Static Internal Performance of a Single Expansion Ramp Nozzle With Multiaxis Thrust Vectoring Capability

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Summary

An investigation has been conducted at static conditions in order to determine the internal performance characteristics of a multi-axis thrust vectoring single expansion ramp nozzle. Yaw vectoring was achieved by deflecting yaw flaps in the nozzle sidewall into the nozzle exhaust flow. In order to eliminate any physical interference between the variable angle yaw flap deflected into the exhaust flow and the nozzle upper ramp and lower flap which were deflected for pitch vectoring, the downstream corners of both the nozzle ramp and lower flap were cut off to allow for up to 30° of yaw vectoring. The effects of nozzle upper ramp and lower flap cutout, yaw flap hinge line location and hinge inclination angle, sidewall containment, geometric pitch vector angle, and geometric yaw vector angle were studied. This investigation was conducted in the static-test facility of the Langley 16-Foot Transonic Tunnel at nozzle pressure ratios up to 8.0.

An analysis of the results of this investigation indicates that removal of the downstream corners of both the upper ramp and lower flap for a yaw flap hinge line downstream of the nozzle throat had little or no effect on resultant thrust ratio. However, losses of up to 3.4 percent in resultant thrust ratio occurred with the yaw flap hinge line near the nozzle throat. Pitch vectoring performance was primarily influenced by yaw flap hinge line location rather than ramp cutout. For the nozzle with the yaw flap hinge line near the nozzle throat, there was a 10.3° decrease in resultant pitch vector angle for a negative geometric pitch vector angle of 20° and about a 5° decrease for a positive geometric pitch vector angle of 20°. Yaw thrust vectoring of nozzles with no geometric pitch vectoring caused resultant thrust ratio losses of up to 3.5 percent per 10° of yaw turning and produced resultant yaw vector angles that were typically 33 to 45 percent of the geometric yaw vector angle. Maximum resultant yaw angles occurred for the nozzle with the yaw hinge line near the nozzle throat and with the maximum sidewalls. Yaw thrust vectoring decreased the resultant pitch vector angle for the negative pitched-vectored nozzle and increased resultant pitch angle for the nozzle with no vectoring or with positive pitch vectoring. Most of the yaw turning was produced from the yaw flap deflected into the nozzle exhaust flow.

Introduction

Studies have shown that significant advantages in air combat are gained with the ability to perform transient maneuvers at high angles of attack including brief excursions into poststall conditions (refs. 1 to 3). Expansion of the angle of attack envelope of fighter airplanes to meet the more demanding mission requirements of the future is possible because of recent technological advances such as thrust vectoring in nozzle design. Thrust vectoring, by virtue of being uncoupled from the airplane aerodynamics, has the potential to augment performance characteristics by allowing greater control beyond stall conditions than that provided by the airplane aerodynamic surfaces.

A number of investigations, conducted at both static conditions (wind off) and at forward speeds, have verified the capability of both axisymmetric and nonaxisymmetric multifunction nozzles to provide pitch and yaw thrust vectoring (refs. 4 to 9). Some of these investigations involved adding yaw vectoring capability to nozzles originally designed for pitch vectoring only. This paper presents results from an investigation in which a single expansion ramp nozzle (SERN) has been modified to include multi-axis thrust vectoring capability. The SERN is a non-axisymmetric, variable-area, internal/external expansion exhaust system (refs. 10 to 14). Basic SERN nozzle components consist of (1) a two-dimensional upper ramp in which a portion of the ramp surface downstream of the throat serves as an external expansion ramp, (2) a relatively short two-dimensional lower flap, and (3) flat, two-dimensional sidewalls. Nozzle power setting (throat area) is changed by varying the geometry of the convergent-divergent upper ramp assembly (refs. 10 to 12), and expansion ratio is varied by rotation of the lower flap. Most SERN designs also provide for pitch thrust vectoring capability through rotation of the entire divergent portion of the ramp surface in conjunction with rotation of the lower flap (refs. 10, 12, and 13).

A single expansion ramp nozzle designed for pitch vectoring (ref. 13) was modified to accommodate yaw vectoring flaps that were located in the nozzle sidewalls. In order to eliminate any physical interference between the yaw flap deflected into the exhaust flow and the nozzle upper ramp and lower flap which were deflected for pitch vectoring, the downstream corners of both the nozzle upper ramp and lower flap were cut off to allow for up to 30° of yaw vectoring. The purpose of this investigation was to study the effects on nozzle internal performance of varying nozzle pitch and yaw vector angle, ramp and flap cutout angle, yaw flap hinge location and inclination angle, and nozzle sidewall containment. This investigation was conducted in the static-test facility of the Langley 16-Foot Transonic Tunnel at static conditions and at nozzle pressure ratios up to 8.0. A summary of some of the results presented herein was previously reported in reference 15.
Symbols

All forces and moments (with the exception of resultant gross thrust) are referred to the model centerline (body axis). The model (balance) moment reference center was located at station 29.39. A discussion of the data reduction procedure and definitions of the force and moment terms and the propulsion relationships used herein can be found in reference 16.

\( A_e \) nozzle exit area, \( \text{in}^2 \)
\( A_t \) nozzle throat area, \( \text{in}^2 \)
\((A_e/A_t)_{i}\) internal expansion ratio (\(A_e\) measured at end of nozzle lower flap)
\( F \) measured thrust along body axis, lbf
\( F_i \) ideal isentropic gross thrust,
\[ w_p \left( \frac{R T_{t,j}^{1/2}}{g^{1/2}} \frac{2 \gamma}{\gamma-1} \left[ 1 - \left( \frac{1}{\text{NPR}} \right)^{(\gamma-1)/\gamma} \right] \right)^{1/2} \]
\( F_N \) measured normal force, lbf
\( F_r \) resultant gross thrust,
\[ \sqrt{F^2 + F_N^2 + F_Y^2} \text{, lbf} \]
\( F_Y \) measured side force, lbf
\( g \) gravitational constant, 32.174 ft/sec\(^2\)
\( h_t \) nozzle throat height (fig. 1(b)), in.
\( l_r \) axial length of upper ramp measured from nozzle throat to end of ramp, in.
\( \text{NPR} \) nozzle pressure ratio, \( p_{t,j}/p_a \)
\((\text{NPR})_{\text{des}} \) design nozzle pressure ratio for ideally expanded flow
\( p_a \) ambient pressure, psi
\( p_f \) flap local static pressure, psi
\( p_r \) ramp local static pressure, psi
\( p_{t,j} \) jet total pressure, psi
\( R \) gas constant for air, 1716 ft\(^2\)/sec\(^2\)-°R
\( T_{t,j} \) jet total temperature, °R
\( w_i \) ideal weight-flow rate, lbf/sec
\( w_p \) measured weight-flow rate, lbf/sec
\( x \) axial distance measured from nozzle connect station, positive downstream (fig. 1(a)), in.
\( x_p \) location of ramp or flap pressure orifices (relative to unvectored nozzle) measured from nozzle throat, positive downstream, in.
\( x_r \) longitudinal distance to yaw hinge line measured from nozzle throat along upper ramp (fig. 1(a)), in.
\( x_t \) length from nozzle connect station to throat location on ramp or lower flap (fig. 1(b)), in.
\( y \) vertical distance measured from model centerline, positive up (fig. 1(a)), in.
\( y_e \) vertical distance of nozzle ramp or lower flap trailing edge from model centerline, positive up (fig. 1(b)), in.
\( y_t \) vertical distance of nozzle ramp or lower flap throat location from model centerline, positive up (fig. 1(b)), in.
\( z \) lateral distance of sidewall measured from inside surface of sidewall (fig. 1(c)), positive for sidewall deflected into flow, in.
\( \gamma \) ratio of specific heats for air, 1.3997
\( \delta_p \) resultant pitch vector angle, \( \tan^{-1}\frac{F_N}{F} \), deg
\( \delta_{v,p} \) geometric pitch vector angle measured from nozzle centerline, positive for downward deflection, deg
\( \delta_{v,y} \) geometric yaw vector angle measured from nozzle centerline, positive deflection to left looking upstream, deg
\( \delta_y \) resultant yaw vector angle, \( \tan^{-1}\frac{F_Y}{F} \), deg
\( \theta \) upper ramp cutout angle (fig. 1(d)), deg
\( \phi \) hinge line inclination angle (fig. 1(e)), deg

Subscripts:
1 lower flap
\( r \) ramp
\( u \) upper ramp

Abbreviations:
max maximum
med medium
expansion cxhaust system. Basic SERN nozzle com-
sta. model station: in.
SERN single expansion ramp nozzle
min minimum
sta. model station, in.

Nozzle Designs

The single expansion ramp nozzle (SERN) is
a nonaxisymmetric, variable-area, internal/external
expansion exhaust system. Basic SERN nozzle com-
ponents consist of (1) a two-dimensional upper ramp
in which a portion of the ramp surface downstream
of the throat serves as an external expansion ramp,
(2) a relatively short two-dimensional lower flap, and
(3) flat, two-dimensional sidewalls. Nozzle power set-
ting (throat area) is changed by varying the geo-
metry of the convergent-divergent upper ramp assembly
(refs. 10 to 12), and expansion ratio is varied by ro-
tation of the lower flap. Most SERN designs also
provide for pitch thrust vectoring capability through
rotation of the entire divergent portion of the ramp
surface in conjunction with rotation of the lower flap
(refs. 10, 12, and 13). For the present investigation,
the SERN nozzles with geometric pitch vector angles
of 0°, -20°, and 20° of referenc 13 were chosen
as baseline nozzles. All the nozzles had a nominally
constant exhaust flow-path width of 4.00 in., throat
height of 1.0 in., and a throat area of 4.0 in². The
throat area of the current SERN test nozzles sim-
ulated a typical dry power (cruise) engine setting.
Parametric geometry changes were achieved by using
interchangeable upper ramps, lower flaps, and side-
walls. All the nozzle configurations tested are pre-
sented in table 1. This table includes the ramp, flap,
and sidewall that were used for each nozzle and the
major geometric parameters for each nozzle, which
are the geometric vector angles δx,p and δy,p, loca-
tion of the yaw hinge line xe/r, ramp or flap cutout
angle θ, and hinge line inclination angle φ. In ad-
dition, table 1 serves as an index to both tabulated
performance and pressure data for each nozzle.

A sketch of the baseline unvectored (δx,p = 0°)
nozzle is presented in figure 1(a). The baseline
upper ramp contained a moderate amount of axial
ramp curvature (concave shape). The ratio of ramp
length to the nominal throat height was 3.621 and
the ramp chord angle was 5.1°. The exit area that
is associated with the nozzle internal expansion ratio
is determined at the end of the flap or at xe, shown
in figure 1(b). This exit area is the product of the
nozzle width and the distance made up of ye, plus the
vertical distance to the upper ramp from the nozzle
centerline. The exit area associated with the nozzle
external expansion ratio is determined at the end of
the ramp or at xe,u, also shown in figure 1(b). This
exit area would be the product of the nozzle width
and the distance made up of ye, + ye,u.

The two pitch-vectored nozzle configurations that
were tested in this investigation are shown in figure
1(b). The locations of both the ramp and lower
flap hinge points result from mechanical design con-
siderations since the nozzles were designed to have a
pitch vector range of up to 60° (ref. 13). For geo-
metric pitch vector angles of -20° and 0°, the lower
flap remains fixed. For a pitch vector angle of 20°,
the lower flap is rotated downward. As the geometric
pitch vector angle is increased, the nozzle geometric
throat (shown for δx,p = 0°) translates toward the
lower flap exit. Of course, this also means that the
nozzle internal area ratio varies (approaches unity)
with increases in pitch vector angle. Coordinates for
the upper ramp and lower flap centerline profiles are
found in tables 2 and 3, respectively.

All the nozzles were tested with varying amounts
of sidewall containment from minimum to maximum
as shown in figure 1(c). Consideration must be given
to the size of sidewalls because they can have a di-
rect impact on the weight of the full-scale nozzle,
on the amount of surface area that requires cooling,
and on the extent of seals required between the noz-
ple ramp and flap and sidewalls. The minimum and
maximum containment sidewalls were those used in
reference 13, whereas the medium containment side-
wall was designed as an intermediate step between
the other two sidewalls. The amount of sidewall area
for the maximum containment sidewall was 11.9 per-
cent greater than that for the medium containment
sidewall and 36.3 percent greater than that for the
minimum containment sidewall. Coordinates for all
the sidewalls used in this investigation are given in
table 4. Each sidewall in table 4 is also identified by
the amount of sidewall containment.

In this investigation, thrust vectoring in the yaw
plane was accomplished by deflecting the sidewalls
about a vertical hinge line. In order to eliminate any
physical interference between the yaw flap deflected
into the exhaust stream and the upper ramp or lower
flap, which are used for pitch thrust vectoring, the
downstream corners of both the ramp and lower
flap were cut off to allow for up to 30° of yaw flap
deflection. As shown in figure 1(d), this cutout
was made on both sides of the ramp and lower flap
to allow for both positive and negative yaw vector
angles. Nozzles were tested with cutout angles of
θ = 20° and 30°. The cutout started at the edge of
the ramp and lower flap, where the yaw flap hinge line
was located and ended at the end of the ramp or lower
flap. Three separate yaw flap hinge line locations
were also investigated as indicated in figure 1(d).
These locations correspond to 42, 20, and 2 percent of the upper ramp length. The most upstream location of \( x_r/l_r = 0.02 \) was used to examine the effects of placing the hinge line close to the nozzle throat. The inclination angle \( \phi \) of one of the yaw hinge lines was also varied as a parameter. As seen in figure 1(e), the top of the hinge line located at \( x_r/l_r = 0.20 \) was pivoted to the rear about the nozzle centerline. Inclination angles of 0°, 15°, and 30° were investigated.

As previously mentioned, thrust vectoring in the yaw plane was accomplished by deflecting a yaw flap (portion of sidewall) about a vertical or inclined hinge line. One flap was deflected into the exhaust flow, and the other yaw flap was deflected the same amount away from the exhaust flow. Some typical yaw thrust vector configurations are shown in figure 1(f). The location of the nozzle throat on the ramp is also shown in order to show the proximity of the throat to the yaw hinge line. A photograph of a typical test nozzle is presented in figure 2.

Apparatus and Procedure

Static-Test Facility

This investigation was conducted in the static-test facility of the Langley 16-Foot Transonic Tunnel. The test apparatus was installed in a room with a high ceiling. The simulated jet exhausts to the atmosphere through a ceiling-mounted vent located aft of the nozzle test apparatus. The control room is remotely located from the test area, and a closed-circuit television camera is used to observe the model. This facility utilizes the same clean, dry air supply as that used in the 16-Foot Transonic Tunnel and a similar air control system—including valves, filters, and a heat exchanger (to operate the jet flow at constant stagnation temperature).

Single-Engine Propulsion Simulation System

A sketch of the single-engine propulsion simulation system is presented in figure 3 with a typical nozzle configuration installed, and a photograph is shown in figure 4.

An external high-pressure air system provided a continuous flow of clean, dry air at a controlled temperature of about 540°F at the nozzles. This high-pressure air was brought through the dolly-mounted support strut by six tubes which connect to a high-pressure plenum chamber. As shown in figure 3, the air was then discharged perpendicularly into the model low-pressure plenum through eight multiholed sonic nozzles equally spaced around the high-pressure plenum. This method was designed to minimize any forces imposed by the transfer of axial momentum as the air passed from the nonmetric high-pressure plenum to the metric low-pressure plenum (mounted on the force balance). Two flexible metal bellows were used as seals and served to compensate for axial forces caused by pressurization. The air was then passed from the model low-pressure plenum through a transition section, a choke plate, instrumentation section, and nozzles, as shown in figure 3.

Instrumentation

A six-component strain-gauge balance was used to measure forces and moments on the model (fig. 3). Jet total pressure was measured at a fixed location in the instrumentation section by means of a four-probe rake through the upper surface, a three-probe rake through the side, and a three-probe rake through the corner. (See fig. 3.) A thermocouple, also located in the instrumentation section, was used to measure jet total temperature. Weight flow of the high-pressure air supplied to the exhaust nozzle was measured by a pair of critical flow venturis. Internal static pressure orifices were located along the upper ramp and lower flap as indicated in table 5. All pressures were measured simultaneously with individual pressure transducers.

Data Reduction

All data were recorded simultaneously on magnetic tape. Approximately 50 frames of data, taken at a rate of 10 frames/sec, were used for each data point; average values were used in computations. Data were obtained in an ascending order of \( p_t/j \).

The basic performance parameters used for the presentation of results were \( F/F_i, F_r/F_i, \delta_p, \delta_y, \) and \( \omega_p/\omega_i \). With the exception of resultant gross thrust \( F_r \), all force data in this report are referenced to the body axis (centerline). Internal thrust ratio \( F/F_i \) represents the ratio of actual nozzle thrust (along the body axis) to ideal nozzle thrust, where ideal nozzle thrust is based on measured weight-flow rate and total pressure and total temperature conditions in the instrumentation section, as defined by the equation in the symbol definitions. Significant differences between \( F_r/F_i \) and \( F/F_i \) can occur when the jet-exhaust flow is directed away from the axial direction. Resultant thrust vector angles in the longitudinal (pitch) plane \( \delta_p \) and the lateral (yaw) plane \( \delta_y \) are presented for evaluating the exhaust flow turning capability of the various thrust-vectored configurations. Nozzle discharge coefficient \( \omega_p/\omega_i \) is the ratio of measured weight flow to ideal weight flow, where
ideal weight flow is based on jet total pressure \( p_{t,j} \), jet total temperature \( T_{t,j} \), and measured nozzle throat area. Nozzle discharge coefficient reflects the ability of a nozzle to pass weight flow and is reduced by any momentum and vena contracta losses (effective throat area less than measured throat area \( A_t \)).

The balance force measurements from which actual thrust is subsequently obtained are initially corrected for model weight tares and balance interactions. Although the bellows arrangement was designed to eliminate pressure and momentum interactions with the balance, small bellows tares on all balance components still exist. These tares result from a small pressure difference between the ends of the bellows when internal velocities are high and also small differences in the forward and aft bellows spring constants when the bellows are pressurized. As discussed in reference 17, these bellows tares were determined by testing calibration nozzles with known performance over a range of expected normal- and side-force and yawing-, pitching-, and rolling-moment loadings. The balance data were then corrected in a manner similar to that discussed in references 16 and 17. The resultant gross thrust \( F_r \) used in the resultant thrust ratio \( F_r/F_i \) was then determined from these corrected balance data.

