NASA/TM—2007-213601/PART1

A 1/10 Scale Model Test of a Fixed Chute Mixer-Ejector Nozzle in Unsuppressed Mode

Part 1: Test Overview

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December 2007

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A 1/10th Scale Model Test of a Fixed Chute Mixer-Ejector Nozzle in Unsuppressed Mode Part 1: Test Overview

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Abstract

This paper discusses a test of a nozzle concept for a high-speed commercial aircraft. While a great deal of effort has been expended to understand the noise-suppressed, take-off performance of mixer-ejector nozzles, little has been done to assess their performance in unsuppressed mode at other flight conditions. To address this, a 1/10th scale model mixer-ejector nozzle in unsuppressed mode was tested at conditions representing transonic acceleration, supersonic cruise, subsonic cruise, and approach. Various configurations were tested to understand the effects of acoustic liners and several geometric parameters, such as throat area, expansion ratio, and nozzle length on nozzle performance. Thrust, flow, and internal pressures were measured. A statistical model of the peak thrust coefficient results is presented and discussed.

Introduction

To be accepted by airlines, regulatory agencies in various countries, and the general public, a new supersonic passenger aircraft would have to meet strict environmental guidelines while maintaining a high level of efficiency and cost effectiveness. NASA’s High Speed Research (HSR) program sought to develop the technologies needed to meet these challenges. One such challenge is to meet or exceed noise regulations during operations at or near airports. As much of the noise generated by aircraft comes from the exhaust, nozzle technology development is a key to building a system that is both environmentally acceptable and economically viable. This paper reports the results of a 1/10th scale model test of a low noise, high efficiency nozzle concept (ref. 1) developed under the HSR program.

To provide a focus for mission studies and technology development in HSR, a baseline mission was defined: to transport 300 passengers up to 3000 nautical miles (5556 km) at a speed of Mach 2.4. The aircraft was to take off from a conventional runway, with take-off and climb-out noise levels below FAR Part 36, Stage 3 regulations. As techniques to reduce sonic boom to acceptable levels proved elusive, the mission profile included a subsonic cruise leg for operations over land as well as a supersonic cruise leg over water.

A jet noise reduction concept that been much studied in recent years is the mixer-ejector nozzle (refs. 1 to 7). In this concept, the hot, high-speed engine exhaust gas is mixed with entrained ambient air (fig. 1(a)). The resulting cooler, slower exhaust stream produces less noise than the unmixed engine exhaust. Acoustic liners on the walls of the ejector shroud reduce noise produced in the mixing process. This process results in losses, which must be minimized the make the concept viable.

Noise reduction is not required, however, during other parts of the aircraft mission. Moreover, as the aircraft speed increases, the ram drag losses associated with the ejector increase. Therefore the mixer-ejector nozzle is converted to a more conventional two-dimensional variable geometry nozzle for these parts of the aircraft mission. This is accomplished by closing off the ejector inlet and using the flap system of the ejector shroud to control nozzle throat area and expansion ratio (fig. 1(b)).

The nozzle thus has two modes of operation. During take-off and climb-out, when jet noise reduction is needed, the mixer-ejector system is deployed in “suppressed mode.” For the rest of the mission, that is, acceleration, cruise, airport approach, and landing, the nozzle operates in “unsuppressed mode.”

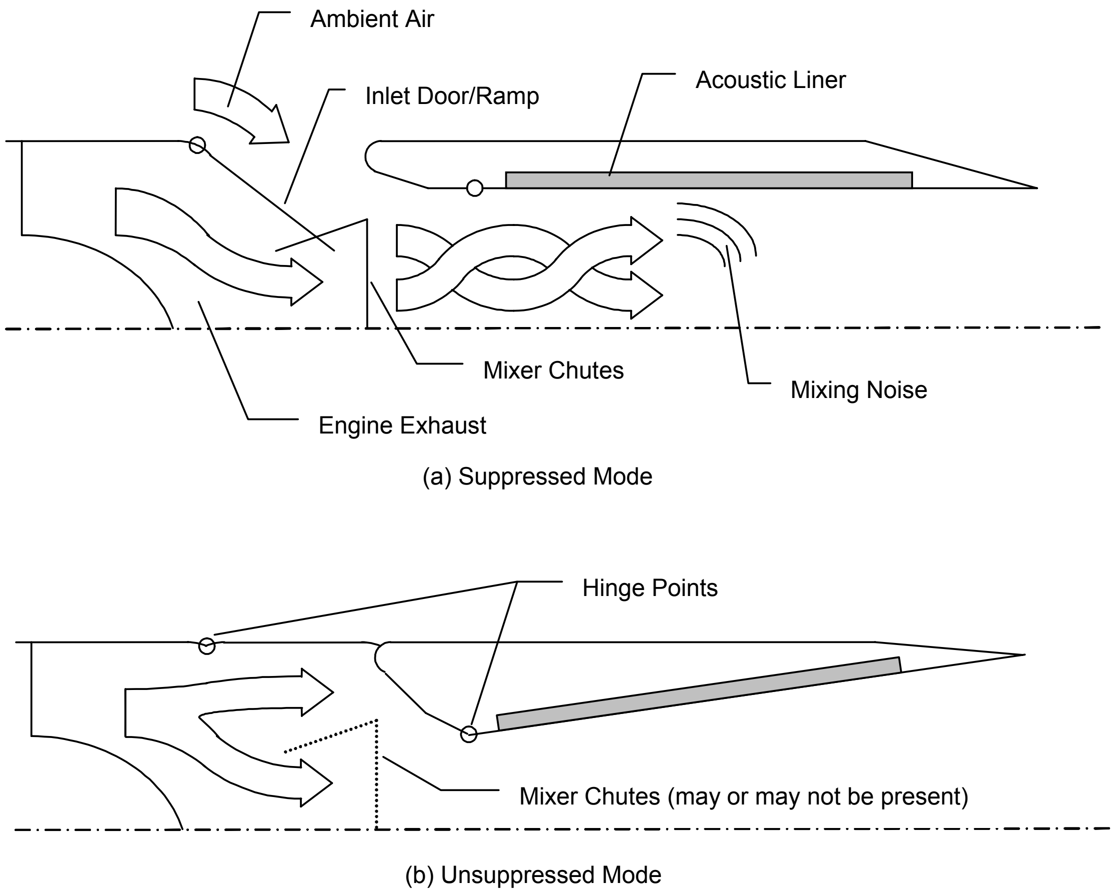

Figure 1.—Mixer-ejector nozzle operation.

The ejector shroud in the nozzle design under study is box-shaped, with two sidewalls forming the sides of the box and two flaps forming the top and bottom of the box. The internal faces of the sidewalls are flat, with the contoured flaps sandwiched between them, so that the flap position can be changed to control the nozzle areas. The flaps are also hinged to allow them to form a convergent-divergent nozzle shape during unsuppressed mode operations. Therefore, the parts of the flap system are referred to as the convergent flaps and the divergent flaps.

