PRATT & WHITNEY TWO DIMENSIONAL HSR NOZZLE TEST IN THE NASA LEWIS 9- BY 15-FOOT LOW SPEED WIND TUNNEL: AERODYNAMIC RESULTS

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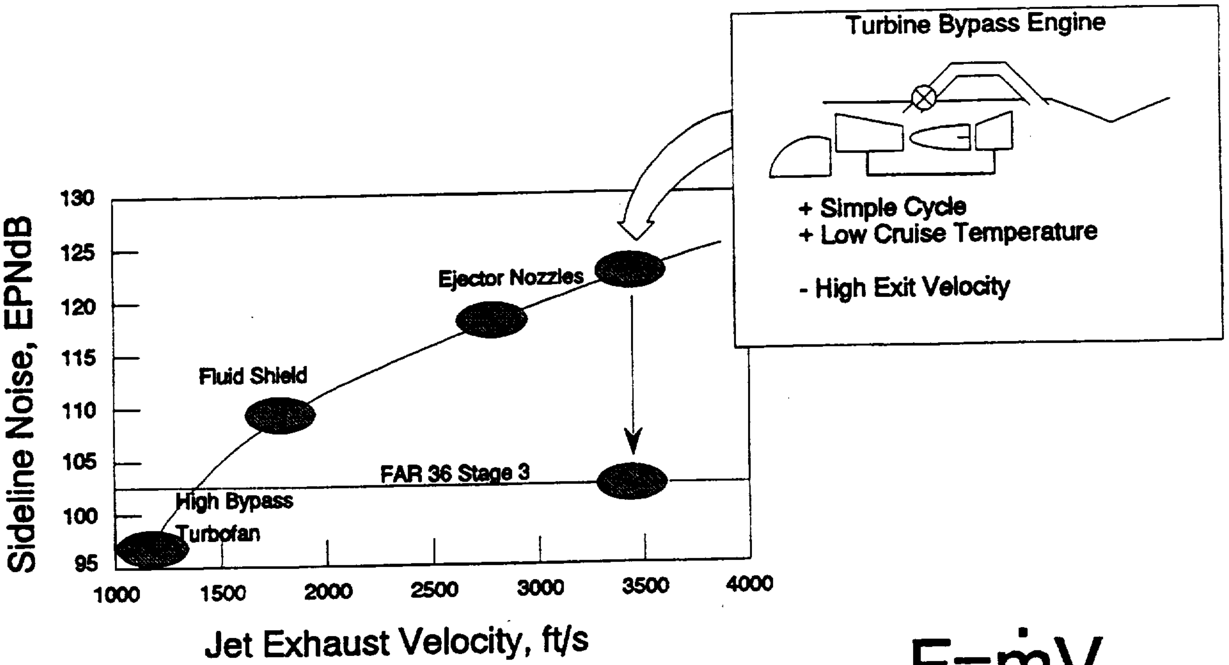
This paper discusses a test that was conducted jointly by Pratt & Whitney Aircraft Engines and NASA Lewis Research Center. The test was conducted in NASA's 9- by 15-Foot Low Speed Wind Tunnel (9x15 LSWT). The test setup, methods, and aerodynamic results of this test are discussed. Acoustical results are discussed in a separate paper by J. Bridges and J. Marino.

Overview

- Background & Previous Work
- Goals & Objectives
- Description of the Test
- Results
- Summary

