PRATT & WHITNEY 2D MODEL IN LeRC 9'×15' ACOUSTICS

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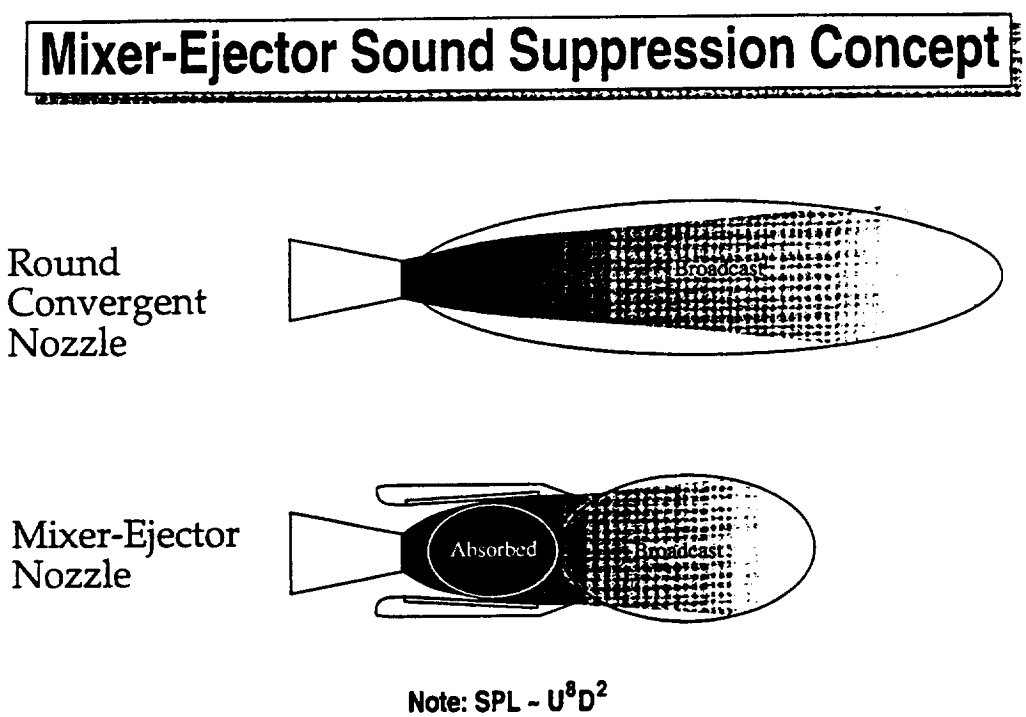
S7-07



The theory of mixer-ejectors for noise suppression is illustrated in this cartoon. Since jet noise SPL scales as velocity to the eighth power and diameter squared, increasing the jet diameter while lowering its velocity and keeping thrust constant decreases the noise. However, in supersonic craft, the drag penalty for increasing diameter at supersonic cruise makes this option very expensive. One would like to have a large engine during takeoff which could be shrunk during cruise. The retractable ejector is such an expandable engine. If the mixer flow can be expanded to the size of the ejector exit, the noise generated downstream of the ejector will be much less than the small diameter mixer nozzle alone. Of course, this also requires that the noise created in expanding the flow to fill the ejector be absorbed by a liner in the ejector walls so that none of this noise is heard. Since this mixing of internal hot gas and external cold air must take place in as short a distance as possible, the mixer must be very effective and therefore probably much noisier than a simple nozzle.

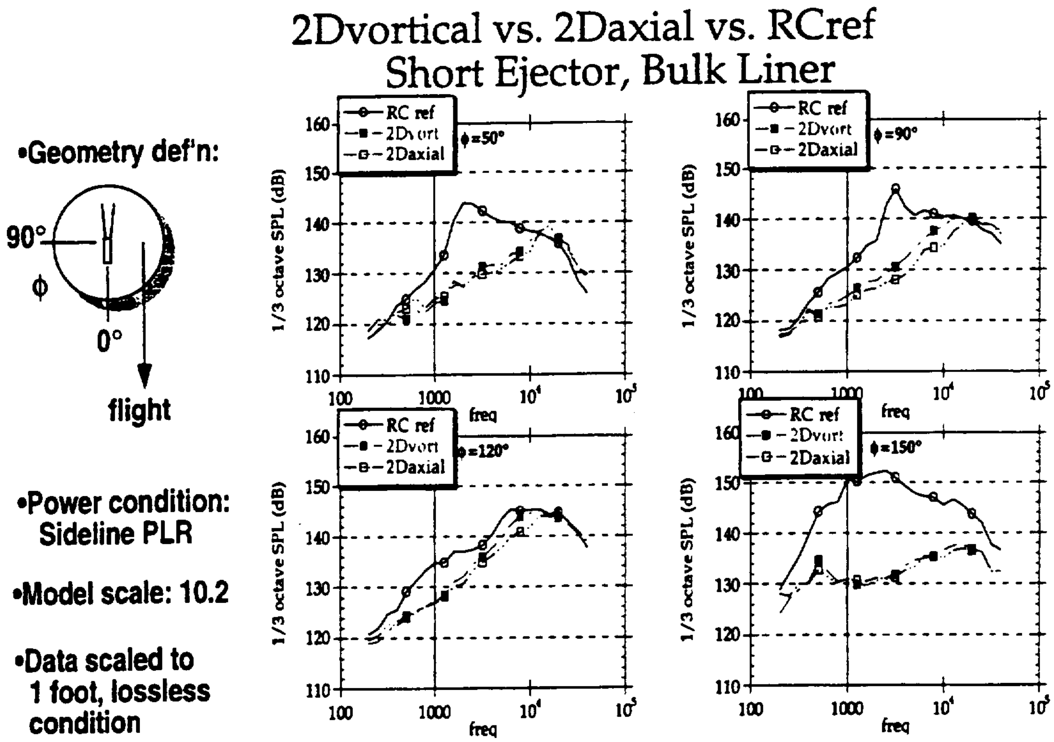
HSR 9x15 Test Highlights-Acoustics

- Showed 12-16 dB EPNL sound reduction over baseline round jet.
- Showed dependence of jet noise on
  - -nozzle geometry
  - -ejector length
  - -ejector area ratio
  - -ejector liner material
  - -ejector liner location
- Obtained agreement between new NASA all-digital acoustic data system and P&W analysis system.