During the course of the HSR Program, several nozzle concepts were developed and studied (ref. 8). Two mixer-ejector concepts were selected for development: The Down Stream Mixer (DSM; fig. 2) and the Fixed Chute Nozzle (FCN; fig. 3). Both were two-dimensional nozzles with a three-dimensional lobed mixer. The difference between the two concepts was that in the DSM the mixer chutes are moved out of the flow stream during unsuppressed operation, whereas in the FCN they are left in the flow stream throughout the aircraft mission (fig. 4). In August of 1995, the FCN nozzle was chosen as the concept to be demonstrated at the end of the HSR program.

The selection of the FCN nozzle was made in part because of the simplicity of the design. The DSM, in contrast, required actuators to move the chutes out of the flow stream, resulting in a heavier nozzle. The selection was made based on calculations showing that due to the low Mach numbers in the duct upstream of the throat, the drag and loss of total pressure caused by leaving the mixer in the flow stream would be manageable. However, the sensitivity of the calculated total pressure loss to the initial assumptions was large. Therefore it was felt that a test to verify the calculation was necessary.

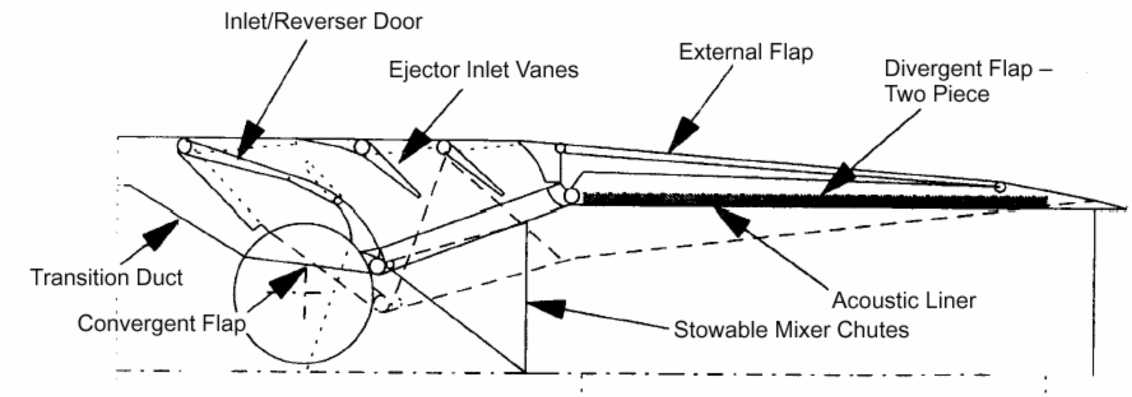

Figure 2.—Down stream mixer (DSM) nozzle.

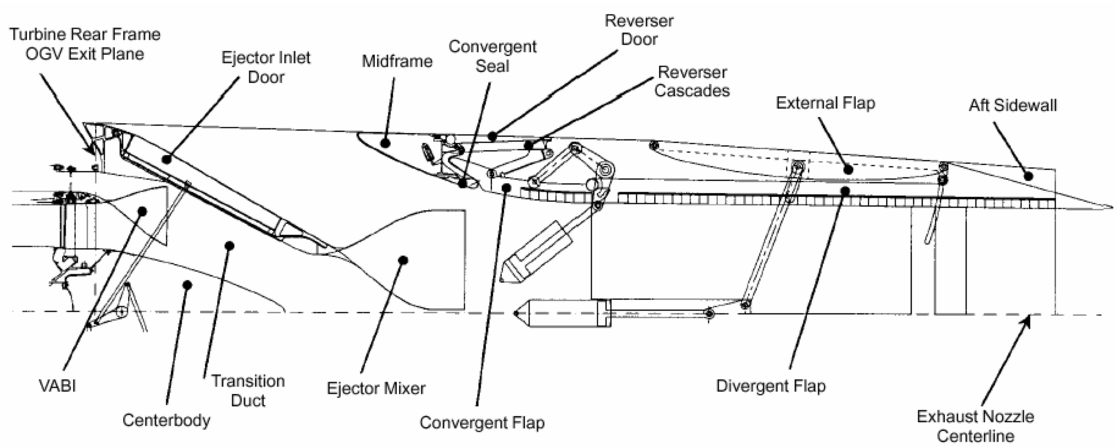

Figure 3.—Fixed chute nozzle (FCN).

