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# HSCT NOZZLE SOURCE NOISE PROGRAMS AT PRATT & WHITNEY

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## 20dB JET NOISE SUPPRESSION NEEDED

Jet noise from the high velocity exhaust flow will dominate takeoff noise spectra of high speed aircraft. Although available noise suppression technologies can be used to quiet other engine noise sources, jet noise requires new, unique developments in noise reduction technology.

With the resurgent interest in the High Speed Civil Transport, successful control of the dominant jet noise (along with emissions and materials) has again been identified as one of the two or three technologies critical to a successful HSCT. Without an economically viable approach to FAR36 Stage 3 noise requirements, there can be no commercial transport. Alternate means of meeting this noise rule (such as engine oversizing) have been shown to adversely impact the system's economics.

Recent low noise nozzle accomplishments at P&W and future plans are discussed in the pages that follow:

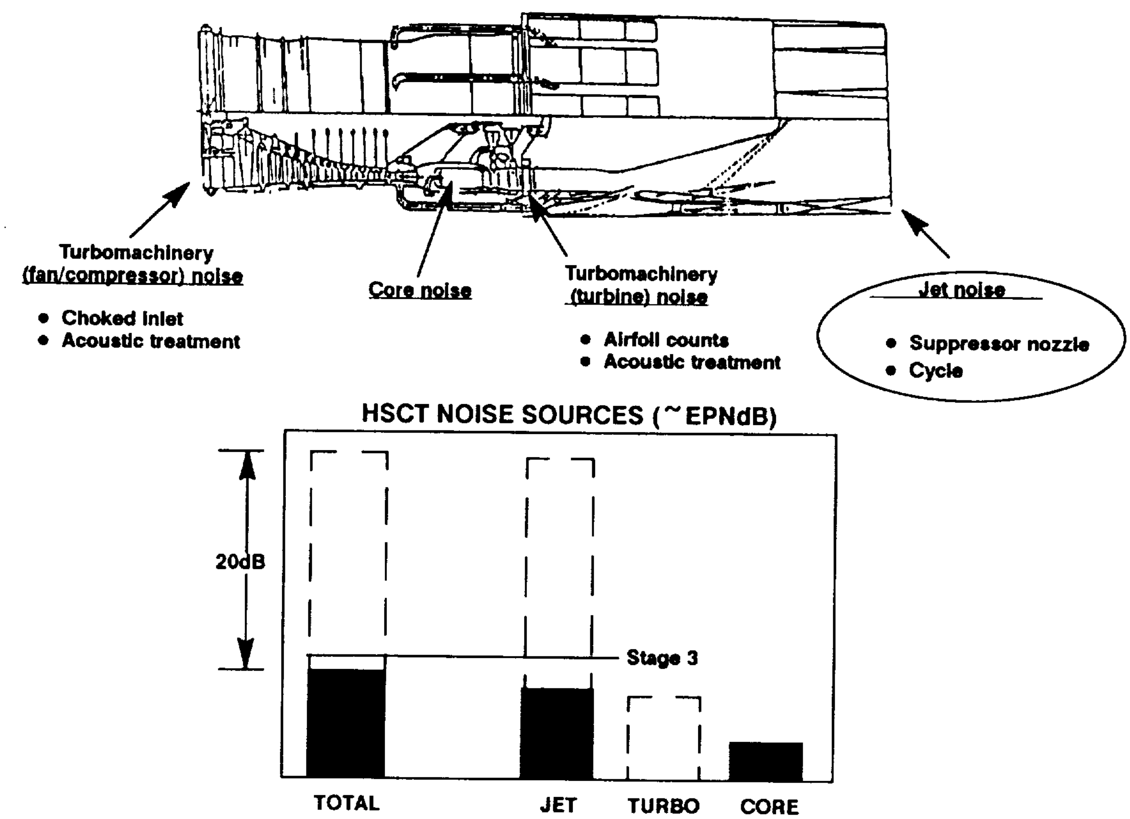


Figure 1

## EJECTOR NOZZLE TECHNOLOGY PROGRAM

## NOISE REDUCTION VS FLOW AUGMENTATION

Jet noise suppression of magnitude 20 EPNdB will be needed relative to a unsuppressed exhaust system optimized for performance only. The major low noise exhaust nozzle effort at P&W has focused on high flowing, mixer ejector nozzle systems with secondary airflow entrainment levels as high as 120–140%.

Since the early days of supersonic transports, both Pratt & Whitney and General Electric Aircraft Engines have been key participants in studies and evaluations of candidate HSCT exhaust nozzle concepts. Teaming between P&W and GEAE to develop a HSCT propulsion system is a major milestone in the United States effort toward a successful program.

GEAE have been looking at similar ejector systems, trading reduced pumping levels for smaller diameter and drag. The lower pumping alternative requires some modest engine resigning to meet Stage III. Having two levels of pumping under parallel investigation by GEAE and P&W provides us the opportunity to better understand the range of ejector capabilities and assess them back-to-back in terms of overall installed performance. One of our objectives is a down select decision to one common ejector type by the end of 1992.