Highlights to be covered in this presentation. The 4dB uncertainty in sound reduction is the difference between the sound of the baseline conic nozzle and its predicted value, which is thought to be caused by the close proximity of the microphones to the nozzle in the 9x15 tunnel. The measurements were thus not in a geometric far-field and attempts to extrapolate them to far field have not been successful.

The agreement between NASA and Pratt & Whitney acquisition and analysis systems is important because there are many elements to these systems and now the new NASA system can be relied on to produce results with much quicker turn-around in tests run at Lewis.

Effect of Mixer/Ejector Geometry



•Power condition: Sideline PLR

•Model scale: 10.2

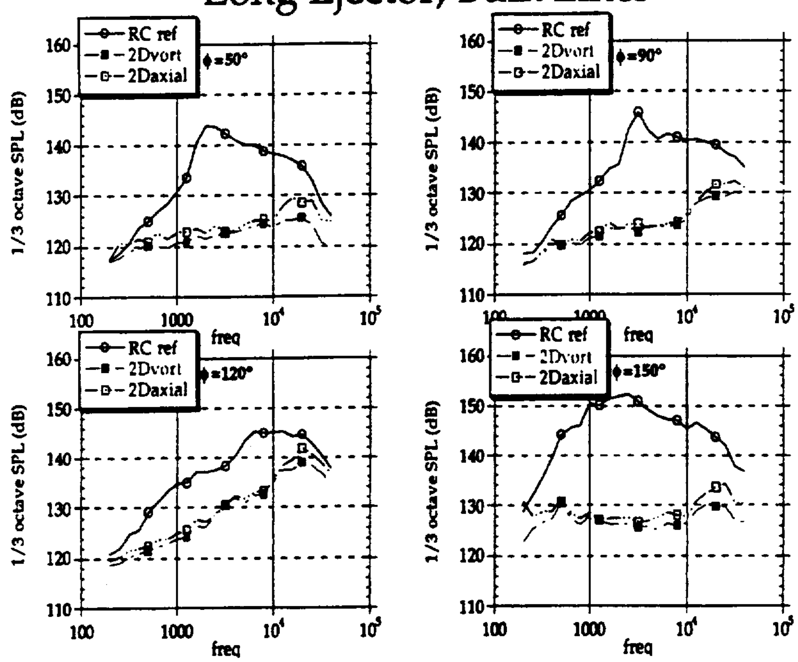
•Data scaled to 1 foot, lossless condition

This is the first of many viewgraphs of data which will have the same form. Each viewgraph contains 1/3 octave SPL spectra taken from four different angles to the jet. Note that the polar angle f is measured from the direction of flight. Also, the data presented here was taken at the Sideline PLR power setting (NPR=4.0, Tj=1960°R) unless otherwise specified. The data is presented in model scale and has been translated to a 1 foot radial distance, removing the atmospheric attenuation.

This slide compares the sound spectra of the two mixer geometries with the bulk-lined, short ejector in place. The baseline round convergent (RC ref) nozzle sound spectra is shown for reference. Both geometries show suppression at all angles, although the suppression at f = 120° is small. The difference between the two mixer geometries is small, even in spectral detail.

Effect of Mixer/Ejector Geometry

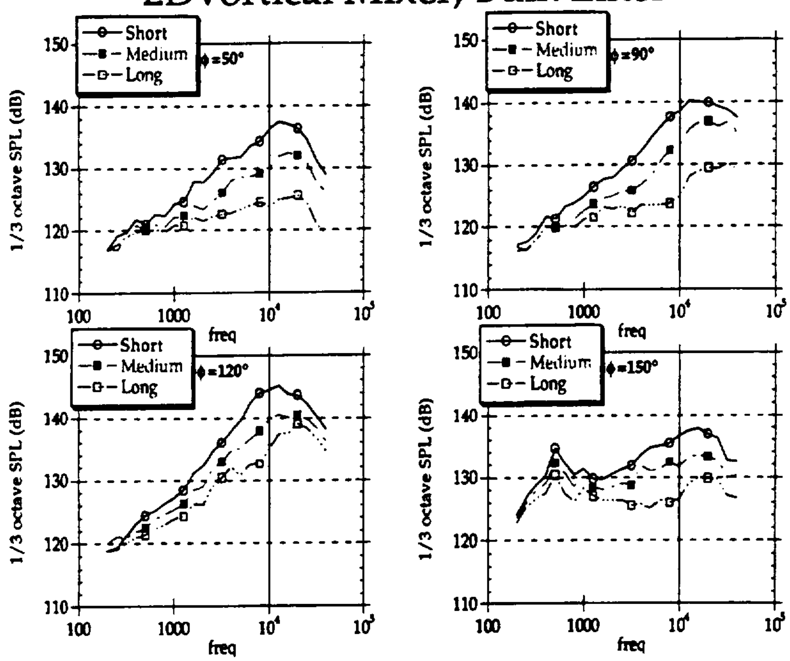
2Dvortical vs. 2Daxial vs. RCref
Long Ejector, Bulk Liner



This slide compares the sound spectra of the two mixer geometries with the bulk-lined, long ejector in place. Again, both geometries show suppression at all angles, and again, the difference between the two mixer geometries is small. However, the vortical nozzle is slightly quieter than the axial, especially around the peak frequency of 20kHz, which weighs most heavily in computing EPNL. By comparing this slide with the previous one the difference between long and short ejectors can be seen.