Presentation of Results

The results of this investigation are presented in both tabular and plotted forms. Table 1 is an index to the tabular results contained in tables 6 to 190. Static internal nozzle performance characteristics are presented in tables 6 to 67, and nozzle internal pressure ratios are given in tables 68 to 190. Nozzle internal performance characteristics are graphically presented as resultant thrust ratio \( F_r/F_i \), internal thrust ratio \( F/F_i \), resultant pitch vector angle \( \delta_p \), and resultant yaw vector angle \( \delta_y \). Comparison and summary plots for selected nozzle configurations are presented as follows:

<table>
<thead>
<tr>
<th>Table 6</th>
<th>Baseline nozzle for ( \phi = 0^\circ ), ( \delta_{v,y} = 0^\circ ), and -</th>
</tr>
</thead>
<tbody>
<tr>
<td>( x_r/l_r = 1.00, \theta = 0^\circ ), ( \delta_{v,p} = 0^\circ ), variable sidewalls</td>
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<tr>
<td>( x_r/l_r = 1.00, \theta = 0^\circ ), max sidewall, variable ( \delta_{v,p} )</td>
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<td>( x_r/l_r = 1.00, \theta = 0^\circ ), ( \delta_{v,p} = -20^\circ ) and ( 20^\circ ), variable sidewalls</td>
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<td>Pressure distributions for baseline nozzle for ( \phi = 0^\circ ), ( \delta_{v,y} = 0^\circ ), and -</td>
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<tr>
<td>( x_r/l_r = 1.00, \theta = 0^\circ ), max sidewall, variable ( \delta_{v,p} )</td>
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</tr>
<tr>
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<td>( \delta_{v,p} = 20^\circ ), ( \delta_{v,y} = 0^\circ ), variable ( \theta ), variable sidewalls</td>
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<td>Summary of effects of hinge line location on nozzle performance for ( \phi = 0^\circ ) and -</td>
<td></td>
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<td>( \delta_{v,p} = 0^\circ ), ( \delta_{v,y} = 0^\circ ), variable ( x_r/l_r ), variable sidewalls</td>
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<td>Pressure distributions for ( \phi = 0^\circ ) and -</td>
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</table>
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Effect of yaw hinge line inclination on performance for \( θ = 30° \), \( x_r/l_r = 0.20 \), \( δ_{u,y} = 30° \), max sidewall, variable \( δ_{u,p} \) and variable \( φ \) ........................................... 29

Discussion of Results

Baseline Nozzle Performance

Forward thrust nozzles. Static performance characteristics for the baseline forward thrust nozzle are presented in figure 5 for the nozzles with each of the three sidewalls. Resultant thrust ratio \( F_r/F_i \), internal thrust ratio \( F/F_i \), resultant pitch thrust vector angle \( δ_p \), and resultant yaw thrust vector angle \( δ_y \) are shown as a function of nozzle pressure ratio NPR. Nozzle discharge coefficients \( w_p/w_i \) for these nozzles are presented in table 6.

The internal performance data presented in figure 5 are typical of other single expansion ramp nozzles (refs. 11 to 14). Generally, a tendency exists for two performance peaks to occur for nozzle thrust ratio for these type nozzles. These peaks occur because the exhaust flow expansion process for single expansion ramp nozzles occurs both internally and externally. That is, internal expansion of the flow occurs from the nozzle throat up to the end of the lower flap, where it is contained by the internal surfaces of the nozzle and is controlled by the internal expansion ratio. External expansion, which occurs downstream of the lower flap trailing edge, is bounded by the expansion ramp and the free (ambient/exhaust) boundary and is controlled by the external expansion ratio.

For the forward thrust nozzle with maximum containment, peak nozzle performance of \( F_r/F_i = 0.989 \) occurred at \( \text{NPR} = 4.0 \), which is above \( \text{NPR}_{des} = 3.23 \), the nozzle pressure ratio for optimum internal expansion; this indicates an increase in the effective internal area ratio. A second performance peak for this nozzle probably occurs at a nozzle pressure greater than was tested. This peak nozzle performance is essentially the same as that reported in reference 13. Resultant thrust ratio levels remained near peak levels over a much wider range of nozzle pressure ratio than would be expected for a typical convergent-divergent nozzle (ref. 18). This performance characteristic, which results from the two separate flow expansion processes (internal and external), could be a significant advantage for SERN nozzles, as less (or no) expansion-ratio control may be required (particularly for an all subsonic-mission airplane) and reductions in exhaust-system weight and complexity could be achieved.

The effect of sidewall containment on nozzle internal performance for the baseline nozzles is also shown in figure 5. For the forward thrust nozzle and for the other nonvectored nozzles tested, the amount of sidewall containment did not significantly affect either resultant or internal thrust ratio characteristics. The minimum containment sidewall caused about a 0.5-percent loss in resultant thrust at the highest NPR. Some consideration must be given to containment variations because they can have a direct impact on the weight of the nozzle, on the amount of surface area that requires cooling, and on the extent of seals required between the nozzle ramp and flap and sidewalls.

The nonlinear variation of resultant pitch vector angle \( δ_p \) with nozzle pressure ratio for the unvectored, forward thrust configurations is characteristic of SERN nozzles and is caused by the changing compression-expansion wave patterns impinging on the ramp (unopposed by an opposite wall) as NPR is varied. An axial-force (body axis) performance penalty would be associated with any value of resultant thrust vector angle which is nonzero because the resultant thrust is being turned away from the axial direction. For example, this performance penalty...
would occur at all nozzle pressure ratios except approximately 3.0 and 5.0. Since the ramp has a large, unopposed, normal projected area, values of normal force can change significantly with varying nozzle pressure ratio.

Nozzle discharge coefficient characteristics for these nozzles are presented in table 6. Nozzle discharge coefficient $W_p/W_i$ is a measure of the ability of the nozzle to pass mass flow and is reduced by boundary-layer thickness and nonuniform flow in the nozzle throat. Changes in nozzle geometry that occur downstream of the nozzle throat (supersonic exhaust) usually do not affect nozzle discharge coefficient characteristics. This characteristic is shown by the data in table 6. The three nozzles shown in figure 5 all have levels of $W_p/W_i$ that are typical for this class of nozzles. Values of $W_p/W_i$ greater than 1 are believed to be caused by an inability to determine accurately the nozzle throat areas. An examination of discharge coefficients presented in the tables for other nozzles shows little or no effect on the discharge coefficients due to varying the geometric parameters used to define the nozzles of this investigation.

**Pitch-vectored nozzles.** The effect of varying geometric pitch vector angle on nozzle internal performance is shown in figures 6 and 7. The results of this investigation show similar variations in nozzle performance parameters and pitch turning capabilities for changes in $\delta_{v,p}$ as reported in references 12 and 13. Axial thrust ratios are quite different in magnitude, depending on the pitch vector angle. These large differences in $F/F_i$ are mostly caused by decreases in the axial component of thrust created by the turning (vectoring) of the flow away from the axial direction by the upper ramp surface. Figure 6 shows that the losses in resultant thrust are only significant for $\delta_{v,p} = -20^\circ$, where losses of 5.7 percent at NPR = 3.0 to losses of 3.0 percent at NPR = 6.0 occurred. It should be noted that decreases in resultant thrust ratio can be interpreted as flow turning losses. Resultant pitch vector angle is also highly dependent on NPR for all $\delta_{v,p}$ settings as previously noted. Pitch turning efficiency is quite high, with $\delta_p$ values exceeding their geometric settings. Resultant pitch vector angle from the unvectored nozzle increased 20° to 27° for $\delta_{v,p} = -20^\circ$, and turning increased 16° to 25° for $\delta_{v,p} = 20^\circ$.

Some insight as to the causes of this behavior can be seen by examining the internal pressure distributions. The effect of pitch vector angle on the upper ramp and lower flap pressures is shown in figure 8. The ramp pressure distributions for $\delta_{v,p} = -20^\circ$ indicate a throat location ($p_r/p_{t,j} = 0.528$) which is upstream of the geometric throat ($x_p/l_r = 0$). As a result, some additional supersonic flow turning is present, which generally results in turning losses. In addition, shock-induced internal flow separation appears to occur on the ramp between $x_p/l_r = 0.20$ and 0.40, which can also contribute to the large losses in resultant thrust ratio experienced by the negative pitch-vectored nozzle (fig. 6). The movement of the sonic line toward the exit plane as the nozzle ramp was pitched down (positive $\delta_{v,p}$) permitted the more effective vectoring of subsonic flow upstream of the throat; this increased $\delta_{v,p}$ and $F_r/F_i$.

As shown in figure 7, flow turning capability improved at both negative and positive geometric pitch vector angles as sidewall containment was increased from minimum to maximum. When the nozzle was vectored negatively in pitch, large differences in internal thrust ratio $F/F_i$ and resultant pitch vector angles occurred with changes in sidewall containment at NPR lower than 5.0 (fig. 7(a)). Increasing containment for the negatively pitched nozzles decreased the internal thrust ratio by almost 5 percent at NPR = 3.0 and increased $\delta_p$ about 8.7°. The net effect on resultant thrust ratio was less than 1 percent. Greater containment allows for a confined expansion of the exhaust gas in the nozzle exit region so that all the exhaust flow can follow the internal surfaces (and most importantly the upper ramp) more closely. For configurations with less sidewall containment, some of the exhaust gas expands laterally and exits the nozzle before being turned. These results are indicated by the internal pressures on the ramp presented in figure 9(a) for $\delta_{v,p} = -20^\circ$. Increasing sidewall containment decreases the static pressure on the ramp downstream of the exhaust shock at $x_p/l_r > 0.3$. These data indicate that a smaller (or more negative) normal force would result from the ramp surface as sidewall containment is increased.

For positive $\delta_{v,p}$, increased resultant thrust ratios and resultant pitch vector angles occurred as sidewall containment increased (fig. 7(b)). These effects suggest that the predominant factor causing poor performance at minimum containment is lateral expansion of the exhaust flow before the flow is expanded or turned by the nozzle geometry. The effect of sidewall containment on the ramp pressure distributions (fig. 9(b)) for the $\delta_{v,p} = 20^\circ$ nozzle is much smaller than those previously discussed for the $\delta_{v,p} = -20^\circ$ nozzle. A small increase occurs in the static pressure at the end of the ramp as containment is increased; this increased positive resultant pitch vector angle. These observations on the effect of sidewall containment for the pitch-vectored nozzles are typically true for other nozzles of this investigation that were tested.
with varying amounts of flap cutout and/or yaw hinge line locations.

Effects of Flap Cutout and Hinge Line Location

The effect of flap cutout angle on nozzle internal performance for the nozzle with \( x_r/l_r = 0.20 \) and maximum containment is shown in figure 10. Figure 11 presents the effect of the location of the yaw hinge line for the nozzle with \( \theta = 30° \) and maximum sidewall containment. These results are similar to those obtained for the other nozzle configurations tested. Only the relative magnitudes of the various performance parameters are different for these other configurations. Consequently, results for the other configurations are presented in the tables but are not plotted. Figures 12 to 17 summarize the effects of cutout angle and hinge line location at nozzle pressure ratios of 3.0 and 6.0.

Forward thrust nozzles. As shown in figure 10(a), essentially no changes in resultant thrust for the forward thrust nozzle occurred as the cutout angle was varied from 0° to 30° up to a nozzle pressure ratio of about 5.0. Above NPR = 5.0, losses in \( F_r/F_i \) were present with a maximum loss of 1.1 percent occurring at NPR = 8.0. For the other nozzle configurations with the hinge line located at \( x_r/l_r = 0.20 \) and 0.42 with any of the sidewalls, resultant thrust ratio was either constant or increased as cutout angle increased (fig. 12). Greater reductions in resultant thrust ratio were observed at NPR = 6.0 as cutout was increased when the yaw hinge line was located at \( x_r/l_r = 0.02 \), the location closest to the nozzle throat (fig. 12). This location created a larger cutout area through which exhaust gases could escape laterally without producing useful thrust. The losses produced by this sideways expansion of the gases result from a reduction in nozzle expansion surface for the exhaust gas to act on as well as a non-axial direction of the exhaust momentum (divergence losses).

Figure 11(a) indicates that there was a loss in \( F_r/F_i \) of about 3.5 percent at NPR = 8.0 when the hinge line location at \( \theta = 30° \) was moved from \( x_r/l_r = 1.00 \) to \( x_r/l_r = 0.02 \). The fact that the differences in \( F_r/F_i \) between \( x_r/l_r = 1.00 \) and \( x_r/l_r = 0.20 \) were less than one half those produced when the hinge was moved from \( x_r/l_r = 0.20 \) to \( x_r/l_r = 0.02 \) (for \( \theta = 30° \)) indicates that ventilation of the exhaust gases is highly accentuated if the jet is not contained in the immediate vicinity of the throat area. In this respect, effects of cutout angle were smaller relative to those produced by changes in hinge line location (fig. 11). These results are similar to those of reference 8 for a two-dimensional convergent-divergent nozzle and to reference 19 for an axisymmetric nozzle with longitudinal slots in the divergent flaps. Note that these nozzle configurations represent the nozzle geometry during cruise which generally constitutes the majority of the airplane flight profile. As always, performance-weight trades exist, and the adverse effect of a loss in thrust ratio due to flap cutout might be offset by a decrease in the nozzle weight and internal nozzle surface to be cooled. In addition, the benefits realized from thrust vectoring (which requires a flap cut out) must be traded against any cruise thrust losses.

Pitch-vectored nozzles. The effect of flap cutout angle on internal performance for the vectored nozzles is shown in figures 10, 13, and 14. In general, as the ramp-flap cutout angle was increased for the \( \delta_{v,p} = -20° \) nozzle, there was a slight increase in \( F_r/F_i \) and a large decrease in the magnitude of negative \( \delta_p \) values, with the largest decreases in \( \delta_p \) occurring at low nozzle pressure ratios and \( x_r/l_r = 0.02 \) (fig. 13). This decrease in negative resultant pitch vector angle was caused by an increase in pressures along the ramp as flap cutout angle was increased as shown in figure 18(b). As shown in figure 14, increasing flap cutout angle when the nozzle was pitched down 20° caused large losses in both resultant thrust ratio and pitch vector angle for the nozzles with \( x_r/l_r = 0.20 \) and 0.02 at NPR = 6.0. Figure 18(c) indicates essentially no effects to the ramp pressures as cutout was increased at NPR = 3.0.

The effects of yaw hinge line location for the vectored nozzles are presented in figures 11, 16, and 17. There was a 1.1-percent increase in \( F_r/F_i \) and a 10.3° decrease in negative \( \delta_p \) values as the hinge line was moved forward from the nozzle exit to \( x_r/l_r = 0.02 \) for \( \delta_{v,p} = -20° \) and \( \theta = 30° \) at NPR = 3.0 (fig. 11(b)). As previously noted, decreases in negative resultant pitch angle for the nozzle with \( \delta_{v,p} = -20° \) result from an increase in pressures on the ramp (fig. 19(b)). For the nozzle with \( \delta_{v,p} = 20° \) and \( \theta = 30° \) at NPR = 3.0 (fig. 11(c)), resultant thrust ratio decreased about 3.2 percent and resultant pitch vector angle decreased about 5° for the same variation in \( x_r/l_r \). Decreases in resultant thrust ratio can be interpreted as turning losses. Because the trends in the variation of either \( F_r/F_i \) and \( \delta_p \) with \( x_r/l_r \) were essentially the same for both \( \theta = 20° \) and 30° (figs. 16 and 17), these results would indicate that the changes in performance noted previously are primarily caused by changes in the location of the yaw hinge line rather than flap cutout.
Although this discussion was for the nozzles with maximum containment, the effects discussed are similar for the negative vectored nozzle with the medium containment sidewalls (fig. 16(b)) and the positive vectored nozzle with the medium and minimum sidewalls (figs. 17(b) and (c)). For the negative vectored nozzle, decreases in negative \( \delta_p \) values were much less for the nozzle with the minimum sidewall (fig. 16(c)) at NPR = 3.0, there was a decrease in \( \delta_p \) of about 3° (compared with 10.3° with the maximum sidewall) as the yaw flap hinge line was moved from \( x_r/l_r = 1.00 \) (nozzle exit) to \( x_r/l_r = 0.02 \).

**Effects of Yaw Vectoring**

*Basic yaw vectoring effect.* Typical effects of yaw vectoring on nozzle performance are presented in figure 20 for the nozzle with \( x_r/l_r = 0.20 \), \( \theta = 30^\circ \), and maximum containment sidewalls. Figures 21 to 26 summarize the effects of yaw vectoring for the remaining nozzle configurations. Losses of 1.9 to 3.5 percent in \( F_r/F_i \) per 10° of turning occurred when vectoring the flow sideways to produce yaw for \( \delta_{v,p} = 0^\circ \). For the two vectored nozzles, losses of 3.8 to 6.3 percent in \( F_r/F_i \) occurred for \( \delta_{v,p} = -20^\circ \), whereas the nozzle with \( \delta_{v,p} = 20^\circ \) experienced losses up to 1.5 percent. These losses for \( \delta_{v,p} = 0^\circ \) and \( \delta_{v,p} = 20^\circ \) are in general small and similar to those observed previously in references 7 and 8 for comparable yaw vectoring schemes. Because the flow being vectored is downstream of the throat and is thus supersonic, these performance losses are related to shock-induced momentum losses resulting from the supersonic flow turning process and from some sidewall spillage. The effect of a turn-generated shock that probably emanates from the corner of the left hinge line (compression turn) in the direction of turning is shown in the pressure distributions on the ramp in figure 27. For \( \delta_{v,y} = 0^\circ \), there is a shock that is located on the ramp at \( x_p/l_r \approx 0.55 \). This shock moves forward to \( x_p/l_r \approx 0.40 \) for \( \delta_{v,y} = -30^\circ \) because of interaction effects of the turn-generated shock. In addition, the pressure distributions indicate that some shock-induced internal flow separation may be present during single-axis yaw vectoring operation. In contrast to the pitch vectoring of 0° and -20° (figs. 27(a) and 27(b)), pressure measurements indicate that for \( \delta_{v,p} = 20^\circ \) (fig. 27(c)), the effect of the turn-generated shock is less than for \( \delta_{v,p} = 0^\circ \) and -20° and may explain why greater resultant thrust ratios were achieved for \( \delta_{v,p} = 20^\circ \) (fig. 20(c)).

Although higher pressure ratios did improve turning effectiveness slightly, resultant yaw turning angles did not amount to more than 33 to 45 percent of the geometric yaw angle for the three nozzle pitch vector angles tested (fig. 20). These results are typical for other nozzle configurations tested with the yaw hinge line located at \( x_r/l_r = 0.42 \) and 0.02. (For example, see figs. 21 and 23.) Maximum resultant yaw vector angles achieved were about 20° and occurred at high nozzle pressure ratios for the nozzle with \( x_r/l_r = 0.02 \) and the maximum sidewall (fig. 23(a)). In general, yaw turning performance is lower than that of reference 8, which utilized a similar simultaneous pitch/yaw vectoring scheme but on a two-dimensional convergent-divergent nozzle. Average resultant yaw vector angles of about 53 percent of the yaw geometric angle were measured for this investigation. The maximum values of \( \delta_y \) were about 75 percent of the geometric angle.

The effects of yaw vectoring on resultant pitch vector angles vary depending on the geometric pitch vector angle \( \theta_{v,p} \). Unlike geometric pitch vector angles of 0° and 20°, where \( \delta_p \) increases in magnitude as the sidewall flaps are deflected, resultant pitch turning angle decreased (becomes less negative) as geometric yaw vector angle increased for \( \delta_{v,y} = -20^\circ \) to result in about one half the geometric pitch angle setting at \( \delta_{v,y} = -30^\circ \) (fig. 20(b)). In general, there was a decrease in negative values of \( \theta_p \) from 7° to 11° for \( \delta_{v,y} = -20^\circ \) for each of the three hinge line locations with both maximum and medium sidewall containments (figs. 21 to 23(b)). For the hinge line location at \( x_r/l_r = 0.02 \) with the minimum sidewall, only a 4° decrease occurred in negative \( \theta_p \) values (fig. 23(c)). For the nozzles with \( \delta_{v,y} = 0^\circ \) and 20°, just the opposite occurred; that is, \( \theta_p \) increased from 7° to 11° or 4° for the same nozzle conditions as stated for the nozzle with \( \delta_{v,y} = -20^\circ \).

**Effect of hinge line location.** The one advantage provided by moving the yaw flap hinge lines upstream was an increase in the sidewall area to be used for yaw vectoring without increasing the size of the sidewall itself. As shown in figure 24, resultant yaw angles can be increased as much as 15° by moving the hinge lines forward from \( x_r/l_r = 0.42 \) to \( x_r/l_r = 0.02 \) for \( \delta_{v,y} = 20^\circ \). Resultant yaw turning was 20 to 42 percent of the geometric flap setting at \( x_r/l_r = 0.20 \) and about 35 to 70 percent at \( x_r/l_r = 0.02 \) (100 percent occurs when \( \delta_y = \theta_{v,y} \)). Yaw turning effectiveness was very low for the hinge line at \( x_r/l_r = 0.42 \). Resultant yaw angles achieved only 15 to 33 percent of the geometric flap setting, compared with 35 to 70 percent for the location at \( x_r/l_r = 0.02 \).