TBE Noise Suppression Requirement

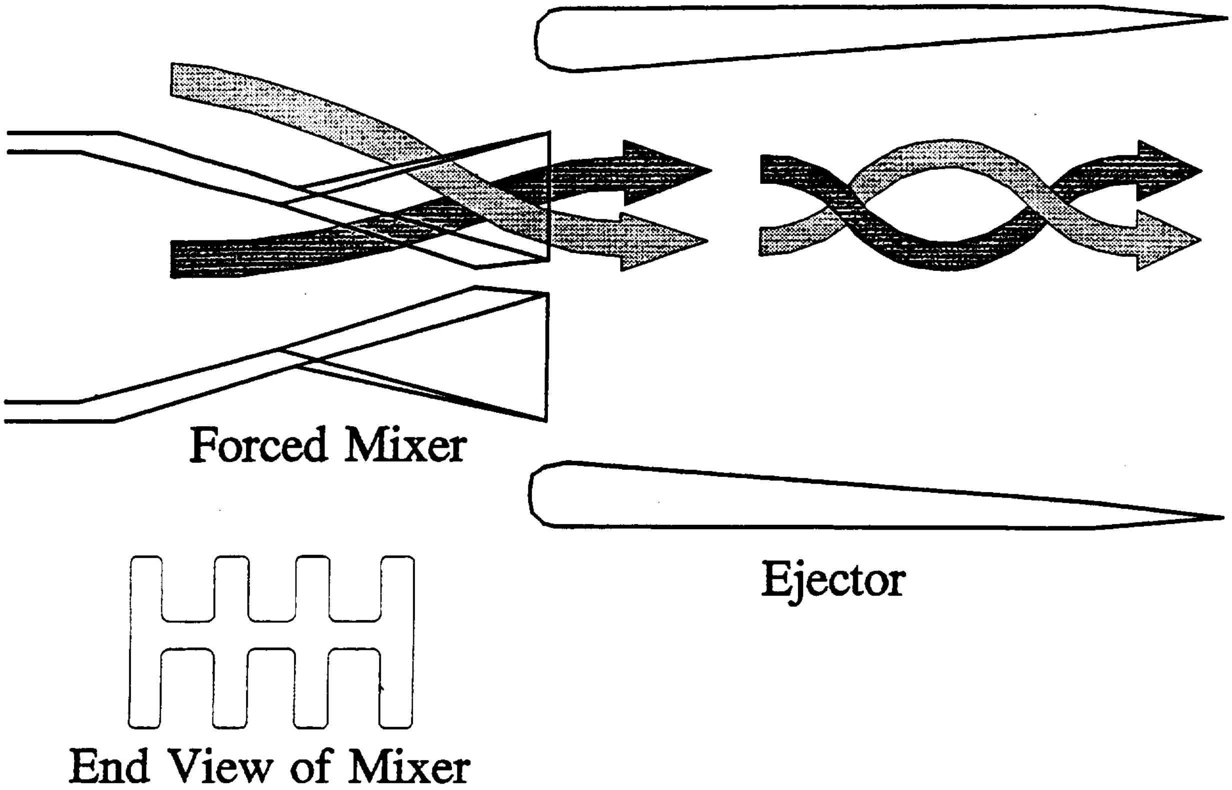


$$F=\dot{m}V$$

One of the proposed engine concepts for the HSCT is the turbine bypass (TBE) engine. This turbojet engine cycle is appealing in its simplicity and low temperature at cruise conditions. However, this engine has a high exit velocity, making it very noisy during take-off and approach. This figure shows the relationship between jet velocity and sideline noise. The TBE engine is at the high end of this spectrum. Consequently, to reduce the noise generated by this type of engine to FAR 36 Stage 3 levels, approximately 20 dB of noise suppression are needed.

To address this requirement, ejector nozzles are being studied. A large amount of ambient air is mixed with the jet exhaust to lower the exhaust velocity. Because the thrust generated is proportional to both the massflow and the velocity, the ejector provides a means of reducing exit velocity while maintaining thrust levels. To adequately lower the exit velocity, the secondary mass flow should be 120% (or more) of the primary mass flow.

The Mixer Ejector Concept



The high velocity jet must mix thoroughly with the entrained air to achieve the noise benefits of an ejector. Using conventional ejector technology, the mixing section of the nozzle would have to be impractically large to achieve this mixing. Instead, a mixer ejector is employed. The primary flow is supplied through a multi-lobed mixer nozzle. The secondary flow is drawn in between the lobes. This provides a large interface area between the flows.

In 1989, Pratt & Whitney and NASA Lewis tested a mixer ejector model in Lewis' 9- by 15-Foot Low Speed Wind Tunnel. This model achieved 120% massflow augmentation with measurable reduction in noise levels. However, at the design condition, the nozzle exhibited hot streaks exiting the ejector and shock noise, due to a mismatch in the primary exit pressure. While this nozzle demonstrated the mixer ejector concept was capable of reducing noise levels, the noise suppression for this nozzle was well below that needed to reach Stage 3. Furthermore, only limited acoustic data could be derived from the test data because the nozzle was operated at modest temperatures, much lower than those of an HSCT engine.

NASA/P&W 2-D HSR Nozzle Noise Test

Design Objectives:

- Increase ejector pumping
- Increase mixing
- Decrease noise to FAR 36 Stage 3 levels
- Maintain high thrust levels

Test Objectives:

- Measure levels of pumping, mixing, noise, and thrust
- Obtain data for comparison to CFD
- Validate techniques/facilities for design/testing of these nozzles

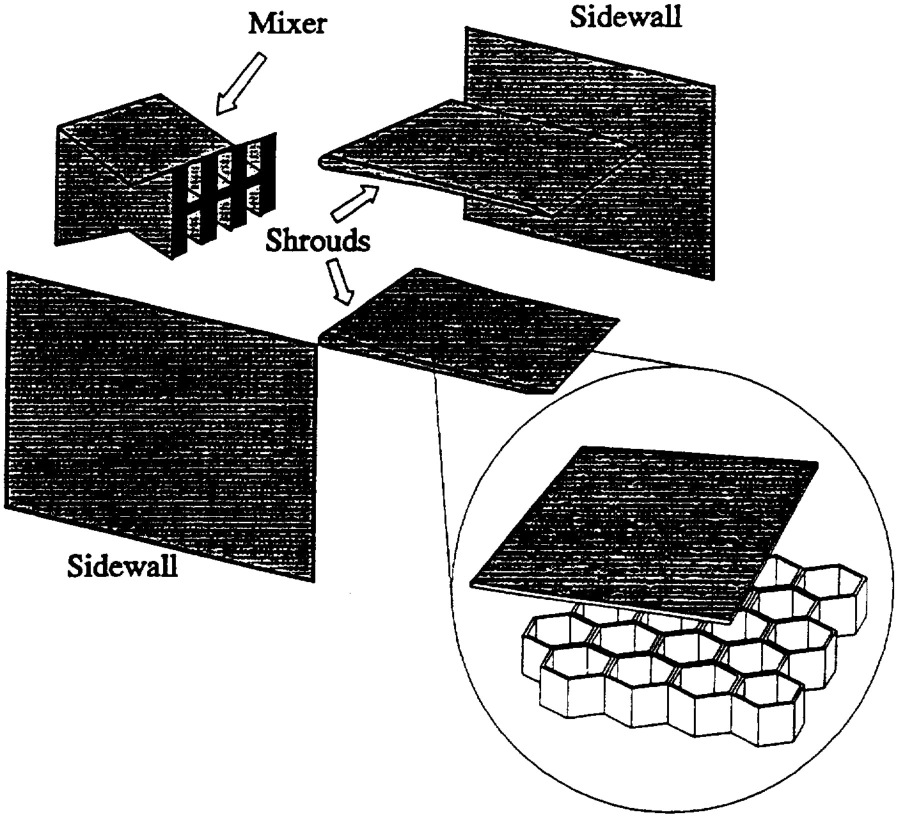
The subject of this study was a new two dimensional mixer ejector nozzle based on the nozzle tested in 1989. The principle difference between the current nozzle and its predecessor is the design of the primary nozzle. These changes were guided by computational studies, which predicted ejector pumping of 145% of the primary flow. The intent of the changes to the design were to increase pumping and mixing and thereby reduce the noise generated by the jet, while maintaining high levels of thrust.

