ASSESSMENT OF INTEGRATED NOZZLE PERFORMANCE

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Presentation Outline

9'x15' Wind Tunnel PAI Test Results (PAIHSR1)

Mixer/ejector Inlet Distortion, an Experimental Study (MIDIS-E)

High-lift Engine Aero-acoustic Technology Test Plans (HEAT)

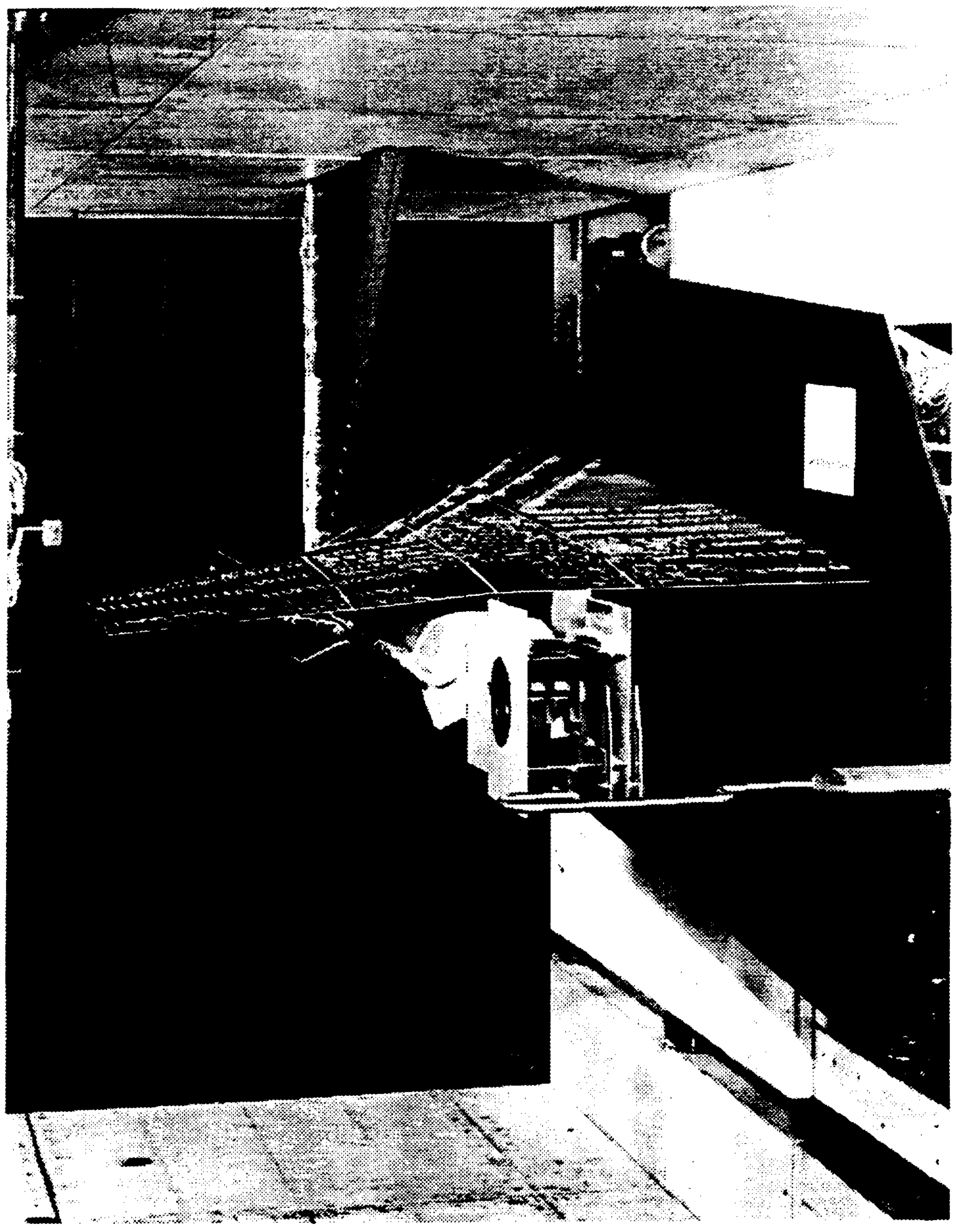
This presentation highlights the activities that researchers at the NASA Lewis Research Center (LeRC) have been and will be involved in to assess integrated nozzle performance. Three different test activities are discussed. First, the results of the Propulsion Airframe Integration for High Speed Research 1 (PAIHSR1) study are presented. The PAIHSR1 experiment was conducted in the LeRC 9'x15' wind tunnel from December 1991 to January 1992. Second, an overview of the proposed Mixer/ejector Inlet Distortion Study (MIDIS-E) is presented. The objective of MIDIS-E is to assess the effects of applying discrete disturbances to the ejector inlet flow on the acoustic and aero-performance of a mixer/ejector nozzle. Finally, an overview of the High-Lift Engine Aero-acoustic Technology (HEAT) test is presented. The HEAT test is a cooperative effort between the propulsion system and high-lift device research communities to assess wing/nozzle integration effects. The experiment is scheduled for FY94 in the NASA Ames Research Center (ARC) 40'x80' Low Speed Wind Tunnel (LWST).

