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INTERNAL PERFORMANCE OF A WEDGE NOZZLE FOR A SUPERSONIC-CRUISE AIRCRAFT WITH A MULTISPOKE PRIMARY FOR NOISE SUPPRESSION

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16. Abstract

Nozzle performance was obtained with cold primary and secondary flows over a range of nozzle pressure ratio from 2 to 31 and corrected secondary- to primary-flow ratio from 0 to 11 percent. Several fixed shroud positions were tested to simulate a translating outer cylindrical shroud to provide data for both supersonic cruise and takeoff configurations. The addition of 14 spokes in the primary nozzle for noise suppression reduced the thrust efficiency 3 percent at supersonic cruise and 4.5 percent at takeoff.

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INTERNAL PERFORMANCE OF A WEDGE NOZZLE FOR A SUPERSONIC-CRUISE AIRCRAFT WITH A MULTISPOKE PRIMARY FOR NOISE SUPPRESSION

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SUMMARY

An experimental investigation was conducted in the Lewis Research Center nozzle static test stand to measure the internal performance of a wedge nozzle for a supersonic-cruise aircraft that featured a spoked primary nozzle for noise suppression. Nozzle performance was obtained with cold primary and secondary flows over a range of nozzle pressure ratios from 2 to 31 and corrected secondary- to primary-flow ratios from 0 to 11 percent. Several fixed-shroud positions were tested to simulate a translating outer cylindrical shroud to provide data for both supersonic-cruise and takeoff configurations. The results are compared to those for a wedge nozzle with an annular throat and to those for a conical plug configuration with and without noise suppression devices.

At supersonic cruise the addition of 14 spokes in the primary nozzle for noise suppression reduced the thrust efficiency of the wedge nozzle from 98 to 95 percent. At takeoff the maximum thrust was obtained with a fully retracted outer shroud. The addition of 14 spokes in the primary nozzle reduced the performance of the wedge nozzle from 96 to 91.5 percent.

INTRODUCTION

As part of a program in airbreathing propulsion, the Lewis Research Center is evaluating the performance of various exhaust nozzle concepts for application to a supersonic-cruise aircraft. A combined wind-tunnel and flight test program is being conducted to provide isolated and installed nozzle performance at off-design conditions. Performance at takeoff and supersonic cruise is obtained in a static test stand, since external flow effects are negligible at these flight conditions. The performance of several nozzle concepts has been studied and reported and is summarized in chapter VIII of reference 1. These concepts include a low-angle conical plug nozzle, an auxiliary inlet ejector, and a variable-flap ejector.

Another nozzle concept of interest is a wedge nozzle (ref. 2). This concept is similar to that of the plug nozzle but utilizes a two-dimensional wedge surface rather than a conical plug. This concept can provide alternative solutions to the mechanical and cooling problems of the axisymmetric plug. For example, the mechanics of achieving a variable-area throat may be simplified by moving a portion of the wedge surface. Accessibility for secondary cooling air is also improved by using the sides of the wedge for cooling the wedge surface and actuator mechanisms. A cylindrical outer shroud is translated to regulate the internal expansion as nozzle pressure ratio increases.

This report presents the internal performance of the low-angle wedge nozzle of reference 2 with and without a noise suppression device. The internal performance was obtained in the nozzle static test stand at the Lewis Research Center and includes performance of both supersonic-cruise and takeoff configurations. The wedge nozzle of reference 2 was retested with some alternative outer shroud configurations, and these data are also presented as a reference nozzle without the spoked primary. The results of this test program are also compared to those for a low-angle conical plug configuration that had been tested with and without noise suppression devices (refs. 3 and 4). Data are presented in this report for cold primary and secondary flows over a range of nozzle pressure ratios from 2 to 31 and corrected secondary- to primary-flow ratios from 0 to 11 percent.

SYMBOLS

A	area
d	diameter
F	thrust
F'	stream thrust parameter
L	axial length of wedge from station 8 plane to tip, 28.65 cm (11.28 in.)
P	total pressure
$\overline{P}$	average total pressure
p	static pressure
Δpndb	reduction in perceived noise level in comparison to a round convergent nozzle
R	internal radius of primary duct (station 7)
r	radial distance from centerline
T	total temperature

w	weight-flow rate
x	axial distance
θ	circumferential position, deg
$\omega\sqrt{\tau}$	corrected secondary-weight-flow-rate ratio, $(w_s/w_p)\sqrt{T_s/T_p}$

Subscripts:

e	wedge tip (flow region between wedge and full-length shroud ending at wedge tip)
i	ideal
j	jet
p	primary
s	secondary
x	condition at axial distance x
0	ambient
7	nozzle inlet
8	nozzle lip (station 8)
9	nozzle exit (shroud tip)

APPARATUS AND PROCEDURE

The internal performance of a 21.6-centimeter-(8.50-in.-) wedge nozzle was obtained in a static test stand at the Lewis Research Center (fig. 1). The nozzle was installed in a test chamber that was connected to the laboratory combustion air and altitude exhaust facility. The nozzle was mounted from an adapter section that contained a bellmouth inlet for the primary air supply. The adapter section was fastened to a mounting pipe which was rigidly attached to a bedplate. The bedplate was freely suspended by four flexure rods. Both external and internal pressure forces acting on the nozzle, bellmouth, and adapter were transmitted from the bedplate to a load cell which was used in measuring thrust.

NOZZLE CONFIGURATIONS

Spoke Supressor Nozzle

The multispoke primary nozzle assembly is shown in figure 2(a) along with top and end views in figure 2(b). The spoked suppressor nozzle configuration consisted of a

10^o half-angle-wedge centerbody attached to a simulated circular afterburner (fig. 2(a)). A secondary-flow passage is provided between the primary nozzle and the outer cylindrical nacelle. Cutouts in the sides of the wedge provided access for secondary flow for wedge cooling air or for base bleed with truncated wedge configurations. The nozzle throat area was fixed in the supersonic-cruise configuration with a ratio of throat area to maximum internal exit of 0.23, which resulted in a design pressure ratio of 36.74. The design pressure ratio of the spoked suppressor nozzle is larger than that of the reference wedge nozzle. In order to apply the suppression concept of interest ($A_s/A_8 \approx 2.00$) without severely reducing the expansion surface of the centerbody, it was necessary that the thickness of the external shrouds be reduced. The reduction in shroud thickness increases the secondary flow area A_s and also the maximum internal exit area A_e (area at the wedge tip) and thereby influences the design pressure ratio. The noise suppression configuration replaces the single flow nozzle (reference nozzle) by 14 small nozzles (spokes). Each spoke was separated by secondary flow passages (chutes) (fig. 2(b)). Details of the 10^o half-angle wedge are shown in figure 2(c) with coordinates of the contour for the forward portion of the wedge. A total of 12 chutes with ramp angles of 22^o, 20^o, and 16^o (fig. 2(d)) made up the secondary-flow area. The secondary-flow to primary-flow-area ratio was 1.70 at station 8. However, the preferred area ratio was 2.00. The preferred area ratio was based on a 14-spoke nozzle operating at a nozzle pressure ratio of 3.00 which had a ratio of Δpndb to percent thrust loss of 1.1 at a 457.2-meter (1500-ft) sideline (fig. 20 of ref. 5). To obtain an area ratio of 2.00 would have reduced the expansion surface by 70 percent from that of the reference wedge.

Various cylindrical shroud lengths were used to regulate internal expansion. Figure 2(e) shows the two shrouds that simulated supersonic-cruise configurations with x/d_{max} equal to 0.671 and 0.350. The shroud is retracted at low pressure ratios and extended as pressure ratio increases. Translation was simulated in this test through the use of several fixed-length shrouds (fig. 2(f)). Two slotted shrouds were tested as a takeoff configuration (fig. 2(f)). These shrouds simulated takeoff with an extended shroud utilizing auxiliary inlets to minimize overexpansion losses. Details of the external shrouds are shown in figure 2(g).

Reference Wedge Nozzle

The assembly of the reference wedge nozzle is shown in figure 3(a). The reference wedge nozzle used the same centerbody as the suppressor configurations. The nozzle throat area was fixed in the supersonic-cruise configuration with a throat area to maximum internal exit area ratio of 0.26. This resulted in a design pressure ratio of 31.5.

The maximum primary flap angle of 10° occurred only at the plan view centerline (top and bottom) and washed out to 0° at the sides of the wedge (figs. 3(b) and (c)). Details of the primary nozzle are shown in figure 3(c). Several external shrouds were tested to simulate shroud translation (fig. 3(d)). Tests were made with and without sideplates which were swept at 25° 30' (fig. 3(e)). Details of the external shrouds are shown in figures 3(e) and (f).

INSTRUMENTATION

Primary and secondary total pressures were measured with pitot probes, as shown in figures 4 and 5. A row of six static-pressure orifices was located in 2 of the 12 chutes (fig. 4(a)). The wedge contained two axial rows of static-pressure orifices (figs. 4(a) and (b)). The axial locations of these static-pressure orifices along with those of the chutes are also given in figure 4.

The primary total pressure at station 7 was calculated by using pressures from an 11-probe area-weighted total-pressure rake and two static-pressure locations around the primary flow channel perimeter (fig. 5). Two thermocouples are also included at station 7 to determine the primary-air temperature T_7. A typical primary total-pressure profile of the flow at station 7 is shown in figure 6.

THRUST MEASUREMENTS

The nozzle primary airflow w_p was calculated from pressure and temperature measurements at the air metering station (fig. 1), and an effective area was determined by calibration with an ASME nozzle. The secondary airflow w_s was measured by means of a standard ASME flowmetering orifice in the external supply line.

Jet thrust was calculated from load-cell measurements corrected for tare forces. The measured mass-flow rates were used to calculate ideal jet thrust for each flow with isentropic expansion assumed from their measured total pressures (P_7, P_s) to P_o. The data are presented in the form of nozzle gross thrust coefficient:

$$\text{gross thrust coefficient} = \frac{F_j}{F_{i,p}}$$

A nozzle efficiency parameter is also presented and defined as the ratio of jet thrust to the combined ideal thrust of the primary and secondary flows:

$$\text{nozzle efficiency} = \frac{F_j}{F_{i,p} + F_{i,s}}$$

The thrust system was calibrated by using a standard ASME sonic nozzle having a throat area of 98.10 square centimeters (15.20 in.^{2}). The measured performance of the ASME nozzle is compared in figure 7 with theoretical performance calculated from ASME flow and velocity coefficients of 0.9935 and 0.996, respectively, taken from reference 6. The results indicate a ±1 percent scatter in force measurements with root-mean-square value of 0.0026.

RESULTS AND DISCUSSION

Nozzle pressure ratios were set by maintaining a constant nozzle inlet pressure P_7 and varying the tank pressure p_0 with the use of exhausters. The supersonic-cruise configurations were tested over a range of nozzle pressure ratios from 14 to 31 at corrected secondary weight flows of 0 and 2 percent. To obtain the effect of secondary flow at the supersonic-cruise nozzle pressure ratio of 28.00, the secondary weight flow was varied from 0 to 11 percent of the primary flow. The takeoff configurations were tested over a range of nozzle pressure ratios from 2 to 14 at corrected secondary weight flows of 0 and 4 percent. At a typical takeoff pressure ratio of 3.25, the secondary weight flow was varied from 0 to 11 percent of the primary flow.

Performance Comparison at Supersonic-Cruise and Takeoff Pressure Ratios

Supersonic cruise. - A comparison of thrust characteristics between the wedge and conical plug nozzles is presented in figure 8. At a supersonic-cruise nozzle pressure ratio of 28.00 and a secondary-flow rate of 2 percent, the reference wedge (x/d_{max} = 0.788) had a thrust efficiency of 0.98 compared to 0.985 for the reference conical plug nozzle (x/d_{max} = 0.674). Both of these shroud extensions produced approximately 80-percent internal expansion. The multispoke wedge (x/d_{max} = 0.35; 85-percent internal expansion) had a 3-percent performance decrement compared to the 2.5-percent decrement for the multispoke plug nozzle (x/d_{max} = 0.449). The gross thrust coefficient is compared in figure 8(b) and shows a similar effect.

Figures 9 and 10 show a comparison of the pressure distributions between the reference and multispoke wedge nozzles. The multispoke static pressures along the wedge surface were generally lower than those of the reference wedge nozzle (fig. 9). This difference accounted for approximately 2 percent of the performance decrement at the supersonic-cruise pressure ratio of 28.00. Although a relatively high pressure level existed on the chutes (fig. 10), the overall thrust from the chutes was insignificant (less than 1/2 percent) because of the small projected area of the chutes.

The effect of shroud extension on the supersonic-cruise performance at a nozzle pressure ratio of 28.00 is presented in figure 11 for both the multispoke and reference primary nozzles. With the multispoke primary nozzle (fig. 11(a)), extending the shroud beyond $x/d_{max} = 0.35$ did not improve the nozzle efficiency. The foregoing shroud extension produced an 85-percent internal expansion. However, the peak efficiency with the reference nozzle (fig. 11(b)) occurred at $x/d_{max} = 0.788$, which corresponds to 80-percent internal expansion.

A comparison of the pumping characteristics (figs. 11(a) and (b)) indicates a higher pressure ratio for the reference nozzle. Although the secondary pressure was measured at the same station for both nozzle configurations, the external shrouds were thinner for the multispoke configurations. Hence, these configurations had a larger annular secondary flow area and thus a lower pressure level for the same amount of secondary flow.

Takeoff. - The nozzle performance of the wedge and conical plug nozzles at a takeoff nozzle pressure ratio of 3.25 and a corrected secondary weight flow ratio of 0.04 is shown in figure 12. The reference wedge had a thrust efficiency of 0.961 compared to 0.972 for the reference conical plug nozzle (fig. 12(a)). The efficiencies of the multispoke nozzles were 4.5 and 2.5 percent lower, for the wedge and plug, respectively, than those of the reference nozzles. The 4.5-percent performance decrement was due to a net loss in primary and wedge thrust and additional internal skin friction losses from the spoke primaries. The best efficiency at the takeoff condition was obtained with a retracted shroud. The gross thrust coefficient is shown in figure 12(b).

The static-pressure distributions of the retracted shroud configuration for both reference and multispoke wedge nozzles are presented in figures 13 and 14. The average static pressure was slightly higher along the centerline of the wedge with the multispoke primary (the average wedge pressure for both configurations was slightly greater than p_o). However, the projected area of the wedge was less than that for the reference nozzle. The net result was a 1-percent-lower wedge surface thrust for the multispoke configuration at takeoff. At 9.33 centimeters off centerline there was generally no difference between the static-pressure levels for the two configurations. The static pressure in the chutes (fig. 14) was less than or equal to p_o, whereas the reference primary-nozzle boattail pressure was slightly greater than p_o.

The effect of shroud extension on the nozzle performance characteristics at a takeoff nozzle pressure ratio of 3.25 is shown in figure 15. Only one takeoff configuration was tested with the reference wedge nozzle shroud retracted. However, several configurations were tested with the multispoke primary, which included two concepts for takeoff. One had the shroud retracted, and the other featured blow-in doors to admit tertiary air through the chutes. Tertiary air reduces the overexpansion of the primary jet. The slotted shroud simulated a supersonic-cruise shroud with blow-in doors fully open at takeoff conditions. The results in figure 15 indicate that the optimum thrust efficiency was obtained with a retracted shroud configuration. The performance of the slotted shrouds was relatively low because of the overexpansion of the primary jet at the low pressure ratios.

Nozzle Performance Characteristics

Supersonic-cruise configurations. - Thrust and pumping characteristics for the supersonic cruise configurations of both the multispoke and reference primary nozzles are presented in figures 16 to 19. The effect of nozzle pressure ratio on performance characteristics is shown in figure 16 for the multispoke nozzle with corrected secondary weight flow of 0 and 2 percent. The secondary total-pressure ratio was independent of nozzle pressure ratio, which indicated that the secondary flow was choked.

The effect of corrected secondary weight flow on internal performance is presented in figure 17 for the multispoke primary nozzle. The secondary flow was varied from 0 to 11 percent of the primary flow at a nozzle pressure ratio of 28.00 with the optimum configuration, $x/d_{max} = 0.349$; the peak efficiency of 0.954 occurred with a 7-percent secondary weight flow.

Figure 18 shows the effect of nozzle pressure ratio on the performance characteristics of the reference wedge nozzle supersonic-cruise configurations with 0 and 2 percent corrected secondary flow. The secondary-total-pressure ratio is independent of nozzle pressure ratio, which indicates that the secondary flow is choked.

The effect on internal performance due to variation in corrected secondary weight flow from 0 to 11 percent of the primary flow is presented in figure 19 for a nozzle pressure ratio of 28.00. For the optimum configuration, $x/d_{max} = 0.788$, the peak efficiency of 0.984 occurred with a secondary weight flow of approximately 5 percent.

Takeoff configurations. - Thrust and pumping characteristics for the takeoff configurations of both the multispoke and reference primary nozzles are presented in figures 20 to 23. The effect of nozzle pressure ratio on nozzle performance characteristics is shown in figure 20 for the multispoke wedge nozzle with corrected secondary weight flow of 0 and 4 percent. The peak efficiency occurred near a nozzle pressure ratio of 4 with the shroud retracted. As the shroud is extended, the pressure ratio of peak efficiency increases because of the overexpansion of the nozzle (fig. 20(c)).

The effect of secondary flow is shown in figure 21. Secondary flow did not improve the nozzle performance appreciably.