The objectives of the test were to evaluate ejector pumping, mixing, acoustics, and thrust performance relative to the previous test; to obtain detailed data for comparison with computational fluid dynamics; and to validate methods and facilities for the design (P&W) and test (NASA) of this type of hardware.

Anatomy of the HSR P&W 2-D Mixer Ejector Nozzle

Inventory:

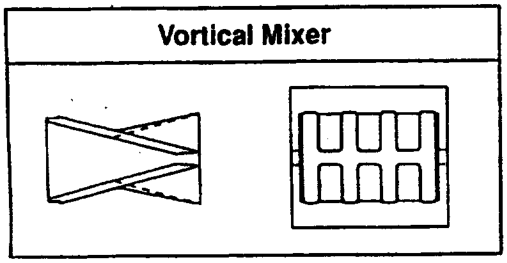
- 2 Mixer Designs
- 3 Shroud Lengths
- 3 Shroud/Sidewall Acoustic Treatments
- Sidewalls with Windows for Flow Visualization

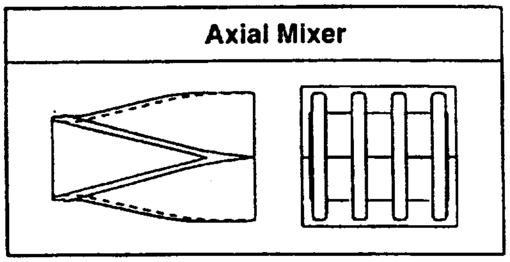


The model consisted of an 8 lobe forced mixer enclosed in an ejector box. The top and bottom of the box were formed by contoured shrouds, whereas the sidewalls were flat plates. This construction was chosen for economy and configuration flexibility. The shrouds could be attached to the sidewalls in one of three spacings to allow variations in primary/secondary area ratio. Shroud boxes in three lengths and three acoustic treatments were constructed. Two mixers were available. In addition, sidewalls with glass windows were built for flow visualization.

The three forms of acoustic treatment were: hardwall (no treatment), bulk, and tuned. Both the bulk and tuned treatments consisted of a honeycomb structure covered by a perforated plate. In the bulk treatment, the honeycomb cells were filled with a broadband acoustic absorber material. In the tuned treatment, the cells were empty, and the height of the cells was tuned to quiet the estimated predominant frequency of the jet noise.

2D Mixer-Ejector Mixer Nozzles


Vortical Mixer

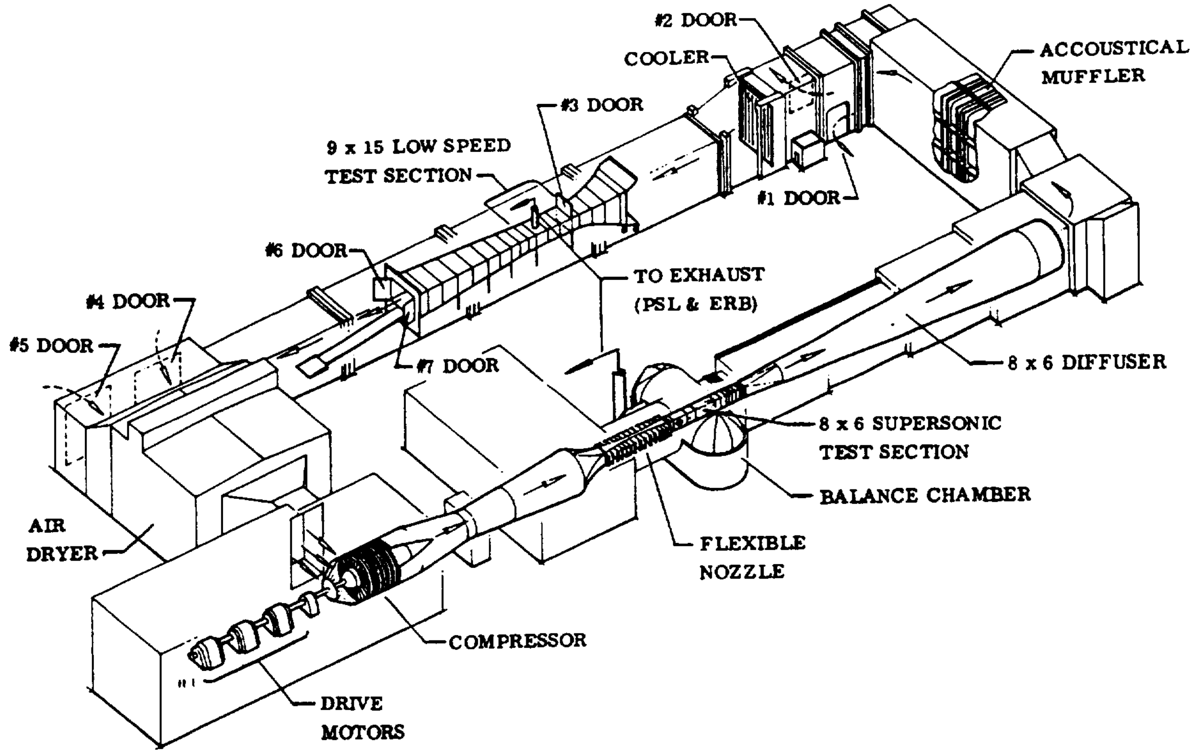

Axial Mixer

Relative Merits

o Non-axial discharge generates large-scale vorticity, promoting rapid mixing o Less wetted surface area o Shorter, more compact design	o Higher thrust performance o More predictable nozzle design
o Non-axial discharge generates higher thrust losses	o Less rapid mixing o Larger wetted area (increased friction) o Longer, less compact