PAIHSR1 Research Objectives

Primary Objective- Determine effects on the acoustic characteristics of a two-dimensional mixer/ejector nozzle due to the non-uniform flow from a wing entering the ejector inlet

Secondary Objective- Determine first-order effects on the aero-performance of a two-dimensional mixer/ejector nozzle due to the non-uniform flow a wing entering the ejector inlet

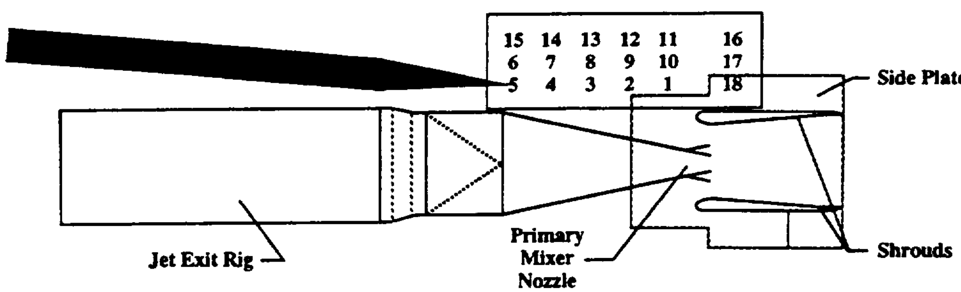
The PAIHSR1 experiment had two objectives. The primary objective was to determine integration effects on the acoustic performance of a two-dimensional mixer/ejector nozzle. The secondary objective was to determine integration effects on the aero-performance of the same two-dimensional mixer/ejector nozzle. Unfortunately, combustor failure precluded the acquisition of acoustic data. Warmed facility air (~200°F) was used for the primary flow to assess changes in mixing at the nozzle exit.



This figure is a photograph of the PAIHSR1 model hardware installation in the LeRC 9'x15' Wind Tunnel. The model hardware included a semi-span wing model, the Pratt & Whitney two-dimensional mixer/ejector nozzle with a vortical mixer, and the LeRC Jet Exit Rig (JER). The semi-span wing model had a generic supersonic planform and deflectable leading and trailing edge flaps. The section of the wing trailing edge directly above the JER, referred to as the interfairing, was not deflectable. Tufts, visible in the photograph, were applied to the wing for flow visualization study. One of the variable parameters in the experiment was ejector inlet orientation. The suppressor nozzle orientation shown is the horizontal orientation, with the ejector inlets oriented sideways with respect to the wing.

Test Parameters

Mach Number	0.2
Primary Nozzle Pressure Ratio	1.4, 1.7, 2.5, 3.0, 3.5, 4.0/4.2
Ejector Inlet Orientation	Vertical, Horizontal
Shroud Length	Short, Long
Flap deflection (LE/TE)	0°/0°, 0°/20°, 20°/40°
Wing Interfairing Length	Short, Long
Wing Position	



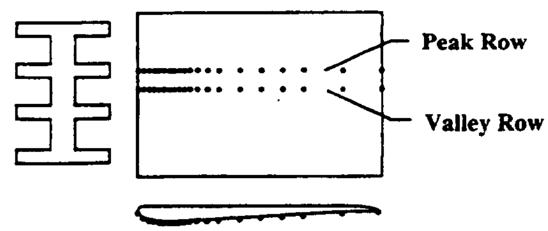
Six parameters were varied during the PAIHSR1 test: primary nozzle pressure ratio (NPR), ejector inlet orientation, shroud length, leading edge (LE) and trailing edge (TE) flap deflection, wing interfairing length, and wing position. Data was primarily recorded at the maximum tunnel Mach number of 0.2. The NPR was varied from 1.4 to ~4.0. Two ejector inlet orientations were examined: horizontal, as shown two pages previously, and vertical, with the ejector inlets oriented on the top and bottom with respect to the wing. Two shroud lengths were studied: long and short. were studied. Three sets of leading and trailing edge flap deflections were selected: 0° LE/0° TE, 0° LE/20° TE, and 20° LE/40° TE These sets of deflections were not selected to represent particular flight configurations but to create different flowfields in the proximity of the ejector inlets. Two interfairing lengths were studied: long and short. Finally, the wing was mounted to a positioning table that allowed the wing trailing edge location to vary axially and vertically with respect to the nozzle. Eighteen predefined positions were examined. A matrix showing the relative location of the different positions is shown.