Effect of Ejector Length

Short vs. Medium vs. Long Ejector
2Dvortical Mixer, Bulk Liner

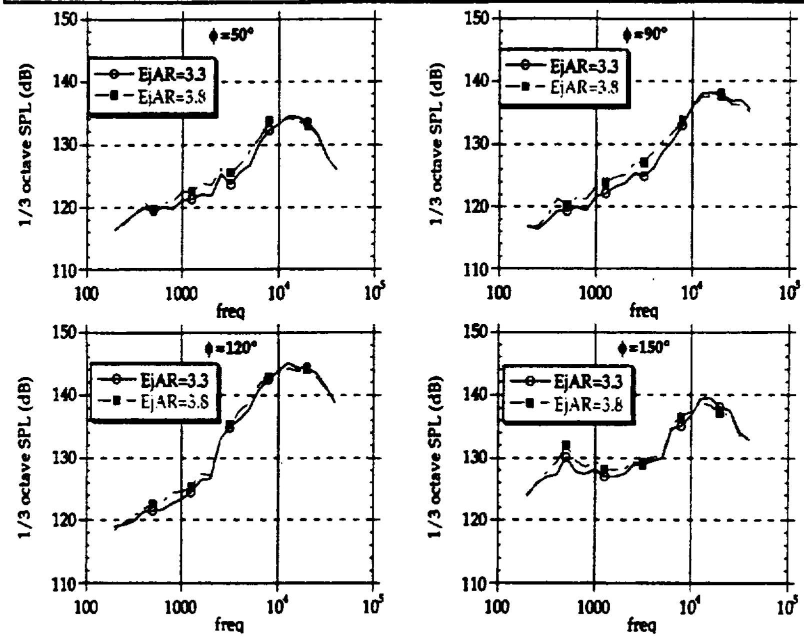


The effect of ejector length is isolated in this comparison of sound spectra of the 2D vortical mixer with the short, medium and long bulk-lined, ejectors. As the lengths of these ejectors were 10.44, 14.64, and 18.84 inches respectively, the amount of suppression (in dB) is approximately proportional to the the ejector length.

Effect of Ejector Pumping

2Dvortical, Long Ejector, No Liner

Ratio of Secondary to Primary Weight Flow:
EjAR=3.3: 1.62   EjAR = 3.8: 1.86

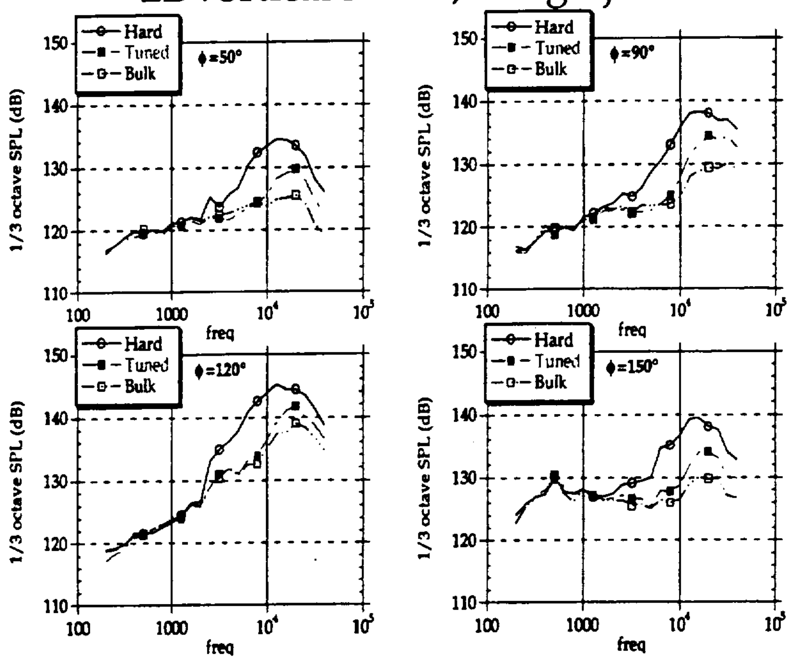


One parameter of the mixer-ejector design which is thought to be important is the pumping ratio, the mass pulled into the ejector relative to the mass through the primary nozzle. In the 9x15 test, the ejector area ratio (EjAR=ratio of ejector secondary area to nozzle primary area) was adjusted from the design point of 3.3 to 3.8. This resulted in a 15% increase in the pumping*, but made no discernable difference in the jet noise. It would seem that the pumping ratio would need to be minimized to reduce thrust losses resulting from the engagement of low momentum ambient fluid. Tests will be conducted in the near future to determine how low the ejector area ratio can be made before an acoustic impact is observed.

*Measurement of pumping ratio is covered in companion presentation by Wolter and Jones.