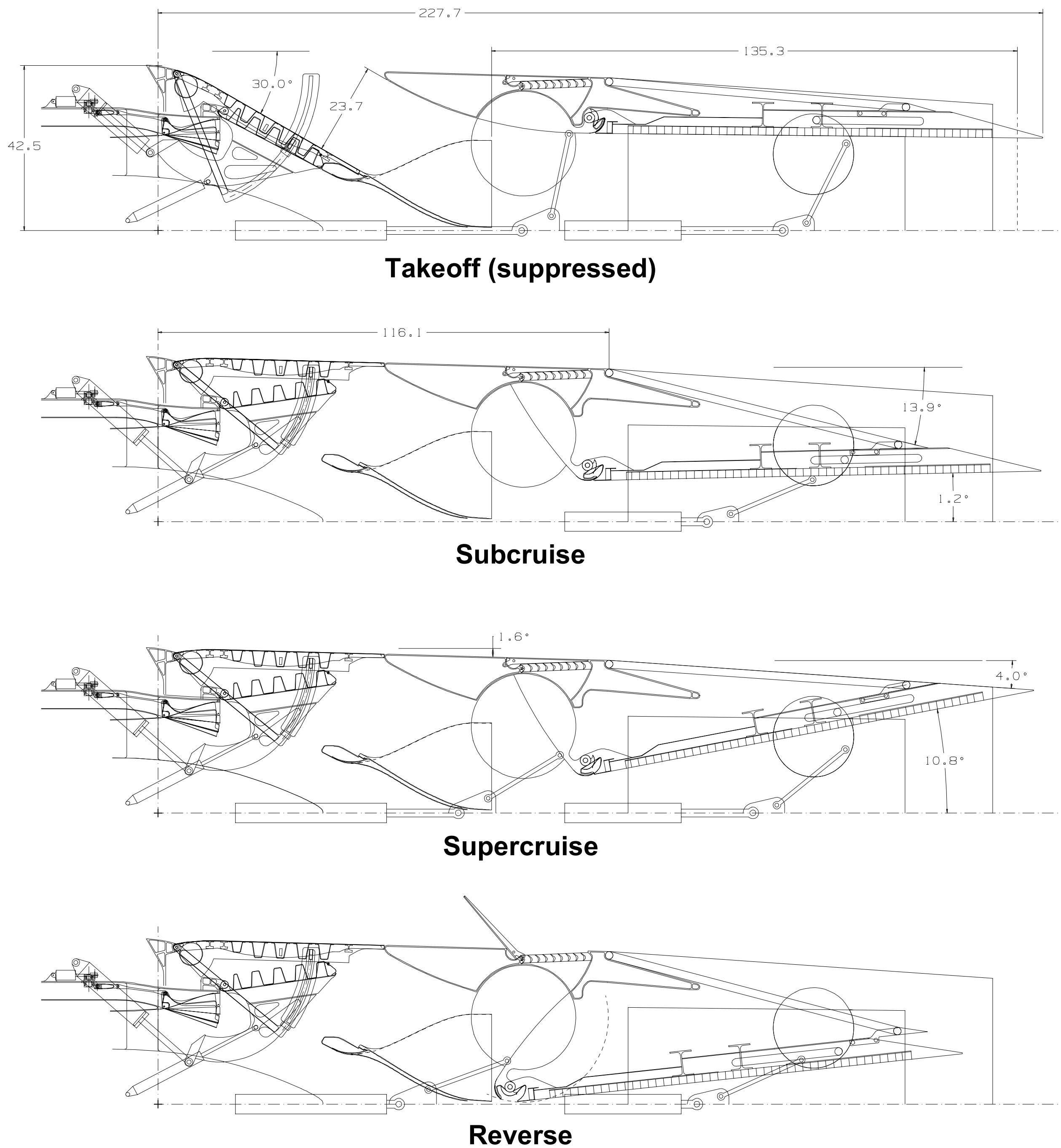

Figure 4.—Operating modes of the fixed chute nozzle.

Other unknowns of the FCN design included the effects of acoustic liners and sidewall length on thrust performance. The acoustic liners are used in a complex environment, involving mixing flows of different temperatures and speeds. There are few existing data that can be applied to this problem. In addition, while there are some data in the literature on perforated plate liners, they are primarily for liners used for cooling that have much lower porosity.

Nozzles for supersonic flight are by nature large to expand the exhaust flow to high velocities. Because of this, the weight of the exhaust system can be very sensitive to changes in the nozzle design. Truncating the nozzle sidewalls short of their optimal length was considered as a means of reducing nozzle weight. The shorter sidewall means that flow along the sidewall will exit the nozzle before it has fully expanded, resulting in a thrust loss. To determine the optimal sidewall length, an examination of nozzle performance at several sidewall lengths was needed.

Nomenclature

A_8	Nozzle throat area, in.^{2}
A_9	Nozzle exit area, measured at exit of flaps, in.^{2}
C_D	Nozzle discharge coefficient, nondimensional
C_{FG}	Gross thrust coefficient, nondimensional
F_G	Gross thrust measured by force balance, lbf
F_{STR}	Stream thrust parameter, nondimensional
g_c	Conversion constant, equal to 32.174 lbm/slug
HSR	High Speed Research
NPR	Nozzle Pressure Ratio, equal to P_T/P_0, nondimensional
P_0	Static pressure in test tank, psia
P_T	Total pressure entering nozzle, psia
R	Gas constant, 53.35 ft lbf/lbm °R
T_T	Total temperature entering nozzle, °R
V_{ID}	Velocity of ideally expanded flow, ft/sec
W_{ID}	Ideal weight flow, lbm/sec
W_{MEAS}	Measured weight flow, lbm/sec
γ	Ratio of specific heats, equal to 1.4 for cold air, nondimensional

Apparatus

Model

The test article was a 1/10th scale model of the FCN. The ejector inlet doors and the nozzle thrust reversers were modeled in their closed positions with fixed hardware. The model was designed and built in a modular fashion so that combinations of the relevant factors could be explored.

To summarize the variations possible with this model, there are:

(1) 2 transition ducts (clean and mixer)
(2) 3 throat areas (subsonic cruise, supersonic cruise, and approach)
(3) 14 flap angles (but only 21 throat area/flap angle combinations)
(4) 4 wall treatments (solid wall, solid wall tray, grid rib, parallel rib)
(5) 3 sidewall lengths

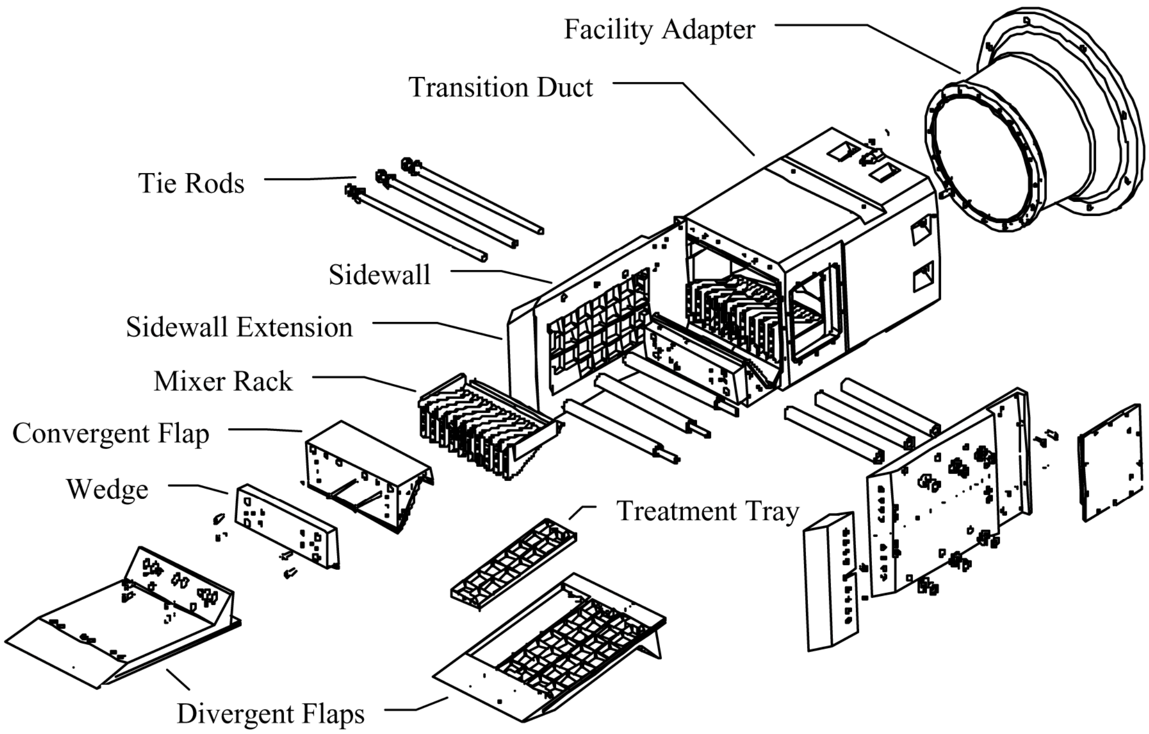

Figure 5.—Exploded view of model.

Figure 5 shows an exploded view of the model. Shown in the upper right corner of the figure, an adapter connects the model to the facility. To this adapter is attached the transition duct, which includes a round-to-rectangular transition as well as the mixer chute racks. A second, interchangeable transition duct part (not shown) is similar, but without the mixer chute racks. This second transition duct is referred to as the “clean” duct. Comparison of the results from these two transition ducts gives the insertion losses associated with the mixer chute racks.