The effect of nozzle pressure ratio on the reference wedge nozzle takeoff performance is presented in figure 22. The peak thrust efficiency occurred near a nozzle pressure ratio corresponding to a Prandtl-Meyer turning angle equal to the throat inclination angle. The peak efficiency was 96.6 at a nozzle pressure ratio of 3.00.

The effect of secondary flow is presented in figure 23. Increasing the secondary flow from zero did not improve the nozzle efficiency.

SUMMARY OF RESULTS

An experimental investigation was conducted in a nozzle static test stand at the Lewis Research Center to measure the internal performance of a wedge nozzle for a supersonic-cruise aircraft that featured a spoked primary nozzle for noise suppression. Nozzle performance was obtained with cold primary and secondary flow over a range of nozzle pressure ratios from 2 to 31 and corrected secondary- to primary-flow ratios from 0 to 11 percent. Several fixed-shroud positions were tested to simulate a translating outer cylindrical shroud and to provide data for both supersonic-cruise and takeoff configurations. The wedge nozzle of reference 2 was retested with some alternative shroud configurations, and these data are also presented as a reference nozzle without the spoked primary. The results presented in this report were also compared to a low-angle conical plug configuration that had been tested previously with and without noise suppression devices. The following results were obtained:

1. The reference wedge nozzle provided a nozzle internal thrust efficiency of about 98 percent at the supersonic-cruise condition compared to 98.5 percent for a conical plug nozzle. The addition of 14 spokes in the primary nozzle for noise suppression reduced the performance of the wedge nozzle to 95 percent (a 3-percent loss). The addition of 12 spokes to the conical plug reduced its performance to 96 percent (a 2.5-percent loss).

2. The reference wedge nozzle provided a takeoff thrust efficiency of about 96 percent compared to 97 percent for the conical plug configuration. The addition of 14 spokes in the primary nozzle reduced the performance of the wedge nozzle to 91.5 percent (a 4.5-percent loss). The addition of 12 spokes in the conical plug configuration reduced the performance to 94.5 percent (a 2.5-percent loss).

3. Maximum thrust efficiency at takeoff was always obtained with a fully retracted outer shroud.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, August 4, 1972,
764-74.

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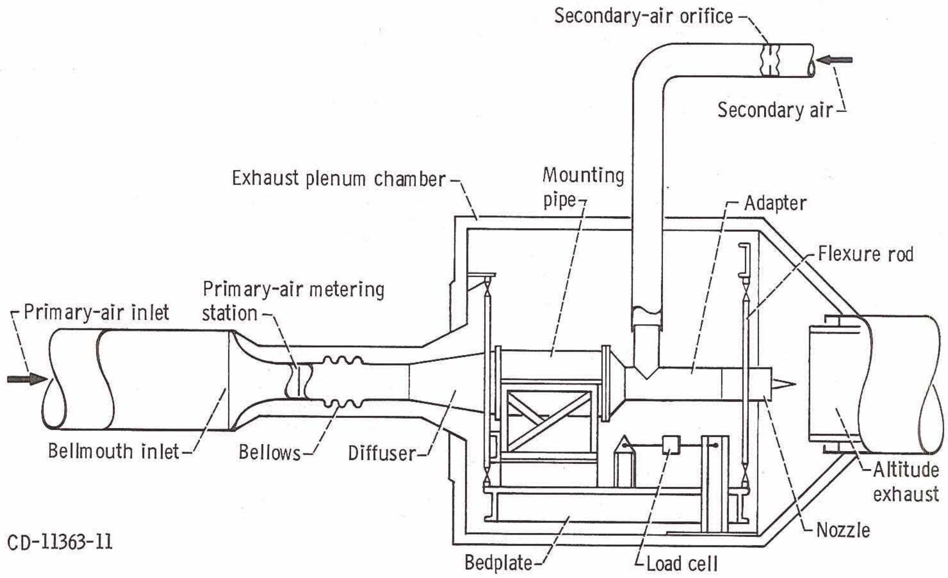


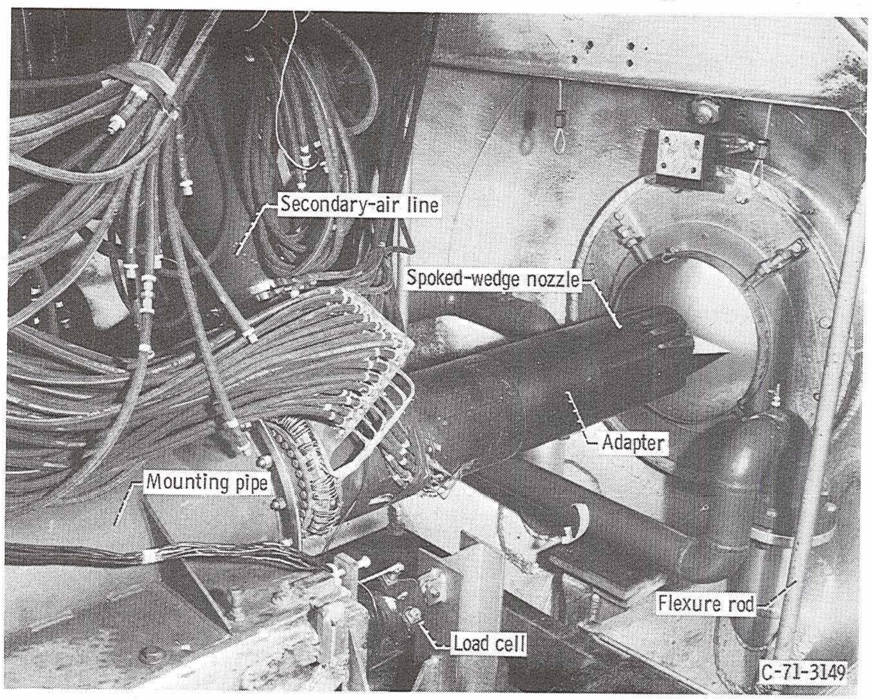
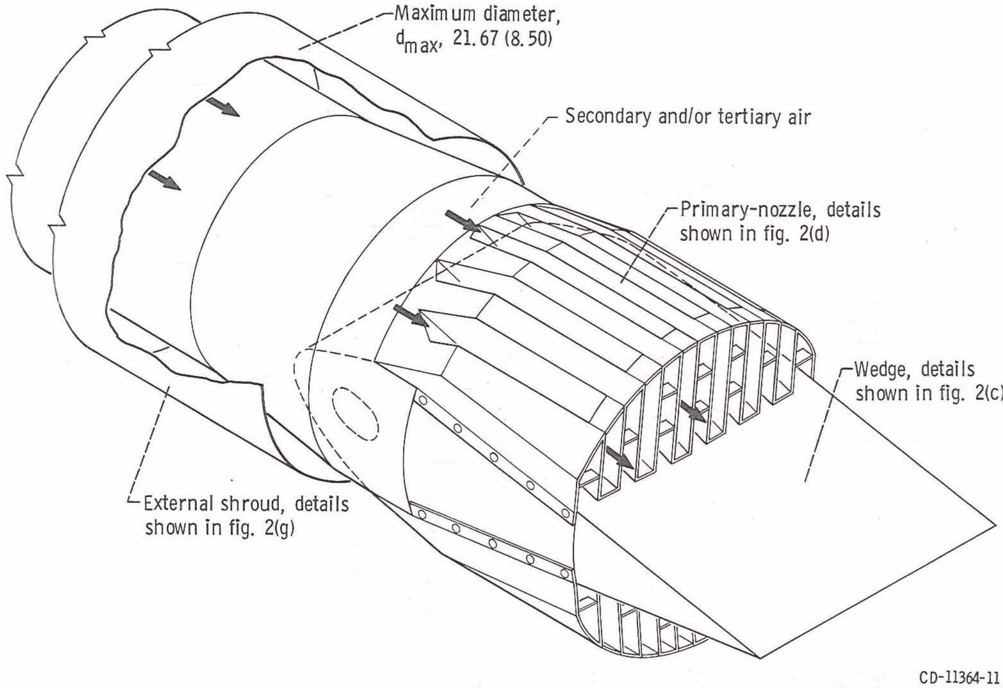
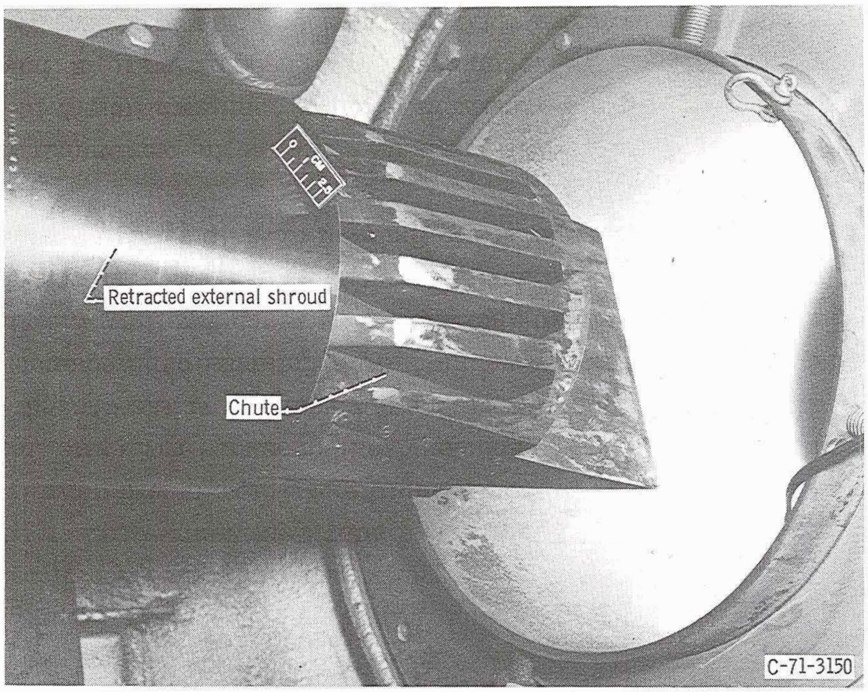


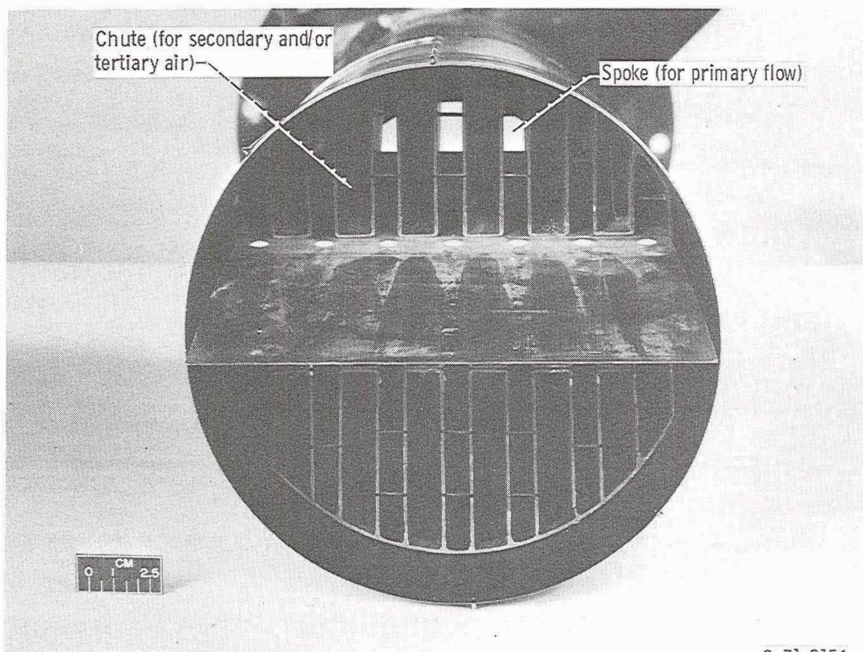
Figure 1. - Installation of multispoke wedge nozzle in static test facility.



(a) Assembly of wedge nozzle with 14-spoke primary nozzle.

Figure 2.- Details of 14-spoke wedge nozzle configurations. (Dimensions are in centimeters (in.)





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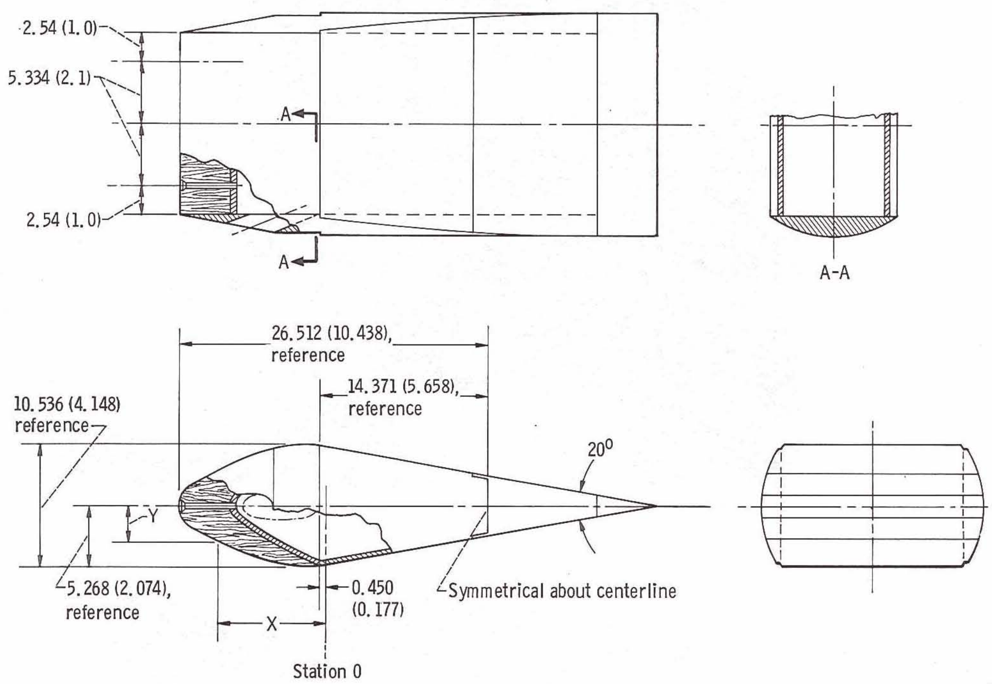
(b) Top and end view of multispoke wedge nozzle.

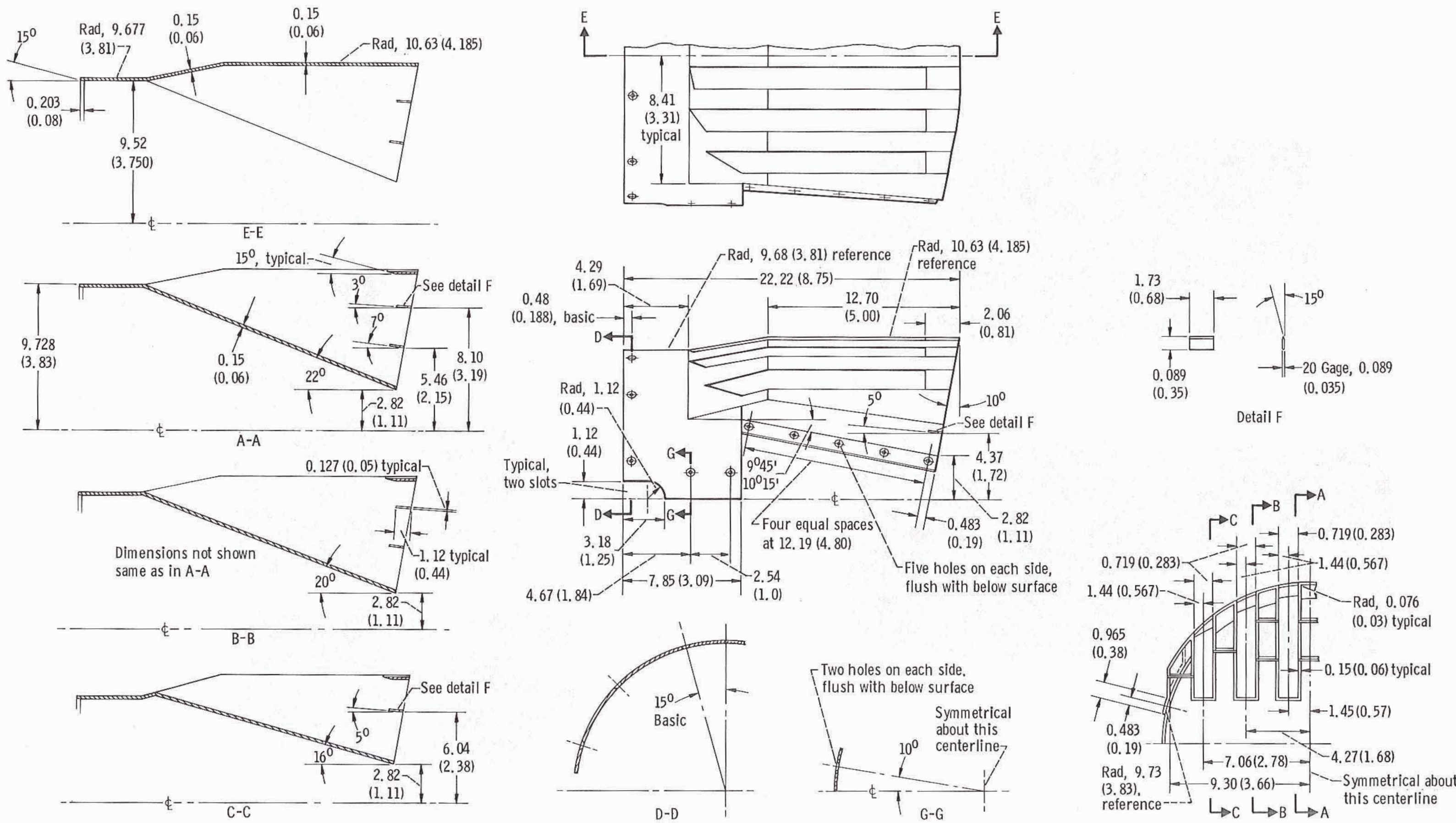
Figure 2. - Continued.