Nozzle Instrumentation

Shroud Static Pressures

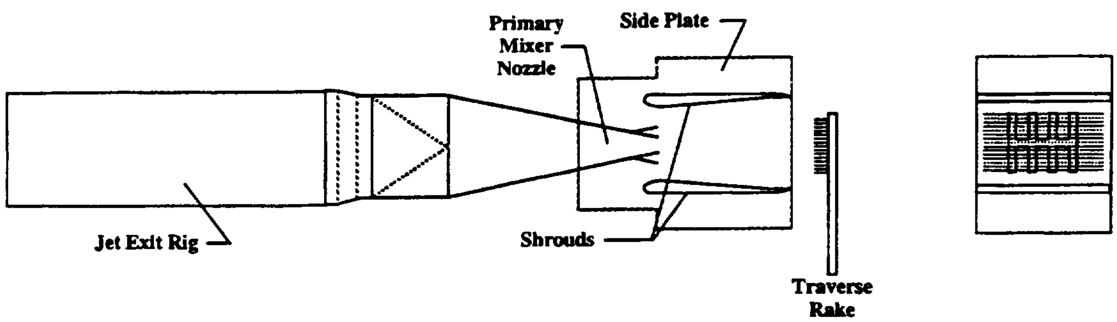
2 Rows of 20 static pressures

- **Primary mixer peak**
- **Primary mixer valley**



Nozzle Exhaust Flow Traverse

- **15 total pressure measurements**
- **15 total temperature measurements**



The data analyzed for this presentation are the shroud static pressures and the nozzle exhaust flow traverse total temperatures and total pressures. Two rows of 20 static pressures each are distributed axially along the nozzle's interior shroud walls. One row is located over the peak of a primary mixer lobe, the other over the valley of a primary mixer lobe. The shroud static pressure profiles are presented as a shroud static pressure ratio defined as Ps_{shroud}/Pt_0, where Pt_0 is the tunnel total pressure. A traverse rake was used to assess the nozzle exhaust flow total temperature and total pressure contours. The traverse rake included 15 total temperature and 15 total pressure measurements. The nozzle exit total temperature contours were examined to identify changes in the mixing characteristics of the nozzle due to integration effects. The total temperature measurements are presented as a non-dimensionalized contour value defined as $(T_T - T_{Tsecondary})/(T_{Tprimary} - T_{Tsecondary})$. The wing tuft flow visualization was recorded on video tape, and proved useful in understanding the nozzle data and installation effects.

Focus of Data Analysis

Vertical Ejector Inlet Orientation

- **Effect of varying wing position**
  - **Long shroud**
  - **Short shroud**
- **Effect of varying interfairing length**

Horizontal Ejector Inlet Orientation

- **Effect of varying wing position for fixed LE/TE flap deflections**
- **Effect of varying LE/TE flap deflections for fixed wing position**

The data for the PAIHSR1 experiment was divided into two sets for parametric analysis: data recorded with the vertical nozzle orientation and data recorded with the horizontal nozzle orientation. Data recorded with the vertical ejector inlet orientation was examined to asses the effect of varying wing interfairing length, wing position with the long shroud installed, and wing position with the short shroud installed. Data recorded with the horizontal ejector inlet orientation was examined to assess the effect of varying wing position for each set of leading edge and trailing edge flap deflections. The same data was also examined to assess the effect of varying leading edge and trailing edge flap deflections at fixed wing positions.

Experimental Results

Combuster failure precluded taking acoustic measurements - warmed facility air was used for the primary flow to assess mixing

Preliminary data was obtained which indicated no first-order PAI effects of the wing on the aero-performance of a two-dimensional mixer/ejector nozzle

- **Unrealistic flap deflections (20°LE/40°TE) were required to show any first order effects**
- **Varying wing position at extreme flap deflections resulted in noticeable changes**

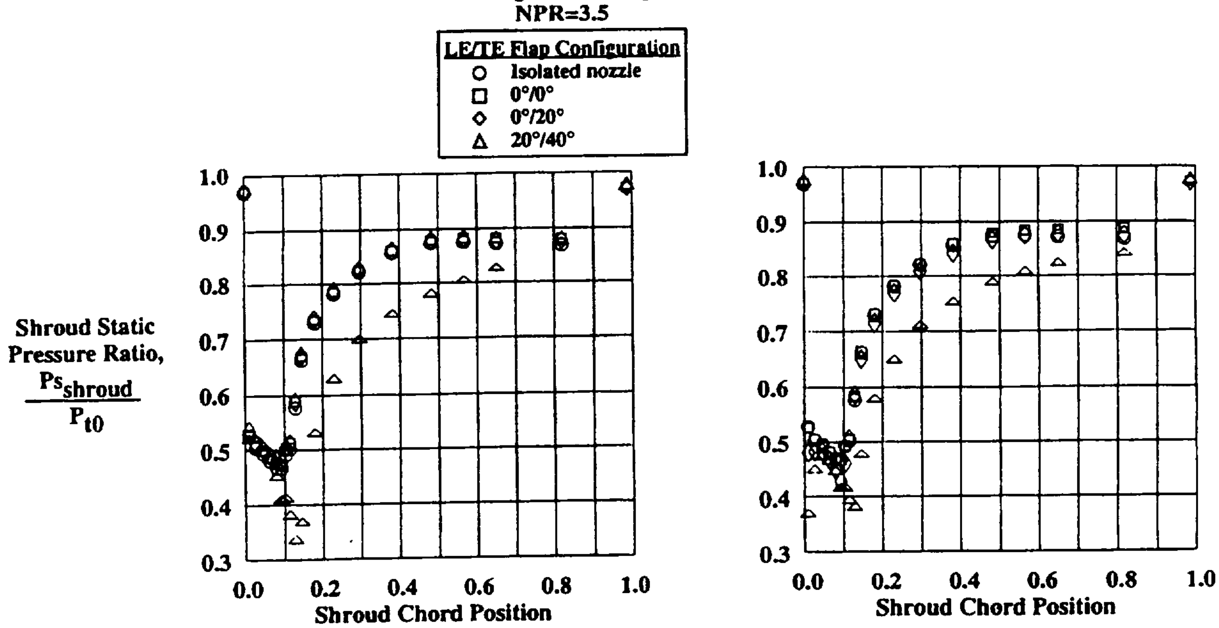
The absence of measureable effects for most test configurations may have been a result of the hardware configuration and limited instrumentation