Effect of Treatment Type

Bulk vs. Tuned vs. No Lining
2Dvortical Mixer, Long Ejector

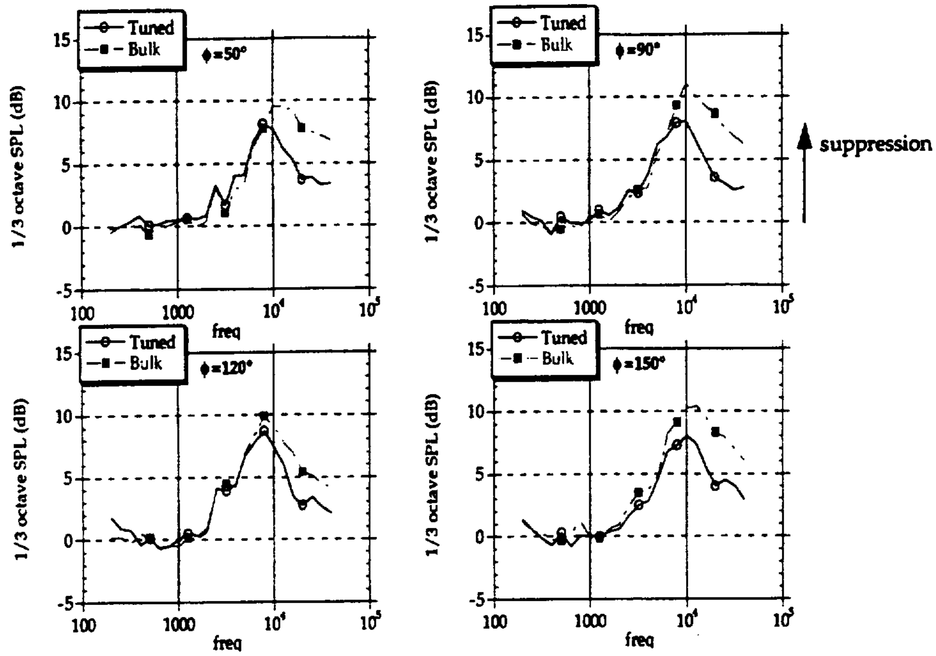


Two types of liner material were used during the test. The tuned liner consistedof a honeycomb panel faced with sheet metal perforated plate*. The bulk liner was similar only the honeycomb was filled with an absorbtive fiber. Both liners held up well during tests (except when the leading edge of the liners were subjected to direct flow from the mixer, which lifted the entire panel from the ejector) and were effective as can be seen in these plots. The bulk liner had a bit better attenuation and was used in the majority of the tests.

*Wolter and Jones give details of liner construction.

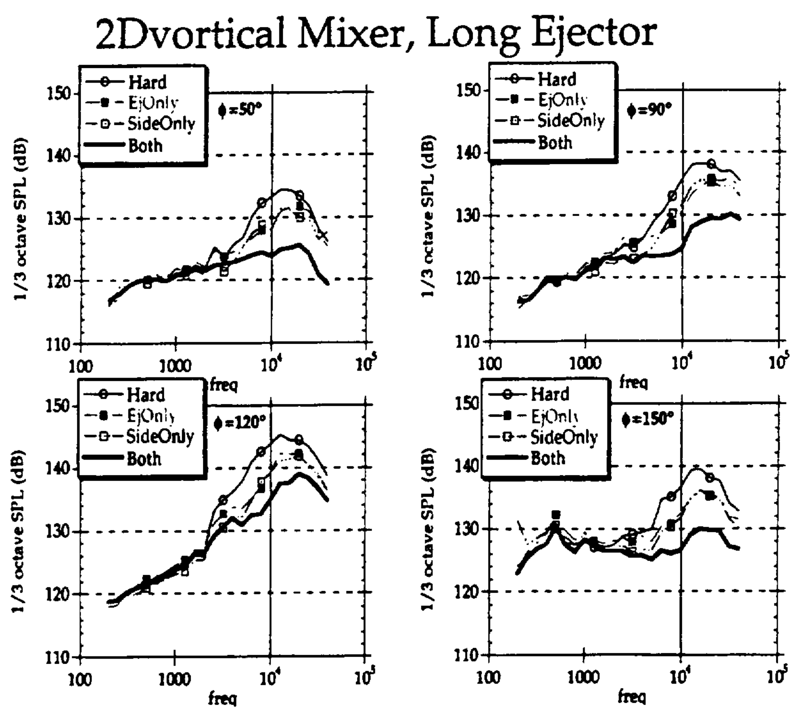
Insertion Loss for Acoustic Liners

2Dvortical Mixer, Long Ejector



This slide gives a direct measure of the sound absorbed by the two types of liners when they were used with the vortical mixer and long ejector. Each curve is the difference between the no liner (hardwall) data and with liner data. The difference between the tuned and bulk material seems to be in their ability to suppress the highest frequencies, including the peak frequency of 20kHz.

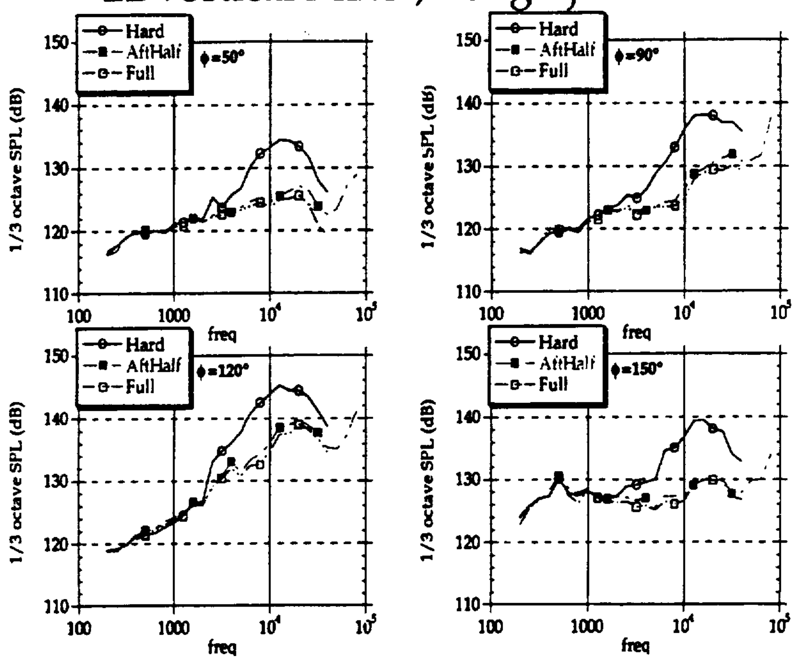
Effect of Treatment Location-Azimuthal



Because of nonaxisymmetry of the mixer-ejector, some azimuthal directionality was expected in the sound produced and in the efficacy of liners on the different walls. Not shown are near-field results taken by the azimuthal microphone array which show that the sound field of the 2D mixer-ejectors were essentially axisymmetric. What is shown in this slide is the sound when the liners were placed on different walls of the ejector. In the plots, sound measured with bulk liner on the walls which constitute the sideplates of the ejector box (parallel to the lobes of the mixer) are noted by SideOnly, while the sound measured when the bulk liner was placed on the ejector walls is called EjOnly. The similarity of the these two curves and the fact that they are about halfway between the no liner and fully lined sound spectra indicates that the mixing noise within the ejector had no azimuthal preference.