Axial distance, x		Longitudinal distance, y	
cm	in.	cm	in.
0	0	5.13	2.020
.914	.360	5.268	2.074
1.295	.510	5.329	2.098
1.727	.680	5.372	2.115
2.159	.850	5.390	2.122
2.591	1.020	5.380	2.118
3.023	1.190	5.347	2.105
3.454	1.360	5.268	2.074
3.901	1.536	5.164	2.033
4.318	1.700	5.034	1.982
51182	2.040	4.768	1.877
6.045	2.380	4.455	1.754
6.909	2.720	4.128	1.625
7.772	3.060	3.774	1.486
8.636	3.400	3.393	1.336
9.500	3.740	2.972	1.170
10.363	4.080	2.512	.989
10.566	4.160	2.393	.942
10.795	4.250	2.255	.887
11.011	4.335	2.116	.833
11.227	4.420	1.969	.775
11.455	4.510	1.806	.711
11.659	4.590	1.623	.639
11.875	4.675	1.417	.558
12.090	4.760	1.184	.466
12.306	4.845	.907	.357
12.522	4.930	.450	.177
12.541	4.957	0	0



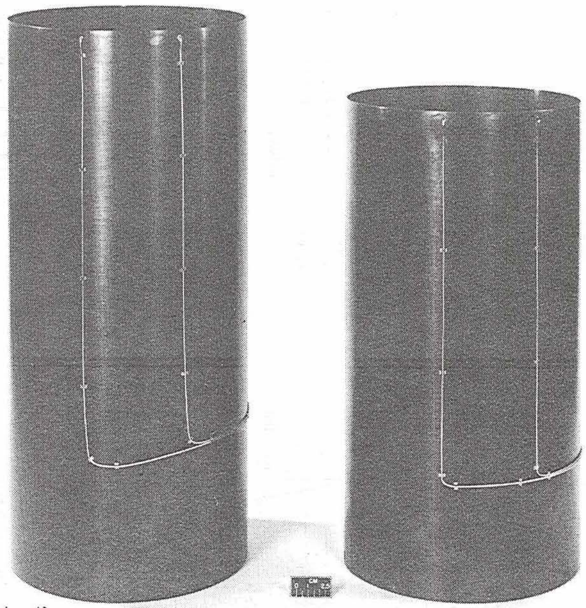
(c) Details of wedge.

Figure 2. - Continued.



(d) Details of primary nozzle.

Figure 2. - Continued.



Axial location, x/d_{max} 0.671 0.35

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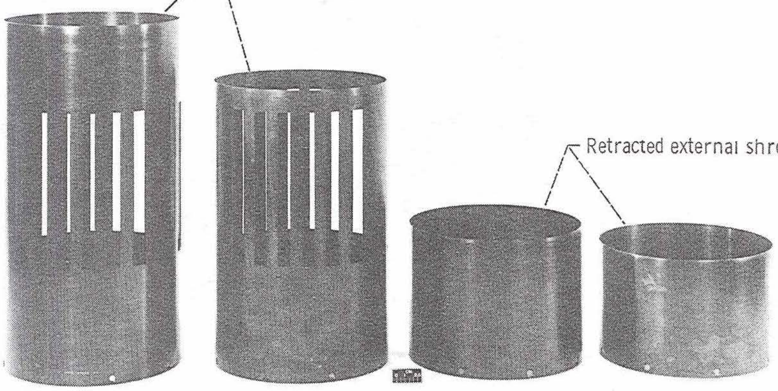
(e) External shrouds for supersonic-cruise configurations.

Simulated fully open blow-in-door configurations

Retracted external shrouds



Axial location, x/d_{max} 0.35 0 -0.82 -0.9

(f) External shrouds for takeoff configurations.

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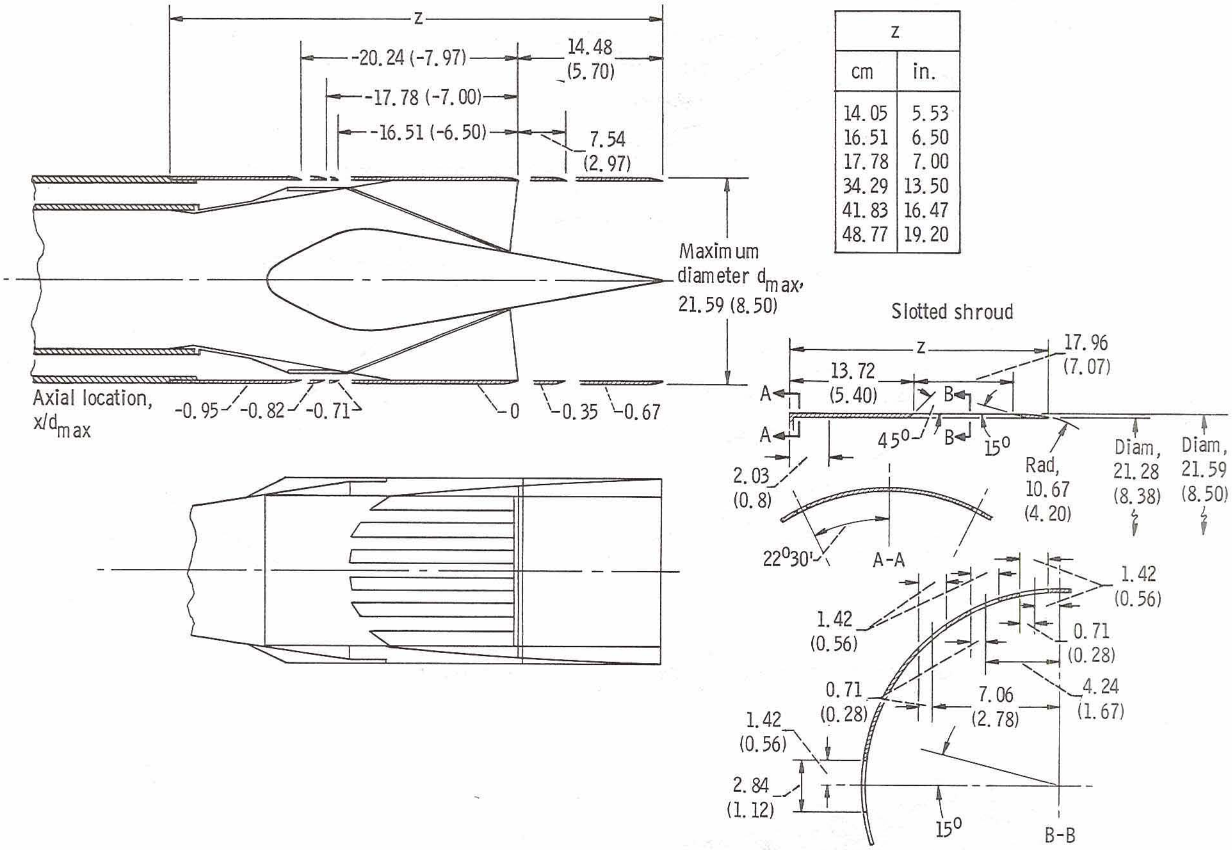
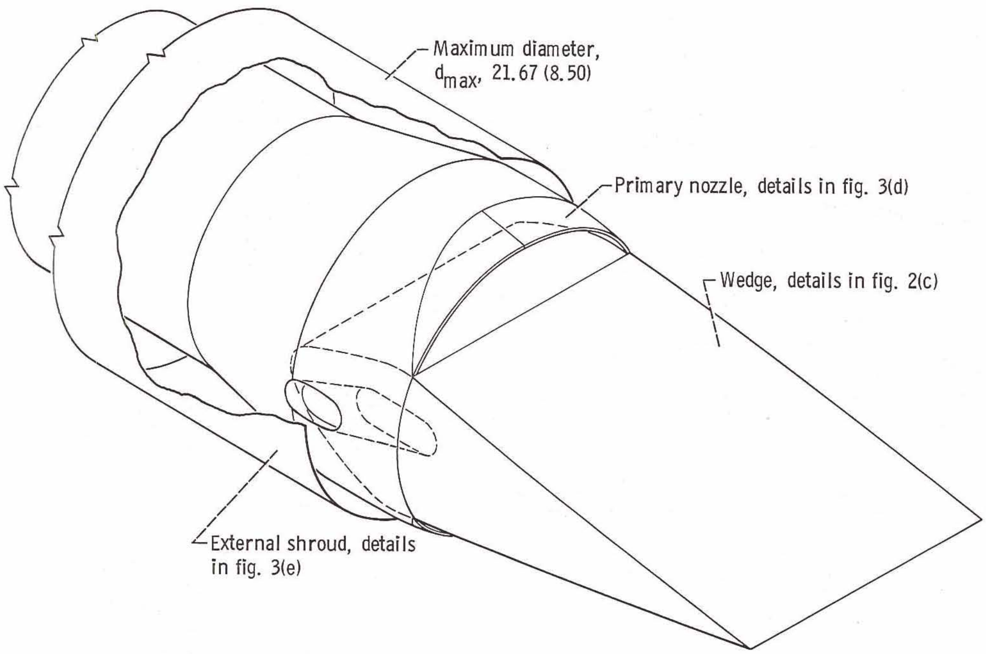
Figure 2. - Continued.



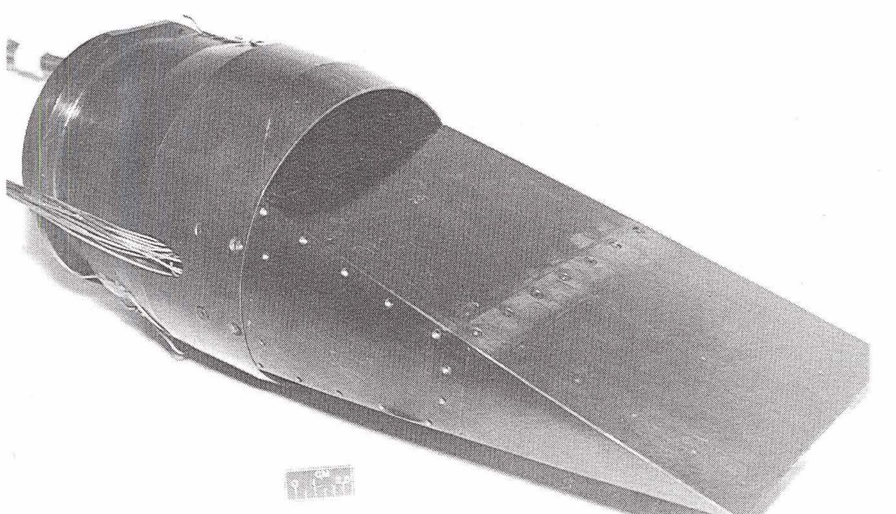
z	
cm	in.
14.05	5.53
16.51	6.50
17.78	7.00
34.29	13.50
41.83	16.47
48.77	19.20

(g) Details of external shrouds.

Figure 2. - Concluded.



(a) Assembly of reference wedge nozzle; design pressure ratio, 31.5.



(b) Installation of reference wedge.

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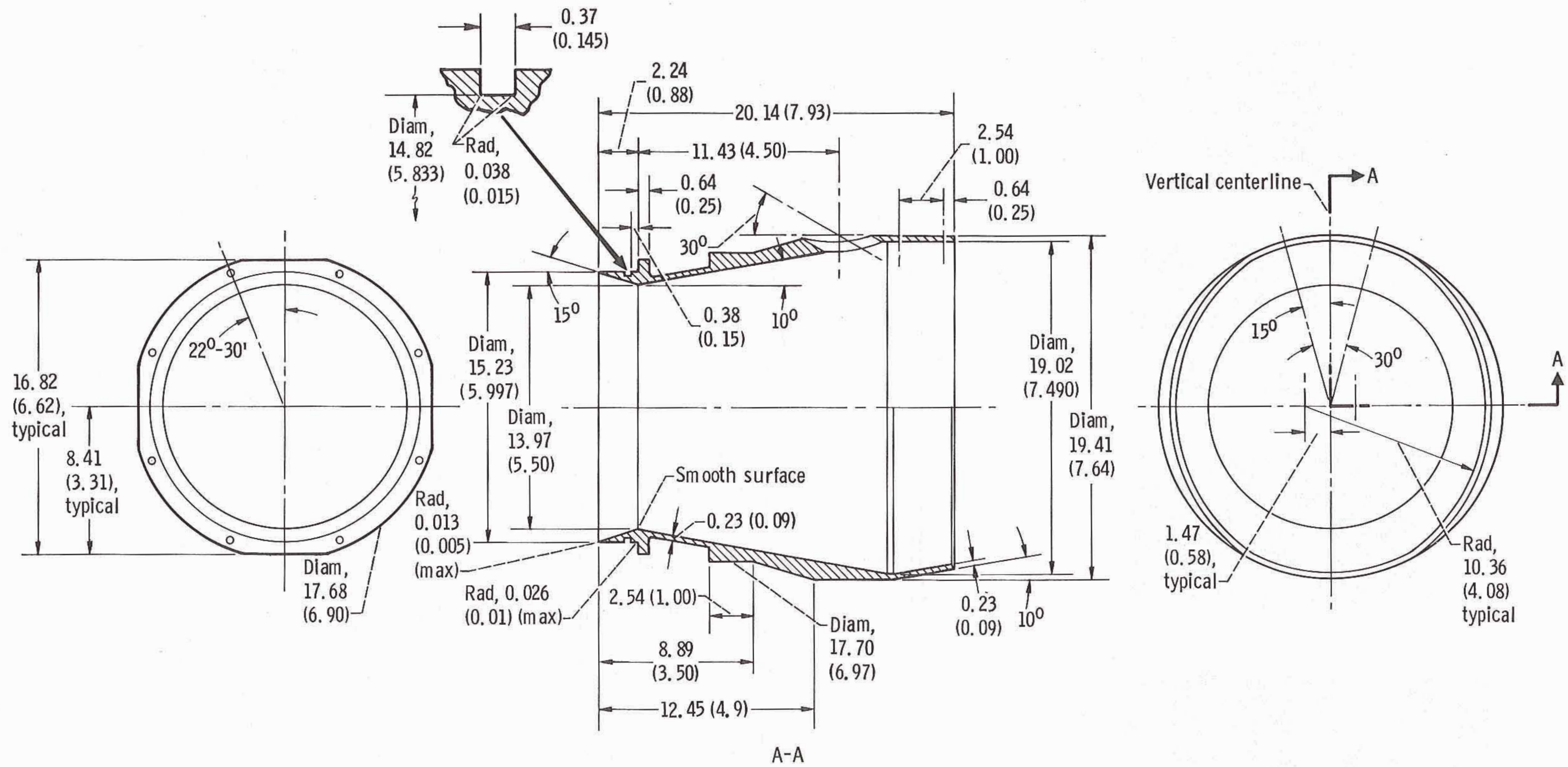
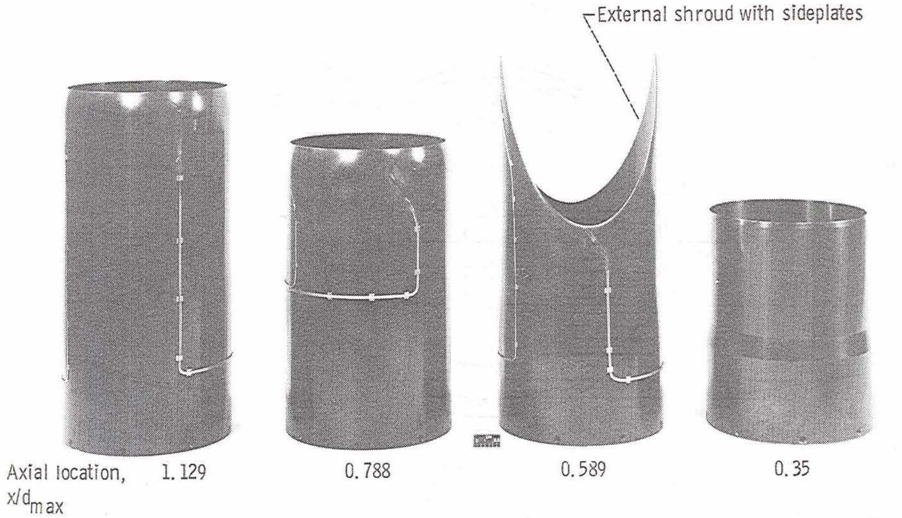
Figure 3. - Details of reference wedge nozzle configurations. (Dimensions are in centimeters (in.).)