**Effect of sidewall containment.** The effects of sidewall containment or yaw flap length on
nozzle performance are summarized in figures 25 and 26. For $\delta_{\nu,\phi} = 0^\circ$ and $20^\circ$, increasing sidewall length had little or no effect on resultant yaw angle. However, for $\delta_{\nu,\phi} = -20^\circ$, lengthening the sidewalls (i.e., increasing containment) for $x_r/l_r = 0.20$ increased magnitude of the resultant yaw turning angle by almost $8^\circ$ at $\delta_{\nu,y} = -30^\circ$ and NPR = 3.0 (fig. 25(a)). However, this improvement in yaw vector performance was accompanied by a loss of resultant thrust that reached values of up to 3.4 percent when $\delta_{\nu,y} = -30^\circ$. For those nozzle configurations with the yaw hinge line at $x_r/l_r = 0.02$ (fig. 26), increasing the length of the yaw flap resulted in increases in resultant yaw vector angle magnitude of $6^\circ$ to $8^\circ$ for the three pitch vector angles tested at NPR = 3.0 and 6.0. Generally (at $\delta_{\nu,y} = -30^\circ$), most of this increase occurred as the sidewall was increased from medium to maximum containment.

**Effect of single yaw flap deflection.** Some limited tests were conducted by deflecting either the left yaw flap into the exhaust flow or the right yaw flap out of the flow while maintaining the other flap at $0^\circ$. These tests were conducted in order to ascertain the performance of a single flap in producing yaw vectoring. Typical effects of single yaw flap vectoring on nozzle performance are presented in figure 28. In general, most of the resultant yaw vector angle is produced by the flap which is deflected into the exhaust flow (left flap for current test). Some turning results from deflection of the opposing (right) flap out of the exhaust flow. The final resultant yaw vector angle is essentially the sum of the values of deflecting the left and right yaw flaps individually. This is in contrast to the results of reference 20 for a two-dimensional convergent-divergent nozzle with sidewall yaw vector flaps, where nearly equal amounts of resultant yaw vector angles were produced with individual single flap deflections. However for the nozzle of reference 20, the yaw vector angles which resulted from deflection of both flaps were greater than the sum of the yaw angles obtained by deflection of the individual flaps; this indicates a favorable interaction between the left and right yaw flaps.

**Effect of Hinge Angle Inclination**

The effect of inclining the yaw hinge axis on nozzle performance is shown in figure 29. These results for $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\delta_{\nu,y} = -30^\circ$, and medium sidewall are typical for the other nozzle configurations. For the entire range of geometric pitch vector angles, but particularly for $\delta_{v,p} = -20^\circ$, inclining the hinge axis had the effect of increasing axial and resultant thrust ratios while shifting $\delta_p$ toward more negative values (beneficial for configurations with negative $\delta_{v,p}$ and detrimental for those with positive $\delta_{v,p}$). For example, figure 29(a) shows an increase of nearly 1 percent in resultant thrust ratio with an accompanying decrease in $\delta_p$ of about $1^\circ$ for $\delta_{v,p} = 0^\circ$ as hinge inclination angle $\phi$ is varied from $0^\circ$ to $30^\circ$ over the nozzle pressure range. However, for $\delta_{v,p} = -20^\circ$, $F_r/F_i$ increased up to 3 percent with an increase in $\delta_p$ magnitude of about $3^\circ$ (more negative values of $\delta_p$). These increases in $F_r/F_i$ and $\delta_p$ were nearly constant over the range of nozzle pressure ratios and occurred primarily as $\phi$ was changed from $15^\circ$ to $30^\circ$ (fig. 29(c)). When the sidewall yaw flaps are deployed, inclining the hinge axis is believed to create a larger cavity between the upper edge of the receding sidewall and the corresponding side of the upper flap. The slanted sidewall surfaces then force the flow to escape through this cavity; this rotates the thrust vector up. The increase in $F_r/F_i$ is most probably caused by a more obtuse vector angle in yaw that would decrease the strength of the sidewall-generated shock.

Although resultant yaw turning angles were still around 30 percent of the geometric setting for $\delta_{v,y} = -30^\circ$, a small increase occurred in yaw turning effectiveness for $\delta_{v,p} = 20^\circ$ (fig. 29(c)), probably because the sidewall hinge line and exhaust flow centerline were more perpendicular for positive pitch-vectored configurations.

**Conclusions**

An investigation has been conducted at static conditions in order to determine the internal performance characteristics of a multiaxis thrust vectoring single expansion ramp nozzle. Yaw vectoring was achieved by deflecting yaw flaps in the nozzle sidewalls. In order to eliminate any physical interference between the yaw flap deflected into the exhaust flow and the nozzle upper ramp and lower flap deflected for pitch vectoring, the downstream corners of both the nozzle ramp and flap were cut off to allow for up to $30^\circ$ of yaw vectoring. The effects of nozzle upper ramp and lower flap cutout, yaw hinge line location and inclination angle, sidewall containment, geometric pitch vector angle, and geometric yaw vector angle were studied. This investigation was conducted in the static-test facility of the Langley 16-Foot Transonic Tunnel at nozzle pressure ratios up to 8.0. An analysis of the results indicates the following conclusions:

1. The removal of the downstream corners of both the upper ramp and lower flap for a yaw hinge line downstream of the nozzle throat had little or no effect on resultant thrust ratio. However, losses of up to 3.4 percent in resultant thrust
ratio occurred with the hinge line located near the nozzle throat.

2. Pitch vectoring performance was primarily influenced by hinge line location rather than ramp cutout. For the nozzle with the hinge line near the nozzle throat, there was a 10.3° decrease in resultant pitch vector angle for the nozzle pitched up 20° and about a 5° decrease for the nozzle pitched down 20°.

3. Yaw thrust vectoring of nozzles with no pitch vectoring caused resultant thrust ratio losses of up to 3.5 percent per 10° of yaw turning and produced resultant yaw vector angles that were typically 33 to 45 percent of the geometric yaw vector angle.

4. Maximum resultant yaw vector angles occurred for the nozzle with the yaw hinge line near the nozzle throat and with the maximum sidewalls.

5. Yaw thrust vectoring decreased the resultant pitch vector angle for the negative pitch- vectored nozzle and increased resultant pitch vector angle for the nozzle with no vectoring or with positive pitch vectoring.

6. Most of the yaw turning was produced from the yaw flap deflected into the nozzle exhaust flow.

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[Values of $z$ are for left sidewall; values of $z$ for right sidewall are negative of those given]

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Table 4. Continued

Maximum containment, sidewall 7

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Maximum containment, sidewall 11

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Medium containment, sidewall 12

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Table 4. Concluded

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Minimum containment, sidewall 21

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Minimum containment, sidewall 22

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Minimum containment, sidewall 23

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Table 5. Location of Ramp and Flap Pressure Orifices

[All pressure orifices are located on centerline of ramp or flap]

(a) Upper ramp

<table>
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<tr>
<th>$\delta_{u,p} = 0^\circ$ and $-20^\circ$</th>
<th>$\delta_{u,p} = 20^\circ$</th>
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<td>--------</td>
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<tr>
<td>-1.115</td>
<td>-0.308</td>
</tr>
<tr>
<td>-0.615</td>
<td>-0.170</td>
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<tr>
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<td>-0.032</td>
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<td>0.385</td>
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<td>0.635</td>
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(b) All lower flaps

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Table 6. Static Performance Characteristics for Nozzles With $\frac{x_r}{l_r} = 1.00$, $\theta = 0^\circ$, $\phi = 0^\circ$, $\delta_{\nu,p} = 0^\circ$, and $\delta_{\nu,y} = 0^\circ$

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<th>NPR</th>
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<th>$\delta_y$, deg</th>
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Table 7. Static Performance Characteristics for Nozzles With
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Table 8. Static Performance Characteristics for Nozzles With $x_r/l_r = 0.20$, $\theta = 20^\circ$, $\phi = 0^\circ$, $\delta_{v,p} = 0^\circ$, and $\delta_{v,y} = 0^\circ$

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Table 9. Static Performance Characteristics for Nozzles With $x_r/l_r = 0.02$, $\theta = 20^\circ$, $\phi = 0^\circ$, $\delta_{v,p} = 0^\circ$, and $\delta_{v,y} = 0^\circ$

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Table 10. Static Performance Characteristics for Nozzles With \( x_r/l_r = 0.42, \theta = 20^o, \phi = 0^o, \delta_{v,p} = 0^o, \) and \( \delta_{v,y} = -20^o \)

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Nozzle 13, maximum sidewall

Table 11. Static Performance Characteristics for Nozzles With \( x_r/l_r = 0.20, \theta = 20^o, \phi = 0^o, \delta_{v,p} = 0^o, \) and \( \delta_{v,y} = -20^o \)

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<th>( F/F_i )</th>
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<th>( \delta_y, \text{deg} )</th>
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(a) Nozzle 14, medium sidewall

(b) Nozzle 15, maximum sidewall
Table 12. Static Performance Characteristics for Nozzles With
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Table 13. Static Performance Characteristics for Nozzles With $x_r/l_r = 0.42$, $\theta = 30^\circ$, $\phi = 0^\circ$, $\delta_{v,p} = 0^\circ$, and $\delta_{v,y} = 0^\circ$

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Table 14. Static Performance Characteristics for Nozzles With
$x_r/l_r = 0.20, \theta = 30^\circ, \phi = 0^\circ, \delta_w,p = 0^\circ, \text{ and } \delta_w,y = 0^\circ$

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Table 15. Static Performance Characteristics for Nozzles With $x_r/l_r = 0.02$, $\theta = 30^\circ$, $\phi = 0^\circ$, $\delta_{v,p} = 0^\circ$, and $\delta_{v,y} = 0^\circ$

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Table 16. Static Performance Characteristics for Nozzles With $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 0^\circ$, $\delta_{v,p} = 0^\circ$, and $\delta_{v,y} = -20^\circ$

<table>
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<th>$F_r/F_i$</th>
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<th>$\delta_y$, deg</th>
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<td>-8.13</td>
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</table>

(a) Nozzle 28, medium sidewall

|     |           |         |                 |                 |           |
|     |           |         |                 |                 |           |
| 2.00 | 0.9534 | 0.9482 | -2.57 | -5.41 | 0.9929 |
| 2.50 | 0.9563 | 0.9523 | -1.63 | -5.04 | 0.9933 |
| 3.00 | 0.9620 | 0.9587 | -0.09 | -4.73 | 0.9941 |
| 3.50 | 0.9603 | 0.9562 | 0.51 | -5.28 | 0.9951 |
| 4.01 | 0.9611 | 0.9562 | 1.68 | -5.53 | 0.9960 |
| 5.00 | 0.9598 | 0.9517 | 4.35 | -6.07 | 0.9974 |
| 6.00 | 0.9575 | 0.9450 | 6.57 | -6.61 | 0.9987 |
| 7.00 | 0.9570 | 0.9400 | 8.41 | -6.93 | 0.9993 |
| 8.00 | 0.9592 | 0.9385 | 9.89 | -6.79 | 1.0000 |

(b) Nozzle 29, maximum sidewall
Table 17. Static Performance Characteristics for Nozzles With $x_r/l_r = 0.02$, $\theta = 30^\circ$, $\phi = 0^\circ$, $\delta_{r,p} = 0^\circ$, and $\delta_{v,y} = -20^\circ$

<table>
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<th>NPR</th>
<th>$F_r/F_i$</th>
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<th>$\delta_y$, deg</th>
<th>$w_p/w_i$</th>
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<td>(a) Nozzle 30, medium sidewall</td>
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(b) Nozzle 31, maximum sidewall

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<th>$\delta_y$, deg</th>
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Table 18. Static Performance Characteristics for Nozzles With $x_r/l_r = 0.42$, $\theta = 30^\circ$, $\phi = 0^\circ$, $\delta_{r,p} = 0^\circ$, and $\delta_{v,y} = -30^\circ$

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<th>$\delta_y$, deg</th>
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Table 19. Static Performance Characteristics for Nozzles With
\( x_r/l_r = 0.20, \theta = 30^\circ, \phi = 0^\circ, \delta_r,p = 0^\circ, \) and \( \delta_{v,y} = -30^\circ \)

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<th>( \delta_y, ) deg</th>
<th>( w_p/w_i )</th>
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(a) Nozzle 33, medium sidewall

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<th>( \delta_y, ) deg</th>
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(b) Nozzle 34, maximum sidewall
Table 20. Static Performance Characteristics for Nozzles With
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Table 21. Static Performance Characteristics for Nozzles With $x_r/l_r = 1.00$, $\theta = 0^\circ$, $\phi = 0^\circ$, $\delta_{v,p} = -20^\circ$, and $\delta_{v,y} = 0^\circ$

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Table 22. Static Performance Characteristics for Nozzles With
\( \frac{x_r}{l_r} = 0.42, \ \theta = 20^\circ, \ \phi = 0^\circ, \ \delta_{v,p} = -20^\circ, \ \text{and} \ \delta_{v,y} = 0^\circ \)

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- **(a) Nozzle 41, minimum sidewall**

- **(b) Nozzle 42, medium sidewall**

- **(c) Nozzle 43, maximum sidewall**
Table 23. Static Performance Characteristics for Nozzles With
$x_r/l_r = 0.20, \theta = 20^\circ, \phi = 0^\circ, \delta_{v,p} = -20^\circ$, and $\delta_{v,y} = 0^\circ$

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Table 24. Static Performance Characteristics for Nozzles With $x_r/l_r = 0.02$, $\theta = 20^\circ$, $\phi = 0^\circ$, $\delta_{v,p} = -20^\circ$, and $\delta_{v,y} = 0^\circ$

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Table 25. Static Performance Characteristics for Nozzles With $\frac{x_r}{l_r} = 0.42$, $\theta = 20^\circ$, $\phi = 0^\circ$, $\delta_{v,p} = -20^\circ$, and $\delta_{v,y} = -20^\circ$

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<th>$\delta_y$, deg</th>
<th>$\frac{w_p}{w_i}$</th>
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Nozzle 50, maximum sidewall

Table 26. Static Performance Characteristics for Nozzles With $\frac{x_r}{l_r} = 0.20$, $\theta = 20^\circ$, $\phi = 0^\circ$, $\delta_{v,p} = -20^\circ$, and $\delta_{v,y} = -20^\circ$

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<th>$\delta_y$, deg</th>
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(a) Nozzle 51, medium sidewall

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(b) Nozzle 52, maximum sidewall
Table 27. Static Performance Characteristics for Nozzles With
\( x_r/l_r = 0.02, \theta = 20^\circ, \phi = 0^\circ, \delta_{v,p} = -20^\circ, \) and \( \delta_{v,y} = -20^\circ \)

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Table 28. Static Performance Characteristics for Nozzles With
\(x_r/l_r = 0.42\), \(\theta = 30^\circ\), \(\phi = 0^\circ\), \(\delta_{v,p} = -20^\circ\), and \(\delta_{v,y} = 0^\circ\)

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Table 29. Static Performance Characteristics for Nozzles With
\( x_r/l_r = 0.20, \theta = 30^\circ, \phi = 0^\circ, \delta_{v,p} = -20^\circ, \) and \( \delta_{v,y} = 0^\circ \)

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Table 30. Static Performance Characteristics for Nozzles With
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Table 31. Static Performance Characteristics for Nozzles With
\( x_r/l_r = 0.20, \theta = 30^\circ, \phi = 0^\circ, \delta_{r,p} = -20^\circ, \) and \( \delta_{r,g} = -20^\circ \)

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Table 32. Static Performance Characteristics for Nozzles With \(x_r/l_r = 0.02\), \(\theta = 30^\circ\), \(\phi = 0^\circ\), \(\delta_{v,p} = -20^\circ\), and \(\delta_{v,y} = -20^\circ\)

(a) Nozzle 67, medium sidewall

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(b) Nozzle 68, maximum sidewall

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Table 33. Static Performance Characteristics for Nozzles With \(x_r/l_r = 0.42\), \(\theta = 30^\circ\), \(\phi = 0^\circ\), \(\delta_{v,p} = -20^\circ\), and \(\delta_{v,y} = -30^\circ\)

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Table 34. Static Performance Characteristics for Nozzles With
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(a) Nozzle 70, medium sidewall

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(b) Nozzle 71, maximum sidewall
Table 35. Static Performance Characteristics for Nozzles With $\kappa_1/l_1 = 0.02$, $\theta = 30^\circ$, $\phi = 0^\circ$, $\delta_{u,p} = -20^\circ$, and $\delta_{u,y} = -30^\circ$

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(a) Nozzle 72, minimum sidewall
(b) Nozzle 73, medium sidewall
(c) Nozzle 74, maximum sidewall
Table 36. Static Performance Characteristics for Nozzles With $x_r/l_r = 1.00$, $\theta = 0^\circ$, $\phi = 0^\circ$, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = 0^\circ$

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Table 37. Static Performance Characteristics for Nozzles With $x_r/l_r = 0.42$, $\theta = 20^\circ$, $\phi = 0^\circ$, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = 0^\circ$

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<th>$\delta_y$, deg</th>
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Table 38. Static Performance Characteristics for Nozzles With $x_r/l_r = 0.20$, $\theta = 20^\circ$, $\phi = 0^\circ$, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = 0^\circ$

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<th>$\delta_y$, deg</th>
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Table 39. Static Performance Characteristics for Nozzles With
\( x_r/l_t = 0.02, \theta = 20^\circ, \phi = 0^\circ, \delta_{v,x} = 20^\circ, \) and \( \delta_{v,y} = 0^\circ \)

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<th>( \delta_y, ) deg</th>
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(a) Nozzle 84, minimum sidewall

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(b) Nozzle 85, medium sidewall

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(c) Nozzle 86, maximum sidewall
Table 40. Static Performance Characteristics for Nozzles With $x_r/l_r = 0.42$, $\theta = 20^\circ$, $\phi = 0^\circ$, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = -20^\circ$

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Table 41. Static Performance Characteristics for Nozzles With $x_r/l_r = 0.20$, $\theta = 20^\circ$, $\phi = 0^\circ$, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = -20^\circ$

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<th>$\delta_y$, deg</th>
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| (b) Nozzle 89, maximum sidewall | | | | | |
| 2.00 | 0.9802    | 0.9193  | 19.05           | -7.59           | 0.9557    |
| 2.50 | 0.9833    | 0.9168  | 20.01           | -7.60           | 0.9619    |
| 3.00 | 0.9808    | 0.9122  | 20.35           | -7.72           | 0.9642    |
| 3.50 | 0.9788    | 0.9027  | 21.57           | -7.98           | 0.9657    |
| 4.01 | 0.9791    | 0.8909  | 23.38           | -8.17           | 0.9664    |
| 5.00 | 0.9782    | 0.8661  | 26.67           | -8.64           | 0.9685    |
| 6.00 | 0.9811    | 0.8480  | 29.24           | -9.02           | 0.9698    |
| 7.00 | 0.9822    | 0.8323  | 31.17           | -9.32           | 0.9710    |
| 7.40 | 0.9843    | 0.8293  | 31.70           | -9.35           | 0.9712    |
Table 42. Static Performance Characteristics for Nozzles With \( x_r/l_r = 0.02, \theta = 20^\circ, \phi = 0^\circ, \delta_{v,p} = 20^\circ, \) and \( \delta_{v,y} = -20^\circ \)