Effect of Treatment Location-Axial

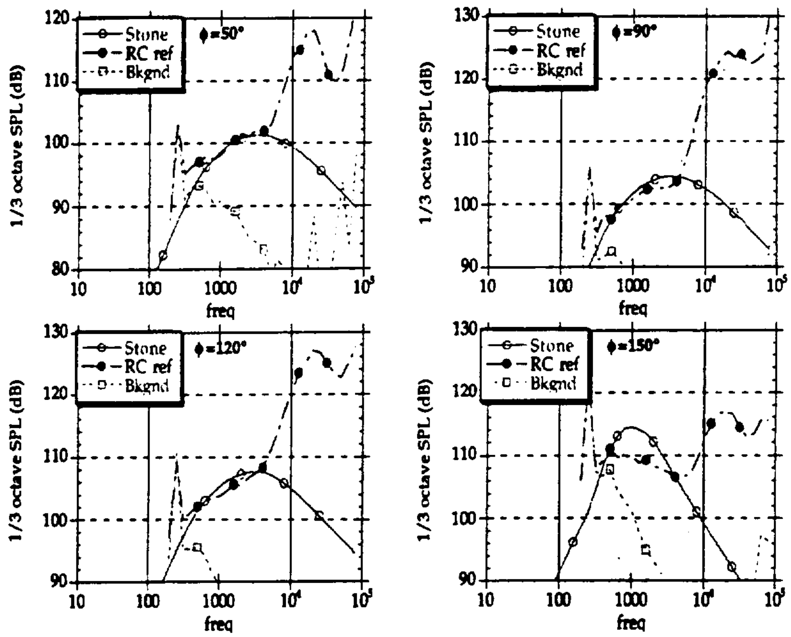
2Dvortical Mixer, Long Ejector



The axial dependence on liner placement was tested by putting the liner in only the aft half of the ejector and comparing the sound of this configuration with that of the unlined and fully lined ejector. As seen in the plots, when the liner was in the aft half of the ejector it absorbed almost the same amount of sound as when the entire length of the ejector was lined, leading to the conclusions that (1) the liner in the front half of the ejector was ineffectual and (2) most of the internally generated mixing noise is either produced near the end of the ejector or is highly directed downstream.

Parasitic Upstream Noise in Rig

Round Convergent Nozzle
Cold Flow, NPR = 1.4 vs. Stone's Prediction



One problem encountered during the test was upstream "valve" noise in the rig. This can be seen clearly in these plots which show the sound spectra measured in a cold low speed jet flow and the predicted spectra. Also shown is the tunnel background spectra, which is well-below the jet noise and is not a factor. At around 20kHz, the same frequency range as the lobed mixer produces sound, the upstream noise can be seen protruding above the prediction.

Procedure for Estimating Upstream Noise

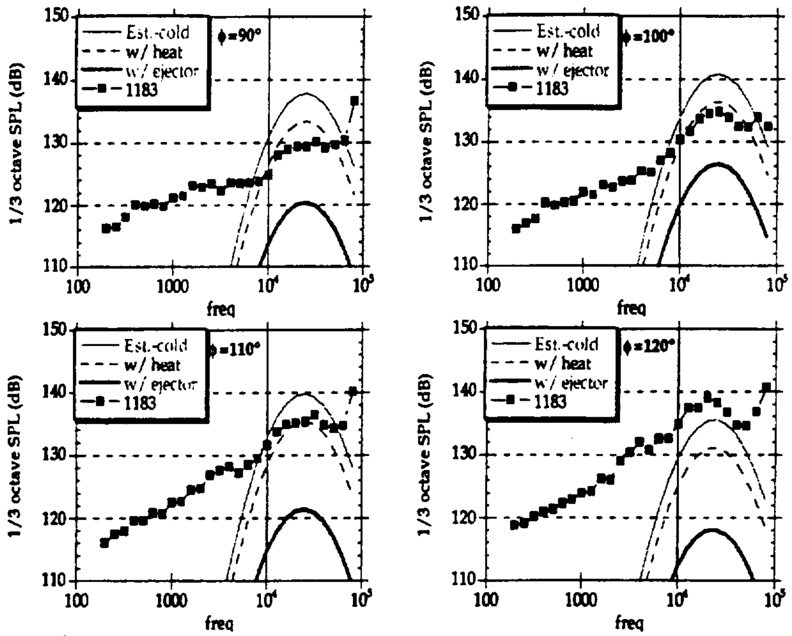
1) Extrapolate cold, subsonic ASME nozzle data to high NPR.
   - The scaling with NPR is assumed to be independent of angle in accordance with experience with internal combustor noise.
   - Spectral shape is best fit to internal noise in 10k-60kHz band.
2) Effect of temperature is extrapolated from 530°R and 1150°R data in RCref nozzle.
3) Sound absorption by liner calculated from cold, subsonic data in RCref and 2Dvortical jets.

geometric angle	Extrapolated from cold, low NPR data (x = log10(f))	Effect of jet temperature	Short bulk liner	Long bulk liner
50	-710.0 + 4*NPR + 385x - 45x2	-0.003*(T-530)	+3	+2
60	-740.0 + 4*NPR + 393x - 45x2	-0.003*(T-530)	+1	-1
70	-736.0 + 4*NPR + 393x - 45x2	-0.003*(T-530)	-4	-6
80	-735.0 + 4*NPR + 393x - 45x2	-0.003*(T-530)	-8	-11
90	-745.0 + 4*NPR + 395x - 45x2	-0.003*(T-530)	-8	-13
100	-742.0 + 4*NPR + 395x - 45x2	-0.003*(T-530)	-6	-10
110	-743.0 + 4*NPR + 395x - 45x2	-0.003*(T-530)	-7	-14
120	-738.5 + 4*NPR + 393x - 45x2	-0.003*(T-530)	-7	-13
130	-738.0 + 4*NPR + 393x - 45x2	-0.003*(T-530)	-3	-9
140	-747.5 + 4*NPR + 393x - 45x2	-0.003*(T-530)	-1	-5
150	-710.5 + 4*NPR + 385x - 45x2	-0.003*(T-530)	+2	-4

Several attempts were made to isolate the source of this noise, such as changing elements in the rig, etc., but the noise seemed independent of these changes. Unable to remove the source of the upstream noise, a method was developed to predict the contribution of the parasitic noise at the test conditions. This involved extrapolating the noise spectrum from low NPR, cold data where the noise was clearly dominating the jet noise, extrapolating the slight modification caused by the difference in temperature (both effects measured in the RC nozzle) and adding the suppression of the parasitic noise by the ejector liners, again measured at low NPR. This table quantifies and documents the fits which were used for estimating the upstream noise at high NPR, hot test conditions.