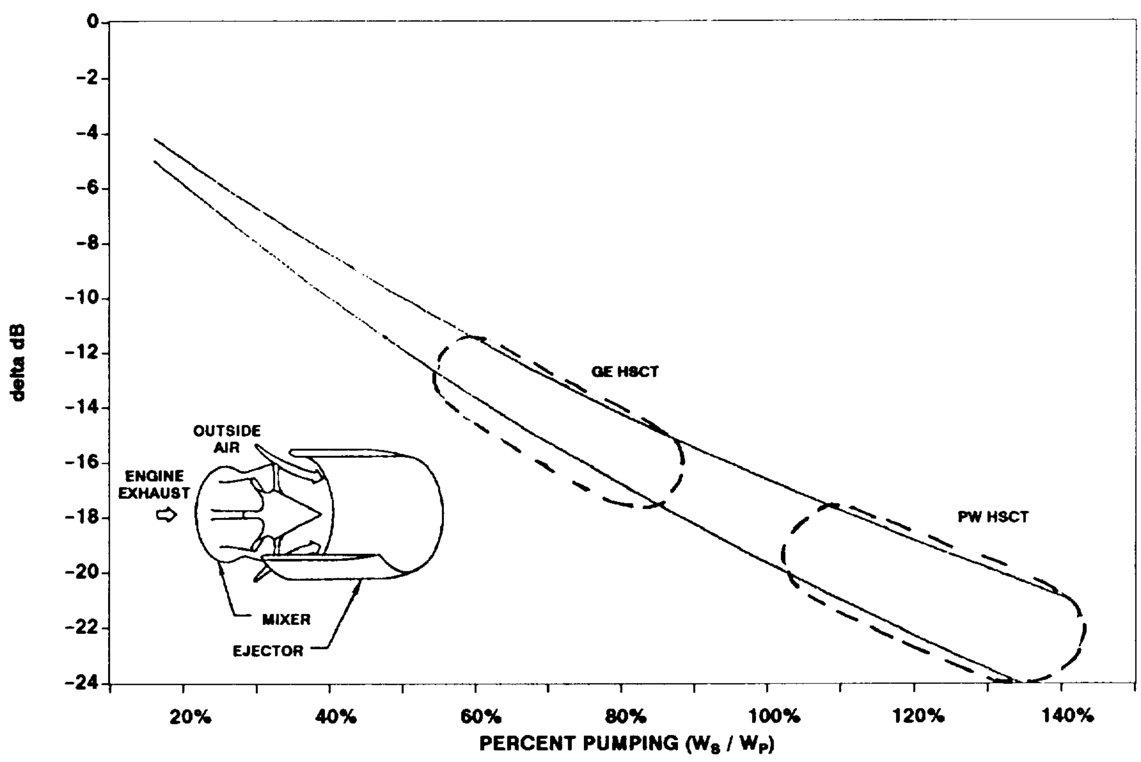


Figure 2

## MIXER EJECTOR NOZZLE

## TECHNOLOGY CHALLENGES

One major noise challenge to a successful mixer ejector nozzle is good aerodynamic design. The major benefit for the ejector comes from reducing overall jet velocity from over 3000 ft/sec to something near 1500 ft/sec, while maintaining thrust. The process of mixing tertiary air with the high velocity primary exhaust flow, however, produces its own noise. This mixing process must be optimized to 1) minimize the internal noise generated and 2) produce this noise in a form more easily attenuated by acoustic liners in the ejector shroud.

Acoustic liner technology capable of effectively attenuating the internally generated noise within the highly turbulent and high velocity and temperature environment of the ejector must also be developed.

Internal expansion ratios can be quite high causing internal shocks with associated shock noise. This also needs to be addressed in the mixer and ejector's aerodynamic design.

Economic viability demands additional considerations such as nozzle performance over the full aircraft operating range and advanced enabling materials.

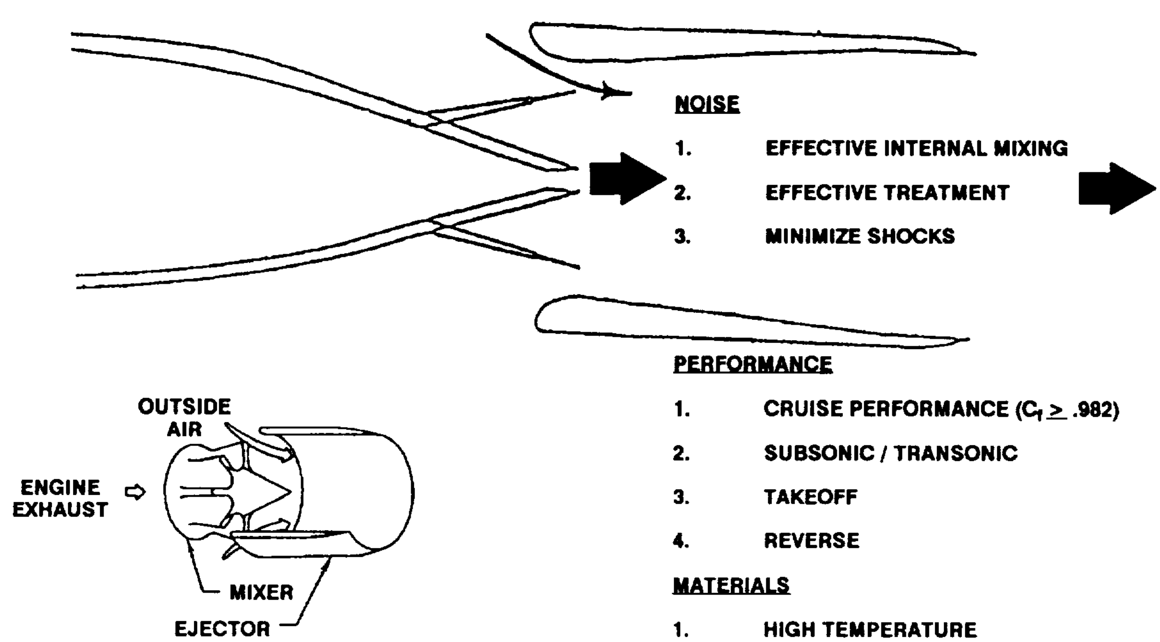


Figure 3

## 1989 HSCT 2D EJECTOR MODEL TEST

## IN NASA 's 9 x 15 TUNNEL

Since 1988, Pratt & Whitney has conducted two HSCT model ejector test programs and will soon begin a third. The original HSCT high-flowing ejector designs were based on related programs conducted at United Technologies Research Center (UTRC) during the 1980's.

P&W's first HSCT ejector model program was conducted in NASA Lewis' 9x15 low speed acoustic wind tunnel in mid-1989. The 2D ejector nozzle hardware was jointly provided by P&W, UTRC, and NASA LeRC. Test facility was provided by NASA and the data analyses were shared among NASA and P&W. The 1/10 scale (approximate) model was tested with and without the ejector shroud and over a range of ejector area ratios and nozzle expansion ratios. A reference, conic nozzle was also evaluated to provide a baseline. Facility limitations at that time restricted testing to 450F jet flow. Ejector shroud static pressure taps and an exit pressure and temperature traverse were used to evaluate pumping and mixing.