Downstream of the transition duct is the ejector shroud section. On the upper and lower surfaces are flap assemblies, comprising a convergent flap, a wedge, and a divergent flap. The convergent flap of the FCN rotates to control throat area in unsuppressed operation. In the model, three sets of convergent flap pieces represent different positions of the convergent flap corresponding to the subsonic cruise and approach conditions, the supersonic cruise condition, and the transonic condition. The wedge in the model is a simple representation of the hinge between the convergent and divergent flaps. Fourteen sets of wedges simulate various positions of the hinge. The divergent flap provides a flat expansion surface for the exhaust flow.

To simplify model configuration changes, the sidewalls were cantilevered from the aft surface of the transition section. Six tie rods clamped the sidewalls to the flap assembly. These tie rods would not be present in a production nozzle. Instead, the flaps and sidewalls would be held together by the actuator assemblies that position the flaps.

The length of the sidewall has an impact on the performance and weight of the nozzle. Weight savings can be obtained by shortening the sidewalls, but this must be balanced against underexpansion losses. To quantify this trade-off, the sidewalls were designed to a minimum length, and two sets of sidewall extensions were built. Thus three sidewall lengths were tested: short (20.40 in.; 51.82 cm), medium (21.48 in.; 54.56 cm) and long (22.56 in.; 57.30 cm).

In the divergent flaps and sidewalls, four wall treatments were tested: solid wall, solid wall tray treatment, parallel rib treatment, and grid rib treatment. The first, solid, wall featured smooth, solid flow surfaces without any steps or gaps. The remaining three treatments were designed to understand the


Figure 6.—Rear view of treatment trays: parallel rib (top), grid rib (middle), solid wall (bottom).

impact of having acoustic liners in these parts of the nozzle. The sidewalls and divergent flaps had cutouts in them to allow the insertion of trays, representing different types of liners. Three sets of trays were tested.

Figure 6 shows the backs (i.e., the surfaces not wetted by the flow) of the three types of tray. The first was solid wall (bottom in figure). The results from this treatment were compared to the solid wall sidewalls and divergent flaps to assess the impact of the potential steps and gaps associated with the tray design. The other two tray sets had a perforated facesheet covering a bulk acoustic absorber material. The parallel rib treatment (top in figure) has ribs separating sections of absorber material. However, there was concern that flow might migrate behind the facesheet from the high-pressure region near the throat to the low-pressure region near the exit, reducing the thrust performance of the nozzle. The grid rib treatment (middle in figure) has lateral ribs to prevent this.

Note that in figure 3, Outlet Guide Vanes (OGV) and a Variable Area Bypass Injector (VABI) to mix the fan and core streams are depicted. Neither of these parts was simulated in the present experiment.

Facility

Testing was conducted in NASA Glenn Research Center's Advanced Nozzle Test Facility (figs. 7 and 8), commonly known as CE-22 (refs. 9 and 10). The test stand in this facility, housed in a cylindrical, 7.5 ft (2.29 m) diameter, 23 ft (7.01 m) long tank, provides nozzle internal performance assessment at simulated pressure altitudes of up to 48,000 ft (14,600 m). Air is supplied to the primary nozzle at up to 40 psig (0.28 MPaG). Flow rate is measured using a bellmouth flow measuring section, calibrated to ASME standard nozzles. Forces are measured using a 6-component loadcell-based force balance. All testing was performed with unheated air. Nozzle inlet conditions were measured by a 5 element total temperature rake and a 14 element total pressure rake mounted upstream of the nozzle entrance (not shown in figures).

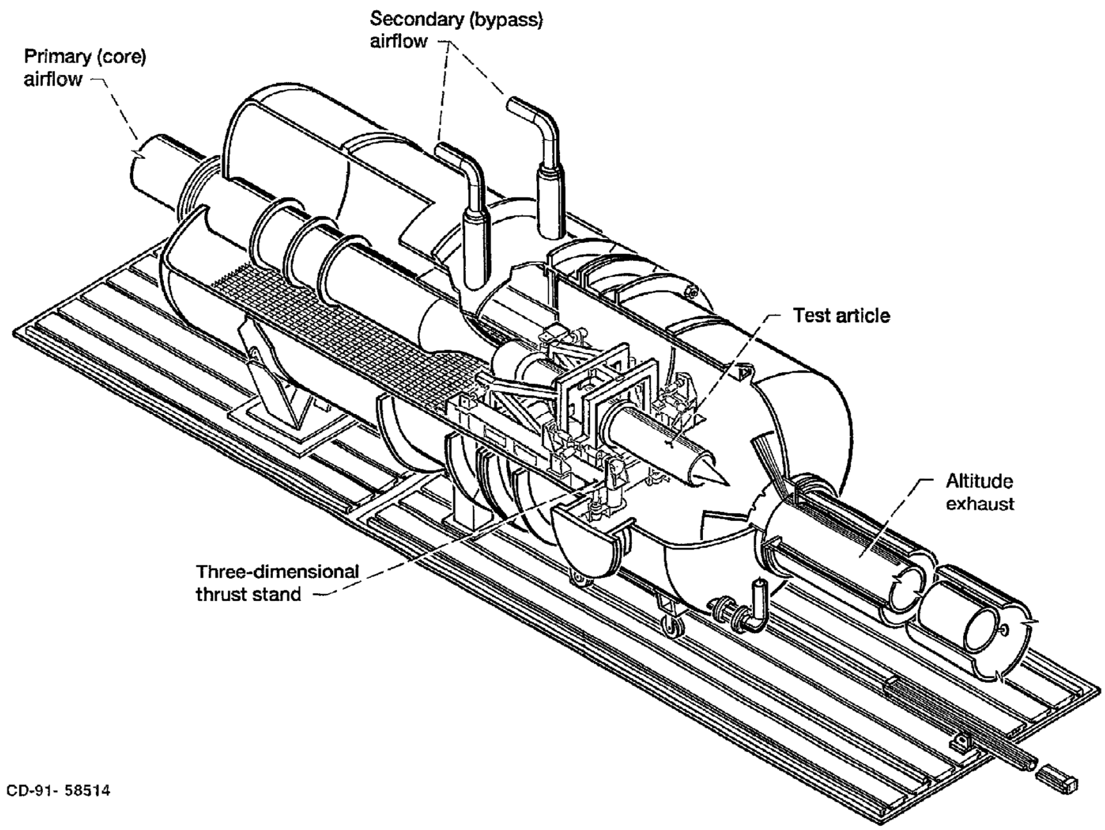

Figure 7.—Advanced nozzle test facility (CE–22).