The PAIHSR1 experimental results indicate that for most of the configurations examined there are no first order effects of the wing on the aero-performance (shroud static pressure profiles and nozzle exhaust total temperature contours) of a two-dimensional mixer/ejector nozzle. Combustor failure precluded acquisition of acoustic data, however warmed facility air was used for the primary nozzle flow to assess nozzle mixing. Extreme flap deflections of 20° LE/40° TE were required to show any first order changes in the static pressure profiles or nozzle exhaust total temperature contours. At this extreme set of flap deflections, varying wing position resulted in changes in the static pressure profiles. It is appropriate to note that test limitations may have contributed to the absence of measurable PAI effects. In order to facilitate variation in wing position, the wing was placed closely above the JER, but the JER was not integrated onto the lower surface of the wing. Further, both the nozzle and external flowfield instrumentation were limited.

Experimental Results

Effect of Varying LE/TE Flap Deflections on the Inboard Shroud Static Pressures

Horizontal nozzle orientation
Short shroud
Long interfairing
NPR=3.5

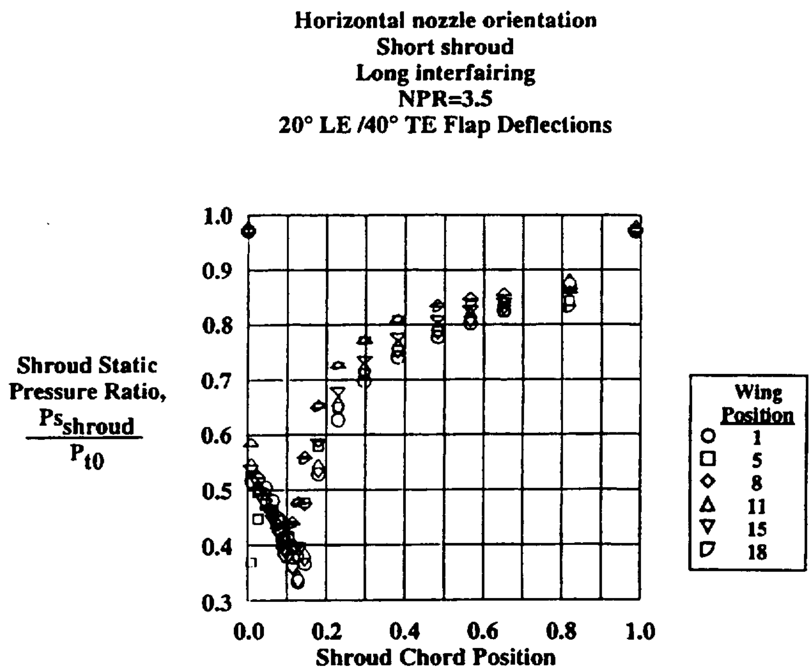


Wing Position 1   Wing Position 5

This figure demonstrates the integration effects observed on the shroud static pressure ratio profiles as a result of varying LE/TE flap deflections. Shroud static pressure ratios are presented as a function of shroud chord position for two different wing positions. Wing position 1 is low and aft with respect to the nozzle, while wing position 5 is low and forward. The data shown was recorded on the inboard shroud for the horizontal nozzle orientation at an NPR of 3.5. The long interfairing and short shroud were installed. Each plot shows the shroud static pressure ratios for the installed nozzle for each set of LE/TE flap deflections, as well as for the isolated nozzle. For both wing positions, the pressure ratio profiles obtained with 0° LE/0° TE and 0° LE/20° TE flap deflections are nearly identical to the profile for the isolated nozzle. The pressure ratio profiles obtained for 20° LE/40° TE flap deflections are significantly lower than the profiles for the other three cases. For all the wing positions examined, the profiles recorded at 20° LE/ 40° TE flap deflections were significantly lower than the profiles recorded for the isolated nozzle or the other flap configurations. The decrease in pressure along the shrouds may indicate an increase in the velocity of the entrained flow and, hence, increased pumping and thrust performance. The pressure decrease may also result from the entrainment of low pressure separated flow off the trailing edge flap. Flow visualization indicated regions of separated flow off the trailing edge flap for 40° deflection, although the flow in the immediate vicinity of the ejector inlets may have remained attached. Entraining separated flow may result in decreased pumping and thrust performance.