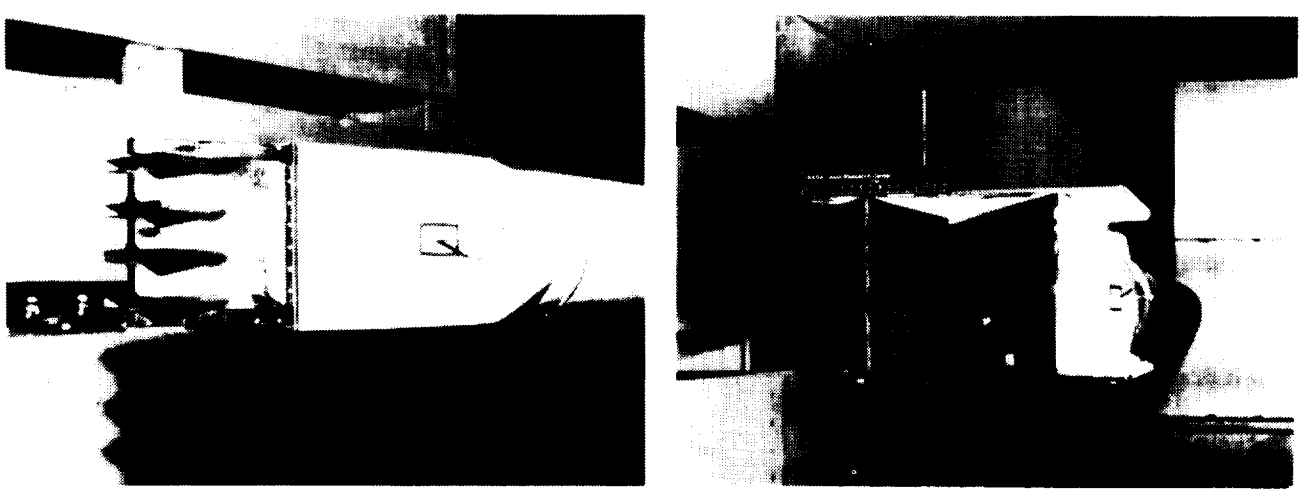

Figure 4

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**TERTIARY AIRFLOW**

**1989 2D EJECTOR TEST**

Wall static pressure taps in the ejector shroud were initially used to assess secondary airflow levels (pumping). These measured levels were later corroborated and calibrated using exit rake temperature and pressure traverses.

Ejector area ratios (Amix/Aprimary) in the range of 3.77 to 4.7 were tested and goal levels of pumping were shown to be technically feasible. When corrected to the engine temperature conditions of a typical HSCT engine, the goal 0.6 corrected pumping level translates to an absolute pumping level of order 120% at HSCT engine exhaust conditions.

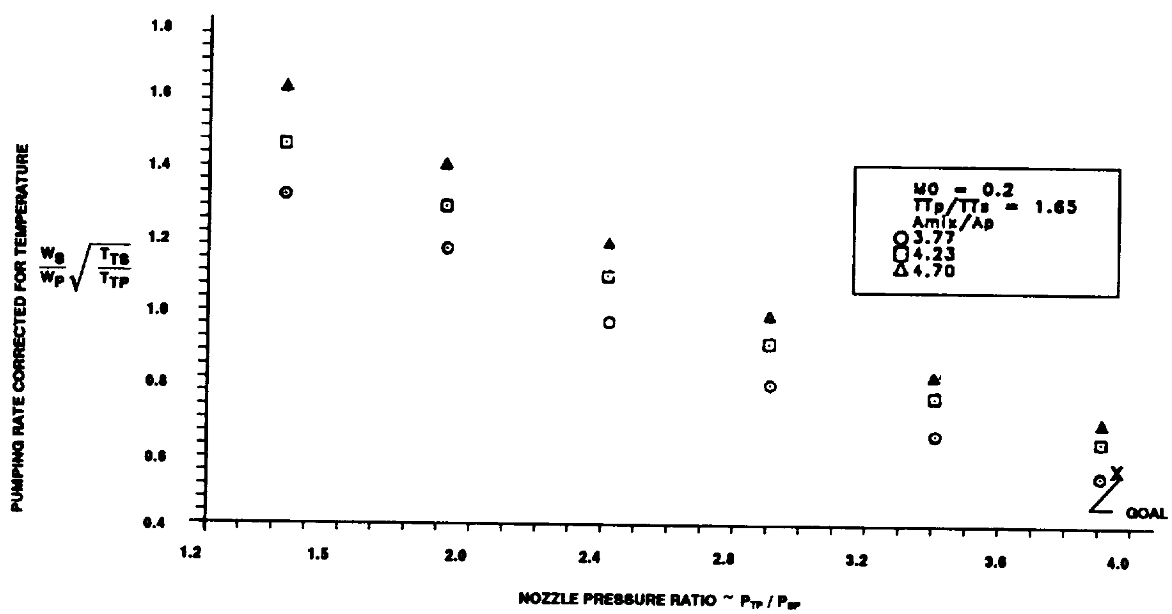



Figure 5

## SHOCK NOISE DOMINATES 2D EJECTOR TEST

With the 450F temperature limit, the 2D model noise data from the 1989 program was dominated by shock noise. The measured levels for the reference conic nozzle were as predicted, verifying that the shock noise dominates. Tunnel background noise was measured and did not directly prevent acquisition and credible data. Without the higher nozzle temperatures needed to simulate realistic engine exhaust conditions (i.e.: jet velocity); the key, jet mixing noise source was not directly observable.