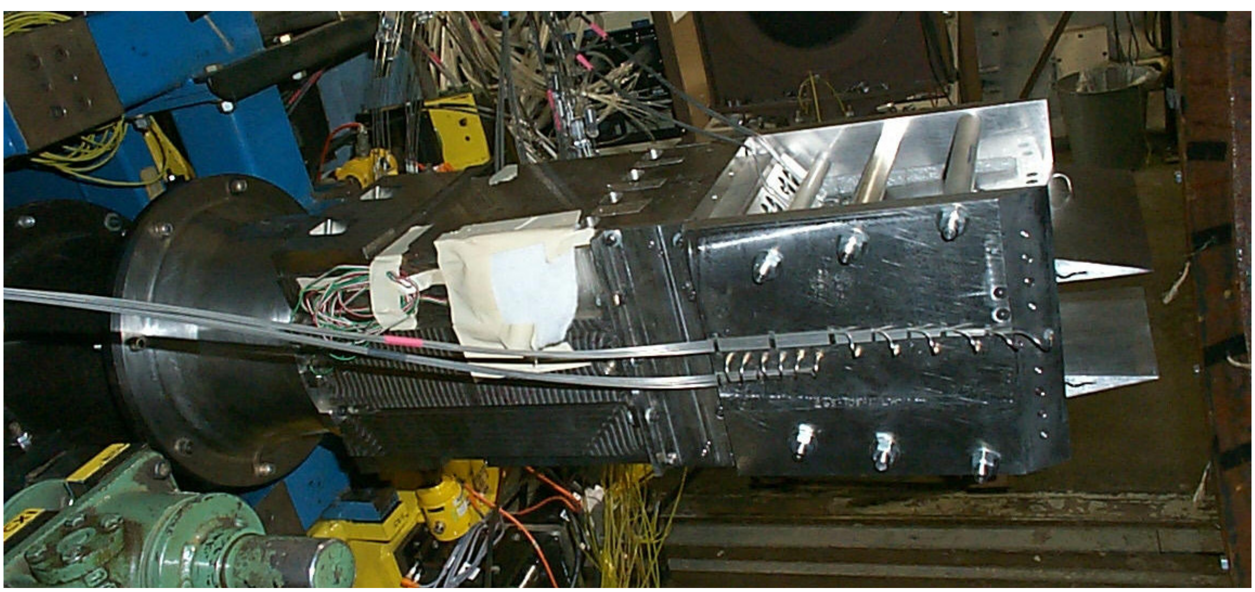

Figure 8.—Model installed in facility.

Methods

Test Matrix

The test matrix was designed around the operating points of the aircraft mission. The three throat areas, for example, were selected to correspond to nozzle operation (1) at supersonic cruise, (2) at transonic acceleration, and (3) at subsonic cruise and approach. The range of wedges used to set the flap expansion angle, and the nozzle pressure ratios for each configuration, were selected to cover the existing mission profile with margins to allow for variations in that profile. The specific set of flap angles (and thus expansion ratios) used, were chosen to cover the selected range while minimizing the number of wedges required. Figure 9 shows the relationship between this test and the anticipated flight envelope of the nozzle. The curves on the figure represent points in the anticipated flight envelope. Callouts point to specific regions of interest that were targeted in this model design.

Testing order of the configurations was randomized to the maximum extent practical, based on available test time. Repeat configurations were distributed through the test matrix. A standard ASME nozzle was tested at the beginning and end of the test to verify the calibration of the force and flow measurement systems. Table 1 lists the configurations tested.

Test conditions were set by fixing nozzle inlet total pressure at 30 psia (0.207 MPa) and then adjusting the pressure in the tank until the desired nozzle pressure ratio was reached. By using a fixed inlet total pressure, the Reynolds Number at the entrance of the nozzle was kept constant throughout the test. Data collection procedures were standardized wherever possible to minimize controllable errors.

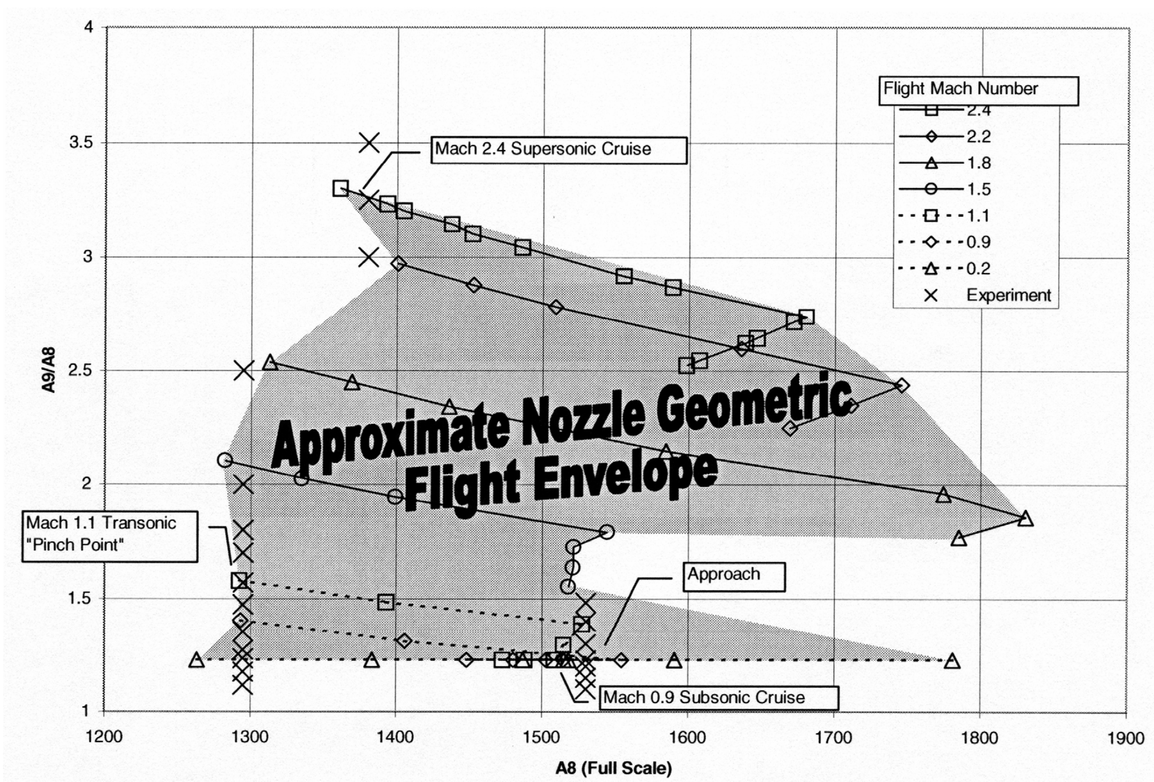

Figure 9.—Areas of interest in flight envelope.