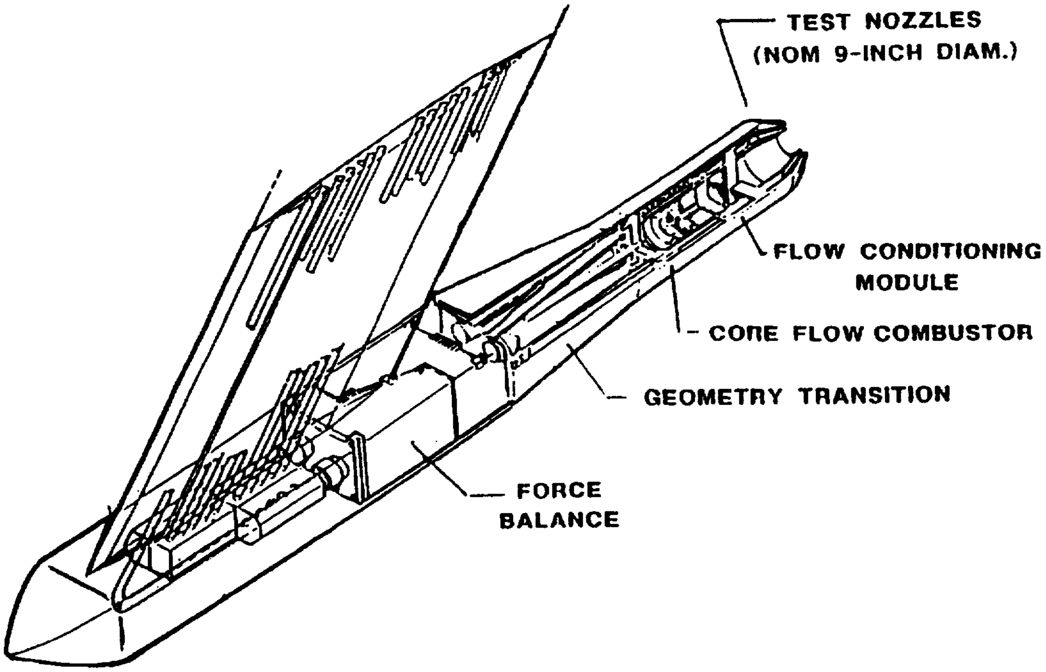
The two mixers tested in this study represented different approaches to achieve substantial mixing. The vortical mixer discharges the hot exhaust at an angle to promote mixing via strong vortices in the axial direction. This approach would be expected to suffer large thrust loss due to the non-axial discharge of the flow. The axial mixer, on the other hand, discharges flow axially, potentially reducing thrust loss at the expense of mixing. The axial mixer is longer, making it heavier, and more difficult to store while in non-suppressor mode.

8-BY 6-FOOT AND 9-BY 15-FOOT WIND TUNNELS



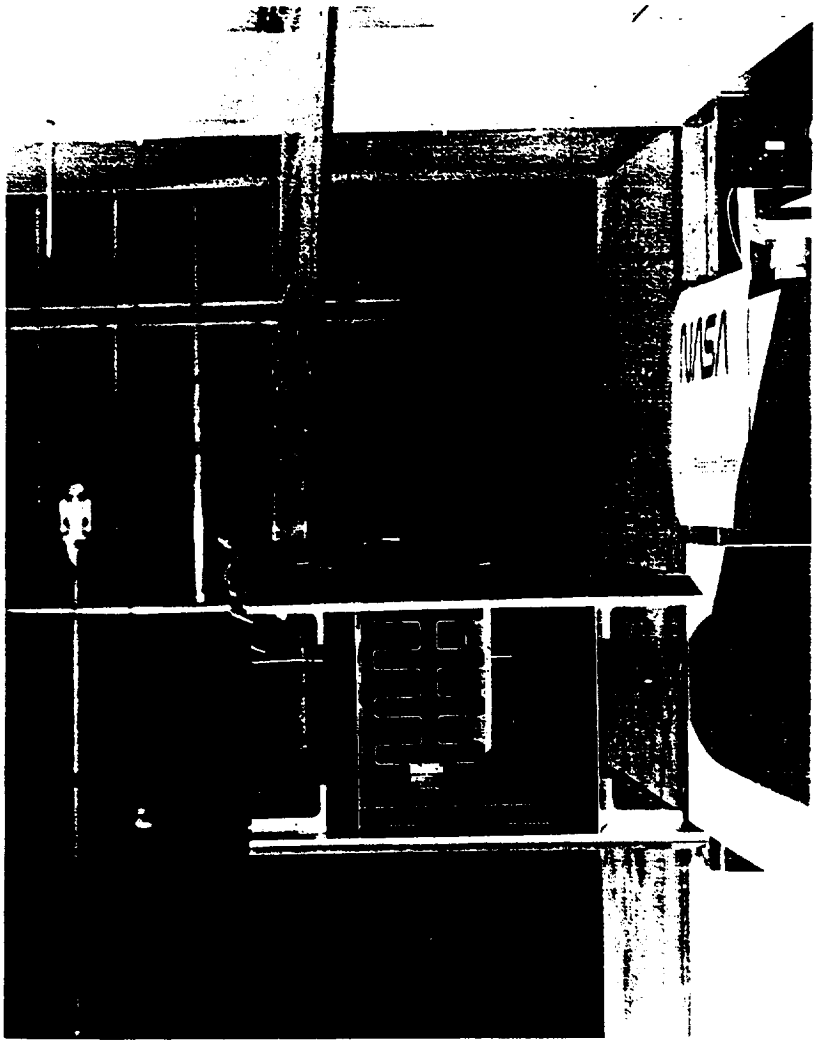
The test was conducted in the NASA Lewis 9- by 15-Foot Low Speed Wind Tunnel (9x15). This facility is a test section in the return leg of Lewis' 8- by 6-Foot Supersonic Wind Tunnel. The 9x15 is capable of wind speeds of 30 to 175 mph (up to Mach 0.2). The test section is lined with acoustic boxes to provide an anechoic environment for acoustic testing. Microphones were placed in the test section to measure noise angles at variouse angles to the model.