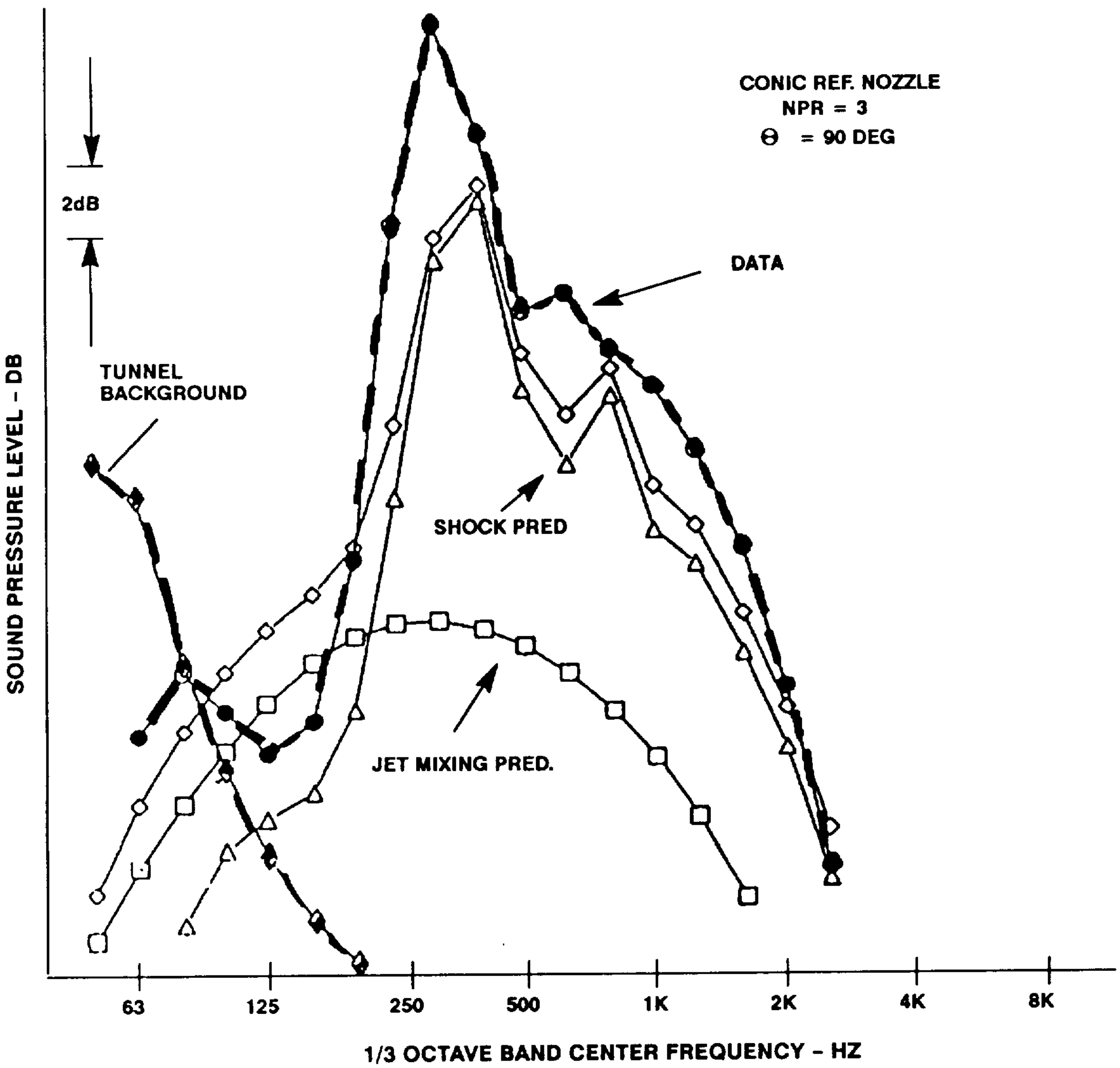


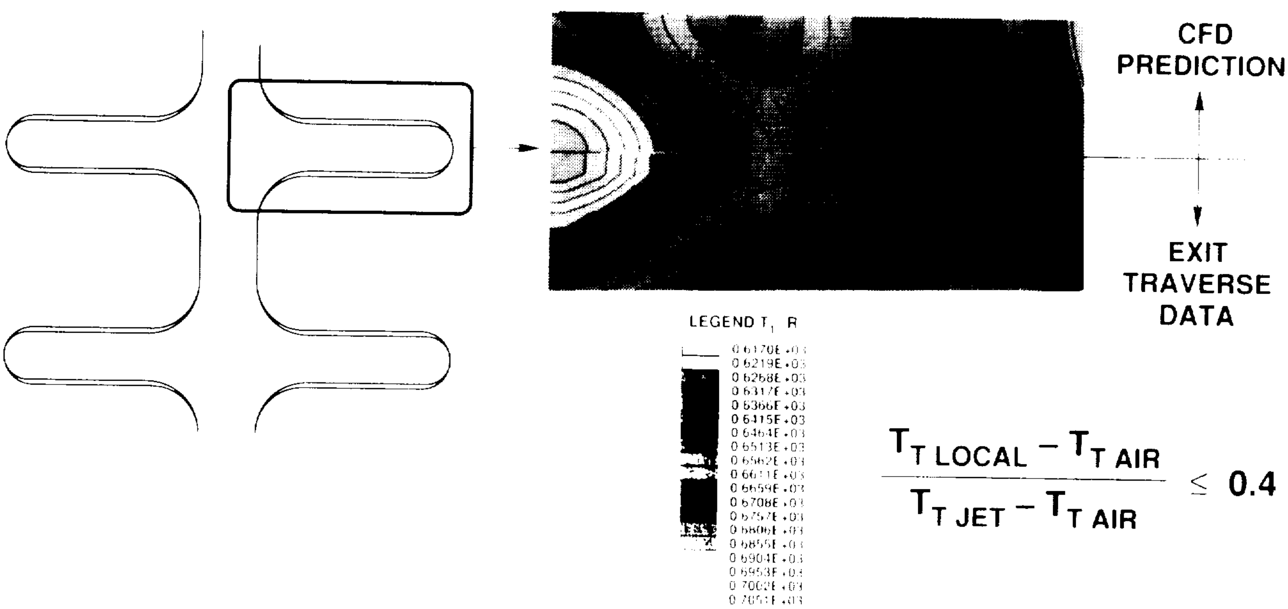

Figure 6

## LESSONS LEARNED: 2D MIXER / EJECTOR IN 9′ x 15′

Pressure and temperature traverses at the ejector exit indicated good mixing was achieved within the ejector. Subsequent CFD analysis of the mixing region using P&W NASTAR Navier Stokes code showed excellent agreement with the traverses. The predicted internal wall static pressure measurements made along the shroud also showed excellent agreement with the NASTAR code.

In summary, the first HSCT model nozzle test showed that very aggressive pumping levels exceeding 120% (at HSCT engine conditions) can be achieved with good mixing. Also learned was the effectiveness of CFD analysis in assessing the mixing region. More realistic temperatures would be needed in future programs, however, to obtain the proper balance between shock and mixing noise in far field noise measurements.