TABLE 1.—CONFIGURATIONS TESTED

Name	Upstream Duct	A8, sq. in.	Flap Angle	A9/A8	Treatment Type	Sidewall Length
A101	Clean	12.95	6.69°	2.500	Solid Wall	Medium
A102	Clean	12.95	4.46°	2.000	Solid Wall	Medium
A103	Clean	12.95	3.57°	1.800	Solid Wall	Medium
A104	Clean	12.95	3.12°	1.700	Solid Wall	Medium
A105	Clean	12.95	2.54°	1.570	Solid Wall	Medium
A106	Clean	12.95	2.11°	1.473	Solid Wall	Medium
A107	Clean	12.95	1.58°	1.354	Solid Wall	Medium
A108	Clean	12.95	1.21°	1.272	Solid Wall	Medium
A109	Clean	12.95	1.05°	1.236	Solid Wall	Medium
A110	Clean	12.95	0.79°	1.177	Solid Wall	Medium
A111	Clean	12.95	0.53°	1.118	Solid Wall	Medium
A201	Clean	13.80	11.93°	3.500	Solid Wall	Medium
A202	Clean	13.80	10.72°	3.250	Solid Wall	Medium
A203	Clean	13.80	9.52°	3.000	Solid Wall	Medium
A301	Clean	15.30	2.54°	1.482	Solid Wall	Medium
A302	Clean	15.30	2.11°	1.400	Solid Wall	Medium
A303	Clean	15.30	1.58°	1.300	Solid Wall	Medium
A304	Clean	15.30	1.21°	1.230	Solid Wall	Medium
A305	Clean	15.30	1.05°	1.200	Solid Wall	Medium
A306	Clean	15.30	0.79°	1.150	Solid Wall	Medium
A307	Clean	15.30	0.53°	1.100	Solid Wall	Medium
B105	Mixer	12.95	2.54°	1.570	Solid Wall	Medium
B202	Mixer	13.80	10.72°	3.250	Solid Wall	Medium
B304	Mixer	15.30	1.21°	1.230	Solid Wall	Medium
C101	Clean	12.95	6.69°	2.500	Grid Rib	Medium
C102	Clean	12.95	4.46°	2.000	Grid Rib	Medium
C105	Clean	12.95	2.54°	1.570	Grid Rib	Medium
C106	Clean	12.95	2.11°	1.473	Grid Rib	Medium
C107	Clean	12.95	1.58°	1.354	Grid Rib	Medium
C109	Clean	12.95	1.05°	1.236	Grid Rib	Medium
C111	Clean	12.95	0.53°	1.118	Grid Rib	Medium
C202	Clean	13.80	10.72°	3.250	Grid Rib	Medium
C303	Clean	15.30	1.58°	1.300	Grid Rib	Medium
C304	Clean	15.30	1.21°	1.230	Grid Rib	Medium
C306	Clean	15.30	0.79°	1.150	Grid Rib	Medium
C307	Clean	15.30	0.53°	1.100	Grid Rib	Medium
D105	Mixer	12.95	2.54°	1.570	Grid Rib	Medium
D304	Mixer	15.30	1.21°	1.230	Grid Rib	Medium

TABLE 1.—CONFIGURATIONS TESTED (CONCLUDED)

Name	Upstream Duct	A8, sq. in.	Flap Angle	A9/A8	Treatment Type	Sidewall Length
E101	Clean	12.95	6.69°	2.500	Solid Wall	Long
E102	Clean	12.95	4.46°	2.000	Solid Wall	Long
E105	Clean	12.95	2.54°	1.570	Solid Wall	Long
E304	Clean	15.30	1.21°	1.230	Solid Wall	Long
F101	Clean	12.95	6.69°	2.500	Solid Wall	Short
F102	Clean	12.95	4.46°	2.000	Solid Wall	Short
F105	Clean	12.95	2.54°	1.570	Solid Wall	Short
F201	Clean	13.80	11.93°	3.500	Solid Wall	Short
F302	Clean	15.30	2.11°	1.400	Solid Wall	Short
F303	Clean	15.30	1.58°	1.300	Solid Wall	Short
F305	Clean	15.30	1.05°	1.200	Solid Wall	Short
F307	Clean	15.30	0.53°	1.100	Solid Wall	Short
G202	Clean	13.80	10.72°	3.250	Grid Rib	Short
H106	Clean	12.95	2.11°	1.473	Parallel Rib	Medium
I106	Clean	12.95	2.11°	1.473	Solid Tray	Medium
J202	Mixer	13.80	10.72°	3.250	Grid Rib	Short

Data Reduction and Analysis

Discharge coefficient was calculated at each data point using the following formula

$$C_D = \frac{W_{MEAS}}{W_{ID}} \tag{1}$$

where,

$$W_{ID} = \begin{cases} \dfrac{A_8 P_T}{\sqrt{T_T}} g_c \sqrt{\dfrac{2}{R}\left(\dfrac{\gamma}{\gamma-1}\right)\left[(\mathrm{NPR})^{-\frac{2}{\gamma}} - (\mathrm{NPR})^{-\frac{\gamma+1}{\gamma}}\right]} & \text{for unchoked flow} \\ \dfrac{A_8 P_T}{\sqrt{T_T}} g_c \sqrt{\dfrac{\gamma}{R}}\left(\dfrac{\gamma+1}{2}\right)^{-\frac{\gamma+1}{2(\gamma-1)}} & \text{for choked flow} \end{cases} \tag{2}$$

Stream thrust parameter was calculated as

$$F_{STR} = \frac{F_G + P_0 A_9}{P_T A_8} \tag{3}$$

Thrust coefficient was calculated as

$$C_{FG} = \frac{F_G g_c}{W_{MEAS} V_{ID}} \tag{4}$$

where,

$$V_{ID}=\sqrt{\left(\frac{2\gamma R g_c}{\gamma-1}\right)T_T\left(1-(\mathrm{NPR})^{-\left(\frac{\gamma-1}{\gamma}\right)}\right)} \tag{5}$$

This thrust coefficient calculation was used for monitoring purposes during the test. However, attempting to determine the peak thrust coefficient from these data can be difficult, as the result is sensitive to small errors in the measured thrust coefficient near the peak. Because the inlet conditions to the nozzle are held constant, the Reynolds number of the flow entering the nozzle remains constant. Therefore, for each model configuration, the discharge coefficient remains constant for choked flow and the stream thrust parameter remains constant except for highly overexpanded flow. It can be shown that the following relationship exists between the principal nozzle performance parameters:

$$C_{FG}=\frac{F_{STR}-\frac{1}{\mathrm{NPR}}\frac{A_9}{A_8}}{C_D\gamma\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}}\sqrt{\frac{\gamma+1}{\gamma-1}\left(1-\mathrm{NPR}^{\frac{1-\gamma}{\gamma}}\right)}} \tag{6}$$

A thrust coefficient curve for the nozzle can be determined from the discharge coefficient and stream thrust parameter, as well as the geometric parameters listed above. For each configuration, average discharge coefficient and stream thrust parameter were calculated to reduce the effect of random errors on the measurement. A peak thrust coefficient was determined by taking the derivative of equation 6 above with respect to NPR and setting it equal to zero.

A linear, least squares fit to the peak C_{FG} data was obtained. A t-test was used to judge the significance of each of the factors, with a significance value of approximately 0.05 or less deemed significant.