Estimate of Upstream Noise Contamination

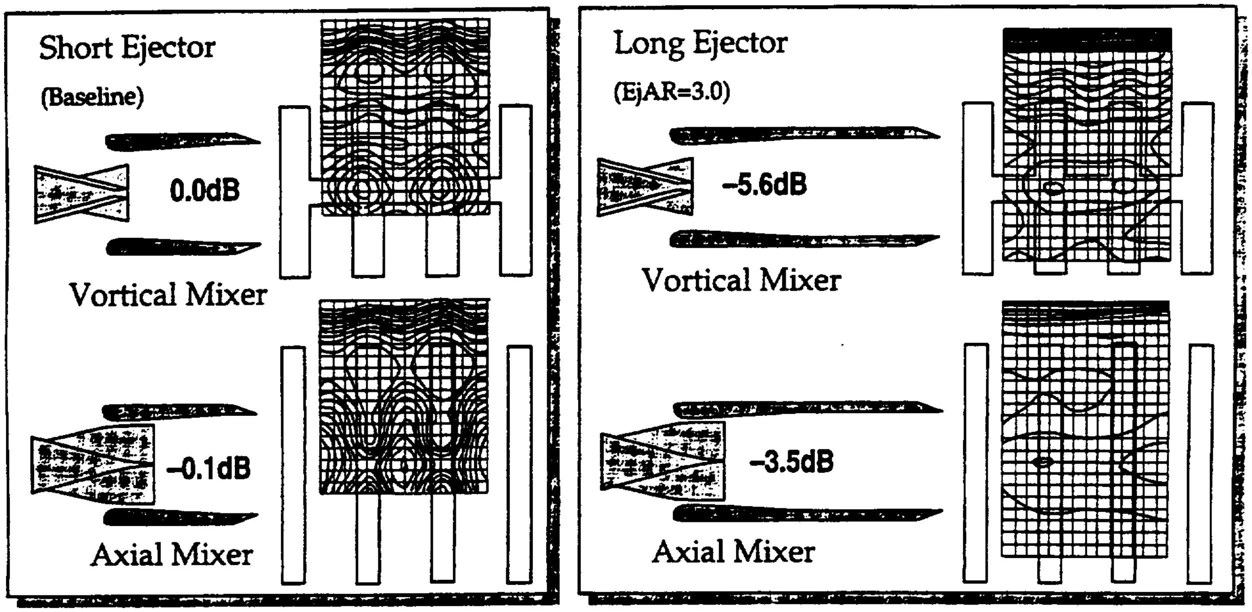
Data: 2Dvortical, Long Ejector, Bulk Liner
Analytical: Estimate of Upstream Noise:
Cold + Heat Effect + Ejector Shielding



These plots show the data for the 2Dvortical mixer with long, bulk-lined ejector and the estimated upstream noise. The curve "Est-cold" is the sound of the upstream noise at the test NPR, but without the burner. The curve "w/heat" shows the slight reduction found when the burner was operating and "w/ejector" the final estimated contribution of the upstream noise to the measured sound. In all but the first two (upstream) polar angles, the estimated sound was well below the measured sound, indicating that the upstream noise did not contaminate the data. However, given the unfortunate spectral overlap between the upstream noise and the jet noise and the uncanny similarity between the upstream noise spectrum and the jet noise data, some uncertainty remains. This will be cleared by aeroacoustic tests of these nozzles in GE's Cell 41 facility this spring.

Correlation of Mixing and Noise

Relative EPNL with Bulk Liner in Ejector and
Total Temperature Profiles at Ejector Exit

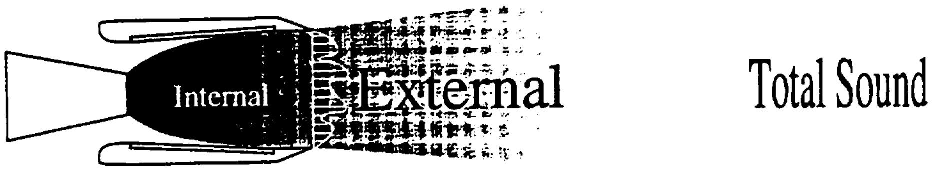


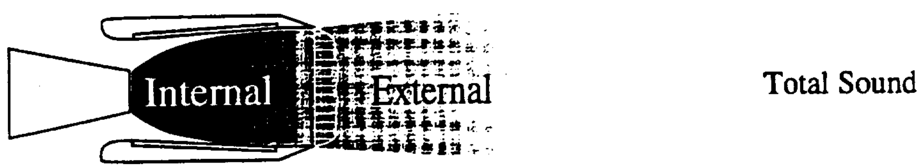
During the design phase of this test, a parametric CFD study was made to determine optimal size and shape of the lobed mixer. At this time the figure of merit for aeroacoustics was the temperature profile at the ejector exit plane. It was thought that the mixer which minimized "hot streaks" and provided the most complete mixing in the ejector would have the quietest flow out of the ejector. How well was this borne out in the tests? The plots above show the total temperature as measured at the exit of the ejector and a relative EPNL (2Dvortical with short ejector taken as arbitrary baseline).

Comparing temperature profiles for the short ejector, the axial mixer has stronger gradients and therefore would have been expected to be noisier. However, it is indistinguishable from the vortical mixer. Comparing temperature profiles from the long ejector (which are not completely comparable due to an unfortunate configuration error which gave the vortical mixer an EjAR=3.0 instead of 3.3--but this difference should have no acoustic effect--see earlier slide!), the axial mixer clearly has a smoother profile and yet produced more sound.