- NEED HIGHER JET TEMPERATURES FOR ACOUSTIC TESTING
- EXCEEDED AIR ENTRAINMENT GOALS
- GOOD MIXING
- CFD : : EXIT TRAVERSE: EXCELLENT AGREEMENT



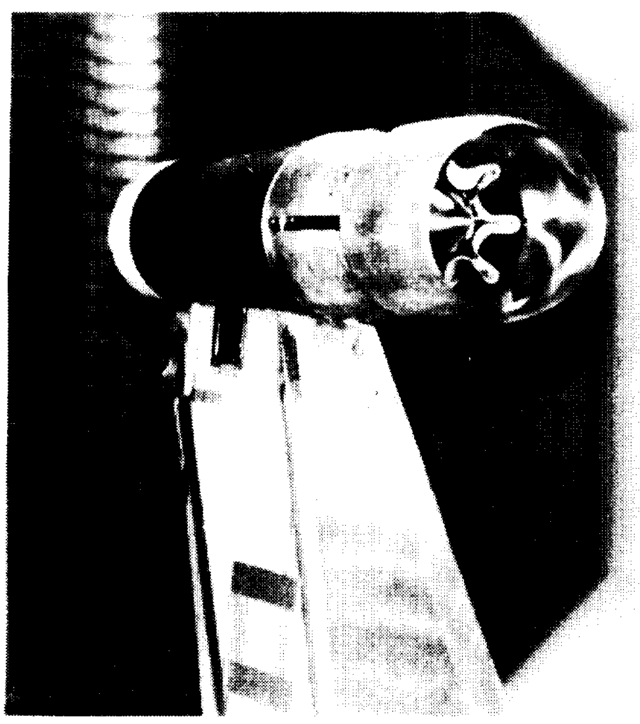

$$\frac{T_{T\ LOCAL} - T_{T\ AIR}}{T_{T\ JET} - T_{T\ AIR}} \leq 0.4$$

Figure 7

## 1990 HSCT AXISYMMETRIC EJECTOR MODEL TEST IN BOEING's LSAF

Based on the encouraging results from the previous year's 2D ejector program at NASA, two axisymmetric ejectors were designed and procured, one with deep penetration and one with shallower lobes. An acoustically treated ejector shroud was also provided to evaluate the ability to attenuate internally generated noise.

The models were tested in Boeing's Low Speed Aeroacoustic Facility (LSAF) in mid 1990 in a joint NASA/Boeing/P&W program with the model hardware provided under NASA LeRC contract and tunnel time provided by Boeing. The models were mounted to Boeing's high temperature jet rig providing primary nozzle flows at temperatures up to 1500F.



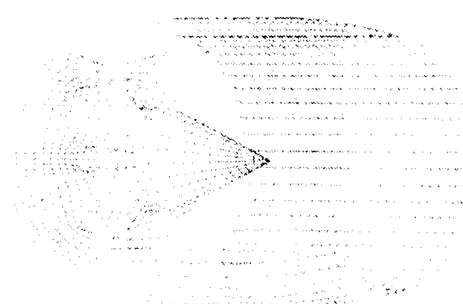


Figure 8

## AXISYMMETRIC MIXER / EJECTOR MACH CONTOURS - PEAK AND VALLEY - NASTAR

## PRE TEST PREDICTIONS

The ability to successfully use P&W's CFD NASTAR code to match the previous year's model data in both exit profile and internal static instrumentation lent impetus to a pretest evaluation of the axisymmetric model. This analysis indicated two potential problems with the existing axisymmetric mixer hardware. Higher than expected local expansion ratios at the mixer exit indicated the presence of strong shocks. Ejector exit hot streaks were also projected at the core coming off the plug and near the outer wall at each mixer lobe. These hot steaks were subsequently confirmed during the test by Boeing with their IR camera.

If present, the noise associated with these hot streaks external to the ejector would not be attenuatable with ejector acoustic treatment. The test, subsequently did show this ejector acoustic liner to be ineffective with the external hot streak dominating the higher frequencies.