Experimental Results

Effect of Varying Wing Position on the Inboard Shroud Static Pressures at Extreme LE/TE Flap Deflections

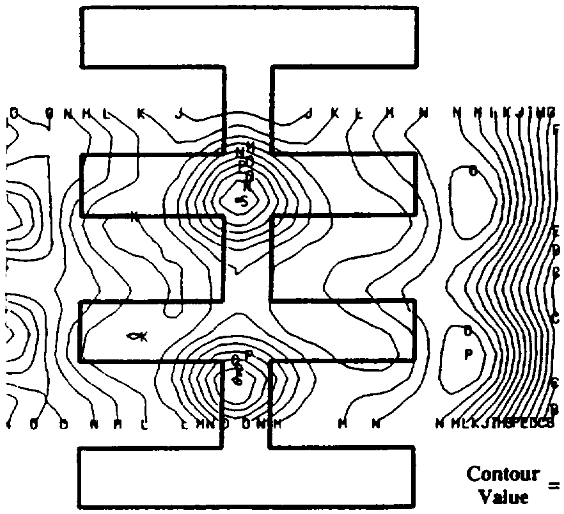


This figure demonstrates the effect of varying wing position on the shroud static pressure ratio profiles for extreme 20° LE/40° TE flap deflections. Shroud static pressure ratios are presented as a function of shroud chord position for six different wing positions. The data shown was recorded on the inboard shroud for the horizontal nozzle orientation at a NPR of 3.5. The long interfairing and short shroud were installed. As mentioned before, flow visualization indicated regions of separated flow off the trailing edge flap for 40° deflection, although the flow in the immediate vicinity of the ejector inlets may have remained attached. There is noticeable variation in the pressure ratio profiles for the different wing positions. The variation in the profiles is partly a function of the relative position of the deflected trailing edge flap to the ejector inlet. Varying wing position affected the acceleration of the entrained flow and the amount of separated flap flow in the proximity of the ejector inlets that may have been entrained.

Experimental Results

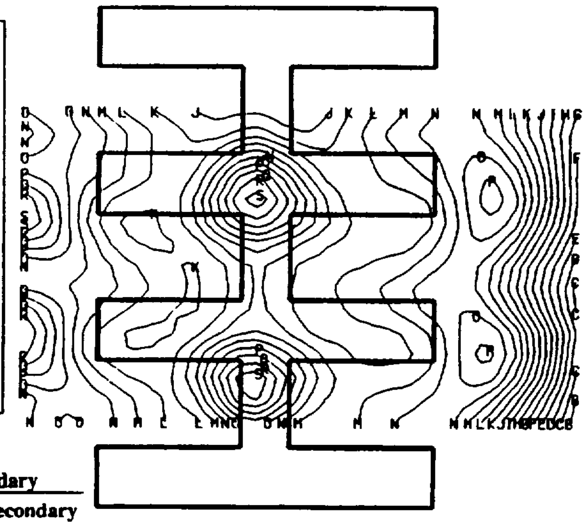
Effect of Varying LE/TE Flap Deflection on the Nozzle Exhaust Total Temperature Contours

Horizontal nozzle orientation
Short shroud
Long interfairing
NPR=3.5



Contour Label	Contour Value
E	0.16
F	0.20
G	0.24
H	0.28
I	0.32
J	0.36
K	0.40
L	0.44
M	0.48
N	0.52
O	0.56
P	0.60
Q	0.64
R	0.68
S	0.72
T	0.76

$$\text{Contour Value} = \frac{T_T - T_{T\ secondary}}{T_{T\ primary} - T_{T\ secondary}}$$



Isolated nozzle

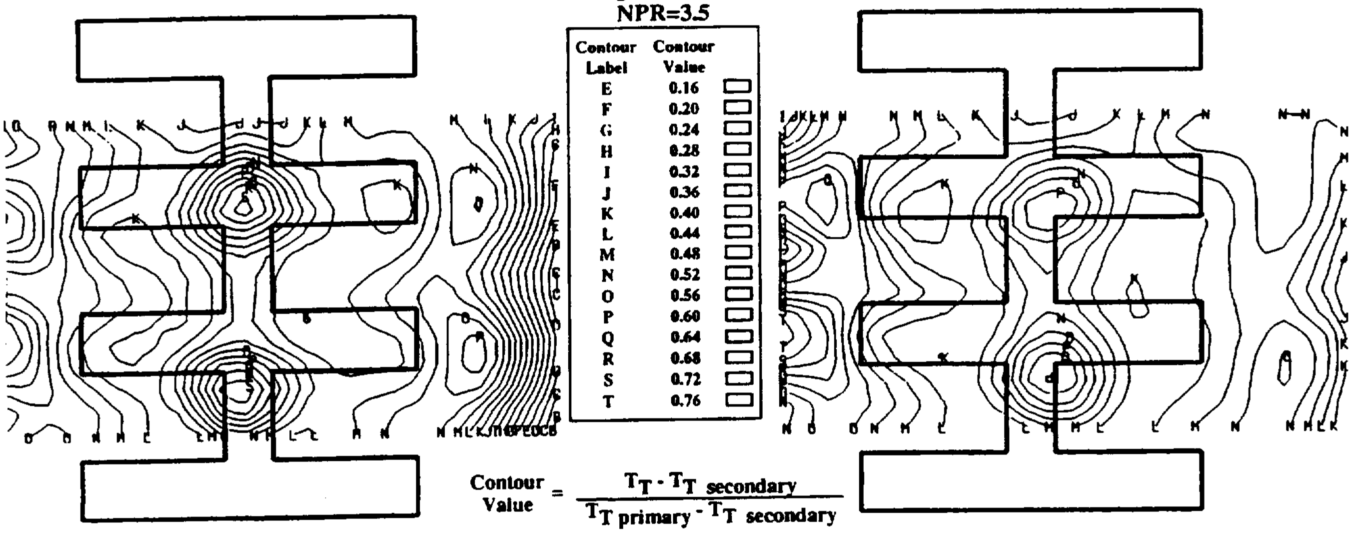
Wing Position 5
0° LE/0° TE Flap Deflections