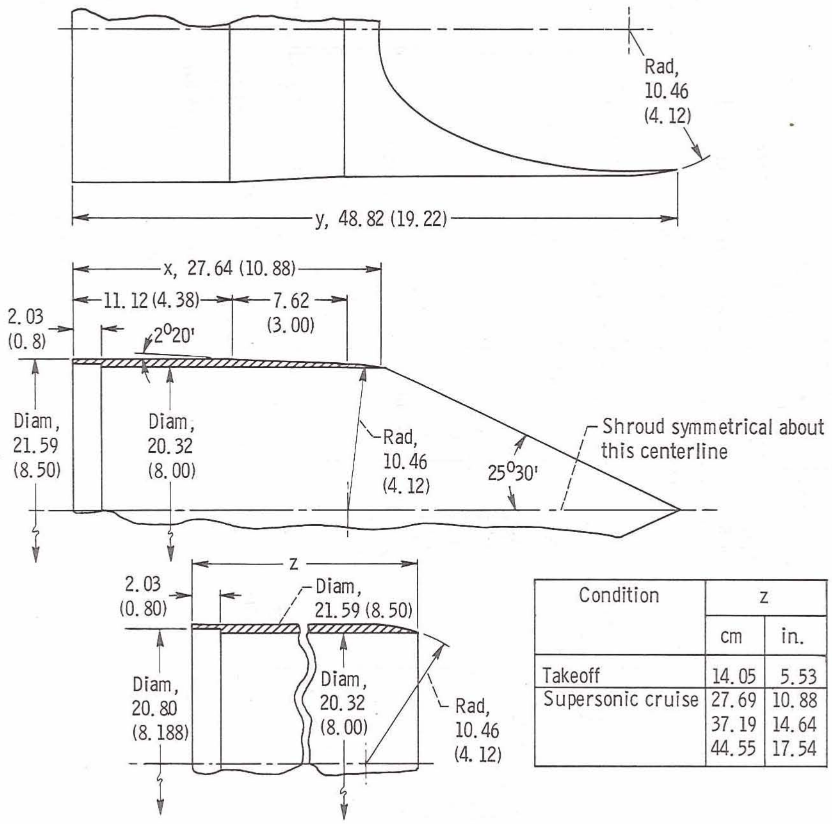


(c) Details of primary nozzle.

Figure 3. - Continued.



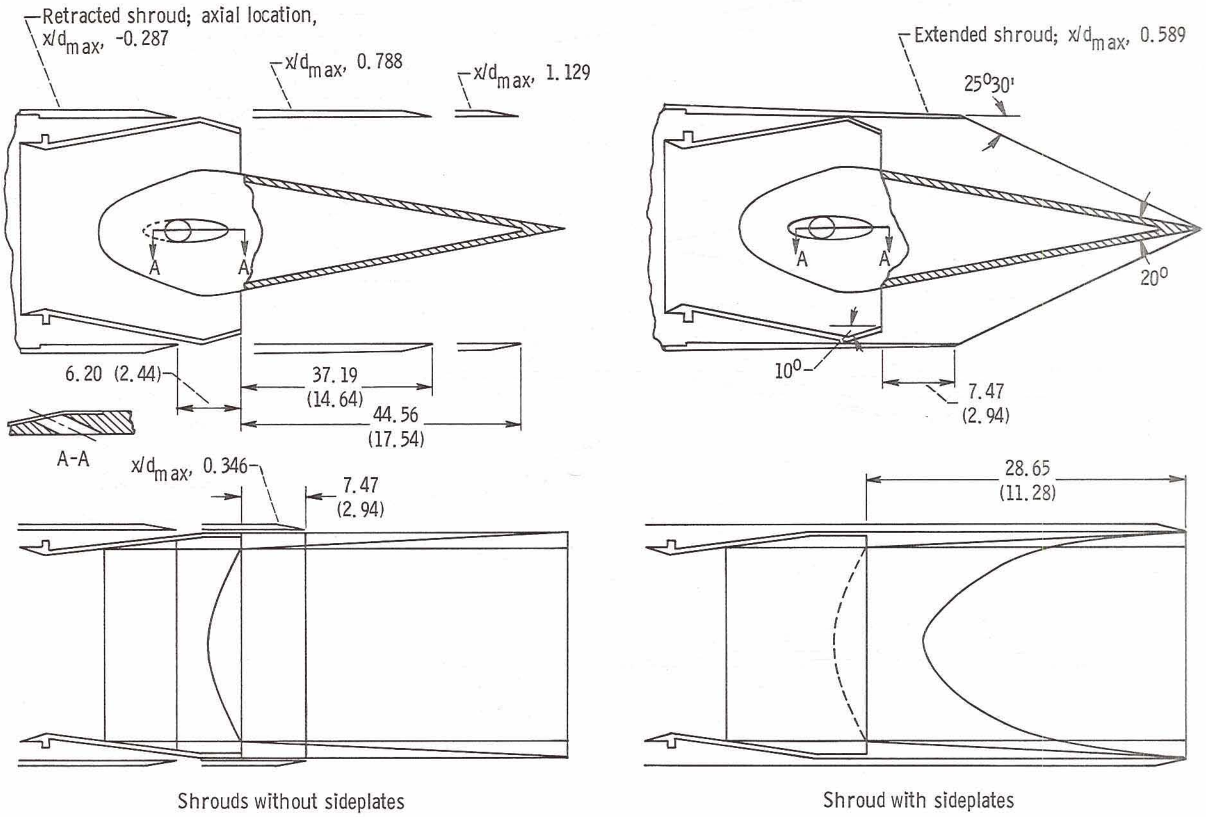
(d) External shrouds for supersonic-cruise configurations.



Condition	z	
	cm	in.
Takeoff	14.05	5.53
Supersonic cruise	27.69	10.88
	37.19	14.64
	44.55	17.54

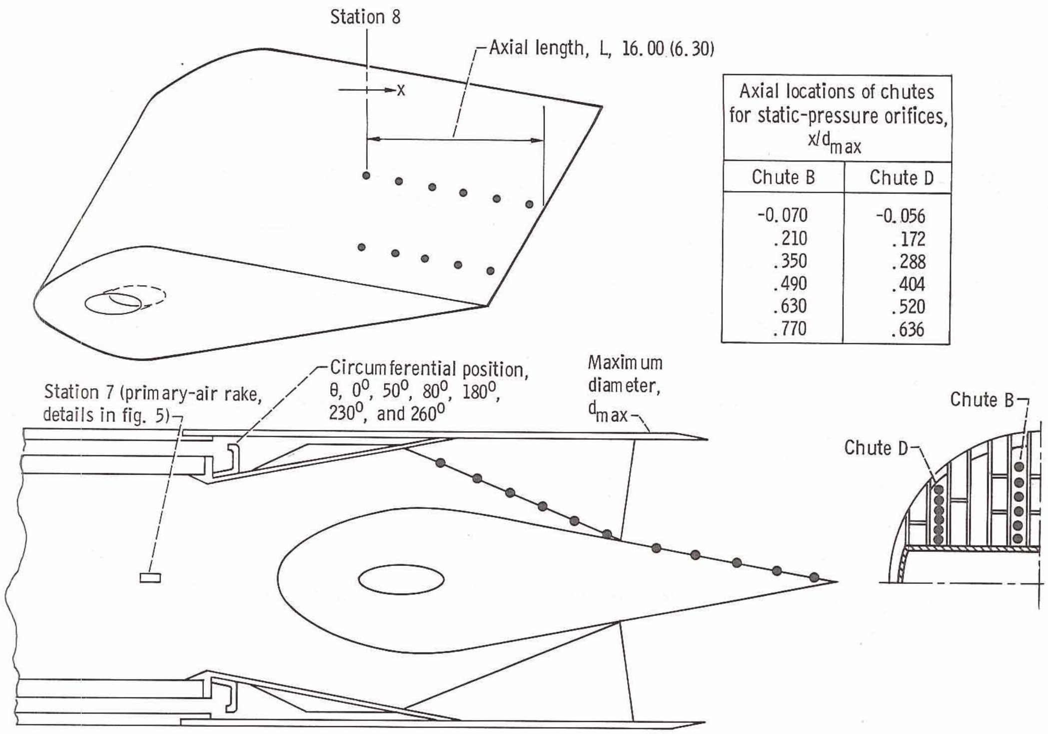
(e) Details of external shrouds.

Figure 3. - Continued.



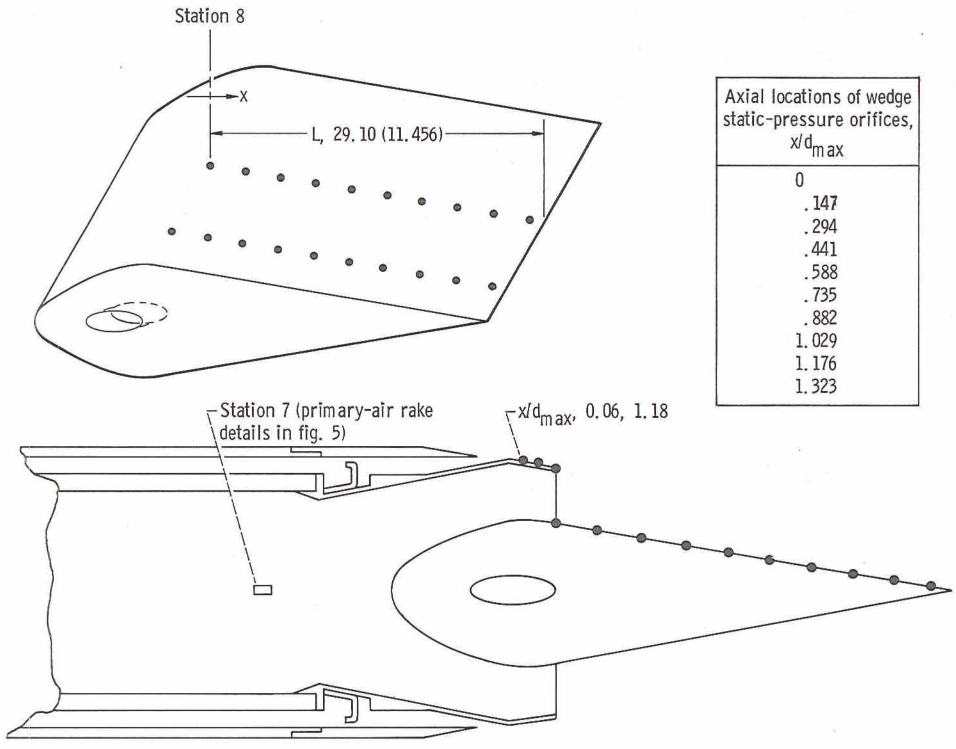
(f) Wedge nozzle with reference primary.

Figure 3. - Concluded.



Axial locations of chutes for static-pressure orifices, x/d_{max}	
Chute B	Chute D
-0.070	-0.056
.210	.172
.350	.288
.490	.404
.630	.520
.770	.636

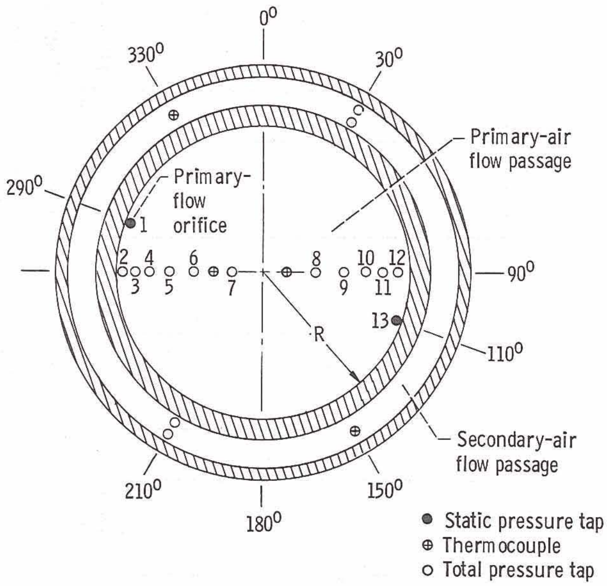
(a) Noise suppressor configuration.



Axial locations of wedge static-pressure orifices, x/d_{max}
0
.147
.294
.441
.588
.735
.882
1.029
1.176
1.323

(b) Reference wedge configuration.

Figure 4. - Model instrumentation.



Primary-flow orifice	Radius ratio, r/R (a)
1	1.000
2	.979
3	.881
4	.770
5	.641
6	.479
7	.215
8	.367
9	.562
10	.705
11	.823
12	.927
13	1.000

[a] R = 7.635 cm (3.006 in.); r is radius from centerline to local probe.

Figure 5. - Details of instrumentation at station 7. View looking downstream.

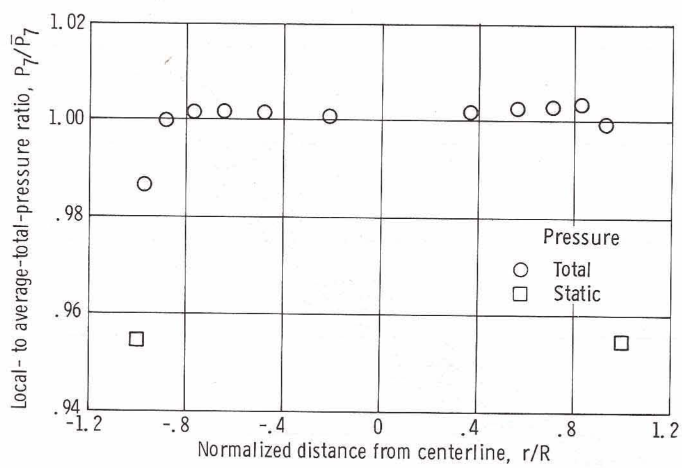


Figure 6. - Primary-total-pressure profile at station 7.

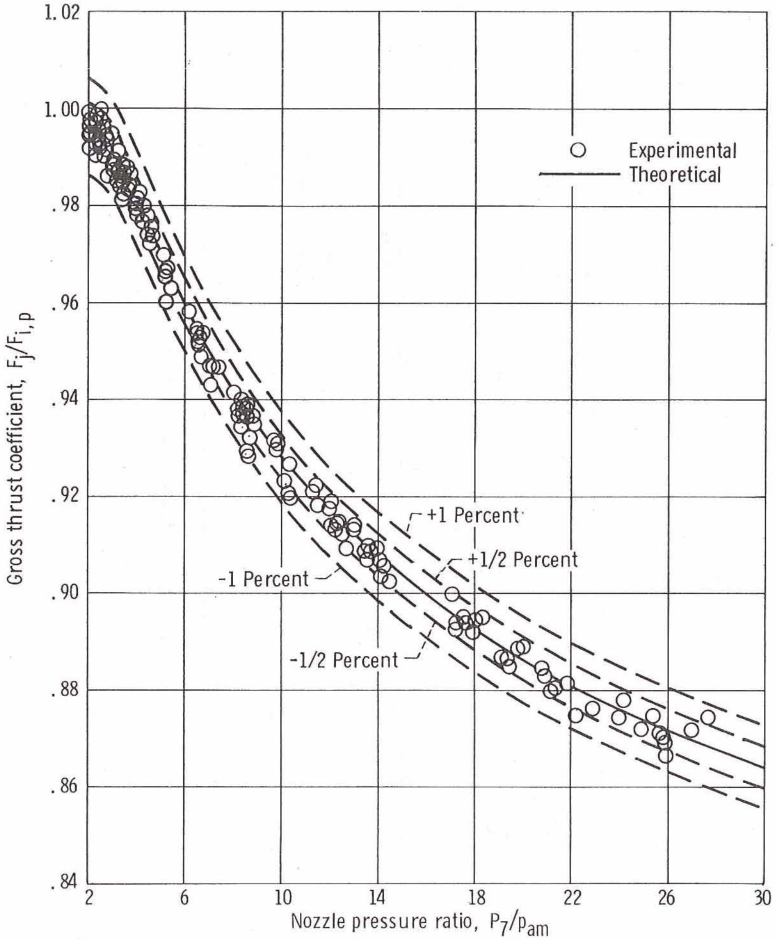
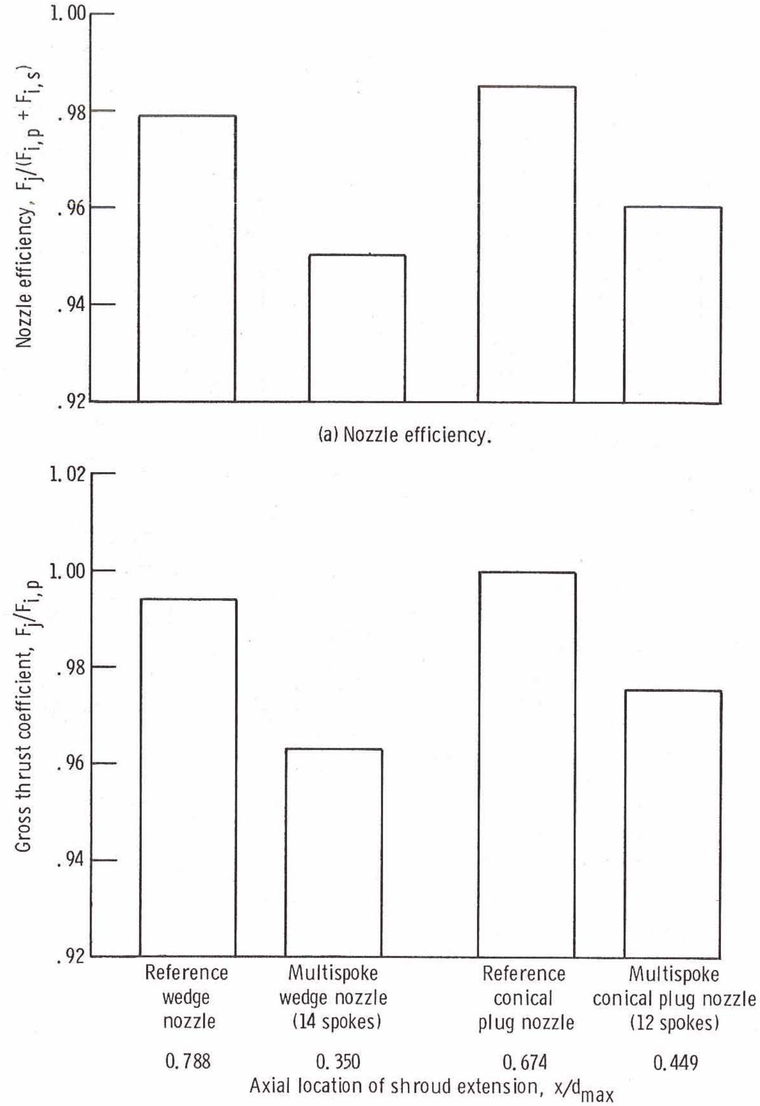
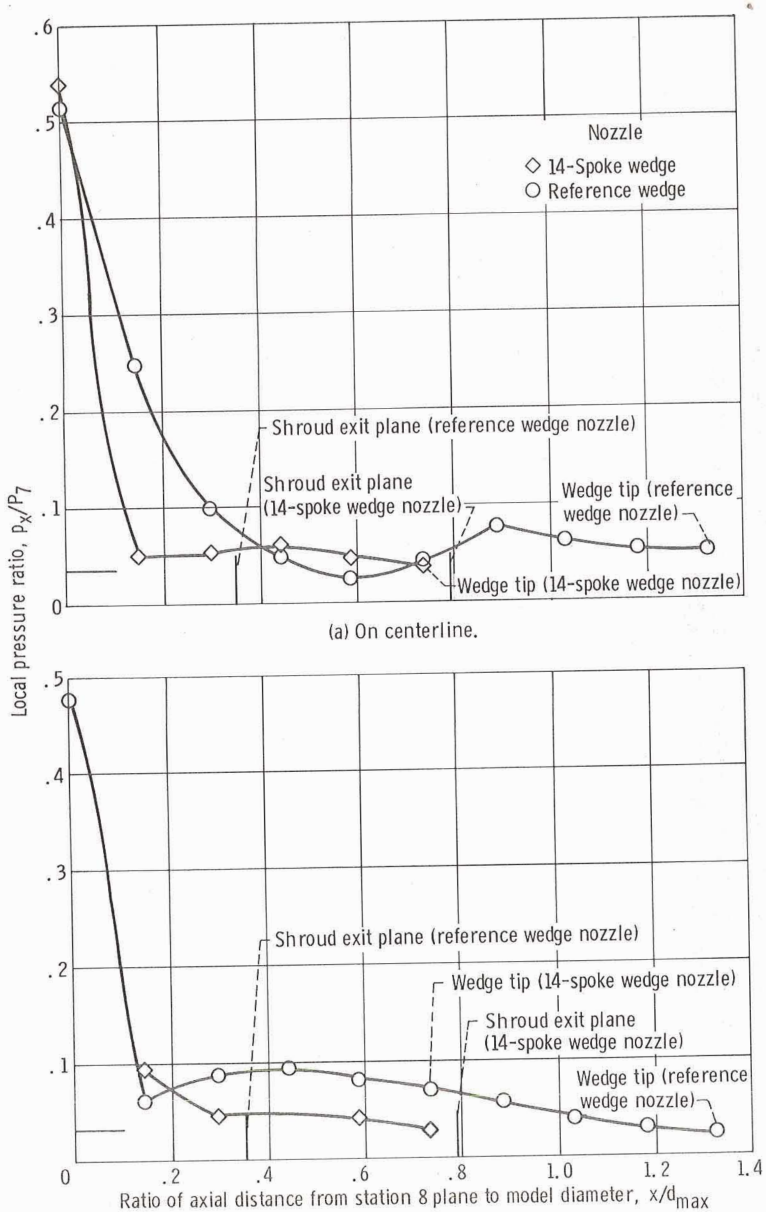