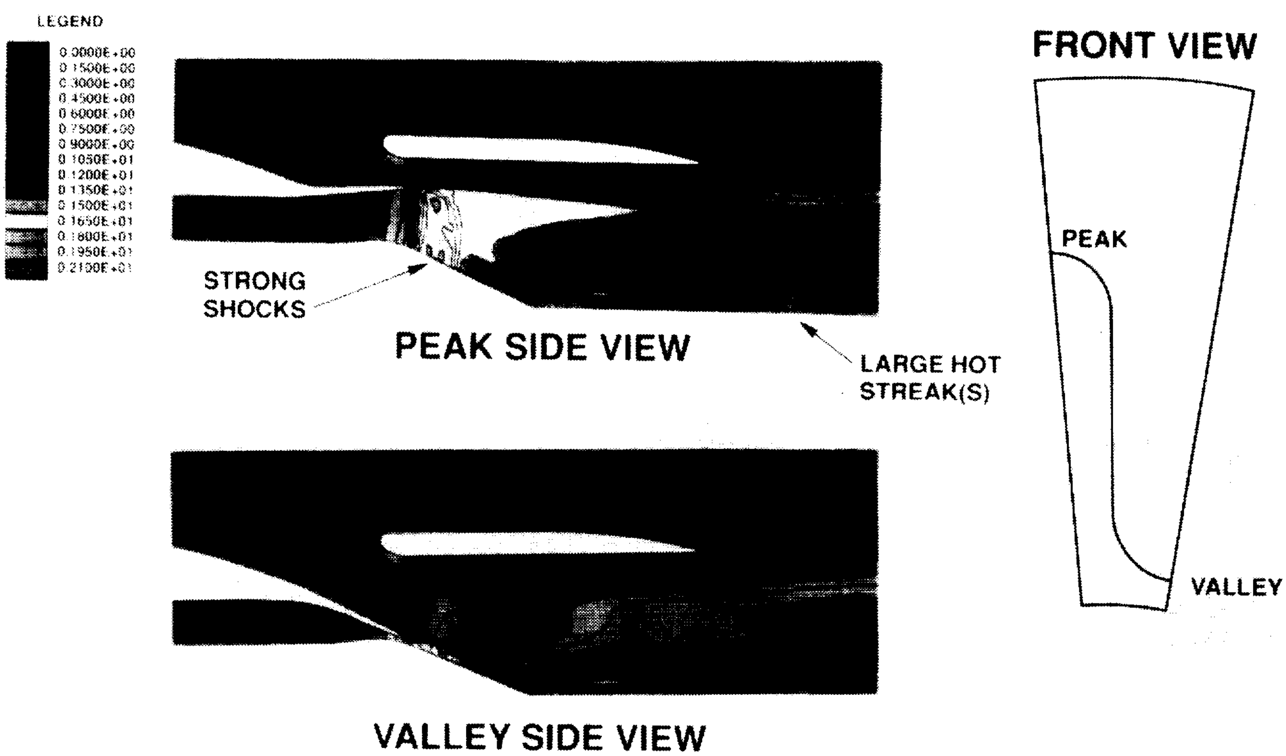



Figure 9

## TERTIARY AIRFLOW OBJECTIVES ACCOMPLISHED

### 1990 AXI MODEL

While indicating mixing levels below target, the pre test NASTAR CFD analysis indicated design pumping levels would be achieved. Similar to the previous year's 2D model in the 9x15, the internal model aero/performance data confirmed excellent agreement with the analysis and with our goals.

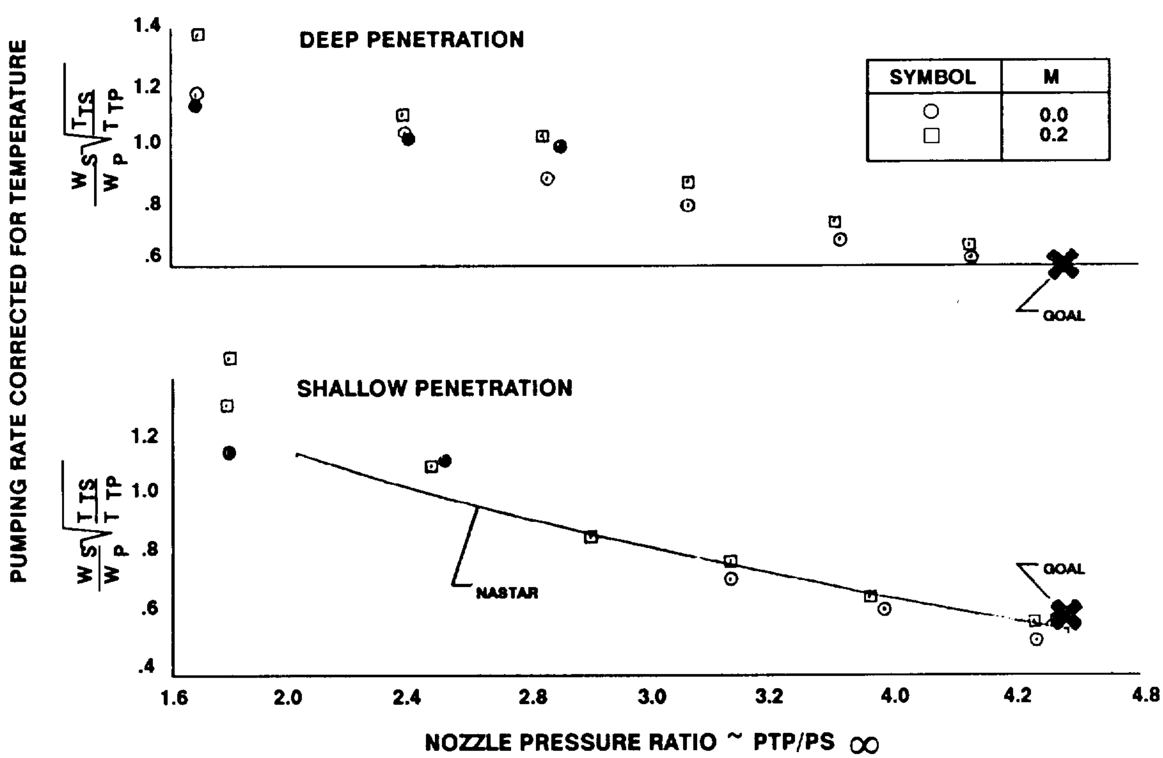



Figure 10

## JET NOISE SUPPRESSOR TECHNOLOGY

## SUPPRESSION VS. NOZZLE PERFORMANCE

In addition to higher temperature capability, the Boeing facility also provided the opportunity to measure nozzle thrust. When compared to the reference conic nozzle, also tested by Boeing, the ejectors showed only minimal thrust decrease at forward flight conditions simulating takeoff. Even with the known aeromixing deficiencies, the ejectors provided significant noise reductions.

Compared to previous generations of jet suppressor nozzles, the ejector concept demonstrated a significant technology leap forward in terms of noise reduction per pound of thrust loss.