The next two figures demonstrate the effect of varying leading and trailing edge flap deflections on the nozzle exhaust total temperature contours. The nozzle exhaust total temperature contours shown were recorded for the horizontal nozzle orientation at a NPR 3.5. The long interfairing and short shroud were installed. This figure shows the total temperature contours for the isolated case and for 0° LE/0° TE flap deflections at wing position 5 (low and forward with respect to the nozzle). For the data shown on this figure, there is negligible difference in the location and intensity of the contour "hot spots", implying little change in the mixing characteristics of the nozzle.

Experimental Results

Effect of Varying LE/TE Flap Deflection on the Nozzle Exhaust Total Temperature Contours

Horizontal nozzle orientation
Short shroud
Long interfairing
NPR=3.5



Wing Position 5
0° LE/20° TE Flap Deflections

Wing Position 5
20° LE/40° TE Flap Deflections

This figure shows the nozzle exhaust total temperature contours recorded at wing position 5 (low and forward with respect to the nozzle) for both 0° LE/20° TE and 20° LE/40° TE flap deflections. Comparison of the total temperature contours for 0° LE/20° TE flap configuration with the contours for the isolated nozzle and the 0° LE/0° TE flap configuration on the previous figure show negligible difference in hot spot location or intensity, again implying little change in the nozzle mixing characteristics. Comparison of the contours for the 20° LE/40° TE flap configuration with the other three cases, however, shows that the contour hot spots for the 20° LE/40° TE flap configuration have decreased in intensity from 0.72 to 0.60 , and have shifted slightly downward and to the right. The changes in the contours appear consistent will either entrainment of separated flap flow or increased secondary flow velocity.

PAISHR1 Comments

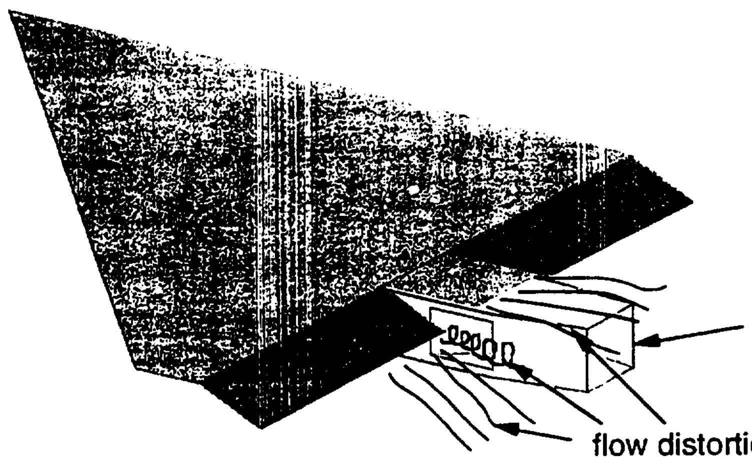
- Isolated mixer/ejector nozzle testing may provide a viable method for designing the nozzle system, but higher-order PAI effects of an integrated nozzle, nacelle, and wing need to be understood
- Wing influences on the acoustic characteristics of a two-dimensional mixer/ejector nozzle still need to be determined
- Future test configurations of a mixer/ejector nozzle integrated with a wing should include a nacelle and pylon/diverter as well as increased internal and external flowfield measurements

In summary, the PAIHSR1 results indicate that isolated nozzle testing provides a viable method for the aero-performance design of a two-dimensional mixer/ejector nozzle system. Higher-order installation effects of an integrated mixer/ejector nozzle, nacelle, and wing on the nozzle flowfield and thrust performance need to be understood. Further, PAI effects on the acoustic performance of two-dimensional mixer/ejector nozzle still need to be determined. Based on the PAIHSR1 experiment, it is recommended that future PAI test configurations of a mixer/ejector nozzle and wing include a nacelle and pylon/diverter to more accurately model integration. Most importantly, future test configurations should include increased internal and external flowfield measurements.

OBJECTIVES

Gain a better understanding of the fluid dynamics of integrating an HSCT mixer-ejector nozzle with the airframe, and the impact on acoustics and aeroperformance.

What are the effects of flow distortion due to the wing, pylon, and flaps, that may be ingested by the ejector inlets?