Source Location–Case I

If External >> Internal, smoother exit profiles indicate
increased internal mixing,
decreased External sound, and
reduced Total Sound.



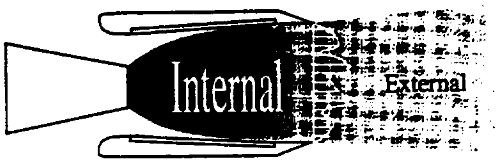


Obviously, there is a flaw with the figure of merit which was used in the design phase. Or more precisely, a flaw in the assumptions which went into it choice.

Consider the situation where the noise generated external to the ejector was much greater than that produced (and radiated out of) the ejector. In this case, improving the external flow by smoothing the temperature and velocity profiles at the ejector exit would reduce the noise generated by external mixing and result in a quieter total sound, even if the improvement in flow profile came at the expense of increased internal mixing and sound generation. This was the picture used in deciding on the figure of merit.

Source Location–Case II

If Internal >> External, smoother exit profiles indicate
increased internal mixing,
increased Internal sound, and
increased Total Sound.



Total Sound

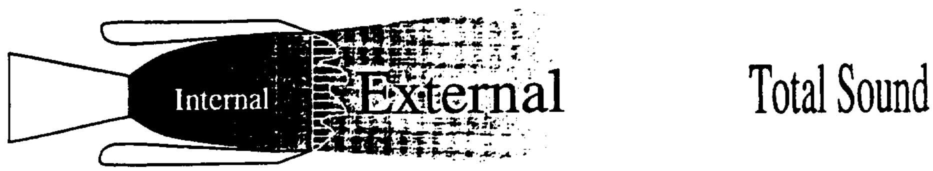
Total Sound

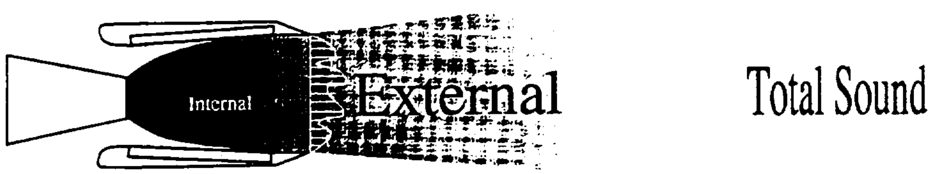
This is the correlation observed in 9x15 data...

Consider instead the situation where the noise generated inside the ejector dominates that produced outside. Now, increasing the mixing within the ejector increases the internal sound, and hence the total sound, rather than reducing it. In other words, having a smoother exit profile means that more sound is being generated internal to the ejector, and since this sound is greater than the external sound, the result is a louder, not quieter, jet. This seems to be the correlation which is observed in the 9x15 tests.

Source Location–Liner Effect

If External >> Internal, inserting liner would have negligible effect on Total Sound.

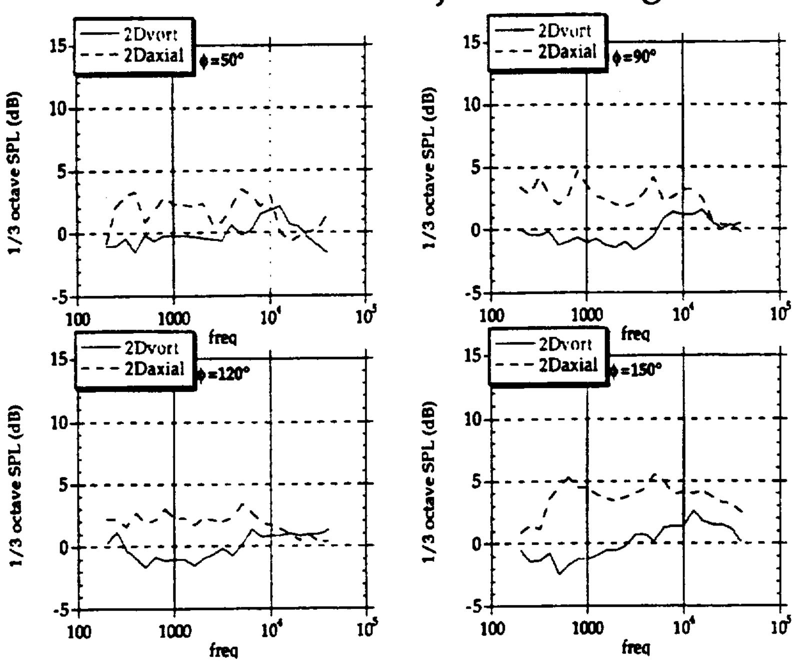




An even better indicator that the total sound is coming predominantly from the mixing within the ejector is the fact that the liners can be seen to have an effect. If the external noise was dominant, changing the internal noise by adding absorptive material would not be noticable.

Effectiveness of Liner
Short Ejector

Small insertion loss indicates that Externally-generated sound dominates in short ejector configurations.