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<th>( \delta_y, \text{ deg} )</th>
<th>( w_p/w_i )</th>
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Table 43. Static Performance Characteristics for Nozzles With $x_r/l_r = 0.42$, $\theta = 30^\circ$, $\phi = 0^\circ$, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = 0^\circ$

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Table 44. Static Performance Characteristics for Nozzles With $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 0^\circ$, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = 0^\circ$

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(b) Nozzle 97, medium sidewall

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(c) Nozzle 98, maximum sidewall

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Table 45. Static Performance Characteristics for Nozzles With $x_r/l_r = 0.02$, $\theta = 30^\circ$, $\phi = 0^\circ$, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = 0^\circ$

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Table 46. Static Performance Characteristics for Nozzles With $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 0^\circ$, $\delta_{u,p} = 20^\circ$, and $\delta_{u,y} = -20^\circ$

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Table 47. Static Performance Characteristics for Nozzles With $x_r/l_r = 0.02$, $\theta = 30^\circ$, $\phi = 0^\circ$, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = -20^\circ$

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(a) Nozzle 104, medium sidewall

(b) Nozzle 105, maximum sidewall

Table 48. Static Performance Characteristics for Nozzles With $x_r/l_r = 0.42$, $\theta = 30^\circ$, $\phi = 0^\circ$, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = -30^\circ$

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(b) Nozzle 105, maximum sidewall

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(a) Nozzle 106, medium sidewall

(b) Nozzle 105, maximum sidewall
Table 49. Static Performance Characteristics for Nozzles With
\( x_r/l_r = 0.20, \theta = 30^\circ, \phi = 0^\circ, \delta_{v,p} = 20^\circ, \) and \( \delta_{v,y} = -30^\circ \)

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Table 50. Static Performance Characteristics for Nozzles With \( x_r/l_r = 0.02, \theta = 30^\circ, \phi = 0^\circ, \delta_{v,p} = 20^\circ, \) and \( \delta_{v,y} = -30^\circ \)

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Table 51. Static Performance Characteristics for Nozzles With \( x_r/l_r = 0.02, \theta = 20^\circ, \phi = 0^\circ, \delta_{v,p} = 0^\circ, \) and Maximum Sidewall

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\( \text{(a) Nozzle 112, } \delta_{v,y,l} = -20^\circ, \delta_{v,y,r} = 0^\circ \)

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\( \text{(b) Nozzle 113, } \delta_{v,y,l} = 0^\circ, \delta_{v,y,r} = -20^\circ \)
Table 52. Static Performance Characteristics for Nozzles With
$x_r/l_r = 0.20$, $\theta = 20^\circ$, $\phi = 0^\circ$, $\delta_{v,y} = 0^\circ$, and Maximum Sidewall

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<th>$\delta_y$, deg</th>
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Table 53. Static Performance Characteristics for Nozzles With $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 0^\circ$, $\delta_{v,p} = 0^\circ$, and Maximum Sidewall

<table>
<thead>
<tr>
<th>NPR</th>
<th>$F_r/F_i$</th>
<th>$F/F_i$</th>
<th>$\delta_p$, deg</th>
<th>$\delta_v$, deg</th>
<th>$w_p/w_i$</th>
</tr>
</thead>
<tbody>
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Table 54. Static Performance Characteristics for Nozzles With $x_r/l_r = 0.02$, $\theta = 20^\circ$, $\phi = 0^\circ$, $\delta_{v,p} = 20^\circ$, and Maximum Sidewall NPR $F_r/F_i$ $F/F_i$ $\delta_{p, \deg}$ $\delta_{v, \deg}$ $w_p/w_i$

(a) Nozzle 118, $\delta_{v,y,t} = -20^\circ$, $\delta_{v,y,r} = 0^\circ$

<table>
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<th>$\delta_{v, \deg}$</th>
<th>$w_p/w_i$</th>
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<td>0.8949</td>
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<td>0.9583</td>
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<td>0.9595</td>
</tr>
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(b) Nozzle 119, $\delta_{v,y,t} = 0^\circ$, $\delta_{v,y,r} = -20^\circ$

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<th>$\delta_{v, \deg}$</th>
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</tr>
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<td>0.8594</td>
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Table 55. Static Performance Characteristics for Nozzles With
$x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 0^\circ$, $\delta_{v,p} = 20^\circ$, and Maximum Sidewall

<table>
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<th>$\delta_y$, deg</th>
<th>$w_p/w_i$</th>
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</tr>
<tr>
<td>(a)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
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Table 56. Static Performance Characteristics for Nozzles With $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 15^\circ$, $\delta_{v,p} = 0^\circ$, and $\delta_{v,y} = -15^\circ$

<table>
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Table 57. Static Performance Characteristics for Nozzles With $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 15^\circ$, $\delta_{v,p} = 0^\circ$, and $\delta_{v,y} = -30^\circ$

<table>
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<th>$\delta_p$, deg</th>
<th>$\delta_y$, deg</th>
<th>$w_p/w_i$</th>
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Table 58. Static Performance Characteristics for Nozzles With
\( x_r/l_r = 0.20, \theta = 30^\circ, \phi = 30^\circ, \delta_{v,p} = 0^\circ, \) and \( \delta_{v,y} = -15^\circ \)

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Table 59. Static Performance Characteristics for Nozzles With $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 30^\circ$, $\delta_{v,p} = 0^\circ$, and $\delta_{v,y} = -30^\circ$

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</tbody>
</table>
| (a) Nozzle 128, medium sidewall
| 2.00 | 0.9630    | 0.9547 | 1.73            | -7.34         | 0.9862   |
| 2.50 | 0.9609    | 0.9507 | 2.57            | -7.96         | 0.9887   |
| 3.00 | 0.9589    | 0.9457 | 4.02            | -8.68         | 0.9897   |
| 3.50 | 0.9604    | 0.9455 | 4.61            | -9.02         | 0.9910   |
| 4.00 | 0.9620    | 0.9446 | 5.77            | -9.30         | 0.9917   |
| 5.01 | 0.9643    | 0.9405 | 8.31            | -9.81         | 0.9934   |
| 6.00 | 0.9666    | 0.9352 | 10.68           | -10.26        | 0.9947   |
| 7.00 | 0.9696    | 0.9308 | 12.64           | -10.57        | 0.9955   |
| 8.00 | 0.9717    | 0.9265 | 14.13           | -10.84        | 0.9962   |

|     |           |        |                 |               |          |
| (b) Nozzle 129, maximum sidewall
| 2.00 | 0.9538    | 0.9373 | 4.54            | -9.69         | 0.9857   |
| 2.50 | 0.9538    | 0.9342 | 5.22            | -10.48        | 0.9881   |
| 3.00 | 0.9563    | 0.9345 | 6.45            | -10.51        | 0.9893   |
| 3.50 | 0.9528    | 0.9289 | 6.68            | -11.06        | 0.9905   |
| 4.00 | 0.9572    | 0.9301 | 7.83            | -11.32        | 0.9913   |
| 5.00 | 0.9591    | 0.9242 | 10.27           | -11.88        | 0.9930   |
| 6.00 | 0.9621    | 0.9176 | 12.57           | -12.56        | 0.9942   |
| 7.00 | 0.9654    | 0.9119 | 14.48           | -13.10        | 0.9949   |
| 7.00 | 0.9655    | 0.9120 | 14.48           | -13.10        | 0.9949   |
| 8.01 | 0.9672    | 0.9063 | 15.91           | -13.52        | 0.9955   |
Table 60. Static Performance Characteristics for Nozzles With $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 15^\circ$, $\delta_{v,p} = -20^\circ$, and $\delta_{v,y} = -15^\circ$

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<th>$F/F_i$</th>
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<th>$\delta_{y, \text{deg}}$</th>
<th>$w_p/w_i$</th>
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(a) Nozzle 130, medium sidewall

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(b) Nozzle 131, maximum sidewall
Table 61. Static Performance Characteristics for Nozzles With \( \frac{x_r}{l_r} = 0.20, \theta = 30^\circ, \phi = 15^\circ, \delta_{v,p} = -20^\circ, \) and \( \delta_{v,y} = -30^\circ \)

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<th>( \delta_y, \text{deg} )</th>
<th>( w_p/w_i )</th>
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Table 62. Static Performance Characteristics for Nozzles With $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 30^\circ$, $\delta_{v,r} = -20^\circ$, and $\delta_{r,y} = -15^\circ$

<table>
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<th>$\delta_y$, deg</th>
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<td>(a) Nozzle 134, medium sidewall</td>
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Table 63. Static Performance Characteristics for Nozzles With $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 30^\circ$, $\delta_{v,p} = -20^\circ$, and $\delta_{v,y} = -30^\circ$

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Table 64. Static Performance Characteristics for Nozzles With
\( x_r/l_r = 0.20, \ \theta = 30^\circ, \ \phi = 15^\circ, \ \delta_{w,p} = 20^\circ, \) and \( \delta_{w,y} = -15^\circ \)

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Table 65. Static Performance Characteristics for Nozzles With $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 15^\circ$, $\delta_{r,p} = 20^\circ$, and $\delta_{r,y} = -30^\circ$

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Table 66. Static Performance Characteristics for Nozzles With \( \frac{x_r}{l_r} = 0.20, \theta = 30^\circ, \phi = 30^\circ, \delta_{r,p} = -20^\circ, \) and \( \delta_{r,y} = -15^\circ \)

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Table 67. Static Performance Characteristics for Nozzles With $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 30^\circ$, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = -30^\circ$

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(a) Nozzle 144, medium sidewall

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(b) Nozzle 145, maximum sidewall
Table 68. Static Pressure Ratios for Nozzle 1, $x_r/l_r = 1.0$, $\theta = 0^\circ$, $\phi = 0^\circ$,
Minimum Sidewall, $\delta_{x,p} = 0^\circ$, and $\delta_{x,y} = 0^\circ$

(a) Upper ramp

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(b) Lower flap

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Table 69. Static Pressure Ratios for Nozzle 2, \( x_r/l_r = 1.0 \), \( \theta = 0^\circ \), \( \phi = 0^\circ \), Medium Sidewall, \( \delta_{\text{x,p}} = 0^\circ \), and \( \delta_{\text{v,y}} = 0^\circ \)

(a) Upper ramp

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(b) Lower flap

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Table 70. Static Pressure Ratios for Nozzle 3, \( x_r/l_r = 1.0 \), \( \theta = 0^\circ \), \( \phi = 0^\circ \),
Maximum Sidewall, \( \delta_{v,p} = 0^\circ \), and \( \delta_{v,y} = 0^\circ \)

(a) Upper ramp

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(b) Lower flap

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Table 71. Static Pressure Ratios for Nozzle 4, \( x_r/l_r = 0.42, \theta = 20^\circ, \phi = 0^\circ \), Minimum Sidewall, \( \delta_{v,p} = 0^\circ \), and \( \delta_{v,y} = 0^\circ \)

(a) Upper ramp

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(b) Lower flap

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Table 72. Static Pressure Ratios for Nozzle 5, \( x_r/l_r = 0.42 \), \( \theta = 20^\circ \), \( \phi = 0^\circ \), Medium Sidewall, \( \delta_{v,p} = 0^\circ \), and \( \delta_{v,y} = 0^\circ \)

(a) Upper ramp

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(b) Lower-flap

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Table 73. Static Pressure Ratios for Nozzle 6, \( x_r/l_r = 0.42, \theta = 20^\circ, \phi = 0^\circ \),
Maximum Sidewall, \( \delta_{v,p} = 0^\circ \), and \( \delta_{v,y} = 0^\circ \)

(a) Upper ramp

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</table>

(b) Lower flap

<table>
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<tr>
<th>NPR</th>
<th>-0.308</th>
<th>-0.170</th>
<th>-0.032</th>
<th>0.037</th>
<th>0.079</th>
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<tbody>
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<td>2.00</td>
<td>0.893</td>
<td>0.841</td>
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<td>0.476</td>
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<td>0.841</td>
<td>0.625</td>
<td>0.475</td>
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<td>0.307</td>
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<td>0.625</td>
<td>0.475</td>
<td>0.398</td>
<td>0.306</td>
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<td>0.840</td>
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Table 74. Static Pressure Ratios for Nozzle 7, $x_r/l_r = 0.20$, $\theta = 20^\circ$, $\phi = 0^\circ$, Minimum Sidewall, $\delta_{c,p} = 0^\circ$, and $\delta_{v,y} = 0^\circ$

(a) Upper ramp

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<tr>
<th>NPR</th>
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<td>0.450</td>
<td>0.418</td>
<td>0.377</td>
<td>0.272</td>
<td>0.212</td>
<td>0.165</td>
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<td>0.450</td>
<td>0.416</td>
<td>0.376</td>
<td>0.272</td>
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<td>0.165</td>
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<tr>
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<td>0.651</td>
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<td>0.480</td>
<td>0.449</td>
<td>0.415</td>
<td>0.376</td>
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<td>0.558</td>
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</table>

(b) Lower flap

<table>
<thead>
<tr>
<th>NPR</th>
<th>$-0.308$</th>
<th>$-0.170$</th>
<th>$-0.032$</th>
<th>$ 0.037$</th>
<th>$ 0.079$</th>
<th>$ 0.120$</th>
<th>$ 0.162$</th>
</tr>
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<tbody>
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<td>2.00</td>
<td>0.893</td>
<td>0.841</td>
<td>0.626</td>
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<td>0.477</td>
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<tr>
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<td>0.843</td>
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<td>0.476</td>
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<td>0.400</td>
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</table>
Table 75. Static Pressure Ratios for Nozzle 8, $x_r/l_r = 0.20$, $\theta = 20^\circ$, $\phi = 0^\circ$, Medium Sidewall, $\delta_{w,p} = 0^\circ$, and $\delta_{w,y} = 0^\circ$

(a) Upper ramp

<table>
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<tr>
<th>NPR</th>
<th>-0.308</th>
<th>-0.170</th>
<th>-0.101</th>
<th>-0.032</th>
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<th>0.106</th>
<th>0.175</th>
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<th>0.520</th>
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<tr>
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<td>0.271</td>
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<td>0.163</td>
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</table>

(b) Lower flap

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.308</th>
<th>-0.170</th>
<th>-0.032</th>
<th>0.037</th>
<th>0.079</th>
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<th>0.162</th>
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Table 76. Static Pressure Ratios for Nozzle 9, \(x_r/l_r = 0.20\), \(\theta = 20^\circ\), \(\phi = 0^\circ\), Maximum Sidewall, \(\delta_{w,p} = 0^\circ\), and \(\delta_{w,y} = 0^\circ\)

(a) Upper ramp

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.308</th>
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<td>4.00</td>
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</table>

(b) Lower flap

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Table 77. Static Pressure Ratios for Nozzle 10, $x_r/l_r = 0.02$, $\theta = 20^\circ$, $\phi = 0^\circ$.
Minimum Sidewall, $\delta_{v,p} = 0^\circ$, and $\delta_{v,y} = 0^\circ$

(a) Upper ramp

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(b) Lower flap

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Table 78. Static Pressure Ratios for Nozzle 11, \( x_r/l_r = 0.02 \), \( \theta = 20^\circ \), \( \phi = 0^\circ \),

Medium Sidewall, \( \delta_{v,p} = 0^\circ \), and \( \delta_{v,y} = 0^\circ \)

(a) Upper ramp

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(b) Lower flap

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Table 79. Static Pressure Ratios for Nozzle 12, $x_r/l_r = 0.02$, $\theta = 20^\circ$, $\phi = 0^\circ$, Maximum Sidewall, $\delta_{v,p} = 0^\circ$, and $\delta_{v,y} = 0^\circ$

(a) Upper ramp

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(b) Lower flap

<table>
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<th>NPR</th>
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<th>-0.170</th>
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Table 80. Static Pressure Ratios for Nozzle 13, $x_r/l_r = 0.42$, $\theta = 20^\circ$, $\phi = 0^\circ$, Maximum Sidewall, $\delta_{v,p} = 0^\circ$, and $\delta_{v,y} = -20^\circ$

(a) Upper ramp

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(b) Lower flap

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Table 81. Static Pressure Ratios for Nozzle 14, $x_r/l_r = 0.20$, $\theta = 20^\circ$, $\phi = 0^\circ$,
Medium Sidewall, $\delta_{v,p} = 0^\circ$, and $\delta_{v,y} = -20^\circ$

(a) Upper ramp

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(b) Lower flap

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Table 82. Static Pressure Ratios for Nozzle 15, $x_r/l_r = 0.20$, $\theta = 20^\circ$, $\phi = 0^\circ$, Maximum Sidewall, $\delta_{v,p} = 0^\circ$, and $\delta_{v,y} = -20^\circ$

(a) Upper ramp

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(b) Lower flap

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Table 83. Static Pressure Ratios for Nozzle 16, \( x_r/l_r = 0.02, \theta = 20^\circ, \phi = 0^\circ, \)
Minimum Sidewall, \( \delta_{u,p} = 0^\circ, \) and \( \delta_{v,y} = -20^\circ \)

(a) Upper ramp

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(b) Lower flap

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Table 84. Static Pressure Ratios for Nozzle 17, $x_r/l_r = 0.02$, $\theta = 20^\circ$, $\phi = 0^\circ$, Medium Sidewall, $\delta_{v,p} = 0^\circ$, and $\delta_{v,y} = -20^\circ$

(a) Upper ramp

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(b) Lower flap

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Table 85. Static Pressure Ratios for Nozzle 18, $x_r/l_r = 0.02$, $\theta = 20^\circ$, $\phi = 0^\circ$, Maximum Sidewall, $\delta_{r,p} = 0^\circ$, and $\delta_{v,y} = -20^\circ$

(a) Upper ramp

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(b) Lower flap

<table>
<thead>
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<th>-0.170</th>
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Table 86. Static Pressure Ratios for Nozzle 19, $x_r/l_r = 0.42$, $\theta = 30^\circ$, $\phi = 0^\circ$, Minimum Sidewall, $\delta_{v,p} = 0^\circ$, and $\delta_{v,y} = 0^\circ$

(a) Upper ramp

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(b) Lower flap

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Table 87. Static Pressure Ratios for Nozzle 20, \( x_r/l_r = 0.42 \), \( \theta = 30^\circ \), \( \phi = 0^\circ \), Medium Sidewall, \( \delta_{v,p} = 0^\circ \), and \( \delta_{v,y} = 0^\circ \)

(a) Upper ramp

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(b) Lower flap

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Table 88. Static Pressure Ratios for Nozzle 21, $x_r/l_r = 0.42$, $\theta = 30^\circ$, $\phi = 0^\circ$,
Maximum Sidewall, $\delta_{v,p} = 0^\circ$, and $\delta_{v,y} = 0^\circ$

(a) Upper ramp

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(b) Lower flap

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<th>0.162</th>
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Table 89. Static Pressure Ratios for Nozzle 22, \( x_r/l_r = 0.20, \theta = 30^\circ, \phi = 0^\circ, \) Minimum Sidewall, \( \delta_{v,p} = 0^\circ, \) and \( \delta_{v,y} = 0^\circ \)

(a) Upper ramp

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(b) Lower flap

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Table 90. Static Pressure Ratios for Nozzle 23, \( x_r/l_r = 0.20 \), \( \theta = 30^\circ \), \( \phi = 0^\circ \), Medium Sidewall, \( \delta_{r,p} = 0^\circ \), and \( \delta_{r,y} = 0^\circ \)

(a) Upper ramp

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(b) Lower flap

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Table 91. Static Pressure Ratios for Nozzle 24, \( x_r/l_r = 0.20 \), \( \theta = 30^\circ \), \( \phi = 0^\circ \),
Maximum Sidewall, \( \delta_{e,y} = 0^\circ \), and \( \delta_{v,y} = 0^\circ \)