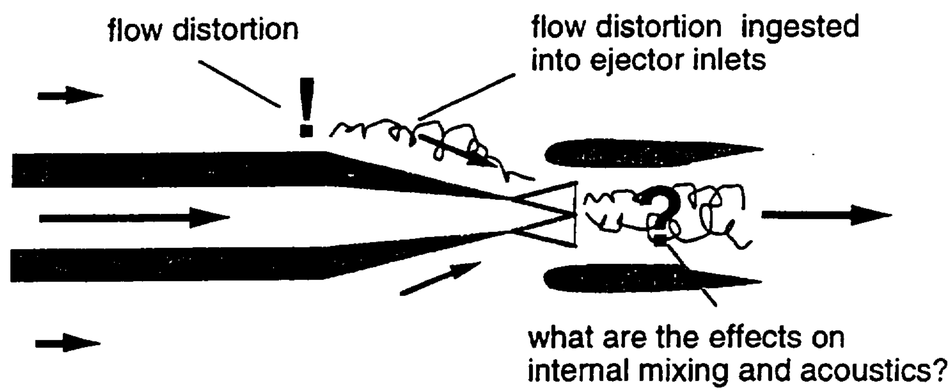


An experimenal study of mixer-ejector nozzle inlet distortion (MIDIS-E) is planned. This is a fundamental study of propulsion-airframe integration (PAI) for an HSCT mixer-ejector nozzle, in the NASA LeRC Nozzle Acoustic Test Rig (NATR). The objective of this study is to gain a better understanding of the fluid dynamics of integrating an HSCT mixer ejector nozzle with the wing, and its impact on acoustics. A more fundamental understanding of the flow physics may help designers to reduce the detrimental PAI effects, and take advantage of the constructive ones. Also, the results may be helpful in designing and interpreting data from future configuration oriented PAI tests, such as the HEAT test.

APPROACH

Discrete flow distortions, representative of flow features off the wing, pylon and flaps, will be applied upstream of ejector inlets.

Separating the overall flowfield into discrete components, and applying each one individually, is analogous to the technique used to study engine inlet distortions. A more fundamental understanding can be gained by studying the effect of each flow feature individually.



Discrete flow distortions will be applied upstream of the ejector inlets, that are representative of flow features expected near the ejector inlets of an installed nozzle, such as the flap nearfield wake, pylon wake, wing shear layer, etc. In contrast, a configuration-oriented test where a nozzle is installed on a model wing-flap-pylon can provide information on the effects of the overall distorted inflow on the acoustics, aeroperformance and mixing; however, it may not be clear as to which particular aspects of the distorted inflow are responsible for the observed effects. By isolating and studying the effect of each flow feature individually, a deeper and more fundamental understanding of the effects of particular flow distortions can be gained. This technique is similar to that used for engine inlet distortion studies; in this way, appropriate idealized flow distortions can be produced without having to construct a model of the entire aircraft forebody or wing.

APPROACH

Most of the time consuming flow surveys will be made with the nozzle running on warm air.

The applicability of the Munk and Prim approximate similarity principle will be verified. The principle asserts that properly chosen nondimensional performance parameters of the nozzle are similar, regardless of the temperatures of the incoming flows, as long as their Mach number and total pressure distributions are the same.

Existing hardware and instruments will be used to advantage

A parallel CFD study will be conducted

If the Munk & Prim approximate similarity principle can be verified for this type of flow, then scaling of cold flow nozzle data to the hot flow case can be done in a more rigorous way and with greater confidence. The principle has been investigated for turbofan forced mixers and STOVL-type ejectors, among other configurations, but apparently not yet explicitly for HSCT type mixer-ejector nozzles. The Pratt & Whitney 2-D vortical mixer nozzle with a short shroud will be used as the baseline configuration.

MEASUREMENTS

Detailed flowfield measurements

A. ejector inlet plane and upstream: flow angle surveys

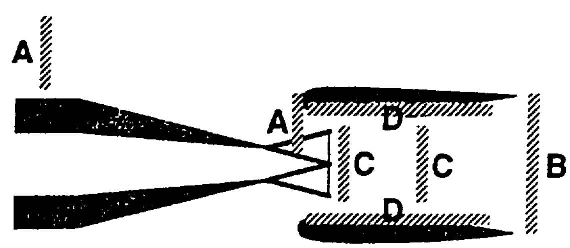
B. ejector exit plane: total pressure, total temperature and static pressure surveys

C. mixing region: 2 component LDV surveys

D. surface static pressure taps

Acoustic measurements

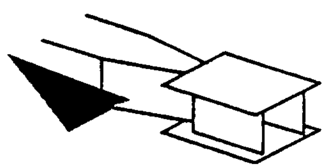
Simple flow visualization



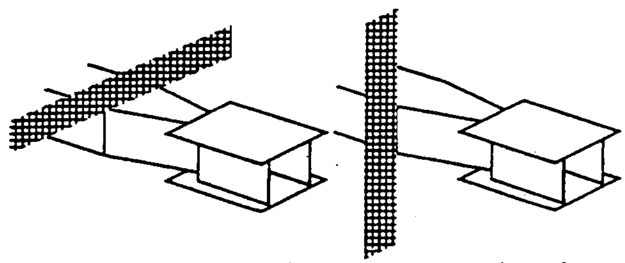
In order to gain greater insight into the nozzle fluid dynamics, detailed flow measurements will be made upstream of the ejector inlets, at the nozzle exit, and inside the mixing region. This information will also be useful for evaluating the Munk and Prim similarity principle.