JET EXIT RIG WITH TRANSITION FOR AXISYMMETRIC NOZZLES

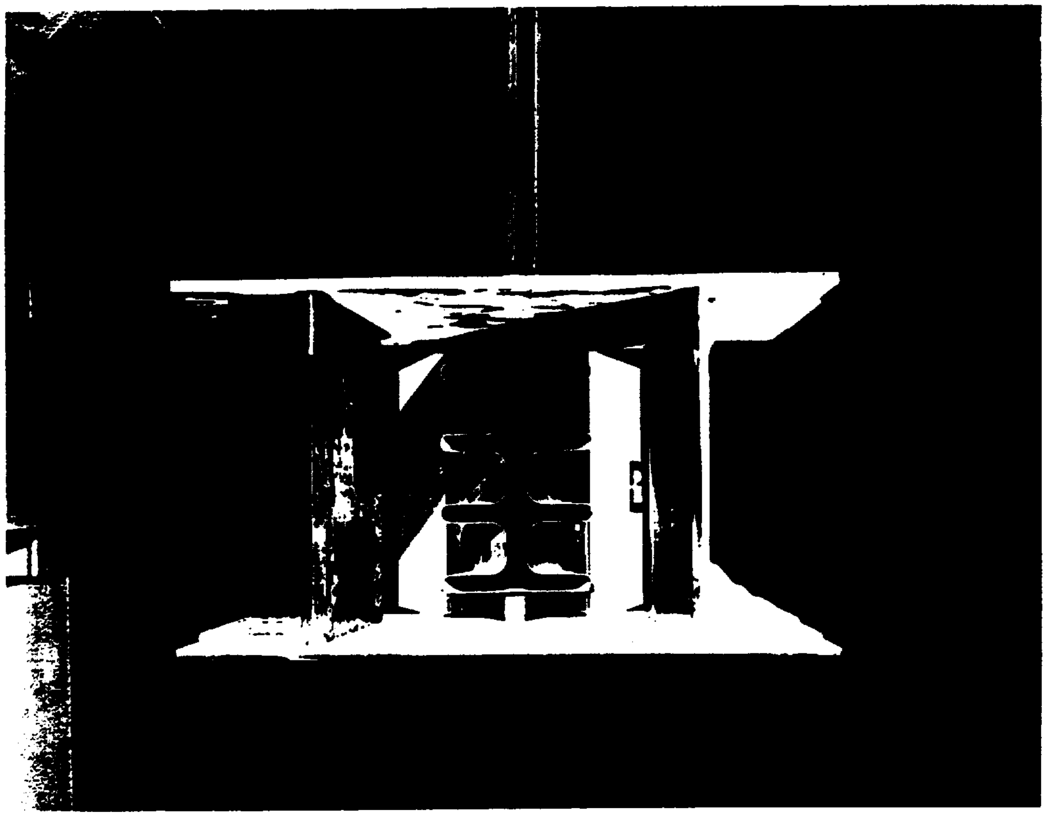


The nozzle was mounted to NASA Lewis' Jet Exit Rig, a small-scale jet engine simulator. The Jet Exit Rig provides two independent streams of air at up to 450 psia. In the axisymmetric configuration shown here, the inner stream can be heated in a hydrogen combustor to up to 2000 degrees Rankine. A flow through balance measures forces on the model. Flow into the jet exit rig is measured by a set of choked flow venturis mounted upstream of the rig. For this test, the outer air passage was blanked off and all air was supplied to the model through the inner stream.

The Jet Exit Rig is a new test rig at NASA Lewis. To date, force balance output from the rig have been unrepeatable. Therefore no forces and moments were acquired. Further testing of the model to obtain this information is currently planned.



This figure shows the model mounted in the wind tunnel. The model is mounted sideways, with the "sidewalls" on the top and bottom. From this view, the lobes of the vortical mixer can be seen. On the walls of the shroud, the bulk acoustic liners can be seen. The microphone arrays (not in picture) are to the left. Note that the model is mounted off the tunnel centerline to allow greater separation between the model and microphone arrays.



This figure shows the 1989 model for comparison with the current nozzle. Most of the visible differences between the two are in the mixer nozzle. The current design incorporates a convergent-divergent primary flow path, as compared to the convergent primary nozzle previously used. The shape and aspect ratio of the mixer lobes were changed based on computational studies of the mixing performance. The current nozzle also included the treated shrouds discussed earlier; the 1989 entry included only hardwall shrouds.

Measurements

- Primary Weight Flow
- Primary Total Conditions (fixed rake)
- Forces & Moments
- Acoustics
- Mixer & Shroud Pressures
- Ejector Exit Total Conditions (traverse rake)
- Ejector Internal Flowfield (schlieren, light sheet)
- Ejector Exit Flowfield (LDV)

A variety of measurements were made to gain an understanding of the characteristics of this model. Temperatures and pressures were measured immediately uptstream of the primary nozzle, in both streams near the mixer exit, and on the shrouds. Forces and moments were measured using the six component flow-through balance in the Jet Exit Rig. Arrays of microphones measured the acoustic output from various directions. A limited number of configurations were studied in further detail using a 15 element total pressure and total temperature traverse rake at the ejector exit plane, and with schlieren, laser light sheet, and laser doppler velocimetry (LDV). The schlieren and laser light sheet testing was performed by K. Mitchell et. al. of NASA Langley and is presented in this symposium.

