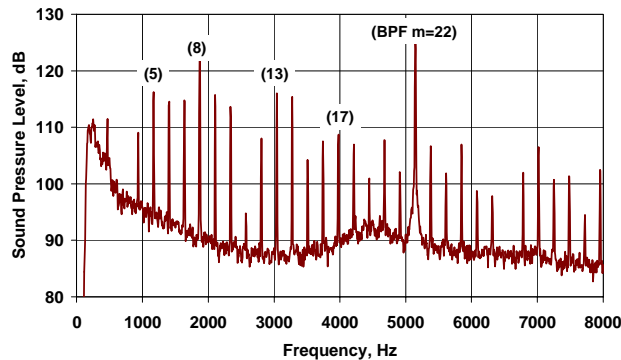


Figure 24.—Far Field Measurements of the Inlet Noise of the Baseline Fan Show the Dominant Modes of the Multiple Pure Tone Noise.

## Summary and Conclusions

LDV data were obtained upstream of the QHSF and baseline rotors to get a better understanding of the shocks which propagate upstream of the two fans when they are operated at high speeds. Comparison of this data with measured noise data, both in the fan inlet duct and in the far field, confirm that the multiple pure tone noise behaves in the same manner as the variation in the flow characteristics in front of the fan.

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13. ABSTRACT (Maximum 200 words)  A forward-swept fan, designated the Quiet High Speed Fan (QHSF), was tested in the NASA Glenn 9- by 15-foot Low Speed Wind Tunnel to investigate its noise reduction relative to a baseline fan of the same aerodynamic performance. The objective of the Quiet High Speed Fan was a 6-dB reduction in the Effective Perceived Noise Level relative to the baseline fan at the takeoff condition. The intent of the Quiet High Speed Fan design was to provide both a multiple pure tone noise reduction from the forward sweep of the fan rotor and a rotor-stator interaction blade passing tone noise reduction from a leaned stator. The tunnel noise data indicted that the Quiet High Speed Fan was quieter than the baseline fan for a significant portion of the operating line and was 6 dB quieter near the takeoff condition. Although reductions in the multiple pure tones were observed, the vast majority of the EPNdB reduction was a result of the reduction in the blade passing tone and its harmonics. Laser Doppler Velocimetry (LDV) and shroud unsteady pressure measurement data were obtained upstream of the QHSF and baseline rotors to improve the understanding of the shocks which propagate upstream of the two fans when they are operated at high speeds. The flow phenomena that produce multiple pure tone noise is discussed and compared to measurements of the fan acoustic inlet modes and the far field noise signature of the fan.				
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