Figure 7. - Internal performance of ASME sonic nozzle in static test stand. Nozzle throat area, 98.1 square centimeters (15.20 in.^{2}).



(b) Gross thrust coefficient.

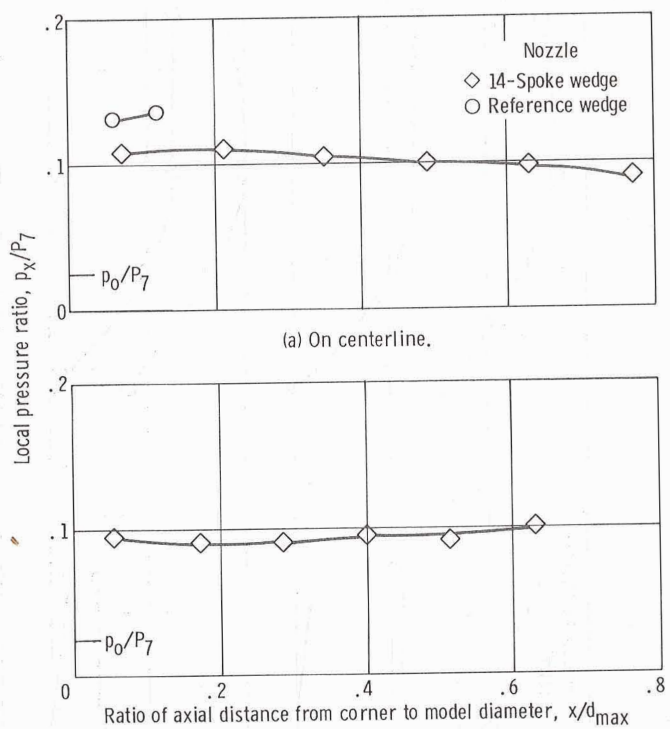
Figure 8. - Comparison of wedge nozzle to a conical plug nozzle at supersonic-cruise. Nozzle pressure ratio, 28.00; corrected secondary-weight-flow ratio, 0.02.



(a) On centerline.

(b) 9.33 Centimeters (2.10 in.) off centerline.

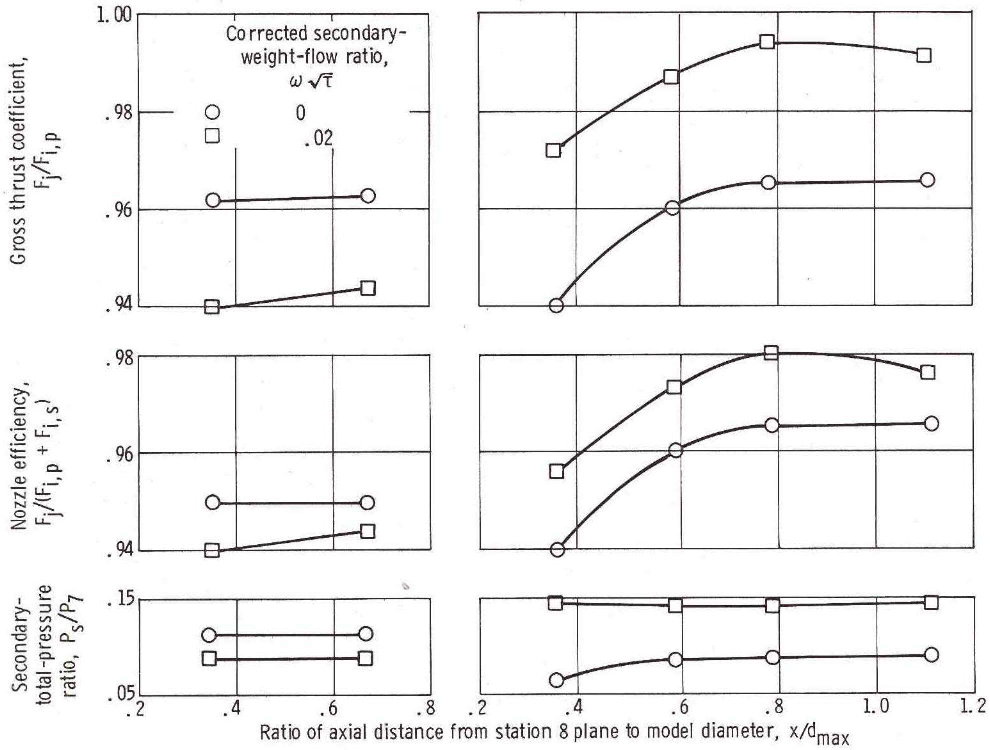
Figure 9. - Comparison of static-pressure distribution on wedge surface with supersonic-cruise configuration. Nozzle pressure ratio, 28.00; corrected secondary-weight-flow ratio, 0.02.



(a) On centerline.

(b) 9.33 Centimeters (2.10 in.) off centerline

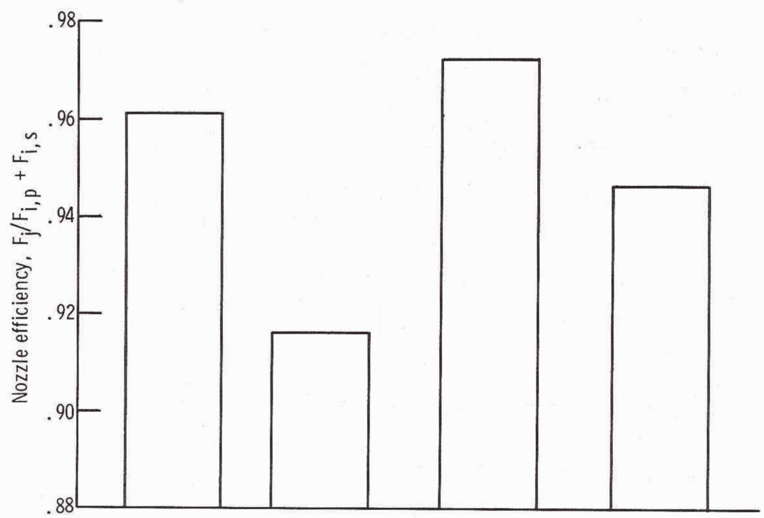
Figure 10. - Static-pressure distribution on reference nozzle boattail and multispoke nozzle chutes with supersonic-cruise configuration. Nozzle pressure ratio, 28.00; corrected secondary-weight-flow ratio, 0.02.



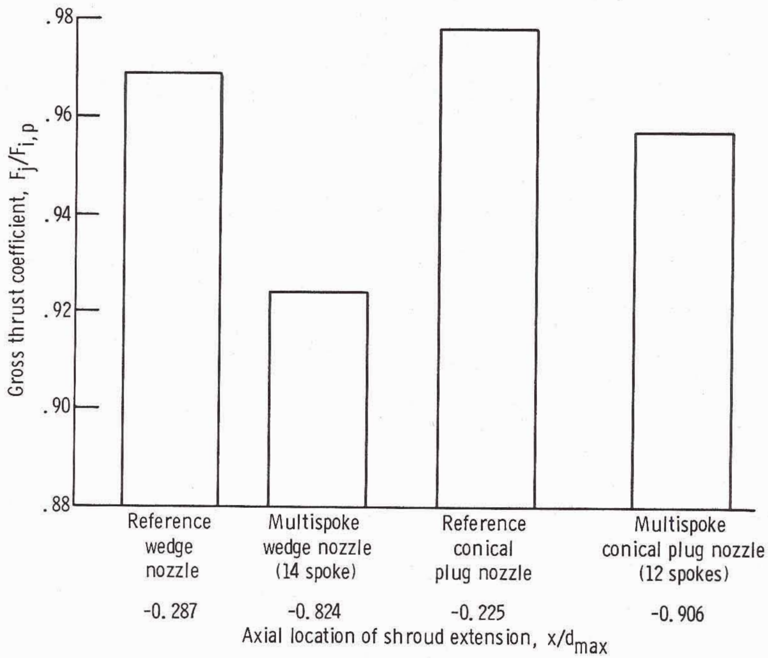
(a) 14-Spoke wedge nozzle.

(b) Reference wedge nozzle.

Figure 11. - Effect of shroud extension on nozzle performance characteristics with supersonic-cruise configurations. Nozzle pressure ratio, 28.00.

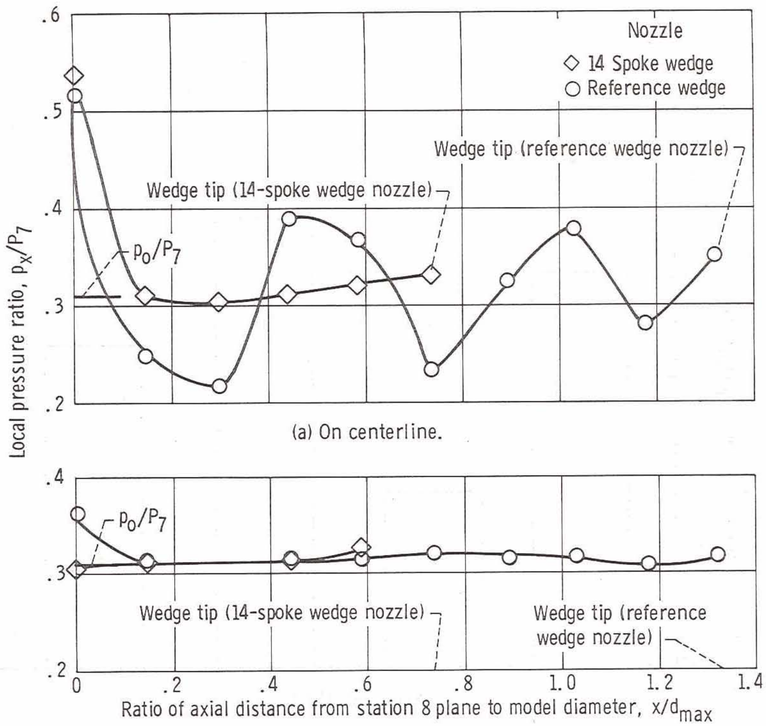


(a) Nozzle efficiency.



(b) Gross thrust coefficient.

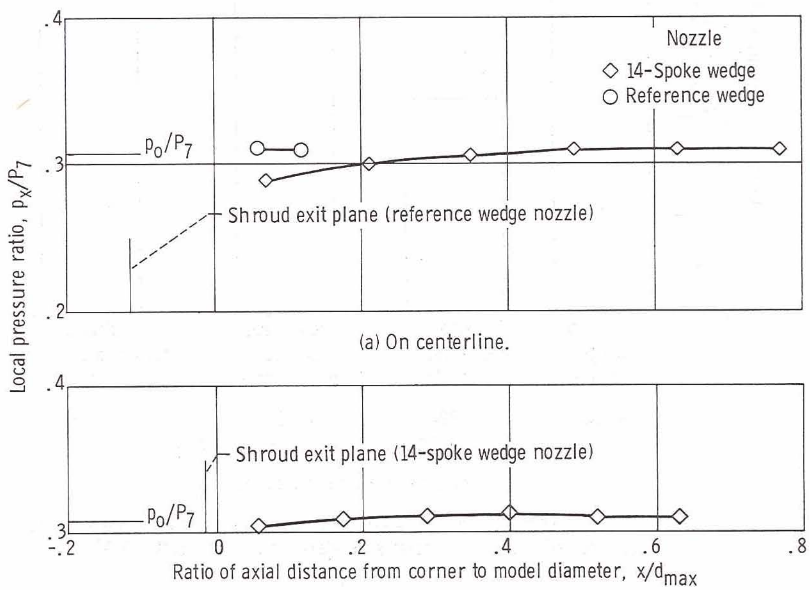
Figure 12. - Comparison of wedge nozzle to a conical plug nozzle at takeoff. Nozzle pressure ratio, 3.25; corrected secondary-weight-flow ratio, 0.04.



(a) On centerline.

(b) 9.33 Centimeters (2.10 in.) off centerline.

Figure 13. - Comparison of static-pressure distribution on wedge surface with takeoff configuration (retracted shroud). Nozzle pressure ratio, 3.25; corrected secondary-weight-flow ratio, 0.04.



(a) On centerline.

(b) 9.33 Centimeters (2.10 in.) off centerline.

Figure 14. - Static-pressure distribution on reference nozzle boattail and multispoke nozzle chutes with takeoff configuration (retracted shroud). Nozzle pressure ratio, 3.25; corrected secondary-weight-flow ratio, 0.04.