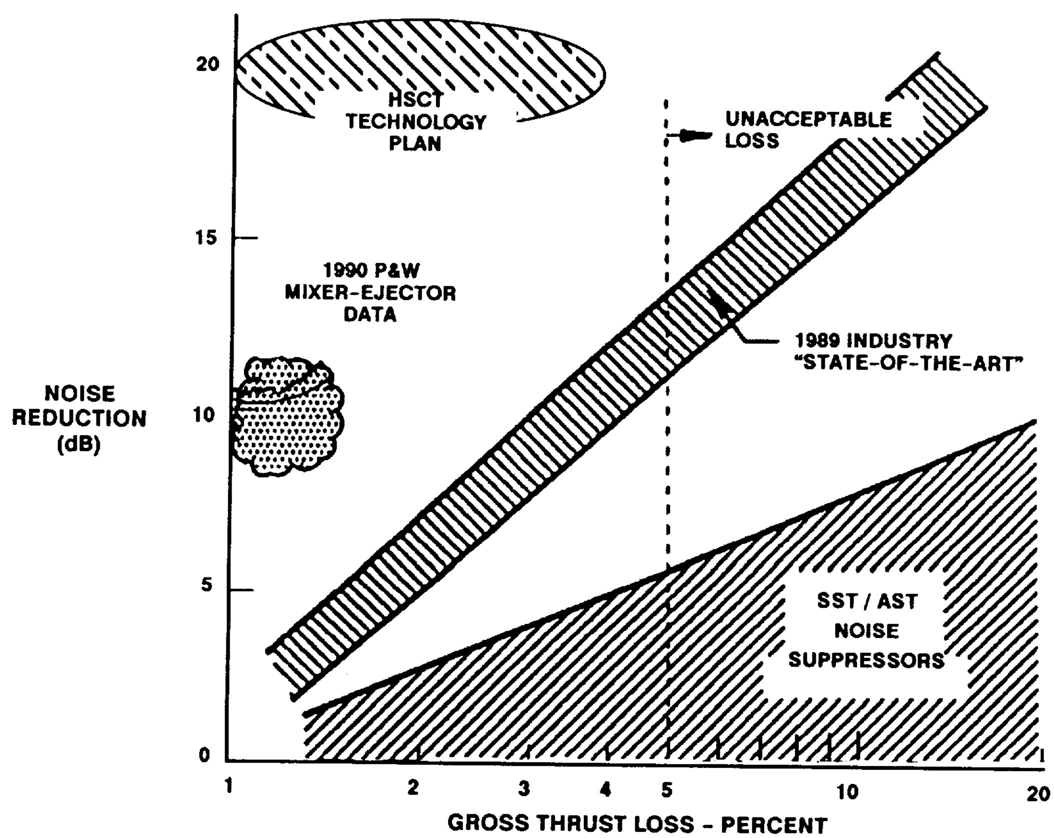



Figure 11

## 1991 PW / NASA HSCT EJECTOR MODEL NOISE PROGRAM

P&W and NASA are currently preparing to test the next generation 2D HSCT ejector nozzle in Lewis' 9x15 tunnel during the third quarter of 1991. In addition to a new mixer/ejector design based of CFD tools, the use of the NASA jet exit rig will provide both the higher temperature capability (1500F) and thrust measurement capability lacking in the first 9x15 test program.

The current program is a joint, cooperative effort with P&W providing the CFD analysis, hardware being procured under contract to NASA Lewis, and using the NASA 9x15 tunnel and jet exit rig. Further, windows in the ejector sidewalls will also be procured enabling NASA Langley to measure the internal mixing using flow visualization techniques. The program is also being coordinated with GE's 1991 2DCD HSCT ejector model program covering a complimentary range of ejector design parameters.

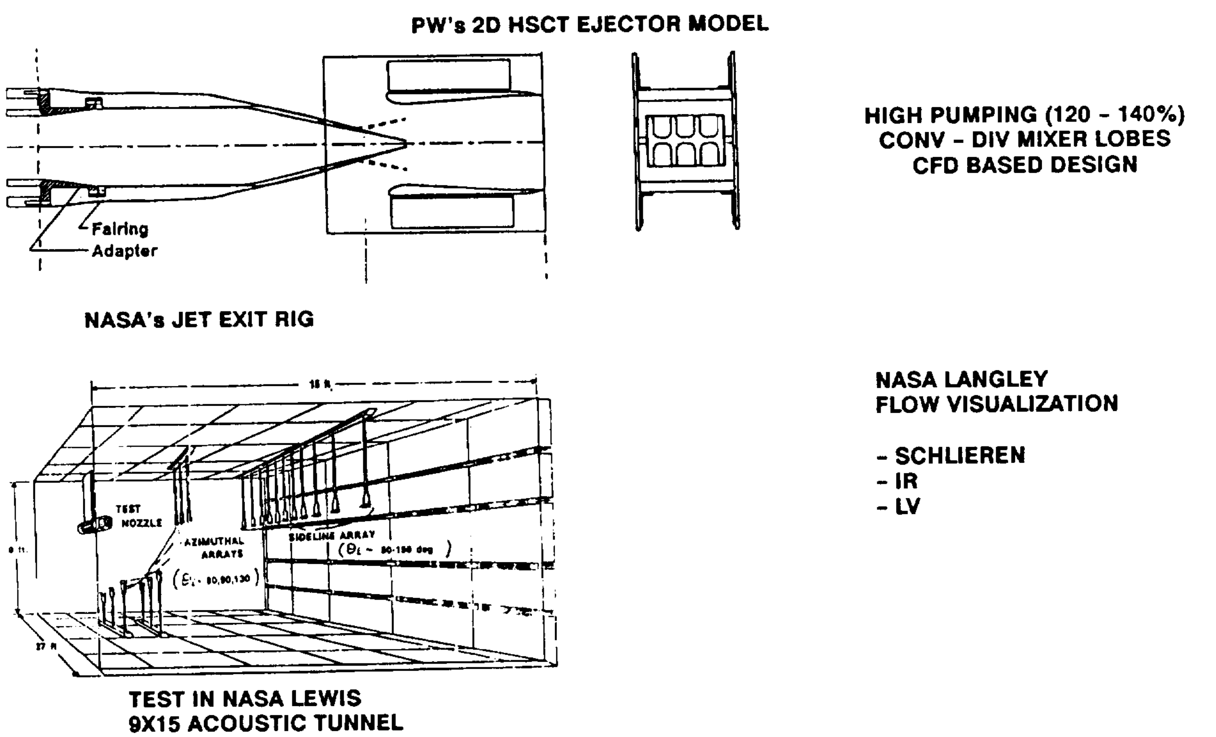



Figure 12

## EJECTOR LENGTH STUDIES

An understanding of mixing length and ejector acoustic liner quantity are critical parameters in the design of a effective low noise HSCT exhaust nozzle. The upcoming 2D ejector model program in NASA Lewis' 9x15 Tunnel will specifically address both of these technology issues. A range of mixing lengths will be tested utilizing both hardwall and treated ejector shrouds and sidewalls.