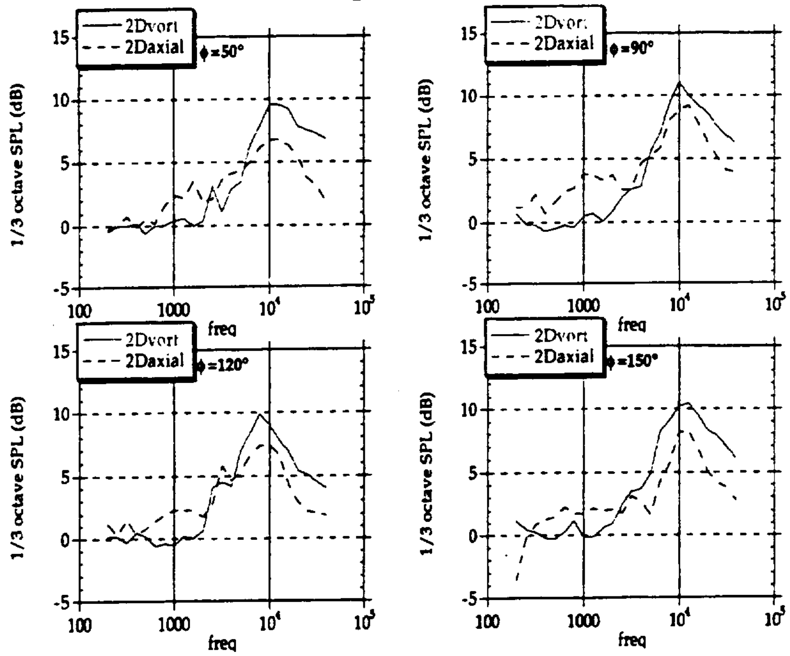


In the short ejector configuration, the absorption by the liner is very small, roughly none with the vortical mixer and less than 3dB with the axial mixer. Here, the mixing noise produced within the ejector is only comparable to or smaller than the noise produced downstream of the ejector. Apparently, the axial mixer produces more sound near the mixer (especially considering that it protruded roughly 3/4" further into the ejector than the vortical anyway) than the vortical mixer. Either that, or the internal mixing of the axial mixer produced sound which was directed more to the liners and less downstream.

Effectiveness of Liner

Long Ejector

Significant insertion loss indicates that Internally-generated sound dominates in long ejector configurations.

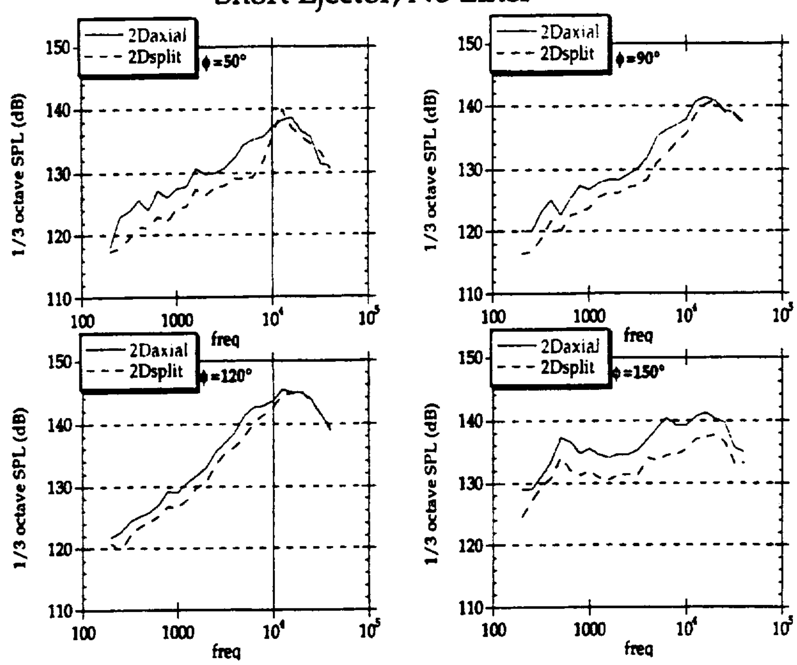


When the ejector is extended to cover more of the mixing (and perhaps change the mixing by the change in static pressure with increasing length), the noise from the mixing which occurs within the ejector is clearly stronger than that which occurs downstream of the ejector. In this case, inserting a liner in either mixer configuration produces significant absorption. Actually, one cannot say whether the sound coming from within the fully lined ejector is greater than that generated downstream, as the liner may have brought the internal noise down to the level of the external. However, the insertion loss at the Sideline PLR condition is roughly the same as that of the upstream parasitic noise, indicating that if more attenuation was possible with a better liner, the total noise could still be reduced with the long ejector.

2Daxial With and Without Center Gap

Schlieren showed that 2Dsplit had significant shock cell structure

Short Ejector, No Liner



Another interesting observation concerning the noise-mixing relationship within the ejector was made during runs using focussed-Schlieren, results of which are presented elsewhere at this Symposium. Due to a flaw in the design of the axial mixer, the two halves of the nozzle split apart making the axial nozzle similar topologically to the vortical. However, the nozzle was no longer convergent-divergent and shock-free. The gap opened up produced a long shock train which was clearly visible in the Schlieren. One would think that this would produce additional sound (probably above 40kHz judging by the shock spacing), but in fact, the sound was reduced, especially at low frequencies such as are produced far downstream in the jet.

The point of this observation may be that different mixing mechanisms, such as screech or edgetone, may prove better in the mixer design even though they are, by themselves, thought to be more noisy. The mixing which occurs within the ejector must not only be effective, but also have beneficial directivity and spectra to allow effective liner strategies and have minimal impact in the human-factor weighting of jet noise evaluation.

Conclusions

9'x15' test results suggest the following course for improvement:

- Find ways to increase internal mixing while beneficially changing either the amplitude, directivity, or spectrum of its sound generation.
- Optimize ejector length to balance internal sound (after absorption) with external sound.
- Improve ejector liners and see how near-field (nonlinear) acoustics changes their performance.

Post-test analysis of the 9x15 test data show several important parametrics for the continued development of mixer-ejectors for jet noise suppression. The analysis finds several misconceptions or incorrect assumptions which must be corrected and understood before the next iteration of mixer-ejectors is designed. Most importantly, the data shows that in the present application, 'mixing' cannot be treated as a scalar quantity to be reduced or increased; the mixing processes produced by different mixer geometries within the ejector must be understood in more detail and their noise generation differentiated to drive the optimization of mixer design. Simple-minded increase of the mixing within the ejector when the internal noise already dominates the total sound will only increase the jet noise, not reduce it. It appears from here that the optimal ejector length will be that which encloses enough of the flow so that bnternal noise is balanced by external noise. It appears that a reasonable-length ejector can still benefit from an increase in absorption by the liner, indicating that the upcoming liner technology program will be directly applicable to the current mixer-ejector program.