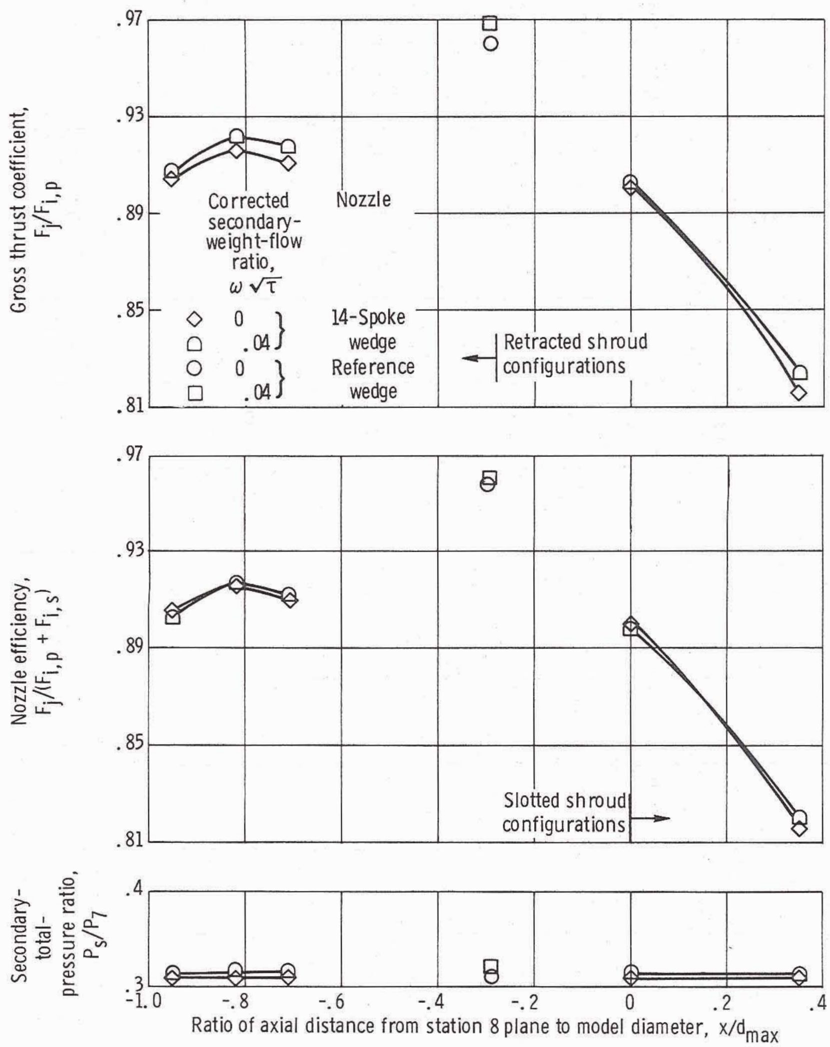
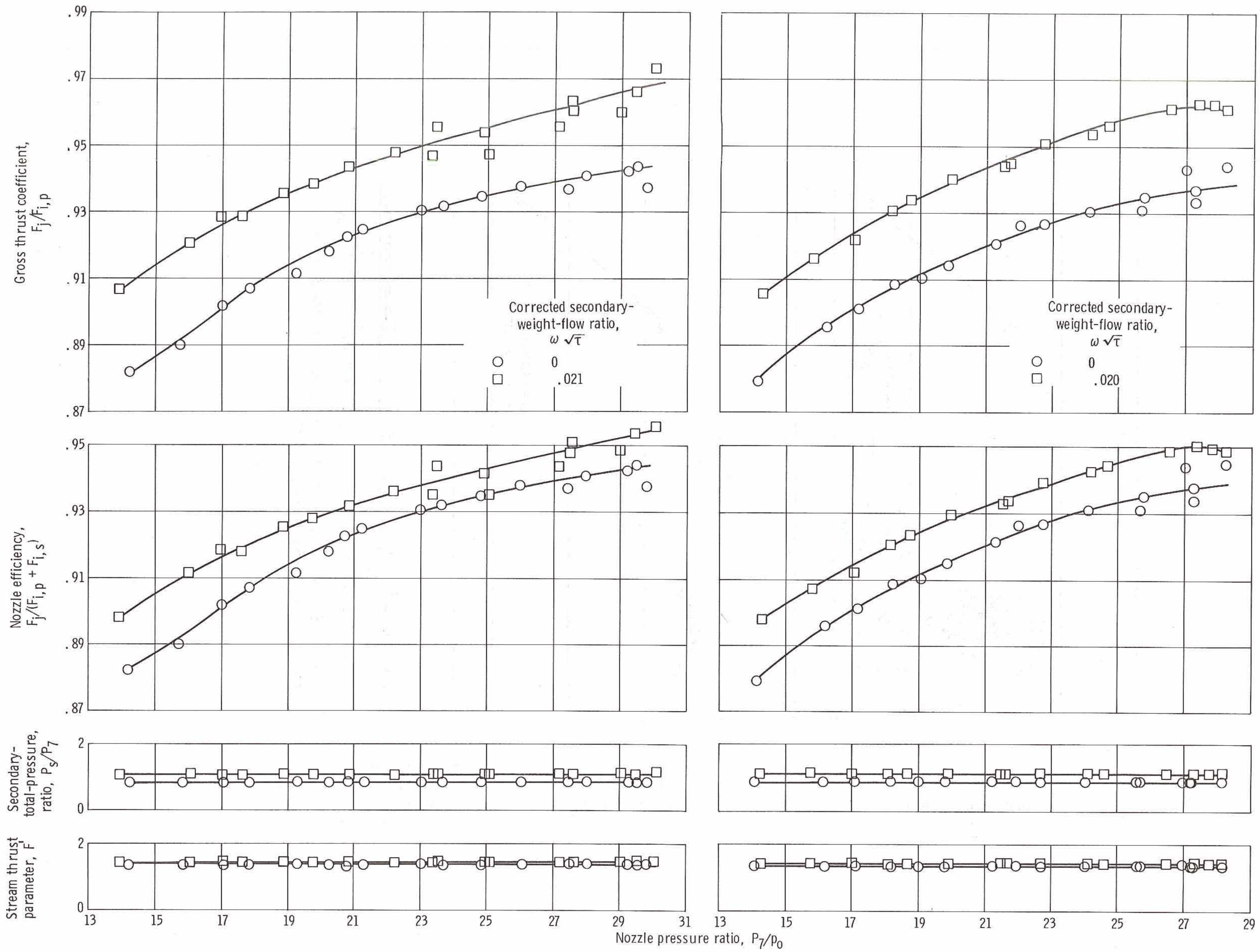


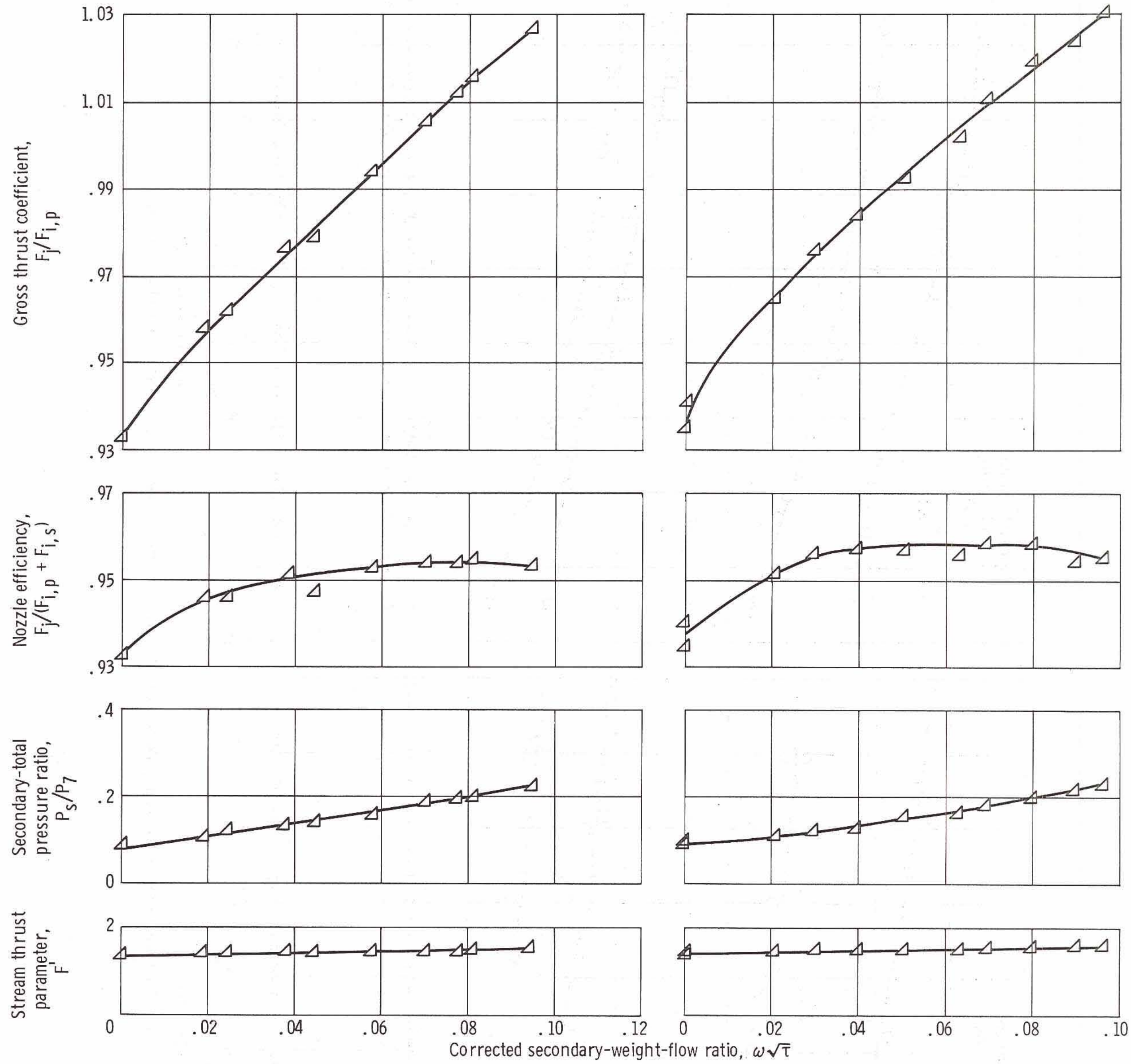
Figure 15. - Effect of shroud extension on nozzle performance characteristics with takeoff configurations, $P_7/p_0 = 3.25$.



(a) Axial location, 0.349.

(b) Axial location, 0.671.

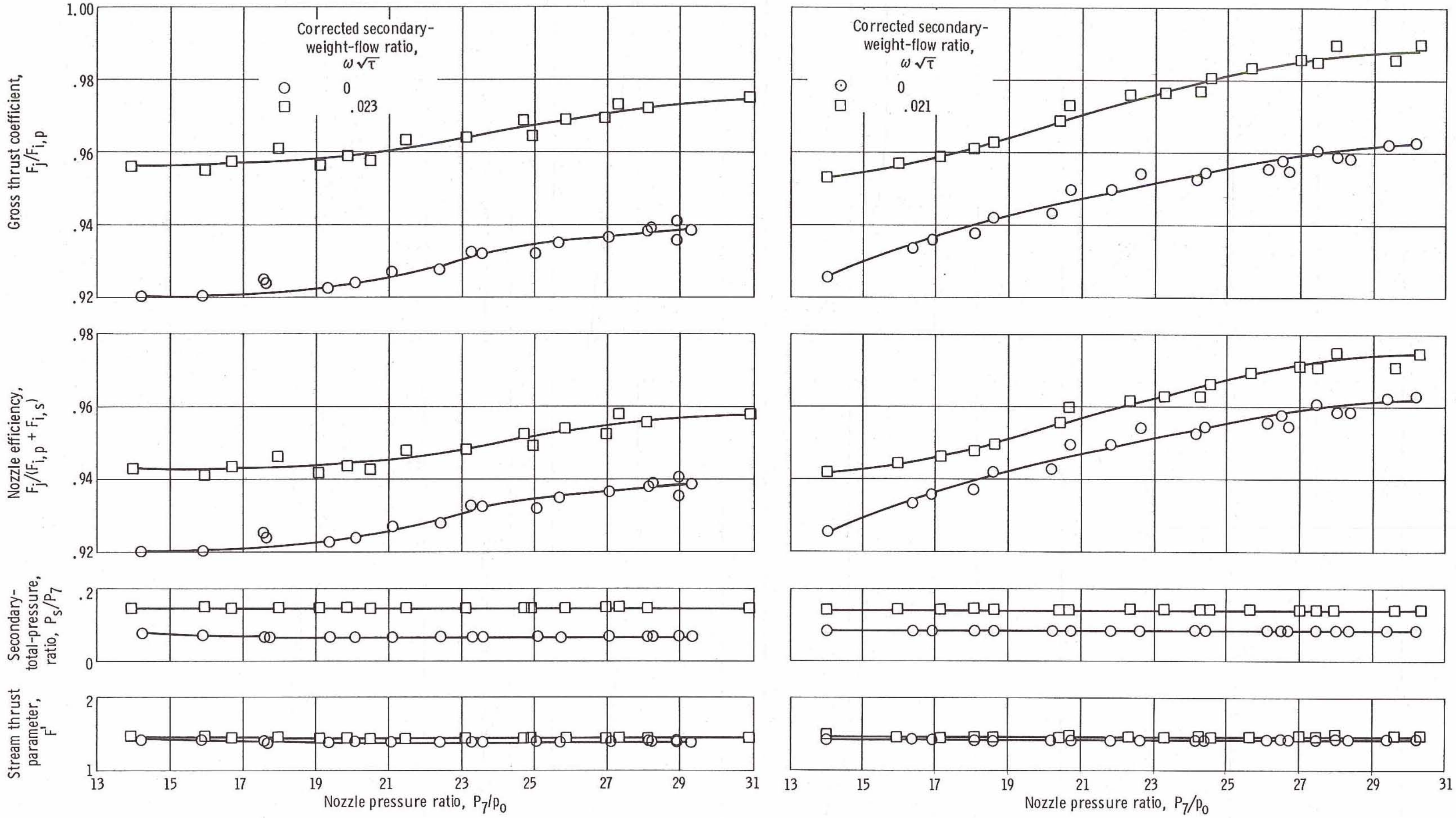
Figure 16. - Effect of nozzle pressure ratio on nozzle performance characteristics; 14-spoke primary nozzle; supersonic-cruise configuration.



(a) Axial location, 0.349.

(b) Axial location, 0.671.

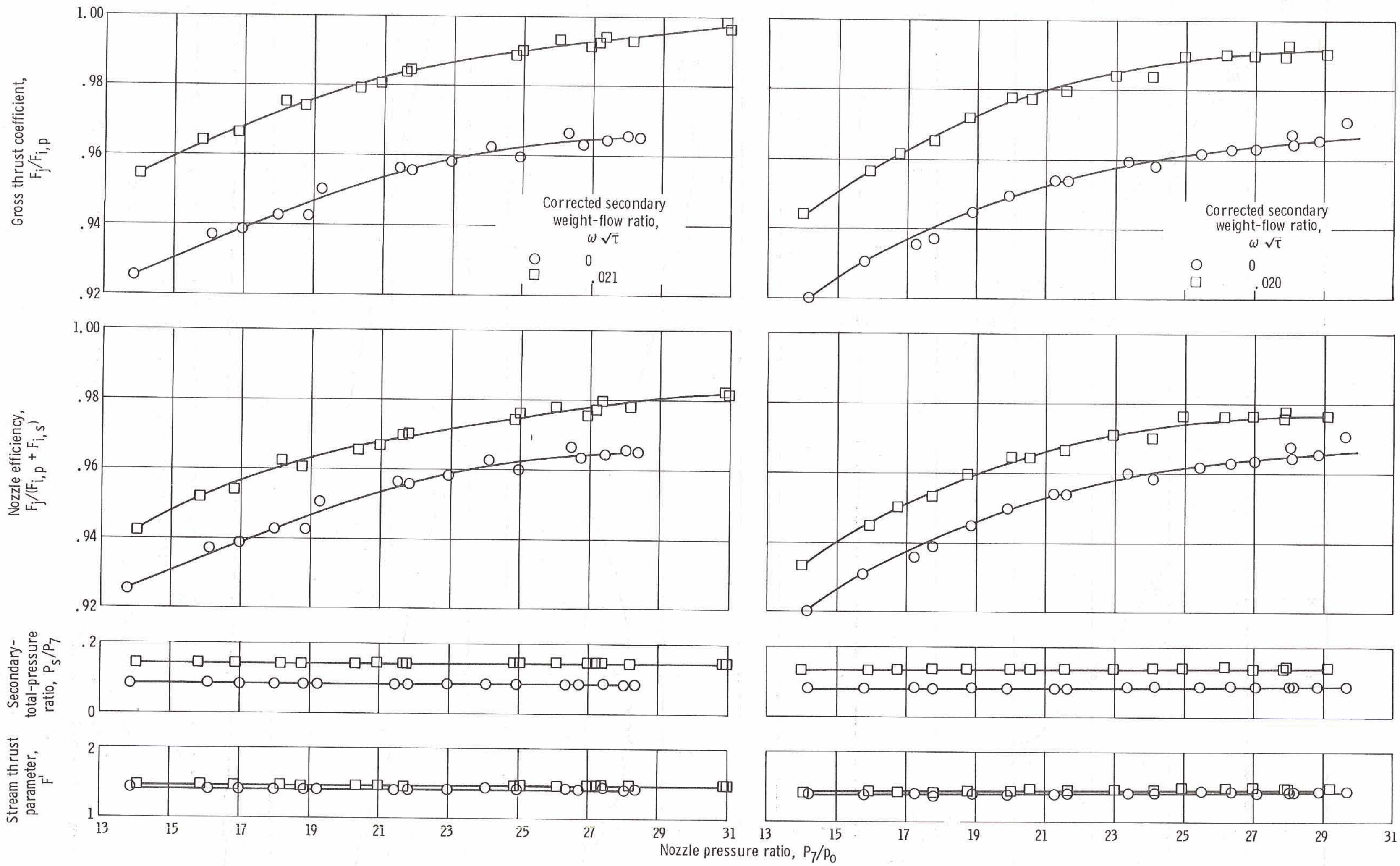
Figure 17. - Effect of corrected secondary-weight-flow ratio on nozzle performance characteristics. Supersonic-cruise configuration; 14-spoke primary nozzle; nozzle pressure ratio, 28.00.



(a) Axial location, 0.346.

(b) Axial location, 0.589.