(a) Upper ramp

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(b) Lower flap

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Table 92. Static Pressure Ratios for Nozzle 25, \( x_r/I_r = 0.02, \theta = 30^\circ, \phi = 0^\circ, \) 
Minimum Sidewall, \( \delta_v,p = 0^\circ, \) and \( \delta_v,y = 0^\circ \)

(a) Upper ramp

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(b) Lower flap

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Table 93. Static Pressure Ratios for Nozzle 26, \(x_r/l_r = 0.02\), \(\theta = 30^\circ\), \(\phi = 0^\circ\), Medium Sidewall, \(\delta_{r,p} = 0^\circ\), and \(\delta_{r,y} = 0^\circ\)

(a) Upper ramp

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(b) Lower flap

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Table 9.1. Static Pressure Ratios for Nozzle 27, \( x_r/l_r = 0.02 \), \( \theta = 30^\circ \), \( \phi = 0^\circ \), Maximum Sidewall, \( \delta_{r,p} = 0^\circ \), and \( \delta_{r,y} = 0^\circ \)

(a) Upper ramp

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(b) Lower flap

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Table 95. Static Pressure Ratios for Nozzle 32, \( x_r/l_r = 0.42 \), \( \theta = 30^\circ \), \( \phi = 0^\circ \),
Maximum Sidewall, \( \delta_{v,p} = 0^\circ \), and \( \delta_{v,y} = -30^\circ \)

(a) Upper ramp

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(b) Lower flap

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Table 96. Static Pressure Ratios for Nozzle 33, $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 0^\circ$, Medium Sidewall, $\delta_{v,p} = 0^\circ$, and $\delta_{v,y} = -30^\circ$

(a) Upper ramp

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<th>NPR</th>
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(b) Lower flap

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Table 97. Static Pressure Ratios for Nozzle 34, \( x_r/l_r = 0.20, \theta = 30^\circ, \phi = 0^\circ, \)
Maximum Sidewall, \( \delta_{x,y} = 0^\circ, \) and \( \delta_{z,y} = -30^\circ \)

(a) Upper ramp

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(b) Lower flap

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Table 98. Static Pressure Ratios for Nozzle 35, $x_r/l_r = 0.02$, $\theta = 30^\circ$, $\phi = 0^\circ$, Minimum Sidewall, $\delta_{v,p} = 0^\circ$, and $\delta_{v,y} = -30^\circ$

(a) Upper ramp

<table>
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(b) Lower flap

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<th>0.037</th>
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Table 99. Static Pressure Ratios for Nozzle 36, $x_r/l_r = 0.02$, $\theta = 30^\circ$, $\phi = 0^\circ$, Medium Sidewall, $\delta_{c,p} = 0^\circ$, and $\delta_{v,y} = -30^\circ$

(a) Upper ramp

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<td>0.514</td>
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<td>0.621</td>
<td>0.592</td>
<td>0.564</td>
<td>0.549</td>
<td>0.515</td>
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<td>0.410</td>
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(b) Lower flap

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<th>NPR</th>
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<th>$-0.170$</th>
<th>$-0.032$</th>
<th>$0.037$</th>
<th>$0.079$</th>
<th>$0.120$</th>
<th>$0.162$</th>
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<td>0.534</td>
<td>0.457</td>
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</tr>
<tr>
<td>4.00</td>
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Table 100. Static Pressure Ratios for Nozzle 37, $x_r/l_r = 0.02$, $\theta = 30^\circ$, $\phi = 0^\circ$, Maximum Sidewall, $\delta_{r,p} = 0^\circ$, and $\delta_{r,y} = -30^\circ$

(a) Upper ramp

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(b) Lower flap

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.308</th>
<th>-0.170</th>
<th>-0.032</th>
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Table 101. Static Pressure Ratios for Nozzle 38, \( x_r/l_r = 1.00 \), \( \theta = 0^\circ \), \( \phi = 0^\circ \), Minimum Sidewall, \( \delta_{v,p} = -20^\circ \), and \( \delta_{v,y} = 0^\circ \)

(a) Upper ramp

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(b) Lower flap

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.308</th>
<th>-0.170</th>
<th>-0.032</th>
<th>0.037</th>
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<th>0.120</th>
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Table 102. Static Pressure Ratios for Nozzle 39, \( x_r/l_r = 1.00 \), \( \theta = 0^\circ \), \( \phi = 0^\circ \), Medium Sidewall, \( \delta_{v,p} = -20^\circ \), and \( \delta_{v,y} = 0^\circ \)

(a) Upper ramp

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(b) Lower flap

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Table 103. Static Pressure Ratios for Nozzle 40. $x_r/l_r = 1.00$. $\theta = 0^\circ$. $\phi = 0^\circ$.
Maximum Sidewall, $\delta_{c,p} = -20^\circ$, and $\delta_{c,y} = 0^\circ$

(a) Upper ramp

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(b) Lower flap

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Table 104. Static Pressure Ratios for Nozzle 41, \( x_r/l_r = 0.42 \), \( \theta = 20^\circ \), \( \phi = 0^\circ \), Minimum Sidewall, \( \delta_{v,p} = -20^\circ \), and \( \delta_{v,y} = 0^\circ \)

(a) Upper ramp

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(b) Lower flap

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Table 105. Static Pressure Ratios for Nozzle 42, \( x_r/l_r = 0.42, \theta = 20^\circ, \phi = 0^\circ, \)
Medium Sidewall, \( \delta_{v,p} = -20^\circ, \) and \( \delta_{v,y} = 0^\circ \)

(a) Upper ramp

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(b) Lower flap

<table>
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<th>NPR</th>
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<th>-0.170</th>
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<th>0.037</th>
<th>0.079</th>
<th>0.120</th>
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<td>0.842</td>
<td>0.624</td>
<td>0.472</td>
<td>0.392</td>
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Table 106. Static Pressure Ratios for Nozzle 43, $x_r/l_r = 0.42$, $\theta = 20^\circ$, $\phi = 0^\circ$, Maximum Sidewall, $\delta_{v,p} = -20^\circ$, and $\delta_{v,y} = 0^\circ$

(a) Upper ramp

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<th>-0.170</th>
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<th>0.382</th>
<th>0.520</th>
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<th>0.797</th>
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<td>0.183</td>
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<td>0.159</td>
<td>0.134</td>
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(b) Lower flap

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.308</th>
<th>-0.170</th>
<th>-0.032</th>
<th>0.037</th>
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<th>0.120</th>
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<tbody>
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### Table 107. Static Pressure Ratios for Nozzle 44, $x_r/l_r = 0.20$, $\theta = 20^\circ$, $\phi = 0^\circ$, Minimum Sidewall, $\delta_{r,p} = -20^\circ$, and $\delta_{r,v} = 0^\circ$

(a) Upper ramp

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<th>-0.170</th>
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<th>-0.032</th>
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<td>0.401</td>
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<td>0.441</td>
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<td>0.077</td>
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(b) Lower flap

<table>
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<tr>
<th>NPR</th>
<th>-0.308</th>
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<th>0.079</th>
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<td>2.01</td>
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<td>0.394</td>
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118
Table 108. Static Pressure Ratios for Nozzle 45, $x_r/l_r = 0.20$, $\theta = 20^\circ$, $\phi = 0^\circ$
Medium Sidewall, $\delta_{n,p} = -20^\circ$, and $\delta_{n,g} = 0^\circ$

(a) Upper ramp

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<td>0.136</td>
<td>0.119</td>
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</tbody>
</table>

(b) Lower flap

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.308</th>
<th>-0.170</th>
<th>-0.032</th>
<th>0.037</th>
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Table 109. Static Pressure Ratios for Nozzle 46, $x_r/l_r = 0.20$, $\theta = 20^\circ$, $\phi = 0^\circ$,
Maximum Sidewall, $\delta_{v,p} = -20^\circ$, and $\delta_{v,y} = 0^\circ$

(a) Upper ramp

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(b) Lower flap

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Table 110. Static Pressure Ratios for Nozzle 47, \( x_r/l_r = 0.02 \), \( \theta = 20^\circ \), \( \phi = 0^\circ \), 
Minimum Sidewall, \( \delta_{v,p} = -20^\circ \), and \( \delta_{v,y} = 0^\circ \)

(a) Upper ramp

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(b) Lower flap

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Table 111. Static Pressure Ratios for Nozzle 48. $x_r/l_r = 0.02$. $\theta = 20^\circ$. $\phi = 0^\circ$.
Medium Sidewall. $\delta_{v,p} = -20^\circ$ and $\delta_{v,y} = 0^\circ$

(a) Upper ramp

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(b) Lower flap

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Table 112. Static Pressure Ratios for Nozzle 49. \(x_r/l_r = 0.02, \theta = 20^\circ, \phi = 0^\circ\). Maximum Sidewall. \(\delta_{c,p} = -20^\circ\) and \(\delta_{c,y} = 0^\circ\).

(a) Upper ramp

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(b) Lower flap

<table>
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<tr>
<th>NPR</th>
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<th>-0.170</th>
<th>-0.032</th>
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Table 113. Static Pressure Ratios for Nozzle 50, $x_r/l_r = 0.42$, $\theta = 20^\circ$, $\phi = 0^\circ$,
Maximum Sidewall, $\delta_{e,p} = -20^\circ$, and $\delta_{e,y} = -20^\circ$

(a) Upper ramp

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(b) Lower flap

<table>
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<th>NPR</th>
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Table 114. Static Pressure Ratios for Nozzle 51, \( x_r/l_r = 0.20 \), \( \theta = 20^\circ \), \( \phi = 0^\circ \), Medium Sidewall, \( \delta_{v,p} = -20^\circ \), and \( \delta_{v,y} = -20^\circ \)

(a) Upper ramp

<table>
<thead>
<tr>
<th>NPR</th>
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<td>0.573</td>
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<td>0.239</td>
<td>0.184</td>
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(b) Lower flap

<table>
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<tr>
<th>NPR</th>
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<td>0.174</td>
</tr>
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<td>0.297</td>
<td>0.247</td>
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<tr>
<td>5.00</td>
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Table 115: Static Pressure Ratios for Nozzle 52, $x_r/l_r = 0.20$, $\theta = 20^\circ$, $\phi = 0^\circ$, Maximum Sidewall, $\delta_{v,p} = -20^\circ$, and $\delta_{v,y} = -20^\circ$

(a) Upper ramp

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(b) Lower flap

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.308</th>
<th>-0.170</th>
<th>-0.032</th>
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Table 116. Static Pressure Ratios for Nozzle 53. \( x_r/l_r = 0.02 \). \( \theta = 20^\circ \). \( \phi = 0^\circ \).
Minimum Sidewall. \( \delta_{r,p} = -20^\circ \). and \( \delta_{r,y} = -20^\circ \)

(a) Upper ramp

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(b) Lower flap

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Table 117. Static Pressure Ratios for Nozzle 54, $x_r/l_r = 0.02$, $\theta = 20^\circ$, $\phi = 0^\circ$, Medium Sidewall, $\delta_{u,p} = -20^\circ$, and $\delta_{u,y} = -20^\circ$

(a) Upper ramp

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(b) Lower flap

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Table 118. Static Pressure Ratios for Nozzle 55, $x_r/l_r = 0.02$, $\theta = 20^\circ$, $\phi = 0^\circ$, Maximum Sidewall, $\delta_{v,p} = -20^\circ$, and $\delta_{v,y} = -20^\circ$

(a) Upper ramp

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(b) Lower flap

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Table 119. Static Pressure Ratios for Nozzle 56. \( x_r/l_r = 0.42, \theta = 30^\circ, \phi = 0^\circ \).
Minimum Sidewall. \( \delta_{r,p} = -20^\circ \) and \( \delta_{r,y} = 0^\circ \)

(a) Upper ramp

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(b) Lower flap

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Table 120. Static Pressure Ratios for Nozzle 57. $x_l/l_r = 0.42$. $\theta = 30^\circ$. $\phi = 0^\circ$. Medium Sidewall. $\delta_{r,p} = -20^\circ$. and $\delta_{r,y} = 0^\circ$

(a) Upper ramp

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(b) Lower flap

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Table 121. Static Pressure Ratios for Nozzle 58, $x_r/l_r = 0.42$, $\theta = 30^\circ$, $\phi = 0^\circ$, Maximum Sidewall, $\delta_{v,p} = -20^\circ$, and $\delta_{v,y} = 0^\circ$

(a) Upper ramp

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(b) Lower flap

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Table 122. Static Pressure Ratios for Nozzle 59, \( x_r/l_r = 0.20 \), \( \theta = 30^\circ \), \( \phi = 0^\circ \), Minimum Sidewall, \( \delta_{v,y} = -20^\circ \), and \( \delta_{v,y} = 0^\circ \)

(a) Upper ramp

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(b) Lower flap

<table>
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<tr>
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Table 123. Static Pressure Ratios for Nozzle 60, $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 0^\circ$, Medium Sidewall, $\delta_{c,p} = -20^\circ$, and $\delta_{c,y} = 0^\circ$

(a) Upper ramp

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(b) Lower flap

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<td>0.840</td>
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Table 124. Static Pressure Ratios for Nozzle 61, $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 0^\circ$,
Maximum Sidewall, $\delta_{v,p} = -20^\circ$, and $\delta_{v,y} = 0^\circ$

(a) Upper ramp

<table>
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<tr>
<th>NPR</th>
<th>-0.308</th>
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(b) Lower flap

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<th>-0.032</th>
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<td>0.472</td>
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Table 125. Static Pressure Ratios for Nozzle 62, $x_r/l_r = 0.02$, $\theta = 30^\circ$, $\phi = 0^\circ$, Minimum Sidewall, $\delta_{r,p} = -20^\circ$, and $\delta_{r,y} = 0^\circ$

(a) Upper ramp

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(b) Lower flap

<table>
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Table 126. Static Pressure Ratios for Nozzle 63, $x_r/l_r = 0.02$, $\theta = 30^\circ$, $\phi = 0^\circ$, Medium Sidewall, $\delta_{v,p} = -20^\circ$, and $\delta_{v,y} = 0^\circ$

(a) Upper ramp

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(b) Lower flap

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Table 127. Static Pressure Ratios for Nozzle 64, \( x_r/l_r = 0.02 \), \( \theta = 30^\circ \), \( \phi = 0^\circ \), Maximum Sidewall, \( \delta_{v,p} = -20^\circ \), and \( \delta_{v,y} = 0^\circ \)

(a) Upper ramp

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(b) Lower flap

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Table 128. Static Pressure Ratios for Nozzle 69, \( x_r/l_r = 0.42, \ \theta = 30^\circ, \ \phi = 0^\circ. \) Maximum Sidewall, \( \delta_{r,p} = -20^\circ, \) and \( \delta_{r,y} = -30^\circ \)

(a) Upper ramp

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(b) Lower flap

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Table 129. Static Pressure Ratios for Nozzle 70, $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 0^\circ$, Medium Sidewall, $\delta_{v,p} = -20^\circ$, and $\delta_{v,y} = -30^\circ$

(a) Upper ramp

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(b) Lower flap

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Table 130. Static Pressure Ratios for Nozzle 71, \( x_r/l_r = 0.20 \), \( \theta = 30^\circ \), \( \phi = 0^\circ \), Maximum Sidewall, \( \delta_{v,p} = -20^\circ \), and \( \delta_{v,y} = -30^\circ \)

(a) Upper ramp

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<tr>
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(b) Lower flap

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Table 131. Static Pressure Ratios for Nozzle 72. \( x_r/l_r = 0.02 \). \( \theta = 30^\circ \). \( \phi = 0^\circ \).
Minimum Sidewall. \( \delta_{r,p} = -20^\circ \). and \( \delta_{r,y} = -30^\circ \)

(a) Upper ramp

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(b) Lower flap

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Table 132. Static Pressure Ratios for Nozzle 73, $x_r/l_r = 0.02$, $\theta = 30^\circ$, $\phi = 0^\circ$, Medium Sidewall, $\delta_{v,p} = -20^\circ$, and $\delta_{v,y} = -30^\circ$

(a) Upper ramp

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(b) Lower flap

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<thead>
<tr>
<th>NPR</th>
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<th>-0.032</th>
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<td>0.836</td>
<td>0.631</td>
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<td>0.491</td>
<td>0.400</td>
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Table 133. Static Pressure Ratios for Nozzle 74, \( x_r/l_r = 0.02, \theta = 30^\circ, \phi = 0^\circ \),
Maximum Sidewall, \( \delta_{v,p} = -20^\circ \), and \( \delta_{v,y} = -30^\circ \)

(a) Upper ramp

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<tr>
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(b) Lower flap

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<th>-0.170</th>
<th>-0.032</th>
<th>0.037</th>
<th>0.079</th>
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<th>0.162</th>
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<tbody>
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<td>0.836</td>
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<td>0.491</td>
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Table 134. Static Pressure Ratios for Nozzle 75, \( x_{r/l_r} = 1.00 \), \( \theta = 0^\circ \), \( \phi = 0^\circ \), Minimum Sidewall, \( \delta_{v,p} = 20^\circ \), and \( \delta_{v,y} = 0^\circ \)

(a) Upper ramp

<table>
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<tr>
<th>NPR</th>
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<th>0.175</th>
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<th>0.520</th>
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<td>0.750</td>
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<td>0.637</td>
<td>0.548</td>
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<td>0.515</td>
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<td>0.749</td>
<td>0.685</td>
<td>0.632</td>
<td>0.471</td>
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<td>0.749</td>
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<td>0.470</td>
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(b) Lower flap

<table>
<thead>
<tr>
<th>NPR</th>
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<th>-0.170</th>
<th>-0.032</th>
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<td>0.859</td>
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<td>0.655</td>
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<td>0.702</td>
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<td>0.541</td>
<td>0.485</td>
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<td>0.857</td>
<td>0.701</td>
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<td>0.540</td>
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Table 135. Static Pressure Ratios for Nozzle 76, \( x_r/l_r = 1.00 \), \( \theta = 0^\circ \), \( \phi = 0^\circ \), Medium Sidewall, \( \delta_{w,p} = 20^\circ \), and \( \delta_{w,y} = 0^\circ \)

(a) Upper ramp

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<tr>
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<th>(-0.170)</th>
<th>(-0.032)</th>
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<th>0.175</th>
<th>0.244</th>
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(b) Lower flap

<table>
<thead>
<tr>
<th>NPR</th>
<th>(-0.308)</th>
<th>(-0.170)</th>
<th>(-0.032)</th>
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Table 136. Static Pressure Ratios for Nozzle 77, $x_r/l_r = 1.00$, $\theta = 0^\circ$, $\phi = 0^\circ$, Maximum Sidewall, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = 0^\circ$

(a) Upper ramp

<table>
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</table>

(b) Lower flap

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Table 137. Static Pressure Ratios for Nozzle 78, $x_r/l_r = 0.42$, $\theta = 20^\circ$, $\phi = 0^\circ$, Minimum Sidewall, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = 0^\circ$

(a) Upper ramp

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<tr>
<th>NPR</th>
<th>-0.170</th>
<th>-0.032</th>
<th>0.106</th>
<th>0.175</th>
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<th>0.382</th>
<th>0.520</th>
<th>0.659</th>
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(b) Lower flap

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Table 138. Static Pressure Ratios for Nozzle 79, $x_r/l_r = 0.42$, $\theta = 20^\circ$, $\phi = 0^\circ$, Medium Sidewall, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = 0^\circ$

(a) Upper ramp

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(b) Lower flap

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Table 139. Static Pressure Ratios for Nozzle 80, $x_r/l_r = 0.42$, $\theta = 20^\circ$, $\phi = 0^\circ$, Maximum Sidewall, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = 0^\circ$