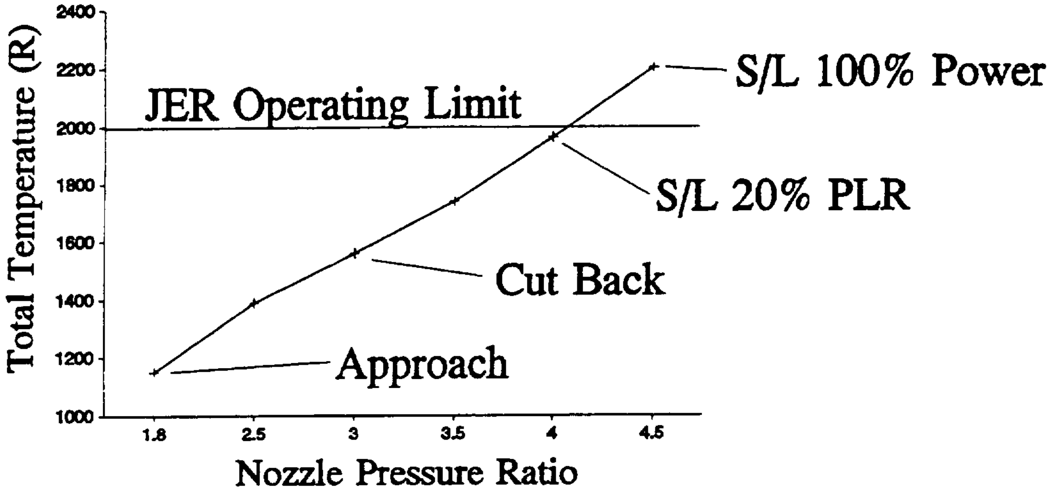
Test Matrix Variables for 2D Nozzle

- Power Setting (NPR and $T_{T,jet}$)
- Tunnel Mach Number
- Primary Nozzle
- Shroud Length
- Ejector Area
- Ejector Treatment

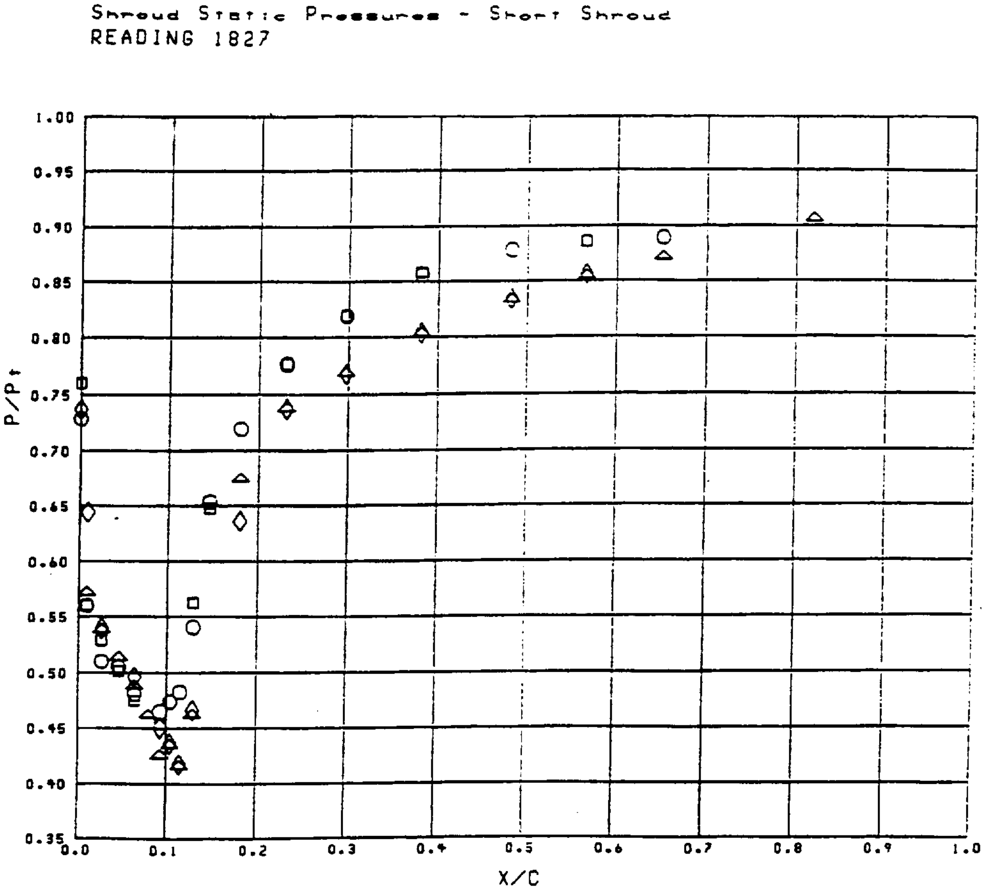
A large number of test variables were studied. Three variables defined the nozzle flow conditions: the nozzle pressure ratio, the primary jet total temperature, and the tunnel Mach number. There were several configuration variables: the choice of nozzle, shroud length, ejector area, and ejector treatment. Typical ranges of these variables were as follows:

NPR	0 - 4.5
$T_{T,jet}$	520 °R - 1960 °R
M_{tunnel}	0 - 0.2
Primary Nozzle	Axial or Vortical
Shroud Length	Short, Long, or Intermediate
Ejector Area	Design, Larger, or Smaller
Ejector Treatment	Hardwall, Bulk, or Tuned

Typical Operating Line (based on PW-STF945)