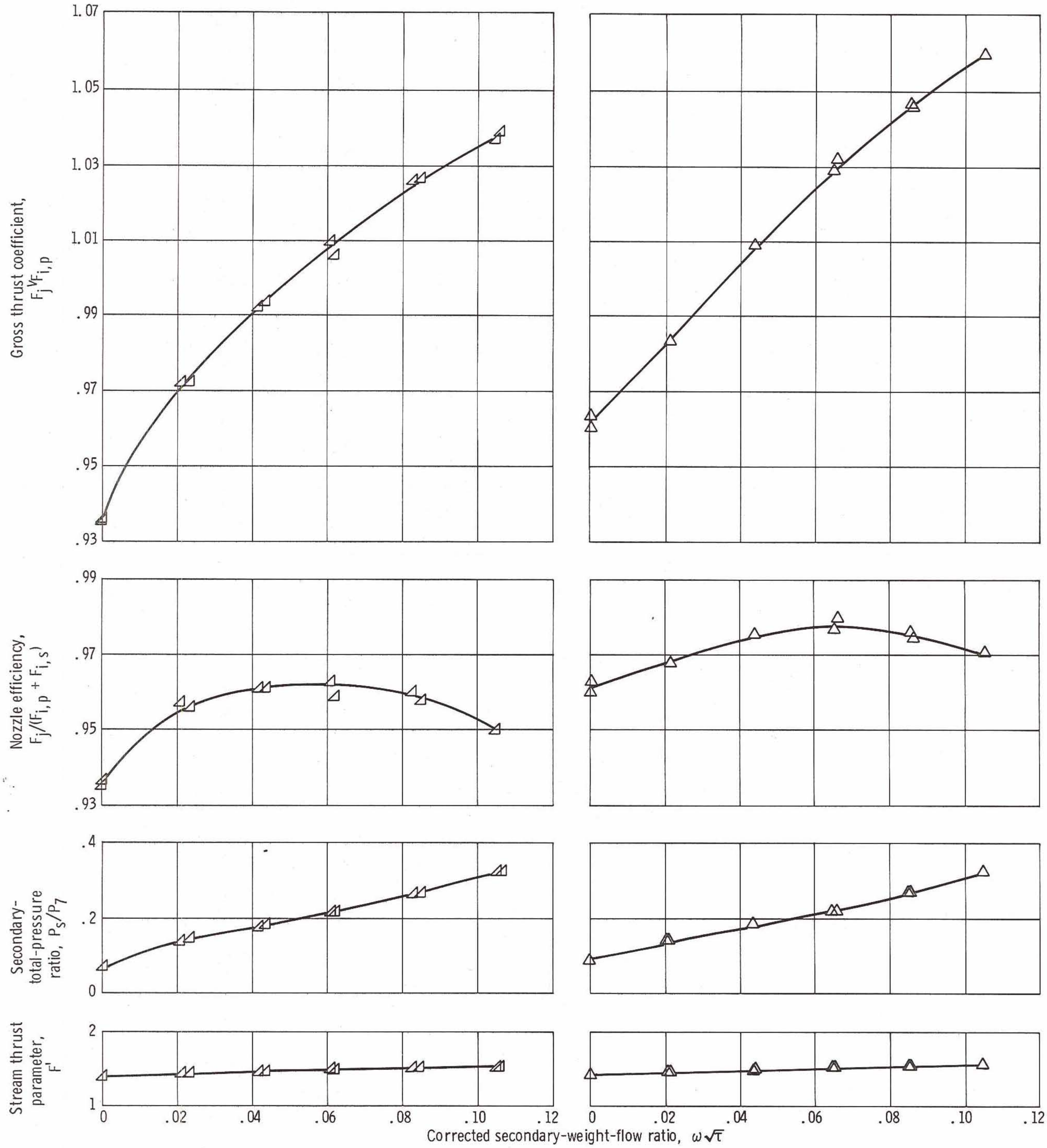
Figure 18. - Effect of nozzle pressure ratio on nozzle performance characteristics. Reference primary nozzle; supersonic-cruise configuration.



(c) Axial location, 0.788.

(d) Axial location, 1.129.

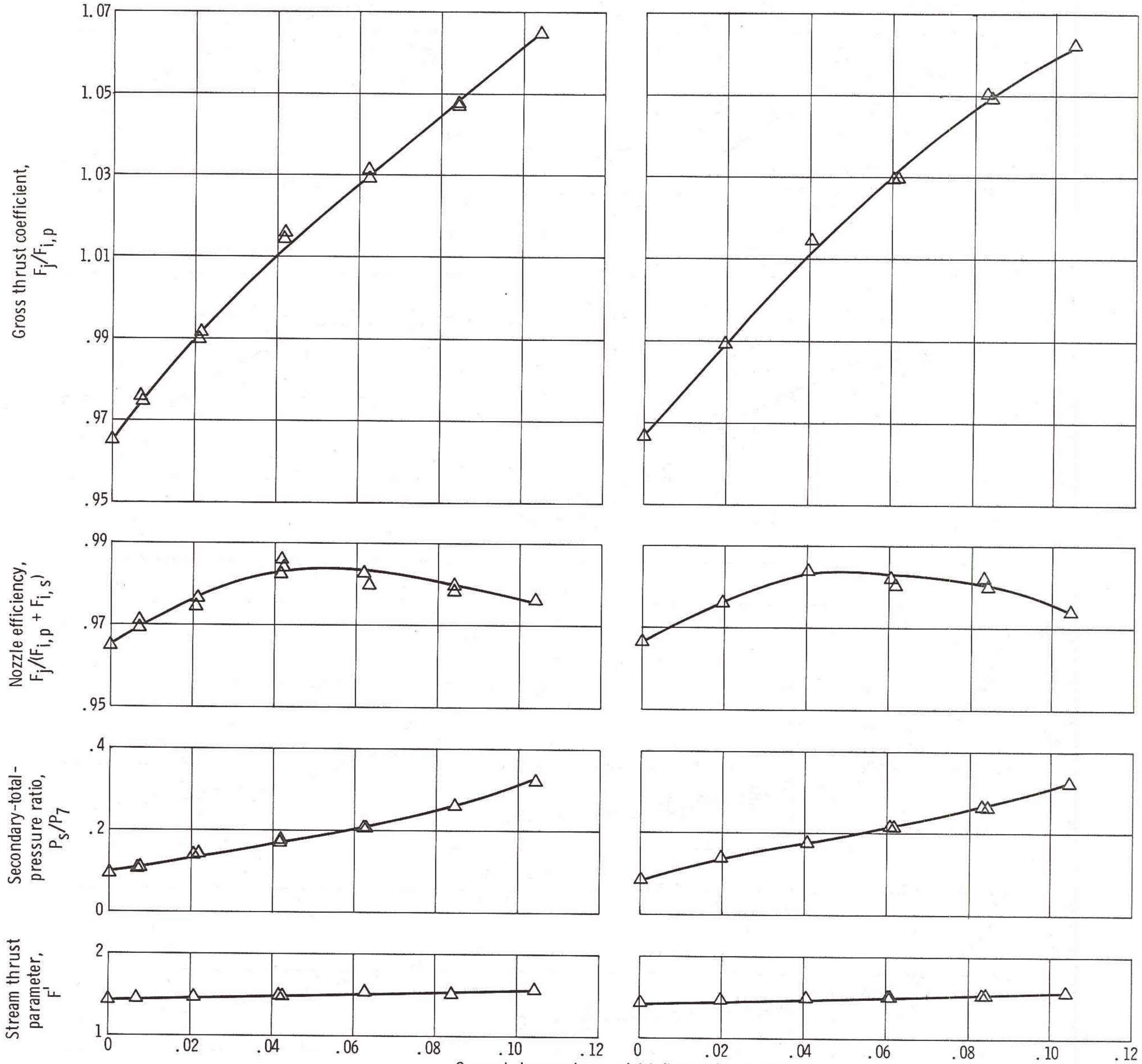
Figure 18. - Concluded.



(a) Axial location, 0.346.

(b) Axial location, 0.589.

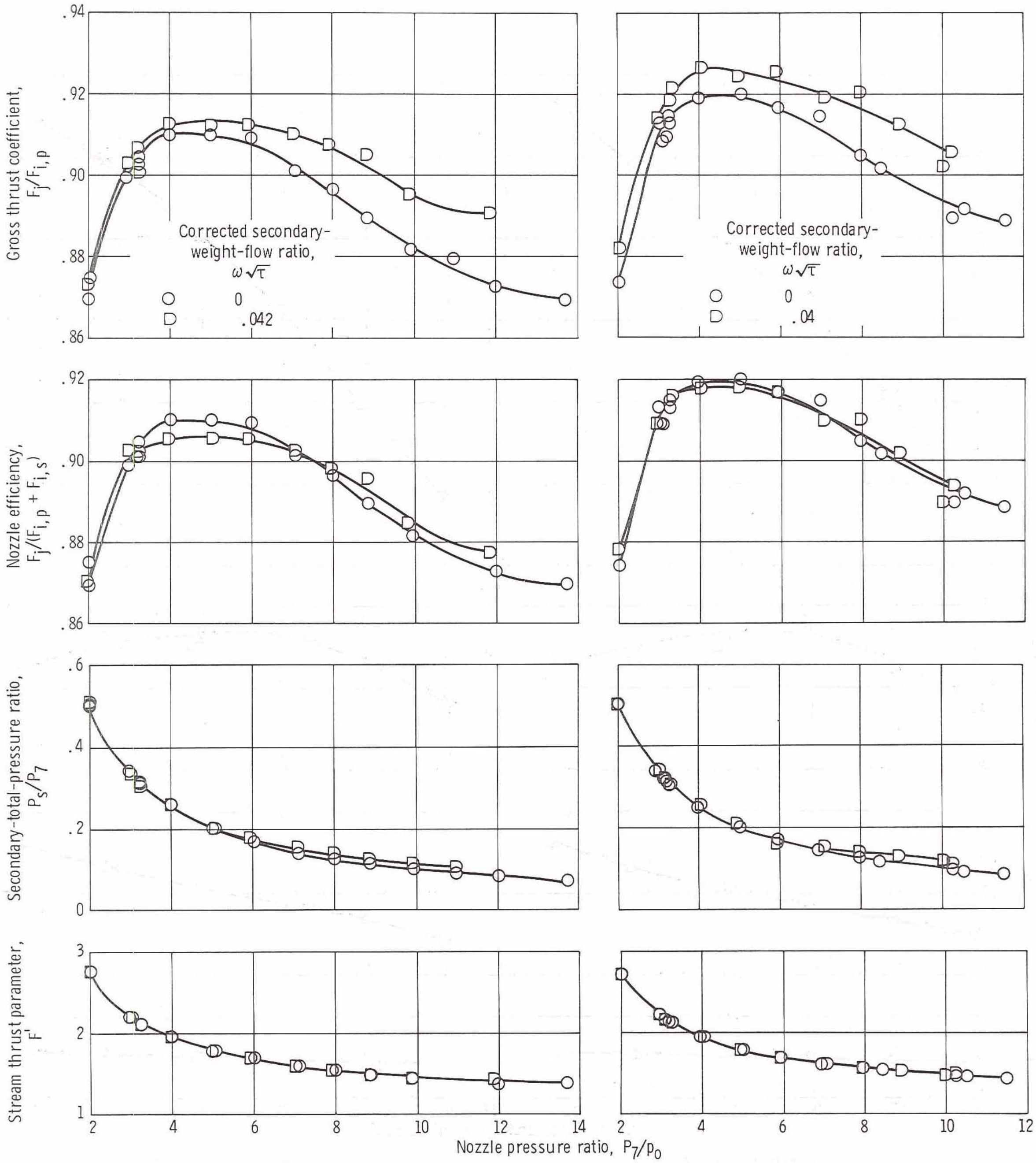
Figure 19. - Effect of corrected secondary-weight-flow ratio on nozzle performance characteristics. Reference wedge; supersonic-cruise configurations; nozzle pressure ratio, 28.99.



(c) Axial location, 0.788.

(d) Axial location, 1.129.

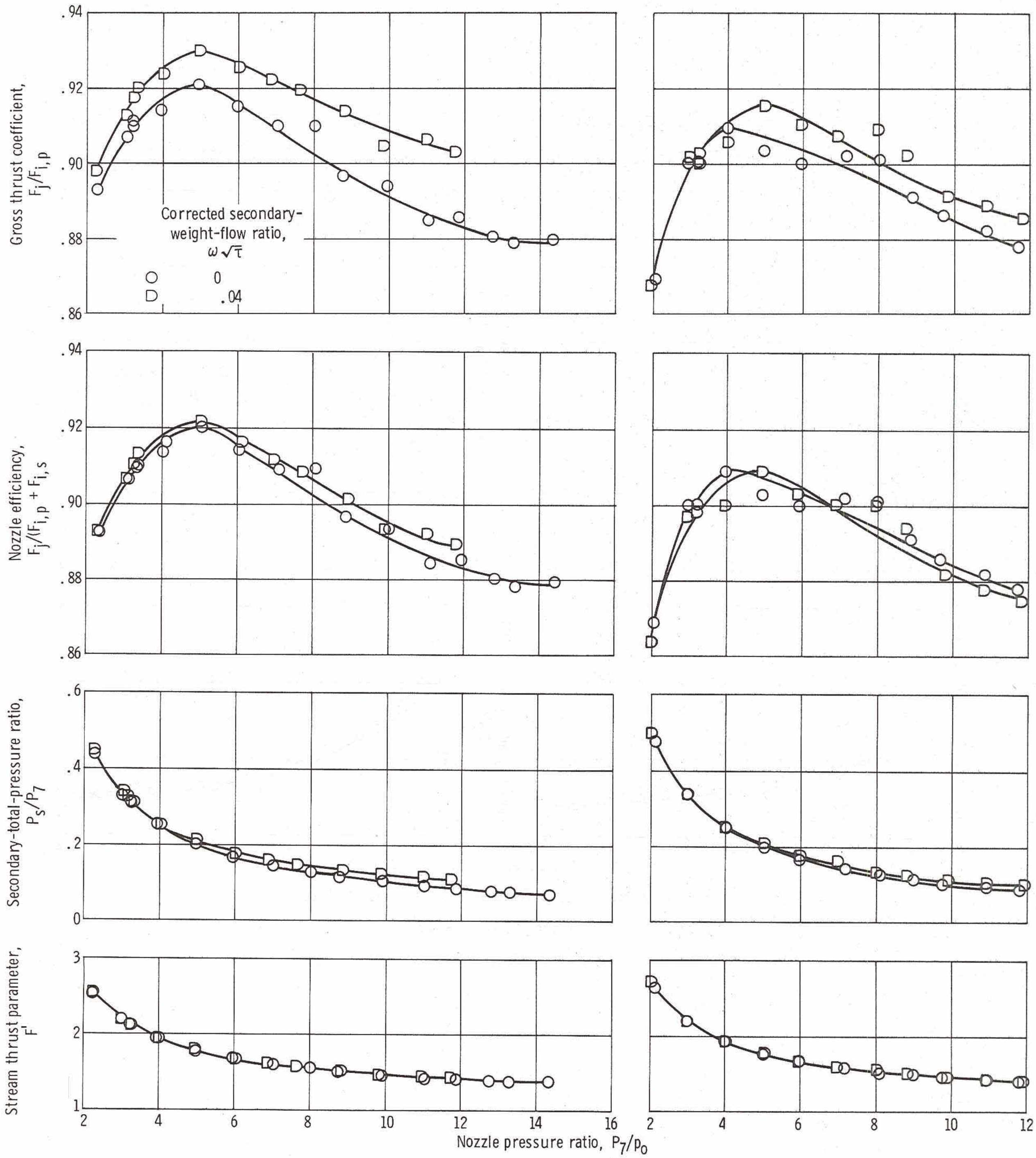
Figure 19. - Concluded.



(a) Axial location, -0.95.

(b) Axial location, -0.824.