(a) Upper ramp

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(b) Lower flap

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Table 140. Static Pressure Ratios for Nozzle 81, $x_r/l_r = 0.20$, $\theta = 20^\circ$, $\phi = 0^\circ$,
Minimum Sidewall, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = 0^\circ$

(a) Upper ramp

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(b) Lower flap

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Table 141. Static Pressure Ratios for Nozzle 82, $x_r/l_r = 0.20$, $\theta = 20^\circ$, $\phi = 0^\circ$, Medium Sidewall, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = 0^\circ$

(a) Upper ramp

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</table>

(b) Lower flap

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.308</th>
<th>-0.170</th>
<th>-0.032</th>
<th>0.037</th>
<th>0.079</th>
<th>0.120</th>
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<tbody>
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<td>2.00</td>
<td>0.906</td>
<td>0.859</td>
<td>0.709</td>
<td>0.654</td>
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<td>0.858</td>
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</tr>
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<td>0.534</td>
<td>0.474</td>
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</table>
Table 142. Static Pressure Ratios for Nozzle 83, $x_r/l_r = 0.20$, $\theta = 20^\circ$, $\phi = 0^\circ$,
Maximum Sidewall, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = 0^\circ$

(a) Upper ramp

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.170</th>
<th>-0.032</th>
<th>0.106</th>
<th>0.175</th>
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<th>0.520</th>
<th>0.659</th>
<th>0.797</th>
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<td>0.473</td>
<td>0.423</td>
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<td>0.749</td>
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<tr>
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<td>0.618</td>
<td>0.475</td>
<td>0.338</td>
<td>0.222</td>
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</table>

(b) Lower flap

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.308</th>
<th>-0.170</th>
<th>-0.032</th>
<th>0.037</th>
<th>0.079</th>
<th>0.120</th>
<th>0.162</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td></td>
</tr>
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<td>0.474</td>
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</table>
Table 143. Static Pressure Ratios for Nozzle 84, $x_r/l_r = 0.02$, $\theta = 20^\circ$, $\phi = 0^\circ$, Minimum Sidewall, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = 0^\circ$

(a) Upper ramp

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.170</th>
<th>-0.032</th>
<th>0.106</th>
<th>0.175</th>
<th>0.244</th>
<th>0.382</th>
<th>0.520</th>
<th>0.659</th>
<th>0.797</th>
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<td>0.677</td>
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<td>0.730</td>
<td>0.671</td>
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<td>0.730</td>
<td>0.671</td>
<td>0.594</td>
<td>0.451</td>
<td>0.319</td>
<td>0.226</td>
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<td>0.780</td>
<td>0.730</td>
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<td>0.451</td>
<td>0.317</td>
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<td>0.730</td>
<td>0.670</td>
<td>0.594</td>
<td>0.452</td>
<td>0.314</td>
<td>0.198</td>
<td>0.128</td>
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</table>

(b) Lower flap

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.308</th>
<th>-0.170</th>
<th>-0.032</th>
<th>0.037</th>
<th>0.079</th>
<th>0.120</th>
<th>0.162</th>
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<td>0.711</td>
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<td>0.489</td>
<td>0.466</td>
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<td>0.901</td>
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<td>0.711</td>
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<td>0.564</td>
<td>0.488</td>
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<tr>
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<td>0.857</td>
<td>0.710</td>
<td>0.628</td>
<td>0.563</td>
<td>0.486</td>
<td>0.466</td>
</tr>
<tr>
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<td>0.710</td>
<td>0.628</td>
<td>0.563</td>
<td>0.485</td>
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<td>0.710</td>
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<td>0.562</td>
<td>0.484</td>
<td>0.466</td>
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<td>0.855</td>
<td>0.709</td>
<td>0.626</td>
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<td>0.467</td>
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</table>
Table 144. Static Pressure Ratios for Nozzle 85, \( x_r/l_r = 0.02, \theta = 20^\circ, \phi = 0^\circ, \)
Medium Sidewall, \( \delta_{v,p} = 20^\circ, \) and \( \delta_{v,y} = 0^\circ \)

(a) Upper ramp

<table>
<thead>
<tr>
<th>NPR</th>
<th>(-0.170)</th>
<th>(-0.032)</th>
<th>(0.106)</th>
<th>(0.175)</th>
<th>(0.244)</th>
<th>(0.382)</th>
<th>(0.520)</th>
<th>(0.659)</th>
<th>(0.797)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.01</td>
<td>0.717</td>
<td>0.784</td>
<td>0.733</td>
<td>0.677</td>
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<td>0.593</td>
<td>0.450</td>
<td>0.316</td>
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<td>0.451</td>
<td>0.314</td>
<td>0.198</td>
<td>0.128</td>
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</table>

(b) Lower flap

<table>
<thead>
<tr>
<th>NPR</th>
<th>(-0.308)</th>
<th>(-0.170)</th>
<th>(-0.032)</th>
<th>(0.037)</th>
<th>(0.079)</th>
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<tbody>
<tr>
<td>2.01</td>
<td>0.901</td>
<td>0.859</td>
<td>0.715</td>
<td>0.635</td>
<td>0.572</td>
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<tr>
<td>2.50</td>
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<td>0.561</td>
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<td>0.464</td>
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<td>0.901</td>
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<td>0.708</td>
<td>0.625</td>
<td>0.560</td>
<td>0.483</td>
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<td>0.625</td>
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<td>0.481</td>
<td>0.464</td>
</tr>
</tbody>
</table>
Table 145. Static Pressure Ratios for Nozzle 86, $x_r/l_r = 0.02$, $\theta = 20^\circ$, $\phi = 0^\circ$.
Maximum Sidewall, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = 0^\circ$

(a) Upper ramp

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.170</th>
<th>-0.032</th>
<th>0.106</th>
<th>0.175</th>
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<th>0.382</th>
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</table>

(b) Lower flap

<table>
<thead>
<tr>
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<th>0.079</th>
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<tbody>
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Table 146. Static Pressure Ratios for Nozzle 87, \( x_r/l_r = 0.42 \), \( \theta = 20^\circ \), \( \phi = 0^\circ \), Maximum Sidewall, \( \delta_{v,p} = 20^\circ \), and \( \delta_{v,y} = -20^\circ \)

(a) Upper ramp

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.170</th>
<th>-0.032</th>
<th>0.106</th>
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(b) Lower flap

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<th>0.079</th>
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<th>0.162</th>
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157
Table 147. Static Pressure Ratios for Nozzle 88, $x_r/l_r = 0.20$, $\theta = 20^\circ$, $\phi = 0^\circ$, Medium Sidewall, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = -20^\circ$

(a) Upper ramp

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(b) Lower flap

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Table 148. Static Pressure Ratios for Nozzle 89, $x_{r/l_r} = 0.20$, $\theta = 20^\circ$, $\phi = 0^\circ$
Maximum Sidewall, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = -20^\circ$

(a) Upper ramp

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<th>$0.797$</th>
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(b) Lower flap

<table>
<thead>
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<th>NPR</th>
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<th>$-0.032$</th>
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<th>$0.079$</th>
<th>$0.120$</th>
<th>$0.162$</th>
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<td>0.727</td>
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</table>
Table 149. Static Pressure Ratios for Nozzle 90, $x_r/l_r = 0.02$, $\theta = 20^\circ$, $\phi = 0^\circ$
Minimum Sidewall, $\delta_{y,p} = 20^\circ$, and $\delta_{y,y} = -20^\circ$

(a) Upper ramp

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<tr>
<th>NPR</th>
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<td>0.472</td>
<td>0.317</td>
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(b) Lower flap

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<th>$-0.308$</th>
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Table 150. Static Pressure Ratios for Nozzle 91, $x_r/l_r = 0.02$, $\theta = 20^\circ$, $\phi = 0^\circ$, Medium Sidewall, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = -20^\circ$

(a) Upper ramp

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<th>0.382</th>
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<th>0.659</th>
<th>0.797</th>
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<td>0.484</td>
<td>0.336</td>
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</table>

(b) Lower flap

<table>
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<th>-0.170</th>
<th>-0.032</th>
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<th>0.120</th>
<th>0.162</th>
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Table 151. Static Pressure Ratios for Nozzle 92, \( \frac{x_r}{l_r} = 0.02 \), \( \theta = 20^\circ \), \( \phi = 0^\circ \),
Maximum Sidewall, \( \delta_{v,p} = 20^\circ \), and \( \delta_{v,y} = -20^\circ \)

(a) Upper ramp

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.170</th>
<th>-0.032</th>
<th>0.106</th>
<th>0.175</th>
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(b) Lower flap

<table>
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<th>-0.032</th>
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Table 152. Static Pressure Ratios for Nozzle 93, \(x_r/l_r = 0.42, \theta = 30^\circ, \phi = 0^\circ\), Minimum Sidewall, \(\delta_{v,p} = 20^\circ\), and \(\delta_{v,y} = 0^\circ\)

(a) Upper ramp

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(b) Lower flap

<table>
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<tr>
<th>NPR</th>
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<th>-0.170</th>
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<td>0.702</td>
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<td>0.701</td>
<td>0.654</td>
<td>0.585</td>
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<td>0.473</td>
</tr>
</tbody>
</table>
Table 153. Static Pressure Ratios for Nozzle 94, $x_r/l_r = 0.42$, $\theta = 30^\circ$, $\phi = 0^\circ$, Medium Sidewall, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = 0^\circ$

(a) Upper ramp

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<th>NPR</th>
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</thead>
<tbody>
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</tr>
<tr>
<td>2.00</td>
<td>0.738</td>
</tr>
<tr>
<td>2.50</td>
<td>0.737</td>
</tr>
<tr>
<td>3.00</td>
<td>0.736</td>
</tr>
<tr>
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</tr>
<tr>
<td>4.00</td>
<td>0.735</td>
</tr>
<tr>
<td>5.00</td>
<td>0.734</td>
</tr>
<tr>
<td>6.00</td>
<td>0.733</td>
</tr>
<tr>
<td>7.00</td>
<td>0.733</td>
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<td>7.40</td>
<td>0.733</td>
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</table>

(b) Lower flap

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<th>Static pressure ratios at $x_r/l_r$ of-</th>
</tr>
</thead>
<tbody>
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<td>-0.308</td>
</tr>
<tr>
<td>2.00</td>
<td>0.907</td>
</tr>
<tr>
<td>2.50</td>
<td>0.906</td>
</tr>
<tr>
<td>3.00</td>
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<tr>
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<td>0.907</td>
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<tr>
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<td>0.907</td>
</tr>
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<td>0.908</td>
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<tr>
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<td>0.908</td>
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Table 154. Static Pressure Ratios for Nozzle 95, \(x_r/l_r = 0.42\), \(\theta = 30^\circ\), \(\phi = 0^\circ\),
Maximum Sidewall, \(\delta_{v,p} = 20^\circ\), and \(\delta_{v,y} = 0^\circ\)

(a) Upper ramp

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<thead>
<tr>
<th>NPR</th>
<th>-0.170</th>
<th>-0.032</th>
<th>0.106</th>
<th>0.175</th>
<th>0.244</th>
<th>0.382</th>
<th>0.520</th>
<th>0.659</th>
<th>0.797</th>
</tr>
</thead>
<tbody>
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<td>0.749</td>
<td>0.698</td>
<td>0.631</td>
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<td>0.543</td>
<td>0.515</td>
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<td>0.746</td>
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<td>0.465</td>
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<td>0.802</td>
<td>0.746</td>
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<td>0.621</td>
<td>0.465</td>
<td>0.322</td>
<td>0.217</td>
<td>0.148</td>
</tr>
<tr>
<td>7.00</td>
<td>0.734</td>
<td>0.802</td>
<td>0.746</td>
<td>0.692</td>
<td>0.622</td>
<td>0.465</td>
<td>0.322</td>
<td>0.217</td>
<td>0.148</td>
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<tr>
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<td>0.733</td>
<td>0.802</td>
<td>0.746</td>
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<td>0.622</td>
<td>0.465</td>
<td>0.322</td>
<td>0.217</td>
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</table>

(b) Lower flap

<table>
<thead>
<tr>
<th>NPR</th>
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<th>-0.170</th>
<th>-0.032</th>
<th>0.037</th>
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<th>0.120</th>
<th>0.162</th>
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<tbody>
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<td>0.713</td>
<td>0.659</td>
<td>0.595</td>
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<td>0.863</td>
<td>0.710</td>
<td>0.657</td>
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<td>0.543</td>
<td>0.477</td>
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<td>0.591</td>
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<td>0.863</td>
<td>0.707</td>
<td>0.657</td>
<td>0.591</td>
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<td>0.476</td>
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<tr>
<td>4.00</td>
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<td>0.863</td>
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<td>0.591</td>
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<td>0.475</td>
</tr>
<tr>
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<td>0.704</td>
<td>0.655</td>
<td>0.589</td>
<td>0.540</td>
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<tr>
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<td>0.861</td>
<td>0.703</td>
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<td>0.588</td>
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<td>0.474</td>
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<td>0.702</td>
<td>0.655</td>
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<td>0.540</td>
<td>0.473</td>
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</table>
Table 155. Static Pressure Ratios for Nozzle 96, $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 0^\circ$;
Minimum Sidewall, $\delta_{w,p} = 20^\circ$, and $\delta_{w,y} = 0^\circ$

(a) Upper ramp

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<tr>
<th>NPR</th>
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</thead>
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<td>8.00</td>
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</table>

(b) Lower flap

<table>
<thead>
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<tr>
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<td>0.905</td>
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<tr>
<td>3.00</td>
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<tr>
<td>4.00</td>
<td>0.906</td>
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<tr>
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<td>0.907</td>
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<td>8.00</td>
<td>0.907</td>
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</table>
Table 156. Static Pressure Ratios for Nozzle 97, $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 0^\circ$, Medium Sidewall, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = 0^\circ$

(a) Upper ramp

<table>
<thead>
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<th>NPR</th>
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<tr>
<td>3.50</td>
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<td>0.728</td>
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<tr>
<td>5.00</td>
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<tr>
<td>6.99</td>
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<tr>
<td>8.00</td>
<td>0.725</td>
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</tbody>
</table>

(b) Lower flap

<table>
<thead>
<tr>
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<th>Static pressure ratios at $x_r/l_r$ of—</th>
</tr>
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<td></td>
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<tr>
<td>2.00</td>
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<tr>
<td>2.50</td>
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<td>3.50</td>
<td>0.906</td>
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<tr>
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<td>0.907</td>
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<tr>
<td>8.00</td>
<td>0.907</td>
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</table>
Table 157. Static Pressure Ratios for Nozzle 98, \( x_r/l_r = 0.20 \), \( \theta = 30^\circ \), \( \phi = 0^\circ \),
Maximum Sidewall, \( \delta_{v,p} = 20^\circ \), and \( \delta_{v,y} = 0^\circ \)

(a) Upper ramp

<table>
<thead>
<tr>
<th>NPR</th>
<th>(-0.170)</th>
<th>(-0.032)</th>
<th>(0.106)</th>
<th>(0.175)</th>
<th>(0.244)</th>
<th>(0.382)</th>
<th>(0.520)</th>
<th>(0.659)</th>
<th>(0.797)</th>
</tr>
</thead>
<tbody>
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<td>0.505</td>
<td>0.536</td>
</tr>
<tr>
<td>2.50</td>
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<td>0.793</td>
<td>0.748</td>
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<td>0.614</td>
<td>0.471</td>
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<td>0.748</td>
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<td>0.614</td>
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<td>0.750</td>
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<td>0.332</td>
<td>0.140</td>
<td>0.213</td>
</tr>
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</table>

(b) Lower flap

<table>
<thead>
<tr>
<th>NPR</th>
<th>(-0.308)</th>
<th>(-0.170)</th>
<th>(-0.032)</th>
<th>(0.037)</th>
<th>(0.079)</th>
<th>(0.120)</th>
<th>(0.162)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.00</td>
<td>0.906</td>
<td>0.861</td>
<td>0.707</td>
<td>0.654</td>
<td>0.589</td>
<td>0.541</td>
<td>0.473</td>
</tr>
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<td>0.470</td>
</tr>
<tr>
<td>3.51</td>
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<td>0.860</td>
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<td>0.651</td>
<td>0.585</td>
<td>0.537</td>
<td>0.469</td>
</tr>
<tr>
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<td>0.907</td>
<td>0.860</td>
<td>0.701</td>
<td>0.651</td>
<td>0.585</td>
<td>0.537</td>
<td>0.469</td>
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<tr>
<td>5.01</td>
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<td>0.699</td>
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<td>0.584</td>
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<tr>
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<td>0.907</td>
<td>0.859</td>
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<td>0.584</td>
<td>0.535</td>
<td>0.468</td>
</tr>
<tr>
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</table>
Table 158. Static Pressure Ratios for Nozzle 99, $x_r/l_r = 0.02$, $\theta = 30^\circ$, $\phi = 0^\circ$, Minimum Sidewall, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = 0^\circ$

(a) Upper ramp

<table>
<thead>
<tr>
<th>NPR</th>
<th>$-0.170$</th>
<th>$-0.032$</th>
<th>$0.106$</th>
<th>$0.175$</th>
<th>$0.244$</th>
<th>$0.382$</th>
<th>$0.520$</th>
<th>$0.659$</th>
<th>$0.797$</th>
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<td>0.533</td>
<td>0.527</td>
<td>0.506</td>
</tr>
<tr>
<td>2.50</td>
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<td>0.777</td>
<td>0.711</td>
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<td>0.385</td>
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<td>0.709</td>
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<td>0.659</td>
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<td>0.705</td>
<td>0.655</td>
<td>0.587</td>
<td>0.422</td>
<td>0.297</td>
<td>0.188</td>
<td>0.124</td>
</tr>
</tbody>
</table>

(b) Lower flap

<table>
<thead>
<tr>
<th>NPR</th>
<th>$-0.308$</th>
<th>$-0.170$</th>
<th>$-0.032$</th>
<th>$0.037$</th>
<th>$0.079$</th>
<th>$0.120$</th>
<th>$0.162$</th>
</tr>
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<td>0.856</td>
<td>0.710</td>
<td>0.626</td>
<td>0.564</td>
<td>0.499</td>
<td>0.472</td>
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<td>0.705</td>
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<td>0.703</td>
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<td>0.461</td>
</tr>
<tr>
<td>3.50</td>
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<td>0.854</td>
<td>0.702</td>
<td>0.618</td>
<td>0.555</td>
<td>0.485</td>
<td>0.460</td>
</tr>
<tr>
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<td>0.555</td>
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<td>0.617</td>
<td>0.554</td>
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<td>0.853</td>
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<td>0.554</td>
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Table 159. Static Pressure Ratios for Nozzle 100, $x_r/l_r = 0.02$, $\theta = 30^\circ$, $\phi = 0^\circ$, Medium Sidewall, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = 0^\circ$

(a) Upper ramp

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.170</th>
<th>-0.032</th>
<th>0.106</th>
<th>0.175</th>
<th>0.244</th>
<th>0.382</th>
<th>0.520</th>
<th>0.659</th>
<th>0.797</th>
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<td>0.713</td>
<td>0.667</td>
<td>0.595</td>
<td>0.524</td>
<td>0.532</td>
<td>0.523</td>
<td>0.504</td>
</tr>
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<td>0.711</td>
<td>0.662</td>
<td>0.591</td>
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<td>0.431</td>
<td>0.428</td>
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<td>0.707</td>
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<td>0.586</td>
<td>0.424</td>
<td>0.302</td>
<td>0.189</td>
<td>0.159</td>
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<td>0.707</td>
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<td>0.423</td>
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<td>0.706</td>
<td>0.656</td>
<td>0.586</td>
<td>0.422</td>
<td>0.299</td>
<td>0.188</td>
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<tr>
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<td>0.705</td>
<td>0.655</td>
<td>0.587</td>
<td>0.421</td>
<td>0.297</td>
<td>0.188</td>
<td>0.124</td>
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</tbody>
</table>