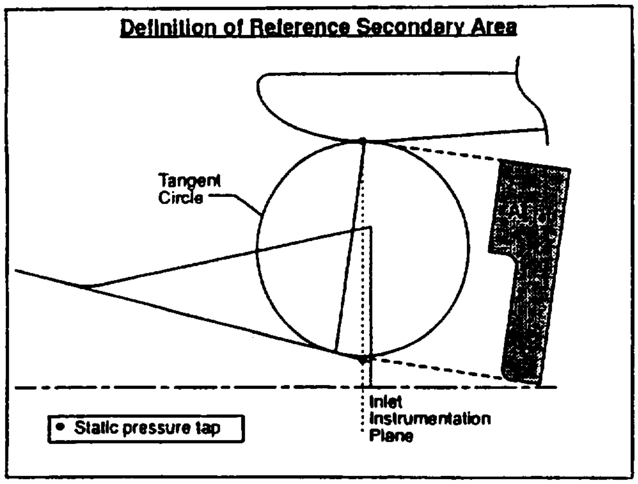
The choice of jet temperature/nozzle pressure ratio pairs for the test matrix was made based on the operating line of the PW-STF945, a Pratt & Whitney turbine bypass engine concept. The jet temperature in the jet exit rig was limited to 2000 °R, so the highest power setting was tested at a lower temperature. The design point for the nozzle was at a NPR of 4.0 and jet temperature of 1960 °R, which corresponds to 80% power at sea level. This setting represents the conditions the nozzle would experience shortly after take-off.



This figure shows the ratios of static to total pressure measured along the shroud wall. The pressure decreases rapidly as the secondary flow is accelerated through the choked secondary throat, and then rises smoothly to ambient pressure. This behavior characterizes the relatively shock-free flow in the ejector and is representative of most configurations.

Ejector Secondary Airflow CFD Calibration Method

- Define a "flow coefficient", $C_{d\text{–}CFD}$, based upon a choked reference area and a representative duct pressure



Definition of Reference Secondary Area

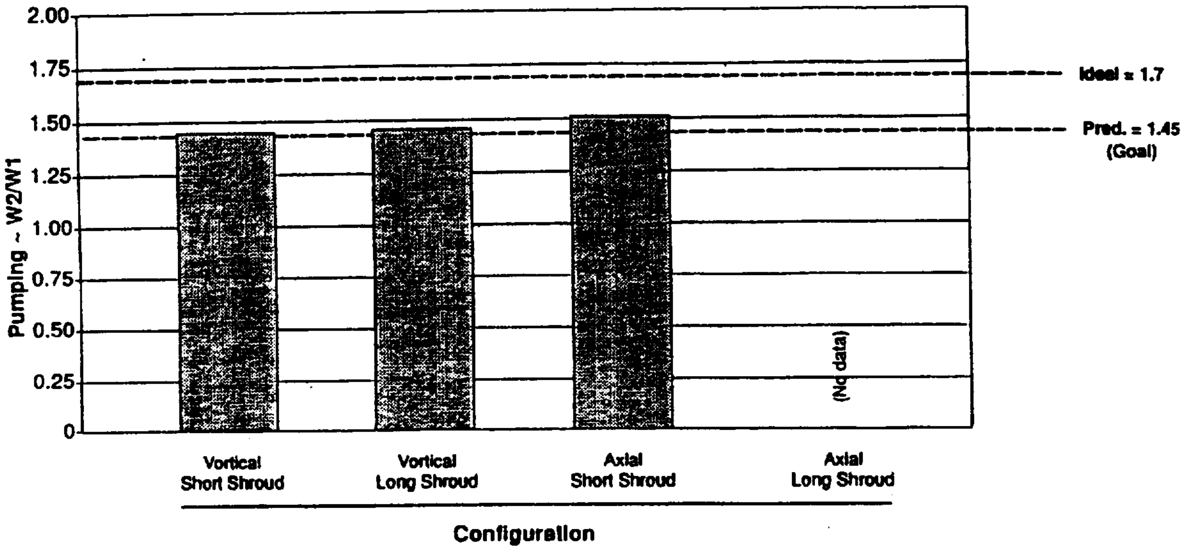
- Define a representative duct pressure:

$$\bar{p}_{sec} = {}^{1}/_{2}\,(p_{shroud} + p_{valley})$$

- Define $w_{s,ref}$ as choked flow at $A_{s,ref}$

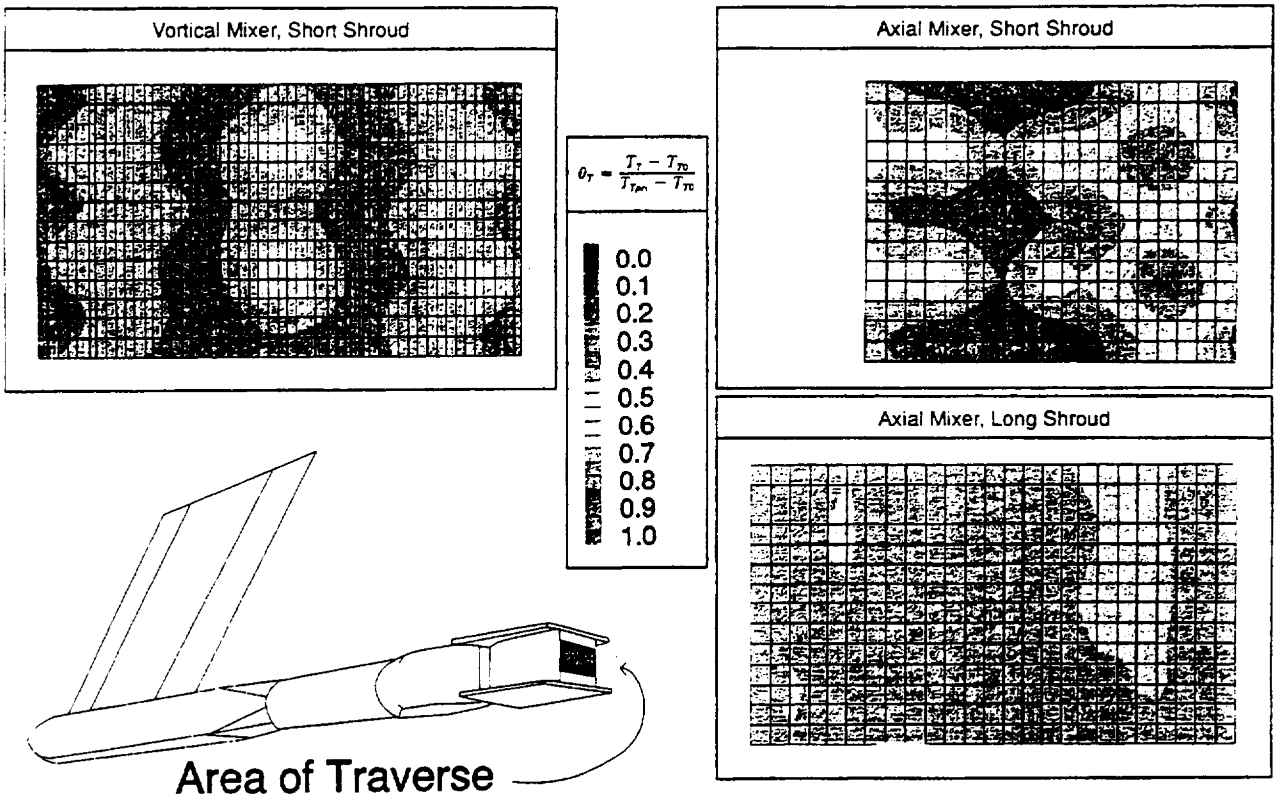
The test setup did not allow for direct measurement of the secondary passage mass flow. Therefore, an alternate method was used for determining this flow. Selected pressures, measured on the shrouds and outside surfaces of the mixer nozzle, were used to determine a representative pressure in this passage. Two CFD studies were made of this secondary passage geometry, one using the VSAero potential flow code, and one using the PARC Navier-Stokes code. From the results of these studies, a discharge coefficient of .95 was calculated for this passage. Mass flow through the secondary duct was calculated as choked flow through a reference area near the exit of the mixer.

Goal Pumping Level Achieved by Both Mixer Nozzles



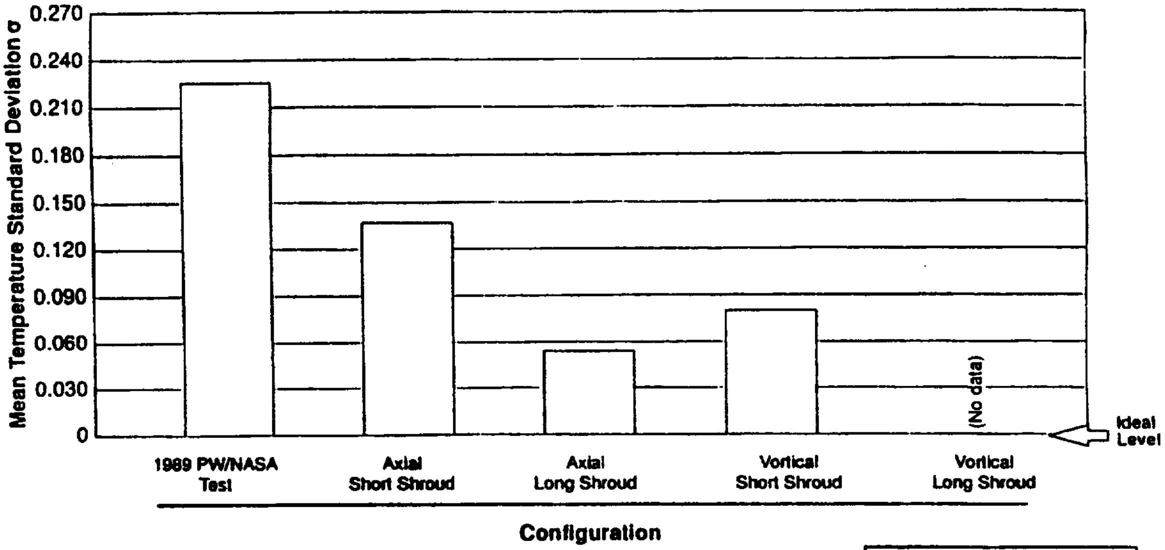
All of the configurations tested showed high levels of pumping. As opposed to the approximately 120% pumping in the 1989 test, these nozzles showed pumping in the 145% to 150% range. This pumping level was found to be independent of the liners used.

Experimental Traverse Results



Rake surveys of the total temperature and total pressure of the flow at the exit of the ejector were performed on several configurations. A non-dimensional temperature parameter was calculated ranging from zero (representing secondary stream inflow temperature) to one (representing primary stream total temperature). Contour plots of this parameter show increased mixing of the streams by the vortical mixer compared to the axial mixer and increased mixing for the long shrouds compared to the short shrouds. These results compare favorably to those of the 1989 test, which showed severe hot streaks near the shroud walls.

Results of Exit Traverse Show Improved Mixing



$$\theta_T = \frac{T_T - T_{T\infty}}{T_{T_{prim}} - T_{T\infty}}$$

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(\theta_T - \bar{\theta}_T)^2}$$

The standard deviation of the temperature parameter over the survey region yields a relative measure of the mixing in the nozzle; lower standard deviation indicates greater uniformity which implies better mixing of the streams. Applying this metric to the 1989 test and the current test, the newer mixers exhibited improved mixing.

Summary

Two nozzles in multiple configurations were tested. Aero results were:

- Significant increases in pumping and mixing were obtained relative to the previous test.
- The vortical mixer showed greater mixing than the axial mixer.
- Liners did not have significant effects on pumping.
- Force balance data were unrepeatable. Further testing is planned to get these data.