Results

A total of 54 configurations of the model were tested. Including ASME nozzle calibrations, a total of 955 data points were collected. Data scatter was a little larger than usual for this facility, probably due to small size of the model. The throat area of this model (A_8) ranged from 12.95 to 15.30 in.^{2} (83.55 to 98.71 cm^2), while typical nozzles tested in this facility range from 20 to 40 in.^{2} (129 to 258 cm^2). The model was designed with this lower throat area to allow for future wind tunnel testing.

Thrust Model

Table 2 lists the results of the statistical analysis of thrust coefficient. This statistical model is the result of a linear regression of the peak C_{FG} values. The baseline peak thrust coefficient was 98.74 percent, as shown on the first line of the table. This baseline represents the model with the following configuration choices: clean transition duct, solid wall shrouds, $A_9/A_8 = 1.1$.

The following lines of the table list deviations from the baseline and the effect observed. For example, the line for “Grid Rib Treatment” indicates that the effect of going to grid rib treatment from the solid wall treatment is to reduce peak C_{FG} by 1.16 percent. The confidence column in the table indicates that we are more than 99.99 percent confident that this value was not the result of random errors, that is, that it is statistically significant.

TABLE 2.—RESULTS OF STATISTICAL ANALYSIS OF PEAK THRUST COEFFICIENT (C_{FG})

Factor	From (baseline)	To	Effect	Confidence	95% Confidence Interval
Statistically Significant					
constant (baseline C_{FG})			98.74%	100.00%	98.29% to 99.20%
Grid Rib Treatment	Solid Wall	Grid	-1.16%	100.00%	-1.39% to -0.93%
Transistion Duct	Clean	Mixer	-0.95%	100.00%	-1.27% to -0.63%
Parallel Rib Treatment	Solid Wall	Parallel	-1.26%	99.90%	-1.99% to -0.54%
Expansion Ratio (A9/A8)	1.1	3.5	0.34%	94.88%	0.00% to 0.68%
Not Statistically Significant					
Throat Area (A8)	12.95	15.3	0.18%	87.69%	
Solid Tray Treatment (STT)	Solid Wall	STT	0.50%	83.19%	
Sidewall Length	20.4	22.56	0.09%	34.29%	

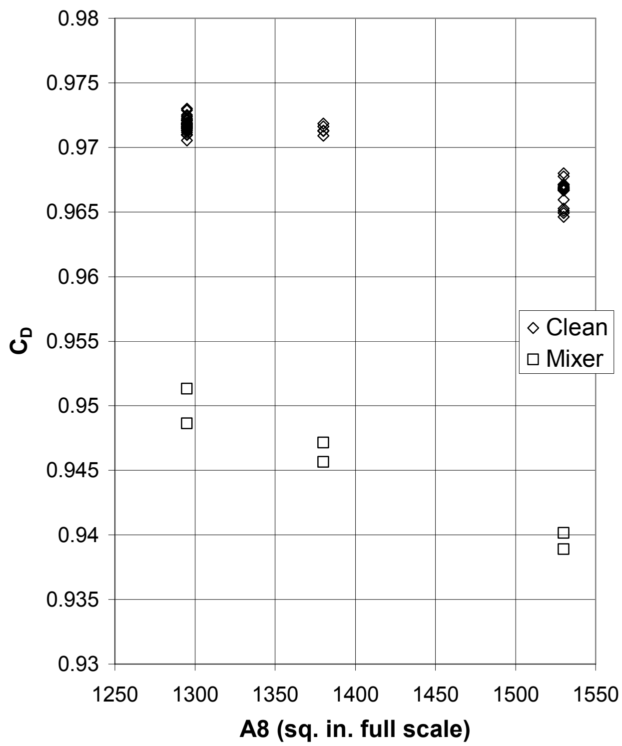

Figure 10.—Discharge coefficient for all configurations.

Four of the model parametrics were judged to be statistically significant. This means that coefficient in the statistical model for these parametrics were found to be different than zero with a confidence level of about 95 percent or greater. The confidence levels are shown in the table. Note that expansion ratio (A_9/A_8) is on the borderline of significance. Three of the model parametrics were not considered statistically significant.

Flow Model

Figure 10 shows discharge coefficient plotted against throat area for all configurations tested. Each point on the figure represents the averaged discharge coefficient over the range of choked NPRs tested for each configuration. It is clear from this figure that the most important influence on discharge coefficient is the presence or absence of the mixer in the transition duct. The effect ranges from 2.2 to 2.6 percent, depending on throat area.

Results From Individual Configurations

Results from individual configurations, including a summary of the peak CFG analysis, performance curves for each configuration, and model static pressure plots, can be found in part II of this report. Examples of these plots can be found in figure 11, which shows typical performance curves and figure 12, which shows typical static pressure plots.

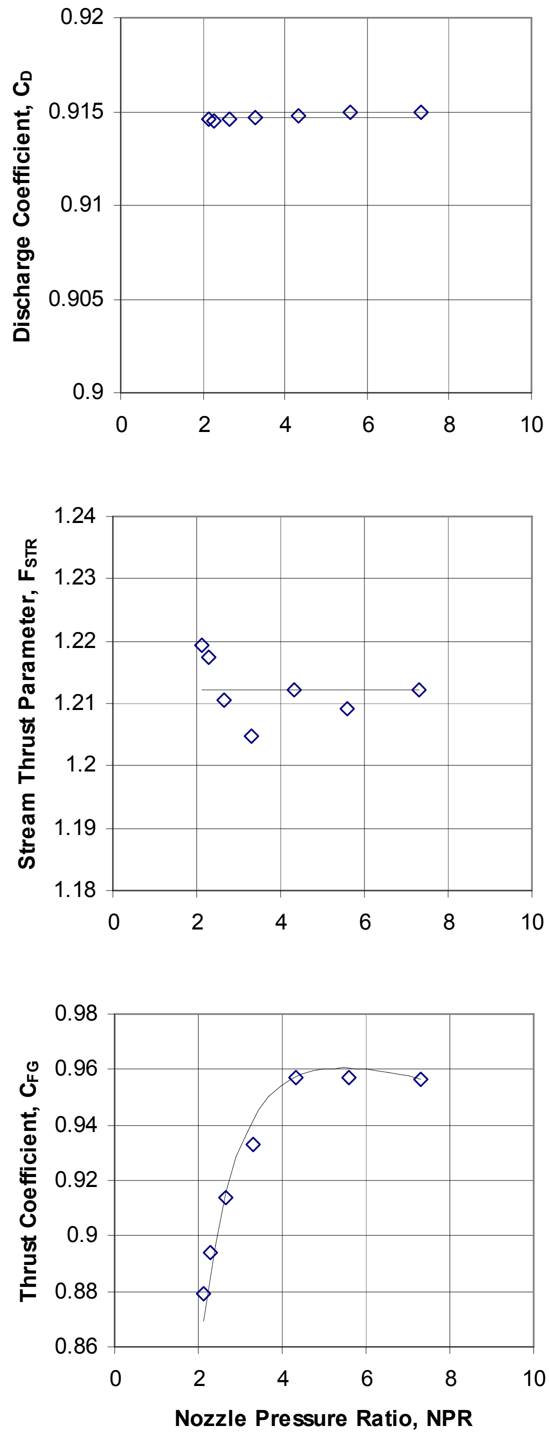

Figure 11.—Typical performance plots.