(b) Lower flap

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.308</th>
<th>-0.170</th>
<th>-0.032</th>
<th>0.037</th>
<th>0.079</th>
<th>0.120</th>
<th>0.162</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.01</td>
<td>0.901</td>
<td>0.856</td>
<td>0.710</td>
<td>0.626</td>
<td>0.564</td>
<td>0.498</td>
<td>0.472</td>
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<td>0.854</td>
<td>0.706</td>
<td>0.621</td>
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<td>0.853</td>
<td>0.703</td>
<td>0.618</td>
<td>0.555</td>
<td>0.485</td>
<td>0.460</td>
</tr>
<tr>
<td>4.00</td>
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<td>0.554</td>
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<td>0.459</td>
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<td>0.701</td>
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<td>0.900</td>
<td>0.853</td>
<td>0.700</td>
<td>0.617</td>
<td>0.554</td>
<td>0.481</td>
<td>0.456</td>
</tr>
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<td>0.852</td>
<td>0.699</td>
<td>0.616</td>
<td>0.553</td>
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<td>0.455</td>
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</table>
Table 160. Static Pressure Ratios for Nozzle 101, $x_r/l_r = 0.02$, $\theta = 30^\circ$, $\phi = 0^\circ$, Maximum Sidewall, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = 0^\circ$

(a) Upper ramp

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.170</th>
<th>-0.032</th>
<th>0.106</th>
<th>0.175</th>
<th>0.244</th>
<th>0.382</th>
<th>0.520</th>
<th>0.659</th>
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<td>0.504</td>
</tr>
<tr>
<td>2.50</td>
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<td>0.775</td>
<td>0.705</td>
<td>0.656</td>
<td>0.587</td>
<td>0.422</td>
<td>0.298</td>
<td>0.188</td>
<td>0.124</td>
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</tbody>
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(b) Lower flap

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.308</th>
<th>-0.170</th>
<th>-0.032</th>
<th>0.037</th>
<th>0.079</th>
<th>0.120</th>
<th>0.162</th>
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<td>0.707</td>
<td>0.622</td>
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<tr>
<td>3.00</td>
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<td>0.556</td>
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<td>0.554</td>
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<td>0.457</td>
</tr>
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<td>0.699</td>
<td>0.616</td>
<td>0.553</td>
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Table 161. Static Pressure Ratios for Nozzle 106, $x_r/l_r = 0.42$, $\theta = 30^\circ$, $\phi = 0^\circ$,
Maximum Sidewall, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = -30^\circ$

(a) Upper ramp

<table>
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<th>NPR</th>
<th>Static pressure ratios at $x_r/l_r$ of--</th>
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</thead>
<tbody>
<tr>
<td></td>
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(b) Lower flap

<table>
<thead>
<tr>
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Table 162. Static Pressure Ratios for Nozzle 107, $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 0^\circ$, Medium Sidewall, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = -30^\circ$

(a) Upper ramp

<table>
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<th>NPR</th>
<th>-0.170</th>
<th>-0.032</th>
<th>0.106</th>
<th>0.175</th>
<th>0.244</th>
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<th>0.520</th>
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</tr>
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<td>0.772</td>
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<td>0.773</td>
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<td>0.182</td>
<td>0.277</td>
</tr>
<tr>
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<td>0.753</td>
<td>0.811</td>
<td>0.773</td>
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<td>0.506</td>
<td>0.375</td>
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</table>

(b) Lower flap

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.308</th>
<th>-0.170</th>
<th>-0.032</th>
<th>0.037</th>
<th>0.079</th>
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<th>0.162</th>
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<td>0.741</td>
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<td>0.590</td>
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</tr>
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<td>2.50</td>
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<td>0.734</td>
<td>0.680</td>
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</tr>
<tr>
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<td>0.874</td>
<td>0.731</td>
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<td>0.621</td>
<td>0.576</td>
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<td>0.874</td>
<td>0.730</td>
<td>0.676</td>
<td>0.620</td>
<td>0.576</td>
<td>0.509</td>
</tr>
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<td>0.873</td>
<td>0.729</td>
<td>0.677</td>
<td>0.620</td>
<td>0.575</td>
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</tr>
<tr>
<td>5.01</td>
<td>0.916</td>
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<td>0.507</td>
</tr>
<tr>
<td>6.00</td>
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Table 163. Static Pressure Ratios for Nozzle 108, $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 0^\circ$, Maximum Sidewall, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = -30^\circ$

(a) Upper ramp

<table>
<thead>
<tr>
<th>NPR</th>
<th>$-0.170$</th>
<th>$-0.032$</th>
<th>$0.106$</th>
<th>$0.175$</th>
<th>$0.244$</th>
<th>$0.382$</th>
<th>$0.520$</th>
<th>$0.659$</th>
<th>$0.797$</th>
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<td>0.727</td>
<td>0.666</td>
<td>0.590</td>
<td>0.564</td>
<td>0.511</td>
<td>0.545</td>
</tr>
<tr>
<td>2.50</td>
<td>0.758</td>
<td>0.814</td>
<td>0.773</td>
<td>0.718</td>
<td>0.649</td>
<td>0.519</td>
<td>0.481</td>
<td>0.443</td>
<td>0.423</td>
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<td>3.00</td>
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<td>0.772</td>
<td>0.716</td>
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<td>0.505</td>
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<td>0.300</td>
<td>0.378</td>
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<td>0.772</td>
<td>0.715</td>
<td>0.644</td>
<td>0.504</td>
<td>0.378</td>
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<td>0.374</td>
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<td>0.278</td>
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(b) Lower flap

<table>
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<th>NPR</th>
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<th>$-0.170$</th>
<th>$-0.032$</th>
<th>$0.037$</th>
<th>$0.079$</th>
<th>$0.120$</th>
<th>$0.162$</th>
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<td>0.510</td>
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<tr>
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<td>0.873</td>
<td>0.730</td>
<td>0.674</td>
<td>0.620</td>
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<td>0.509</td>
</tr>
<tr>
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<td>0.730</td>
<td>0.674</td>
<td>0.620</td>
<td>0.575</td>
<td>0.509</td>
</tr>
<tr>
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<tr>
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<td>0.728</td>
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</tr>
<tr>
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<td>0.619</td>
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<td>0.727</td>
<td>0.670</td>
<td>0.618</td>
<td>0.574</td>
<td>0.506</td>
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Table 164. Static Pressure Ratios for Nozzle 109, $x_r/l_r = 0.02$, $\theta = 30^\circ$, $\phi = 0^\circ$, Minimum Sidewall, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = -30^\circ$

(a) Upper ramp

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.170</th>
<th>-0.032</th>
<th>0.106</th>
<th>0.175</th>
<th>0.244</th>
<th>0.382</th>
<th>0.520</th>
<th>0.659</th>
<th>0.797</th>
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<tbody>
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<td>0.531</td>
<td>0.524</td>
<td>0.504</td>
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<tr>
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<td>0.752</td>
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<td>0.751</td>
<td>0.699</td>
<td>0.629</td>
<td>0.449</td>
<td>0.302</td>
<td>0.185</td>
<td>0.118</td>
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<td>0.815</td>
<td>0.750</td>
<td>0.697</td>
<td>0.630</td>
<td>0.448</td>
<td>0.302</td>
<td>0.185</td>
<td>0.118</td>
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</table>

(b) Lower flap

<table>
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<th>-0.032</th>
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<th>0.079</th>
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<th>0.162</th>
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<td>0.677</td>
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<td>0.676</td>
<td>0.621</td>
<td>0.560</td>
<td>0.512</td>
</tr>
<tr>
<td>4.00</td>
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<td>0.883</td>
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<td>0.676</td>
<td>0.620</td>
<td>0.560</td>
<td>0.511</td>
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<td>0.620</td>
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<td>0.509</td>
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<td>0.753</td>
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Table 165. Static Pressure Ratios for Nozzle 110, $x_r/l_r = 0.02$, $\theta = 30^\circ$, $\phi = 0^\circ$, Medium Sidewall, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = -30^\circ$

(a) Upper ramp

<table>
<thead>
<tr>
<th>NPR</th>
<th>$-0.170$</th>
<th>$-0.032$</th>
<th>$0.106$</th>
<th>$0.175$</th>
<th>$0.244$</th>
<th>$0.382$</th>
<th>$0.520$</th>
<th>$0.659$</th>
<th>$0.797$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.00</td>
<td>0.781</td>
<td>0.832</td>
<td>0.775</td>
<td>0.732</td>
<td>0.671</td>
<td>0.567</td>
<td>0.537</td>
<td>0.524</td>
<td>0.507</td>
</tr>
<tr>
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<td>0.776</td>
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<td>0.484</td>
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</table>

(b) Lower flap

<table>
<thead>
<tr>
<th>NPR</th>
<th>$-0.308$</th>
<th>$-0.170$</th>
<th>$-0.032$</th>
<th>$0.037$</th>
<th>$0.079$</th>
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<th>$0.162$</th>
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<td>2.00</td>
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<td>0.891</td>
<td>0.773</td>
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Table 166. Static Pressure Ratios for Nozzle 111, $x_r/l_r = 0.02$, $\theta = 30^\circ$, $\phi = 0^\circ$.
Maximum Sidewall, $\delta_{\nu,p} = 20^\circ$, and $\delta_{\nu,y} = -30^\circ$

(a) Upper ramp

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.170</th>
<th>-0.032</th>
<th>0.106</th>
<th>0.175</th>
<th>0.244</th>
<th>0.382</th>
<th>0.520</th>
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<th>0.797</th>
</tr>
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<tbody>
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<td>2.00</td>
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<td>0.732</td>
<td>0.672</td>
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<td>0.509</td>
</tr>
<tr>
<td>2.50</td>
<td>0.775</td>
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</tr>
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(b) Lower flap

<table>
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<tr>
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Table 167. Static Pressure Ratios for Nozzle 122, $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 15^\circ$,
Medium Sidewall, $\delta_{y,p} = 0^\circ$, and $\delta_{y,y} = -15^\circ$

(a) Upper ramp

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.308</th>
<th>-0.170</th>
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</table>

(b) Lower flap

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.308</th>
<th>-0.170</th>
<th>-0.032</th>
<th>0.037</th>
<th>0.079</th>
<th>0.120</th>
<th>0.162</th>
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<tbody>
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<td>0.894</td>
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<td>0.479</td>
<td>0.395</td>
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<td>0.395</td>
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Table 168. Static Pressure Ratios for Nozzle 123, $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 15^\circ$, Maximum Sidewall, $\delta_v,p = 0^\circ$, and $\delta_v,y = -15^\circ$

(a) Upper ramp

<table>
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<tr>
<th>NPR</th>
<th>-0.308</th>
<th>-0.170</th>
<th>-0.101</th>
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<th>0.520</th>
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</table>

(b) Lower flap

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.308</th>
<th>-0.170</th>
<th>-0.032</th>
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Table 169. Static Pressure Ratios for Nozzle 124, $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 15^\circ$, Medium Sidewall, $\delta_{v,p} = 0^\circ$, and $\delta_{v,y} = -30^\circ$

(a) Upper ramp

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(b) Lower flap

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<th>-0.170</th>
<th>-0.032</th>
<th>0.037</th>
<th>0.079</th>
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<tr>
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<td>0.895</td>
<td>0.833</td>
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<td>0.398</td>
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Table 170. Static Pressure Ratios for Nozzle 125, $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 15^\circ$, Maximum Sidewall, $\delta_{v,p} = 0^\circ$, and $\delta_{v,y} = -30^\circ$

(a) Upper ramp

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(b) Lower flap

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<th>-0.032</th>
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<th>0.079</th>
<th>0.120</th>
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181
Table 171. Static Pressure Ratios for Nozzle 126, \( x_r/l_r = 0.20 \), \( \theta = 30^\circ \), \( \phi = 30^\circ \),
Medium Sidewall, \( \delta_{v,p} = 0^\circ \), and \( \delta_{v,y} = -15^\circ \)

(a) Upper ramp

<table>
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<tr>
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<th>-0.308</th>
<th>-0.170</th>
<th>-0.101</th>
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<th>0.244</th>
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<th>0.520</th>
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<td>0.557</td>
<td>0.550</td>
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<td>0.272</td>
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<td>0.166</td>
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<td>6.00</td>
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(b) Lower flap

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.308</th>
<th>-0.170</th>
<th>-0.032</th>
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<th>0.079</th>
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Table 172. Static Pressure Ratios for Nozzle 127, \( x_r/I_r = 0.20 \), \( \theta = 30^\circ \), \( \phi = 30^\circ \), Maximum Sidewall, \( \delta_{v,p} = 0^\circ \), and \( \delta_{v,y} = -15^\circ \)

(a) Upper ramp

<table>
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(b) Lower flap

<table>
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<tr>
<th>NPR</th>
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<th>-0.170</th>
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<th>0.079</th>
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<td>0.832</td>
<td>0.622</td>
<td>0.486</td>
<td>0.395</td>
<td>0.315</td>
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<td>0.392</td>
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Table 173. Static Pressure Ratios for Nozzle 128, $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 30^\circ$, Medium Sidewall, $\delta_{v,p} = 0^\circ$, and $\delta_{v,y} = -30^\circ$

(a) Upper ramp

<table>
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<th>NPR</th>
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<th>-0.170</th>
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(b) Lower flap

<table>
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<tr>
<th>NPR</th>
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<th>-0.170</th>
<th>-0.032</th>
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<td>0.616</td>
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<td>0.404</td>
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<td>0.251</td>
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Table 174. Static Pressure Ratios for Nozzle 129, $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 30^\circ$,
Maximum Sidewall, $\delta_{w,p} = 0^\circ$, and $\delta_{w,y} = -30^\circ$

(a) Upper ramp

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</table>

(b) Lower flap

<table>
<thead>
<tr>
<th>NPR</th>
<th>$-0.308$</th>
<th>$-0.170$</th>
<th>$-0.032$</th>
<th>$0.037$</th>
<th>$0.079$</th>
<th>$0.120$</th>
<th>$0.162$</th>
</tr>
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<td>0.619</td>
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<td>0.405</td>
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<tr>
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<td>0.618</td>
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Table 175. Static Pressure Ratios for Nozzle 130, $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 15^\circ$, Medium Sidewall, $\delta_{v,p} = -20^\circ$, and $\delta_{v,y} = -15^\circ$

(a) Upper ramp

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(b) Lower flap

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.308</th>
<th>-0.170</th>
<th>-0.032</th>
<th>0.037</th>
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Table 176. Static Pressure Ratios for Nozzle 131, $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 15^\circ$, Maximum Sidewall, $\delta_v,u = -20^\circ$, and $\delta_v,y = -15^\circ$

(a) Upper ramp

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<tr>
<th>NPR</th>
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<th>-0.170</th>
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(b) Lower flap

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Table 177. Static Pressure Ratios for Nozzle 132, \( x_r/l_r = 0.20 \), \( \theta = 30^\circ \), \( \phi = 15^\circ \), Medium Sidewall, \( \delta_{v,p} = -20^\circ \), and \( \delta_{v,y} = -30^\circ \)

(a) Upper ramp

<table>
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<th>NPR</th>
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(b) Lower flap

<table>
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<tr>
<th>NPR</th>
<th>-0.308</th>
<th>-0.170</th>
<th>-0.032</th>
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<th>0.079</th>
<th>0.120</th>
<th>0.162</th>
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<td>0.892</td>
<td>0.832</td>
<td>0.612</td>
<td>0.474</td>
<td>0.389</td>
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<td>0.479</td>
</tr>
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<td>0.389</td>
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Table 178. Static Pressure Ratios for Nozzle 133, $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 15^\circ$, Maximum Sidewall, $\delta_{v,p} = -20^\circ$, and $\delta_{v,y} = -30^\circ$

(a) Upper ramp

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<tr>
<th>NPR</th>
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(b) Lower flap

<table>
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<tr>
<th>NPR</th>
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<th>$-0.170$</th>
<th>$-0.032$</th>
<th>$0.037$</th>
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Table 179. Static Pressure Ratios for Nozzle 130, $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 30^\circ$, Medium Sidewall, $\delta_{v,p} = -20^\circ$, and $\delta_{v,y} = -15^\circ$

(a) Upper ramp

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<tr>
<th>NPR</th>
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<th>$-0.170$</th>
<th>$-0.101$</th>
<th>$-0.032$</th>
<th>0.037</th>
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(b) Lower flap

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<th>0.120</th>
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<td>0.237</td>
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Table 180. Static Pressure Ratios for Nozzle 135, \( x_r/l_r = 0.20 \), \( \theta = 30^\circ \), \( \phi = 30^\circ \),

Maximum Sidewall, \( \delta_{v,p} = -20^\circ \), and \( \delta_{v,y} = -15^\circ \)

(a) Upper ramp

<table>
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<tr>
<th>NPR</th>
<th>(-0.308)</th>
<th>(-0.170)</th>
<th>(-0.101)</th>
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(b) Lower flap

<table>
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<tr>
<th>NPR</th>
<th>(-0.308)</th>
<th>(-0.170)</th>
<th>(-0.032)</th>
<th>0.037</th>
<th>0.079</th>
<th>0.120</th>
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<tbody>
<tr>
<td>2.00</td>
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<td>0.618</td>
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<td>0.386</td>
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Table 181. Static Pressure Ratios for Nozzle 136, $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 30^\circ$, Medium Sidewall, $\delta_{v,p} = -20^\circ$, and $\delta_{v,y} = -30^\circ$

(a) Upper ramp

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</table>

(b) Lower flap

<table>
<thead>
<tr>
<th>NPR</th>
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<th>-0.170</th>
<th>-0.032</th>
<th>0.037</th>
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<td>0.395</td>
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</tr>
<tr>
<td>5.00</td>
<td>0.894</td>
<td>0.831</td>
<td>0.611</td>
<td>0.465</td>
<td>0.395</td>
<td>0.297</td>
<td>0.232</td>
</tr>
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<td>0.831</td>
<td>0.611</td>
<td>0.464</td>
<td>0.395</td>
<td>0.296</td>
<td>0.231</td>
</tr>
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<td>0.894</td>
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</tr>
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<td>0.830</td>
<td>0.612</td>
<td>0.464</td>
<td>0.395</td>
<td>0.296</td>
<td>0.231</td>
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Table 182. Static Pressure Ratios for Nozzle 137, \( x_r/l_r = 0.20 \), \( \theta = 30^\circ \), \( \phi = 30^\circ \), Maximum Sidewall, \( \delta_{w,p} = -20^\circ \), and \( \delta_{v,y} = -30^\circ \)

(a) Upper ramp

<table>
<thead>
<tr>
<th>NPR</th>
<th>(-0.308)</th>
<th>(-0.170)</th>
<th>(-0.101)</th>
<th>(-0.032)</th>
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<th>(0.175)</th>
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<th>(0.382)</th>
<th>(0.520)</th>
<th>(0.659)</th>
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<td>0.478</td>
</tr>
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<td>0.574</td>
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<td>0.314</td>
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<td>0.461</td>
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<td>0.572</td>
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(b) Lower flap

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<tr>
<th>NPR</th>
<th>(-0.308)</th>
<th>(-0.170)</th>
<th>(-0.032)</th>
<th>(0.037)</th>
<th>(0.079)</th>
<th>(0.120)</th>
<th>(0.162)</th>
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<td>0.831</td>
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<td>0.469</td>
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<tr>
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<td>0.614</td>
<td>0.468</td>
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Table 183. Static Pressure Ratios for Nozzle 138, $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 15^\circ$, Medium Sidewall, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = -15^\circ$