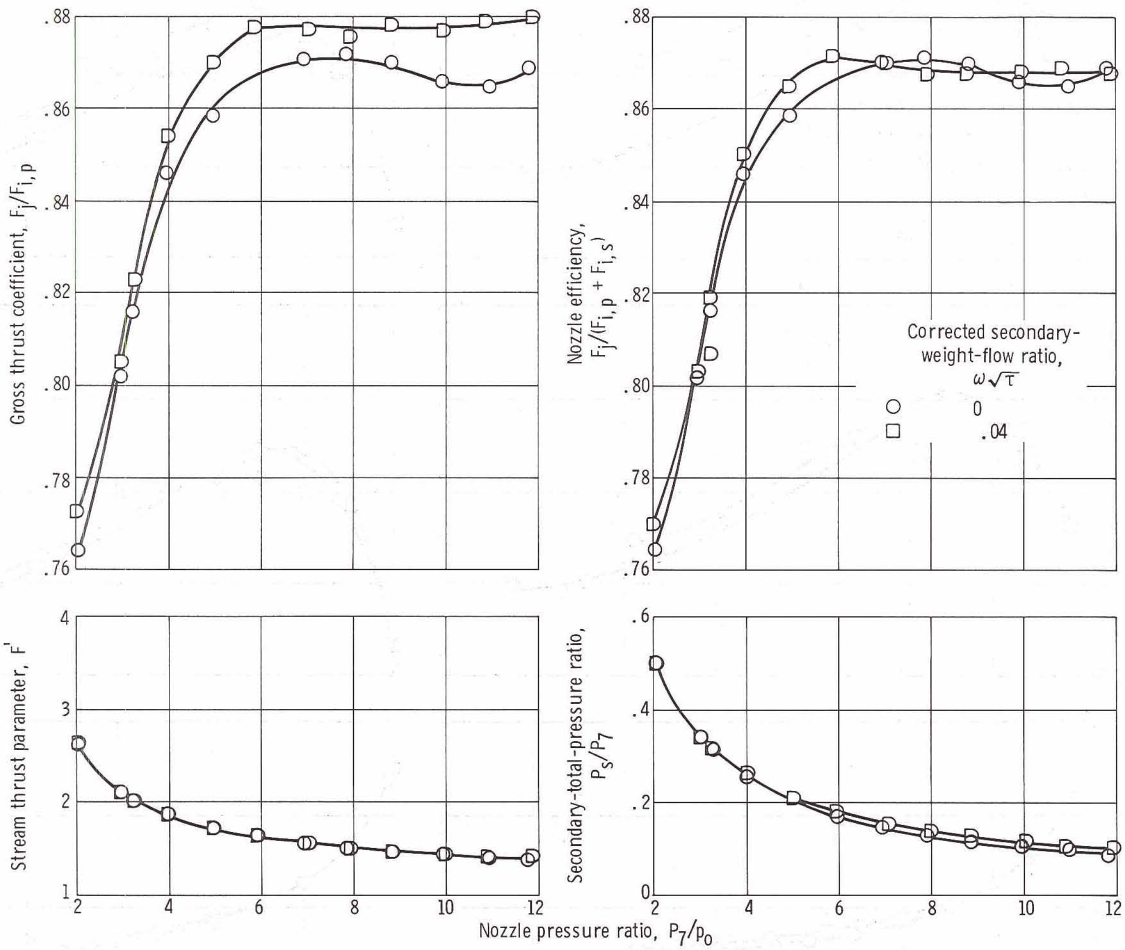
Figure 20. - Effect of nozzle pressure ratio on nozzle performance characteristics. Takeoff configurations; 14-spoke primary nozzle.



(c) Axial location, -0.706.

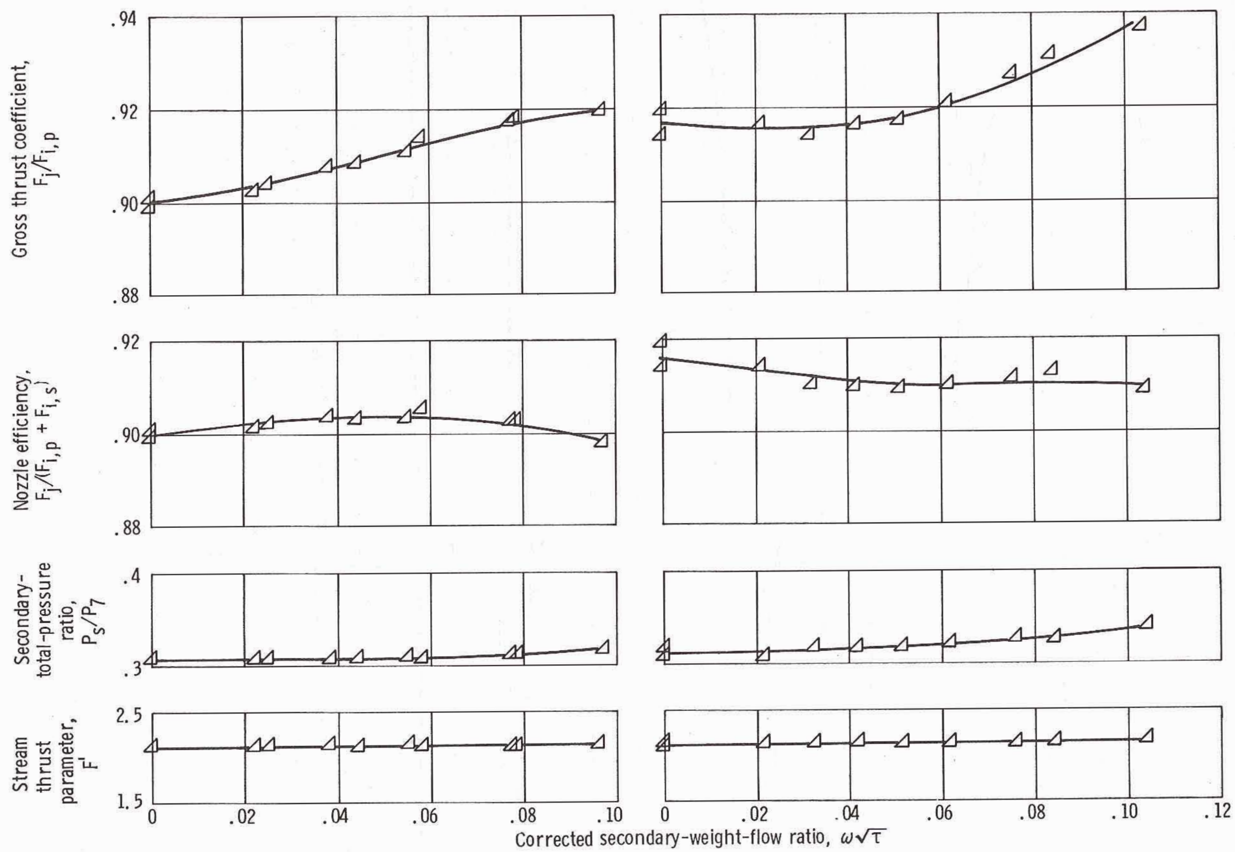
(d) Axial location, 0 (simulated auxiliary inlet fully open).

Figure 20. - Continued.



(e) Axial location, 0.349 (simulated auxiliary inlets fully open).

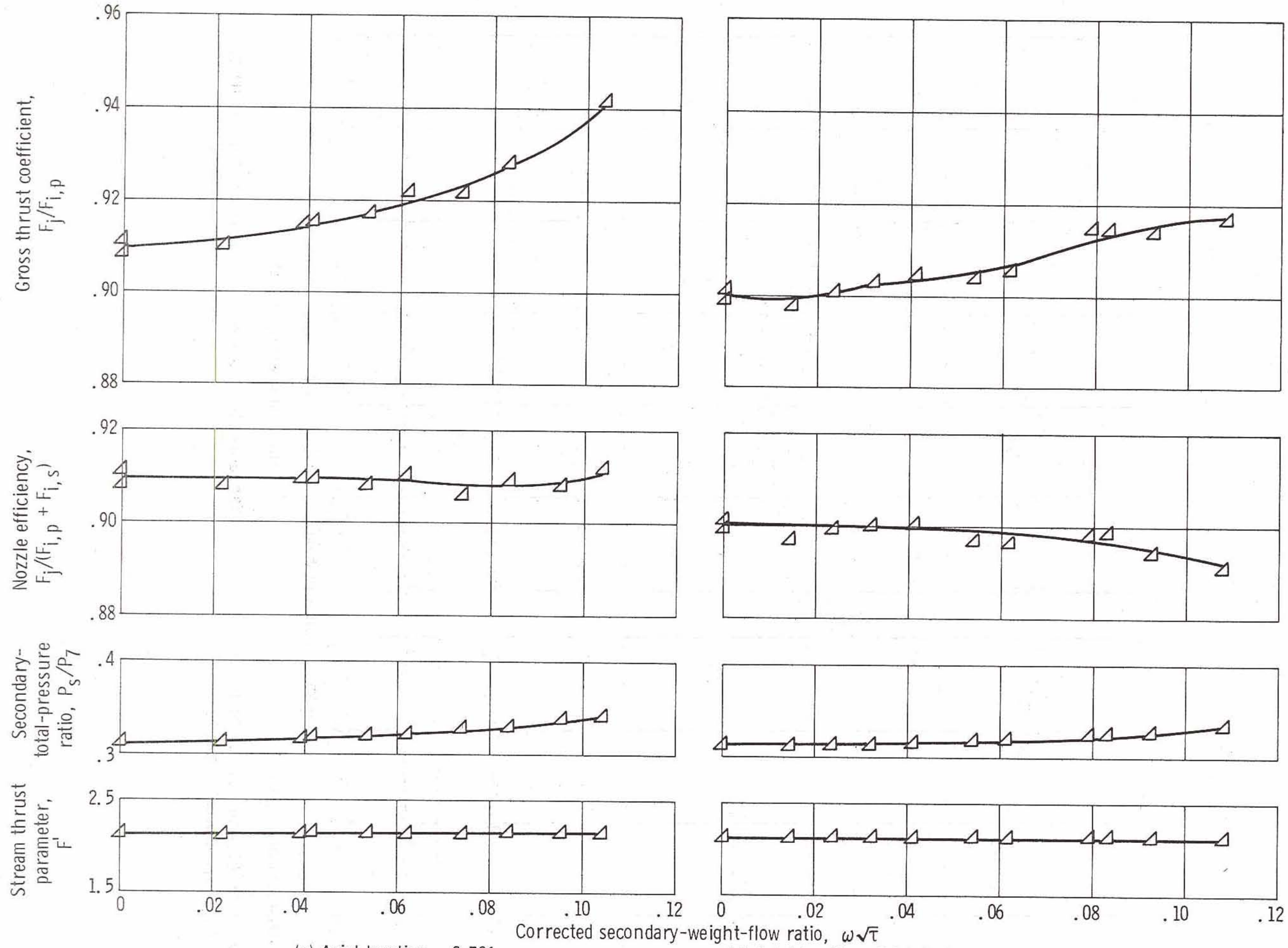
Figure 20. - Concluded.



(a) Axial location, -0.95.

(b) Axial location, -0.824.

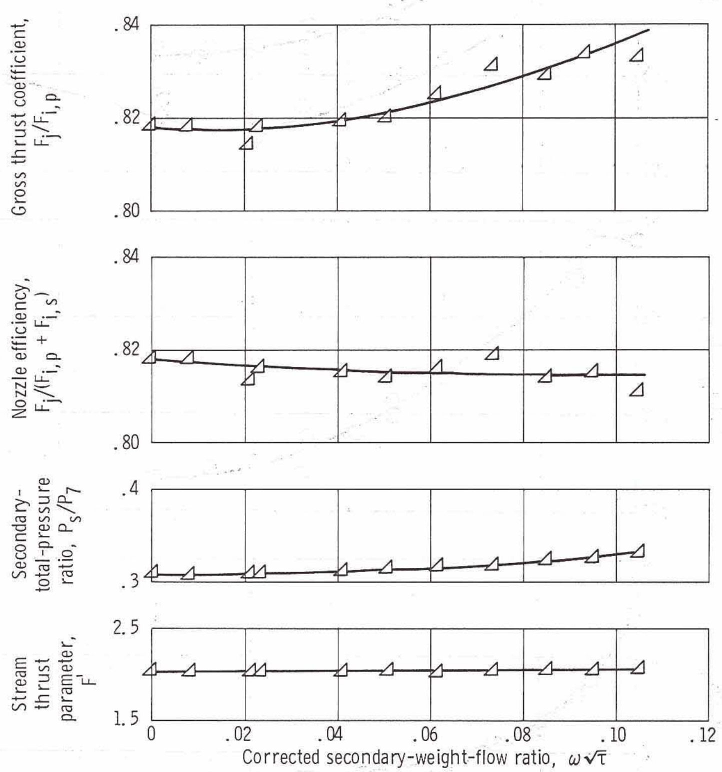
Figure 21. - Effect of corrected secondary-weight-flow ratio on nozzle performance characteristics. Takeoff configurations; nozzle pressure ratio, 3.25; 14-spoke primary nozzle.



(c) Axial location, -0.706.

(d) Axial location, 0 (slotted shroud to simulated auxiliary inlets).

Figure 21. - Continued.



(e) Axial location, 0.349 (slotted shroud to simulated auxiliary inlets).

Figure 21. - Concluded.

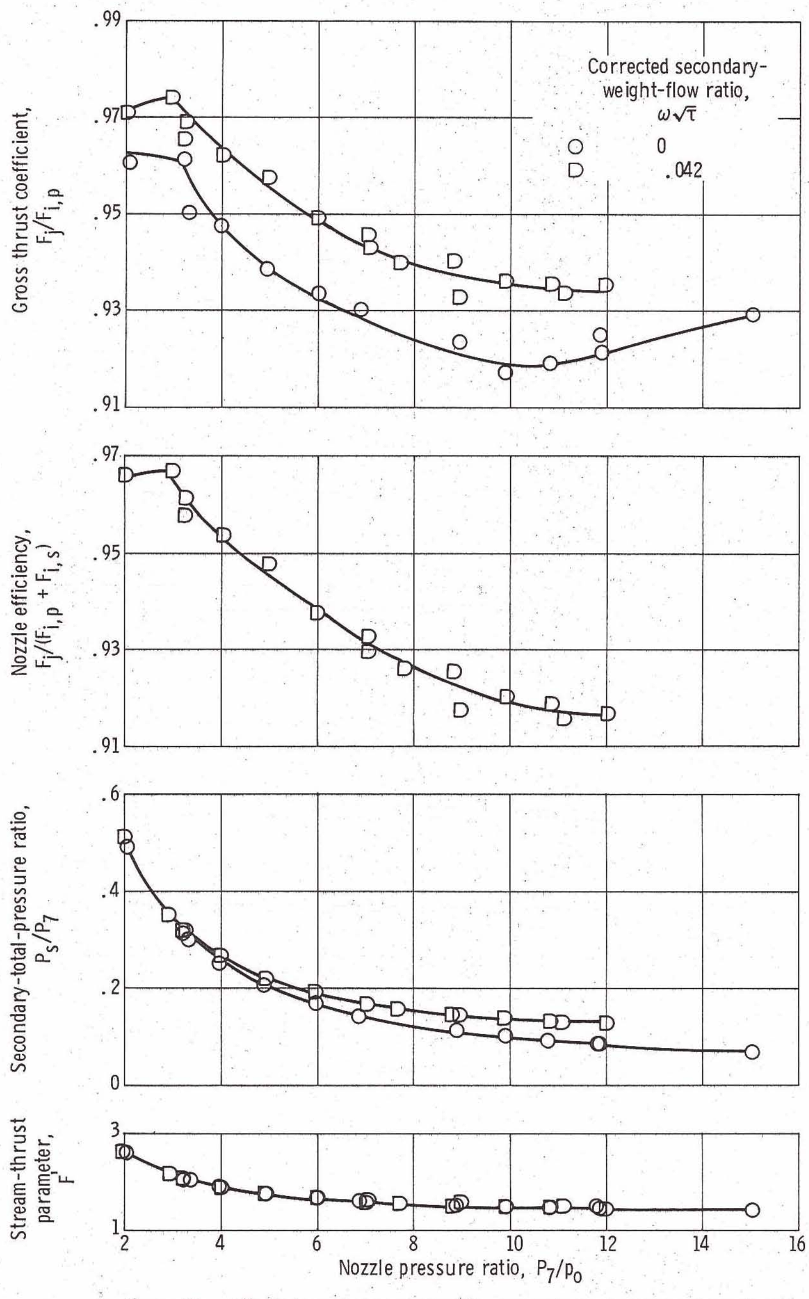


Figure 22. - Effect of nozzle pressure ratio on nozzle performance characterestics. Reference wedge; takeoff configuration; axial location, -0.287.

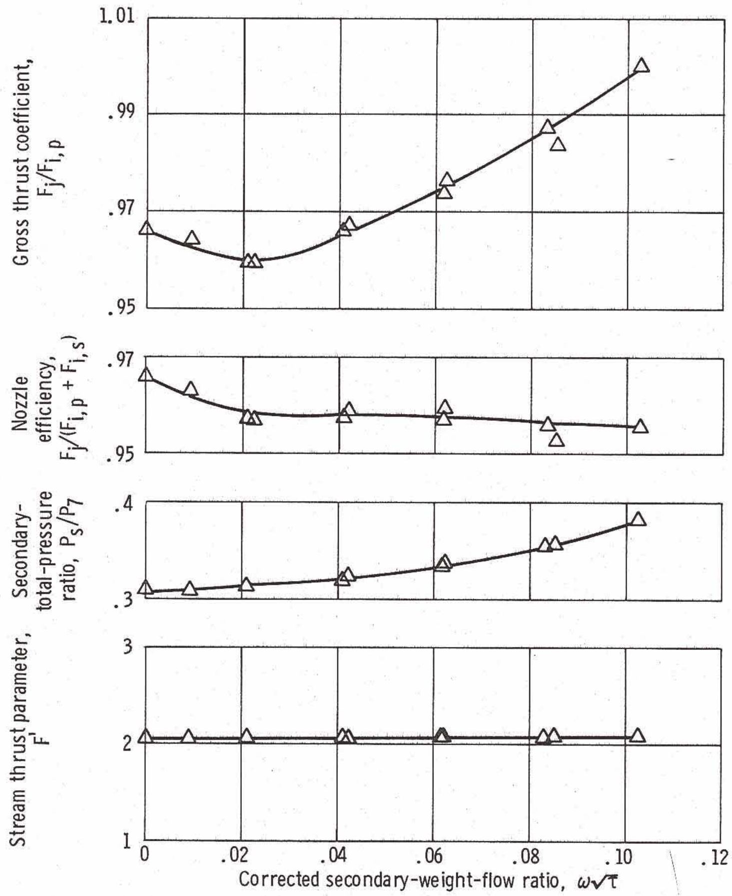


Figure 23. - Effect of corrected secondary-weight-flow ratio on nozzle performance characteristics. Reference wedge; takeoff configuration; axial location, -0.287; nozzle pressure ratio, 3.24.

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