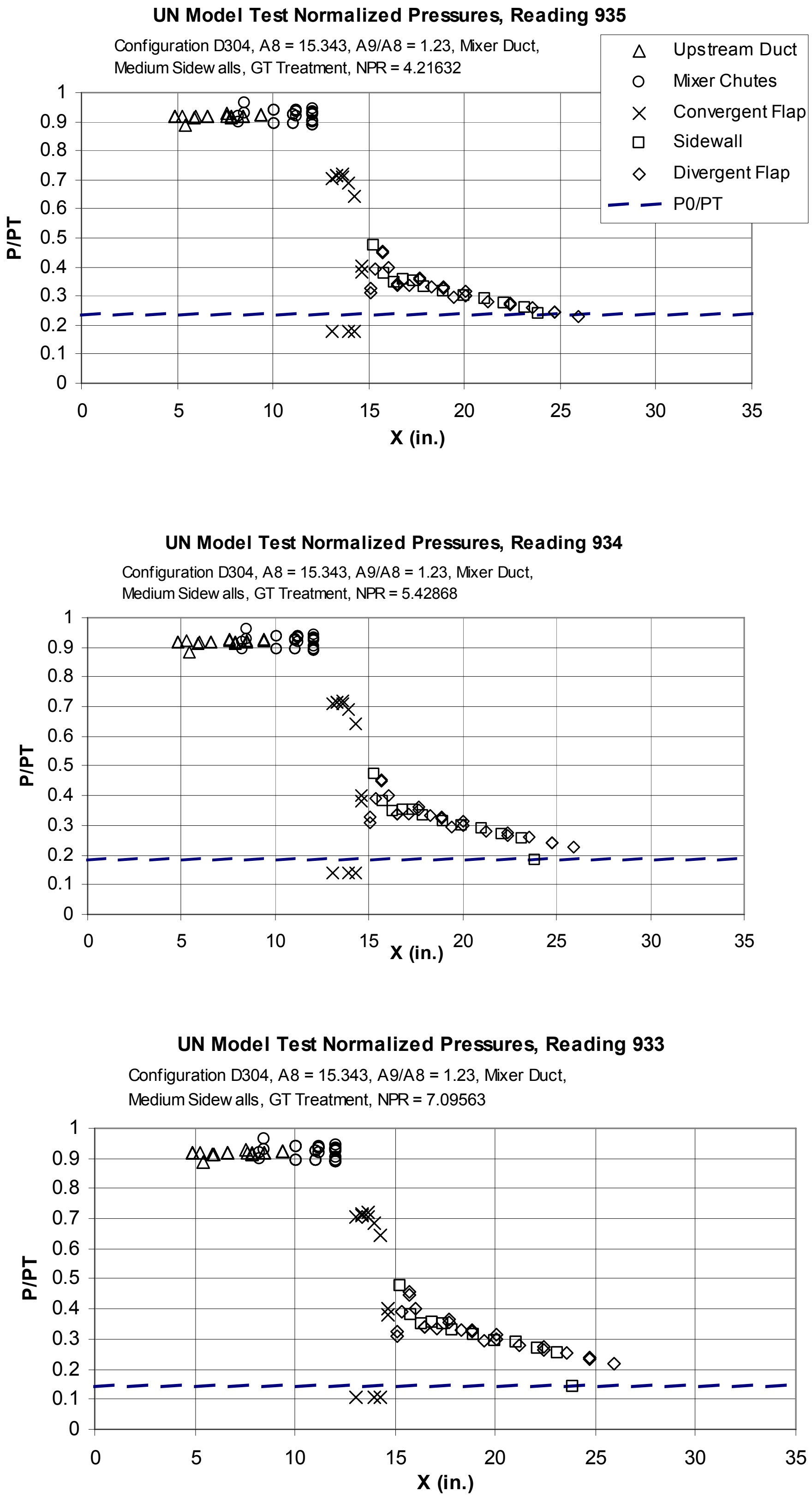

Figure 12.—Typical pressure plots.

Discussion

The results from the peak thrust coefficient statistical model (table 2) are, in general, not surprising. The addition of the mixer to the transition duct, or of any kind of acoustical liner tray to the ejector shroud, had a clear adverse effect on thrust coefficient. These parts were expected to generate additional drag. The effect of throat area on peak thrust coefficient was relatively modest, less than 0.25 percent across the range of throat areas tested.

The solid wall treatment trays, however, had almost no effect on C_{FG}, indicating that flow migration behind the liner trays is not a source of thrust loss in this model. This result suggests that the liner effect for the parallel rib and grid rib liners is due strictly to the added drag associated with the perforated plate liner. The fit of all of the liner trays in this model was quite good, with no detectable steps, and minimal gaps. Additionally, since the tray cavities in the flaps and sidewalls were machined from solid pieces, there is no opportunity for the flow to leak to the exterior.

One surprising result from the peak thrust coefficient statistical model is the absence of sidewall length as a factor in the statistical model. One would expect that a short sidewall would allow underexpanded flow to escape the nozzle, reducing thrust. The statistical model, however, does not show this. Further examination of the data reveals that this is not due to an inability of the statistical model to resolve a subtle trend in the data. Instead, there was no clear correspondence between sidewall length and peak C_{FG}.

Summary and Conclusions

A scale model of a noise-suppressing nozzle design in unsuppressed mode operation was tested in a variety of configurations at a range of operating conditions. The results were summarized in a statistical model which showed statistically significant effects on the peak thrust coefficient caused by the presence of mixing chutes in the flow, the presence of acoustic liner material on the nozzle walls, and variations in the nozzle expansion ratio. Not found to be significant were the presence of the trays used to mount the acoustic liner material, the nozzle throat area, and the nozzle sidewall length. The presence of the mixing chutes in the flow reduced the flow rate through the nozzle by 2.2 to 2.6 percent, depending on throat area.

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14. ABSTRACT
This paper discusses a test of a nozzle concept for a high-speed commercial aircraft. While a great deal of effort has been expended to understand the noise-suppressed, take-off performance of mixer-ejector nozzles, little has been done to assess their performance in unsuppressed mode at other flight conditions. To address this, a 1/10th scale model mixer-ejector nozzle in unsuppressed mode was tested at conditions representing transonic acceleration, supersonic cruise, subsonic cruise, and approach. Various configurations were tested to understand the effects of acoustic liners and several geometric parameters, such as throat area, expansion ratio, and nozzle length on nozzle performance. Thrust, flow, and internal pressures were measured. A statistical model of the peak thrust coefficient results is presented and discussed.

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