FLOW DISTORTION DEVICES

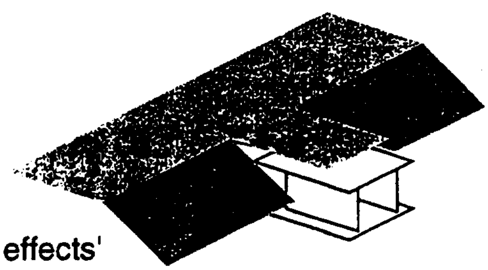
Typical distortion generators, to model flow features found in wing - flap - pylon flowfields. Attempt to match the relevant flow parameters, e.g. vortex size and circulation, BL displacement and momentum thicknesses, etc.



vortex generator for
flap tip vortex



screens for wing shear layer, two nozzle orientations



bent plate for 'flap effects'

Typical flow distortion devices are depicted.

HEAT Test Research Objectives

Identify suppressor-entrained flow effects on the efficiency of the high-lift device concepts under consideration for the HSR

Identify integration effects on the aero and acoustic performance of an HSR mixer/ejector suppressor nozzle

- **Quantify changes in the acoustic, force, and moment measurements**
- **Identify and *understand* the flow phenomena contributing to the changes**
- **Obtain an integrated design database for "optimizing" subsequent suppressor nozzle designs for integration; minimizing the impact of adverse flow dynamics, capitalizing on positive flow dynamics**

Cooperative effort between the High-Lift and Suppressor Nozzle Research communities to investigate wing/nozzle integration effects

ARC, LaRC, LeRC, and Industry collaboration

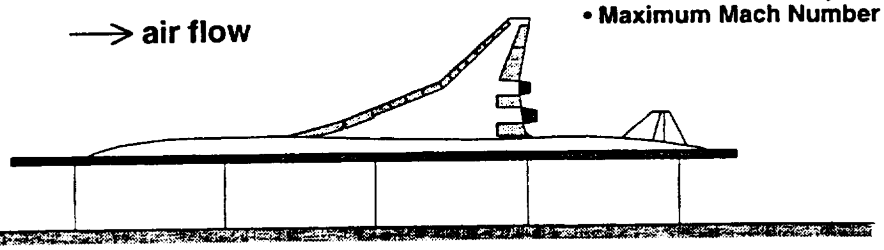
The HEAT test is scheduled for FY94 in the ARC 40'x80' LSWT, and represents a collaboration between NASA's Ames, Langley and Lewis Research Centers, as well as industry. From the High-lift perspective, the research objective is to identify the effects of secondary entrainment on the efficiency of the high-lift device concepts under consideration for the HSR program. From the propulsion system perspective, the HEAT test objective is to identify integration effects on the aero and acoustic performance of an HSR mixer/ejector suppressor nozzle. More specifically, there are three goals. The first is to quantify the changes in the nozzle acoustic, force and moment performance resulting from integration. The second is to identify and understand the flow phenomena contributing to the changes. The third is to obtain an integrated design database for use in subsequent suppressor nozzle designs. An understanding of integrated nozzle performance would allow designers to minimize the impact of adverse flowfield phenomena and capitalize on beneficial flowfield phenomena.

HEAT Test Hardware Description

- 13.5% semi-span model installation in the ARC 40'x80' Low Speed Wind Tunnel
  - Wing shape based on the Reference H geometry
- HSR suppressor nozzle
- Two nacelles, based on the Reference H geometry
  - Inboard powered nacelle with suppressor nozzle
  - Outboard flow-through nacelle
- Appropriate high-lift devices
- Take-off and climb-out configurations

40x80 Flow Characteristics:

- Turbulence intensity 0.5 %
- Maximum Mach Number 0.5



A sketch of the proposed HEAT test model hardware installation is shown. The HEAT test model includes a semi-span wing installation, one HSR suppressor nozzle, two nacelles, and high-lift devices. The wing planform and nacelle shapes are based on the Boeing Reference H geometry definition. The suppressor nozzle will be mounted on the inboard nacelle, and powered with a propane burner. The outboard nacelle will be a flow-through nacelle. The 40'x80' LSWT has a maximum tunnel Mach number of 0.5, thus both take-off and climb-out configurations can be examined.

HEAT Test Status

Semi-span model design underway

Design of symmetry plane acoustic treatment underway

- **Initial test to verify symmetry plane acoustic treatment scheduled for November '92 in ARC 7'x10' wind tunnel**

Instrumentation definition

- **Near and farfield acoustic measurements**
- **Force and moment data for the integrated configuration as well as the isolated nozzle**
- **Flow visualization**

Additional instrumentation being considered

- **Assessment of wing flowfield via increased wing and nacelle static pressures and flow visualization**
- **Assessment of the ejector inlet flowfield using removeable inlet rakes**
- **Assessment of nozzle exhaust flow characteristics via total pressure/total temperature contours or laser technology measurements**
- ***Limited* assessment of the nozzle internal flow characteristics from shroud and wall static pressures**

The HEAT test planning is underway. The semi-span model design has been initiated. The design of the acoustic treatment for the symmetry plane has also been initiated. A preliminary test to verify the symmetry plane design is scheduled for November '92 in the ARC 7'x10' wind tunnel. The current instrumentation definition includes near and farfield acoustic measurements, force and moment data for integrated configuration as well as the isolated nozzle configuration, and flow visualization. Additional instrumentation is being considered to better assess the ejector inlet flowfield, the nozzle exhaust flow characteristics, the external flowfield, and to make a limited assessment of the nozzle internal flow characteristics.