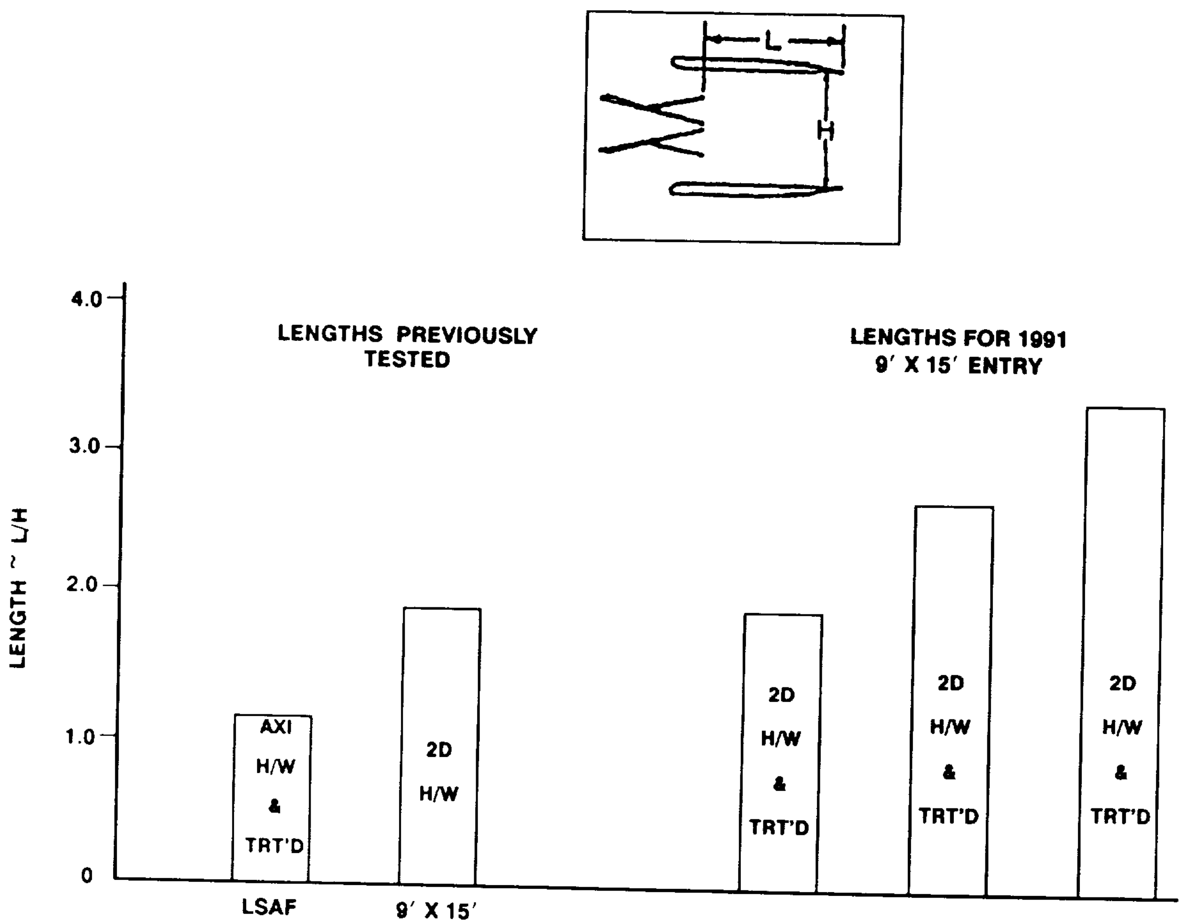



Figure 13

## HSCT LOW NOISE EXHAUST TECHNOLOGY PROGRAMS (MAY 1991)

Pratt & Whitney has conducted two HSCT model ejector test programs and will soon begin a third. These current model programs are focused on the issue of ejector acoustic viability and noise reduction potential. Also being studied are needed mixing length and acoustic liner quantity.

The HSR Phase 2 program will carry the results of the model testing into a large scale demo program to verify exhaust nozzle technologies in the more realistic size. A parallel materials program will provide for critical materials enabling a viable commercial nozzle.

One outstanding issue is ejector nozzle acoustic liner technology which is projected to provide almost half the overall noise reduction from the mixer/ejector concept. Locally high temperatures, Mach numbers, and turbulence as well as large spatial gradients present a technology challenge for acoustic liner which will be required in the HSCT ejector. The section of candidate HSCT liner concepts will also be a key HSR Phase 2 element in directing the nozzle materials effort and in the design of a demo engine nozzle. P&W and GEAE are in process off jointly develop;ing a liner program to address these issues of acoustic liners in the unique environment of the ejector shroud.

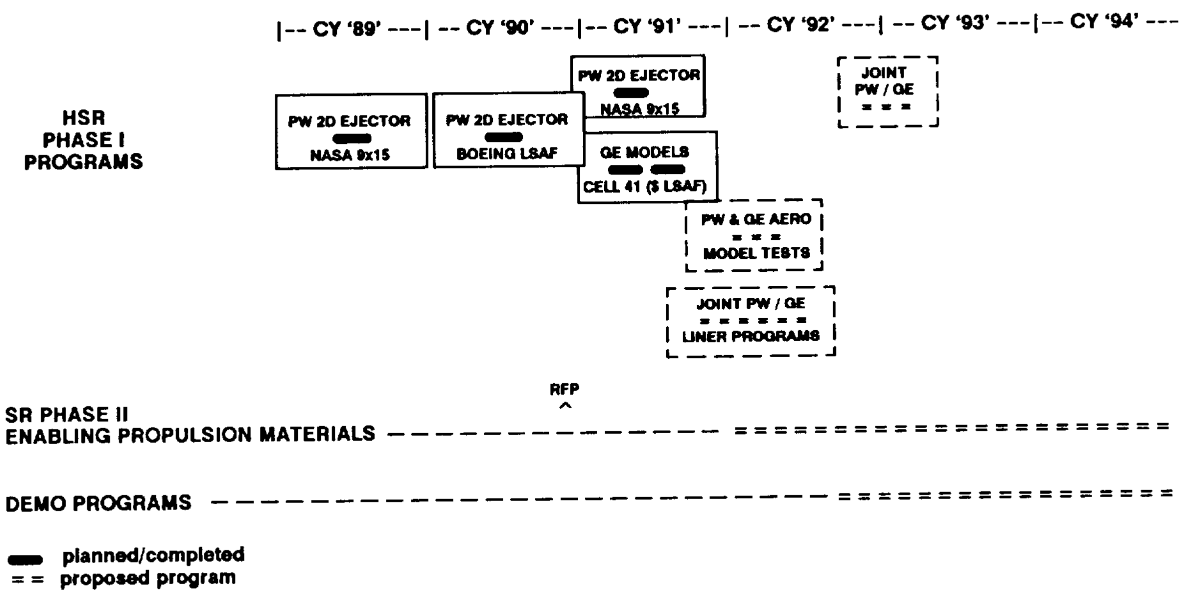



Figure 14

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