(a) Upper ramp

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.170</th>
<th>-0.032</th>
<th>0.106</th>
<th>0.175</th>
<th>0.244</th>
<th>0.382</th>
<th>0.520</th>
<th>0.659</th>
<th>0.797</th>
</tr>
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<td>0.758</td>
<td>0.703</td>
<td>0.643</td>
<td>0.554</td>
<td>0.540</td>
<td>0.540</td>
<td>0.513</td>
</tr>
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<td>0.804</td>
<td>0.754</td>
<td>0.697</td>
<td>0.631</td>
<td>0.478</td>
<td>0.433</td>
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<td>0.445</td>
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<td>0.476</td>
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<td>0.335</td>
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<td>0.477</td>
<td>0.331</td>
<td>0.224</td>
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(b) Lower flap

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.308</th>
<th>-0.170</th>
<th>-0.032</th>
<th>0.037</th>
<th>0.079</th>
<th>0.120</th>
<th>0.162</th>
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<tbody>
<tr>
<td>2.00</td>
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<td>0.873</td>
<td>0.744</td>
<td>0.652</td>
<td>0.602</td>
<td>0.554</td>
<td>0.502</td>
</tr>
<tr>
<td>2.50</td>
<td>0.911</td>
<td>0.872</td>
<td>0.741</td>
<td>0.653</td>
<td>0.595</td>
<td>0.546</td>
<td>0.493</td>
</tr>
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<td>0.871</td>
<td>0.740</td>
<td>0.651</td>
<td>0.593</td>
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</tr>
<tr>
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<td>0.739</td>
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<td>0.593</td>
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<tr>
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<td>0.652</td>
<td>0.591</td>
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Table 184. Static Pressure Ratios for Nozzle 139, \(x_{r/l_r} = 0.20\), \(\theta = 30^\circ\), \(\phi = 15^\circ\),
Maximum Sidewall, \(\delta_{v,p} = 20^\circ\), and \(\delta_{v,y} = -15^\circ\)

(a) Upper ramp

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.170</th>
<th>-0.032</th>
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<th>0.175</th>
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<td>0.477</td>
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(b) Lower flap

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.308</th>
<th>-0.170</th>
<th>-0.032</th>
<th>0.037</th>
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Table 185. Static Pressure Ratios for Nozzle 140, \( x_r/l_r = 0.20 \), \( \theta = 30^\circ \), \( \phi = 15^\circ \), Medium Sidewall, \( \delta_{v,p} = 20^\circ \), and \( \delta_{v,y} = -30^\circ \)

(a) Upper ramp

<table>
<thead>
<tr>
<th>NPR</th>
<th>(-0.170)</th>
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</tr>
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<td>0.385</td>
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(b) Lower flap

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<th>(-0.170)</th>
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<th>0.079</th>
<th>0.120</th>
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<td>0.516</td>
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Table 186. Static Pressure Ratios for Nozzle 141, \( x_r/l_r = 0.20 \), \( \theta = 30^\circ \), \( \phi = 15^\circ \),
Maximum Sidewall, \( \delta_{v.p} = 20^\circ \), and \( \delta_{v.y} = -30^\circ \)

(a) Upper ramp

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.170</th>
<th>-0.032</th>
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<th>0.175</th>
<th>0.244</th>
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<th>0.520</th>
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(b) Lower flap

<table>
<thead>
<tr>
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<th>-0.308</th>
<th>-0.170</th>
<th>-0.032</th>
<th>0.037</th>
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<td>0.584</td>
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<td>0.632</td>
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Table 187. Static Pressure Ratios for Nozzle 142, $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 30^\circ$, Medium Sidewall, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = -15^\circ$

(a) Upper ramp

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(b) Lower flap

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<td>0.911</td>
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<tr>
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Table 188. Static Pressure Ratios for Nozzle 143, $x_{r}/l_{r} = 0.20$, $\theta = 30^\circ$, $\phi = 30^\circ$, Maximum Sidewall, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = -15^\circ$

(a) Upper ramp

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(b) Lower flap

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<tr>
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</tr>
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<td>0.870</td>
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Table 189. Static Pressure Ratios for Nozzle 144, $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 30^\circ$, Medium Sidewall, $\delta_{x,p} = 20^\circ$, and $\delta_{v,y} = -30^\circ$

(a) Upper ramp

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<th>$0.106$</th>
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<th>$0.244$</th>
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<td>0.256</td>
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(b) Lower flap

<table>
<thead>
<tr>
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<th>$-0.170$</th>
<th>$-0.032$</th>
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<th>$0.162$</th>
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<td>0.884</td>
<td>0.765</td>
<td>0.699</td>
<td>0.646</td>
<td>0.581</td>
<td>0.541</td>
</tr>
<tr>
<td>4.00</td>
<td>0.921</td>
<td>0.884</td>
<td>0.764</td>
<td>0.699</td>
<td>0.646</td>
<td>0.581</td>
<td>0.540</td>
</tr>
<tr>
<td>5.00</td>
<td>0.922</td>
<td>0.883</td>
<td>0.762</td>
<td>0.698</td>
<td>0.645</td>
<td>0.578</td>
<td>0.539</td>
</tr>
<tr>
<td>6.00</td>
<td>0.922</td>
<td>0.883</td>
<td>0.761</td>
<td>0.698</td>
<td>0.645</td>
<td>0.577</td>
<td>0.538</td>
</tr>
<tr>
<td>7.00</td>
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<td>0.882</td>
<td>0.761</td>
<td>0.698</td>
<td>0.645</td>
<td>0.576</td>
<td>0.537</td>
</tr>
<tr>
<td>7.99</td>
<td>0.922</td>
<td>0.881</td>
<td>0.761</td>
<td>0.697</td>
<td>0.645</td>
<td>0.576</td>
<td>0.537</td>
</tr>
</tbody>
</table>
Table 190. Static Pressure Ratios for Nozzle 145, $x_r/l_r = 0.20$, $\theta = 30^\circ$, $\phi = 30^\circ$, Maximum Sidewall, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = -30^\circ$

(a) Upper ramp

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.170</th>
<th>-0.032</th>
<th>0.106</th>
<th>0.175</th>
<th>0.244</th>
<th>0.382</th>
<th>0.520</th>
<th>0.659</th>
<th>0.797</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.00</td>
<td>0.787</td>
<td>0.830</td>
<td>0.785</td>
<td>0.739</td>
<td>0.681</td>
<td>0.592</td>
<td>0.556</td>
<td>0.541</td>
<td>0.516</td>
</tr>
<tr>
<td>2.50</td>
<td>0.783</td>
<td>0.826</td>
<td>0.778</td>
<td>0.730</td>
<td>0.663</td>
<td>0.527</td>
<td>0.465</td>
<td>0.403</td>
<td>0.458</td>
</tr>
<tr>
<td>3.00</td>
<td>0.782</td>
<td>0.826</td>
<td>0.778</td>
<td>0.729</td>
<td>0.661</td>
<td>0.512</td>
<td>0.423</td>
<td>0.347</td>
<td>0.303</td>
</tr>
<tr>
<td>3.50</td>
<td>0.782</td>
<td>0.825</td>
<td>0.779</td>
<td>0.728</td>
<td>0.661</td>
<td>0.510</td>
<td>0.387</td>
<td>0.323</td>
<td>0.245</td>
</tr>
<tr>
<td>4.00</td>
<td>0.781</td>
<td>0.825</td>
<td>0.779</td>
<td>0.728</td>
<td>0.660</td>
<td>0.509</td>
<td>0.380</td>
<td>0.299</td>
<td>0.216</td>
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<tr>
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<td>0.781</td>
<td>0.825</td>
<td>0.779</td>
<td>0.728</td>
<td>0.661</td>
<td>0.509</td>
<td>0.376</td>
<td>0.278</td>
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<tr>
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<td>0.780</td>
<td>0.825</td>
<td>0.779</td>
<td>0.728</td>
<td>0.661</td>
<td>0.510</td>
<td>0.375</td>
<td>0.277</td>
<td>0.186</td>
</tr>
<tr>
<td>7.00</td>
<td>0.780</td>
<td>0.825</td>
<td>0.779</td>
<td>0.728</td>
<td>0.661</td>
<td>0.510</td>
<td>0.375</td>
<td>0.277</td>
<td>0.185</td>
</tr>
<tr>
<td>7.85</td>
<td>0.779</td>
<td>0.825</td>
<td>0.780</td>
<td>0.727</td>
<td>0.662</td>
<td>0.511</td>
<td>0.375</td>
<td>0.277</td>
<td>0.185</td>
</tr>
</tbody>
</table>

(b) Lower flap

<table>
<thead>
<tr>
<th>NPR</th>
<th>-0.308</th>
<th>-0.170</th>
<th>-0.032</th>
<th>0.037</th>
<th>0.079</th>
<th>0.120</th>
<th>0.162</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.00</td>
<td>0.922</td>
<td>0.886</td>
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<td>0.707</td>
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<td>0.597</td>
<td>0.557</td>
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<tr>
<td>2.50</td>
<td>0.920</td>
<td>0.884</td>
<td>0.767</td>
<td>0.701</td>
<td>0.648</td>
<td>0.586</td>
<td>0.545</td>
</tr>
<tr>
<td>3.00</td>
<td>0.920</td>
<td>0.884</td>
<td>0.765</td>
<td>0.699</td>
<td>0.646</td>
<td>0.583</td>
<td>0.542</td>
</tr>
<tr>
<td>3.50</td>
<td>0.921</td>
<td>0.883</td>
<td>0.764</td>
<td>0.699</td>
<td>0.646</td>
<td>0.581</td>
<td>0.541</td>
</tr>
<tr>
<td>4.00</td>
<td>0.921</td>
<td>0.883</td>
<td>0.764</td>
<td>0.698</td>
<td>0.645</td>
<td>0.580</td>
<td>0.540</td>
</tr>
<tr>
<td>5.01</td>
<td>0.921</td>
<td>0.883</td>
<td>0.763</td>
<td>0.698</td>
<td>0.645</td>
<td>0.579</td>
<td>0.539</td>
</tr>
<tr>
<td>6.00</td>
<td>0.921</td>
<td>0.882</td>
<td>0.762</td>
<td>0.698</td>
<td>0.645</td>
<td>0.578</td>
<td>0.538</td>
</tr>
<tr>
<td>7.00</td>
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<tr>
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<td>0.881</td>
<td>0.761</td>
<td>0.697</td>
<td>0.644</td>
<td>0.576</td>
<td>0.537</td>
</tr>
</tbody>
</table>
(a) Baseline unvectored nozzle.

Figure 1. Sketches defining nozzle geometric parameters.
(b) Pitch-vectored nozzles.

Figure 1. Continued.
(c) Nozzle sidewalls.

Figure 1. Continued.
(d) Ramp cutoff angle and yaw hinge line locations.

Figure 1. Continued.
(e) Inclined yaw range line definition.

Figure 1. Continued.
\( \theta = 20^\circ, \delta v_y = -20^\circ \)

Maximum sidewall

Sta. 41.130 Throat plane

\( x_r / l_r = 0.42 \)

\( \theta = 30^\circ, \delta v_y = -30^\circ \)

Minimum sidewall

Sta. 41.130 Throat plane

\( x_r / l_r = 0.20 \)

Medium sidewall

\( x_r / l_r = 0.20 \)

\( \delta v_y \)

Maximum sidewall

\( x_r / l_r = 0.02 \)

(f) Typical yaw vector configurations. \( \phi = 0^\circ \).

Figure 1. Concluded.
Figure 2. Photograph of SERN. View is from the rear.
Figure 3. Sketch of single-engine propulsion simulation system with SERN installed.
Figure 4. SERN mounted on single-engine propulsion simulation system.
Figure 5. Effect of sidewall containment on nozzle performance. $x_{r}/l_{r} = 1.00; \theta = 0^\circ; \phi = 0^\circ; \delta_{r,p} = 0^\circ; \delta_{v,y} = 0^\circ$. 
Figure 6. Effect of pitch vectoring on nozzle internal performance. Max sidewall: $x_r/l_r = 1.00$; $\theta = 0^\circ$; $\phi = 0^\circ$; $\delta_{p,y} = 0^\circ$.
Figure 7. Effect of sidewall containment on nozzle internal performance at various geometric pitch vector angles. $x_r/l_r = 1.00; \theta = 0^\circ; \phi = 0^\circ; \delta_{v,y} = 0^\circ$. 
(a) $\delta_{v,p} = -20^\circ$. 

Sidewall

○ Max
□ Med
◆ Min
Figure 7, Concluded.

(b) $\delta_{r,p} = 20^\circ$.
Figure 8. Effect of pitch vectoring on internal pressures. Max sidewall; \( x_r/l_r = 1.00; \theta = 0^\circ; \phi = 0^\circ; \delta_{v,p} = 0^\circ; \) NPR = 3.0.
Figure 9. Effect of sidewall containment on nozzle internal pressures at various geometric pitch vector angles.
NPR = 3.0; \( x_r/l_r = 1.00; \theta = 0^\circ; \phi = 0^\circ; \delta_{v,p} = 0^\circ \).
Figure 10. Effect of flap cutout angle on nozzle internal performance at various geometric pitch vector angles. Max sidewall; $x_r/l_r = 0.20$; $\phi = 0^\circ$; $\delta_{v,y} = 0^\circ$. (a) $\delta_{v,p} = 0^\circ$. 
Figure 10. Continued.

(b) $\delta_{v,p} = -20^\circ$.
\( \theta, \deg \)

- • 0
- □ 20
- ◆ 30

\( F_r/F_i \)

\( \delta_y, \deg \)

\( F/F_i \)

\( \delta_p, \deg \)

(c) \( \delta_{v,p} = 20^\circ \).

Figure 10. Concluded.
Figure 11. Effect of yaw hinge line location on nozzle internal performance at various geometric pitch vector angles. Max sidewall; $\theta = 30^\circ$; $\phi = 0^\circ$; $\delta_{v,y} = 0^\circ$; NPR = 3.0.
$x_r/l_r$

- 1.00
- 0.42
- 0.20
- 0.02

![Graphs showing $F_r/F_i$ and $F/F_i$ versus NPR with different symbols for $x_r/l_r$.](image)

(b) $\delta_{v,p} = -20^\circ$.

Figure 11. Continued.
Figure 11. Concluded.

(c) $\delta_{v,p} = 20^\circ$. 

Figure 11. Concluded.
(a) Max sidewall.

Figure 12. Summary of effects of flap cutout angle on nozzle internal performance with various sidewall containments for $\phi = 0^\circ$, $\delta_{w,p} = 0^\circ$, and $\delta_{w,y} = 0^\circ$. 

NPR

- $3.0$
- $6.0$

Fr/Fi

Fr/Fi

Fr/Fi
Figure 12. Continued.

(b) Med sidewall.

Figure 12. Continued.
(c) Min sidewall.

Figure 12. Concluded.
Figure 13. Summary of effects of flap cutout angle on nozzle internal performance with various sidewall containments for $\phi = 0^\circ$, $\delta_{v,p} = -20^\circ$, and $\delta_{v,y} = 0^\circ$. (a) Max sidewall.
NPR

○ 3.0
□ 6.0

(b) Med sidewall.

Figure 13. Continued.
Figure 13. Concluded.

(c) Min sidewall.

NPR

- 3.0
- 6.0
Figure 14. Summary of effects of flap cutout angle on nozzle internal performance with various sidewall containments for $\phi = 0^\circ$, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = 0^\circ$. 

(a) Max sidewall.
Figure 14. Continued.
(c) Min sidewall.

Figure 14. Concluded.
Figure 15. Summary of effects of hinge line location on nozzle internal performance with various sidewall containments for $\phi = 0^\circ$, $\delta_{v,p} = 0^\circ$, and $\delta_{v,y} = 0^\circ$. 

(a) Max sidewall.
(b) Med sidewall.

Figure 15. Continued.
NPR

- ○ 3.0
- □ 6.0

\( F_r/F_i \) VS \( F_r/F_i \) for \( \theta = 20^\circ \) and \( \delta_p \) deg. for \( \theta = 20^\circ \)

\( F_r/F_i \) VS \( F_r/F_i \) for \( \theta = 30^\circ \) and \( \delta_p \) deg. for \( \theta = 30^\circ \)

(c) Min sidewall.

Figure 15. Concluded.
Figure 16. Summary of effects of hinge line location on nozzle internal performance with various sidewall containments for $\phi = 0^\circ$, $\delta_{v,p} = -20^\circ$, and $\delta_{v,y} = 0^\circ$. (a) Max sidewall.
(b) Med sidewall.

Figure 16. Continued.
Figure 16. Concluded.

(c) Min sideline.
Figure 17. Summary of effects of hinge line location on nozzle internal performance with various sidewall containments for $\phi = 0^\circ$, $\delta_{v,p} = 20^\circ$, and $\delta_{v,y} = 0^\circ$. 

(a) Max sidewall.
Figure 17. Continued.

(b) Med sidewall.
Figure 17. Concluded.
Figure 18. Effect of cutout angle on internal pressures at various geometric pitch vector angles. Max sidewall:
$x_r/l_r = 0.20; \phi = 0^\circ; \delta_{r,y} = 0^\circ; \text{NPR} = 3.0.$
(b) $\delta_{r,p} = -20^\circ$.

Figure 18. Continued.
(c) $\delta_{r,p} = 20^\circ$.

Figure 18. Concluded.
Figure 19. Effect of hinge line location on internal pressures at various geometric pitch vector angles. Max sidewall: $\theta = 30^\circ$; $\sigma = 0^\circ$; $\delta_{r,p} = 0^\circ$; NPR = 3.0.
\[ x_r/z_r \]
- \( \bigcirc \) 1.00
- \( \square \) .42
- \( \diamond \) .20
- \( \triangle \) .02

(b) \( \delta_c, p = -20^\circ \).

Figure 19. Continued.
(c) $\delta_{r,p} = 20^\circ$.

Figure 19. Concluded.
Figure 20. Effect of yaw vectoring on nozzle performance at various geometric pitch vector angles. Max sidewall; $x_r/l_r = 0.20; \theta = 30^\circ; \phi = 0^\circ$. 

(a) $\delta_{v,p} = 0^\circ$. 
Figure 20. Continued.

(b) $\delta_{v,p} = -20^\circ$.
(c) $\delta_{v,p} = 20^\circ$.

Figure 20. Concluded.
Figure 21. Summary of effects of yaw vectoring on nozzle performance with max sidewall, $x_r/l_r = 0.42$, $	heta = 30^\circ$, and $\phi = 0^\circ$. 
Figure 22. Summary of effects of yaw vectoring on nozzle performance with various sidewall containments,  
$x_r/l_r = 0.20, \theta = 30^\circ$, and $\phi = 0^\circ$. 

(a) Max sidewall.
NPR

- 3.0
- 6.0

![Graphs showing the relationship between various angles and forces with NPR values of 3.0 and 6.0 for different angles of attack.]  

(b) Mid sidewall.

Figure 22. Concluded.
Figure 23. Summary of effects of yaw vectoring on nozzle performance with various sidewall containments, $x_r/l_r = 0.02$, $\theta = 30^\circ$, and $\phi = 0^\circ$. 

(a) Max sidewall.
(b) Med sidewall.

Figure 23. Continued.
Figure 23. Continued.

(c) Min sidewall.
Figure 24. Summary of yaw vectoring effects on nozzle performance at various values of NPR. max sidewall.

$\theta = 30^\circ$, and $\phi = 0^\circ$. 

(a) NPR = 3.0.
Figure 24. Concluded.
Figure 25. Summary of yaw vectoring effects on nozzle performance at various values of NPR, $x_r/l_r = 0.20$, $\theta = 30^\circ$, and $\phi = 0^\circ$. 

(a) NPR = 3.0.
Figure 26. Summary of yaw vectoring effects on nozzle performance at various values of NPR, $x_r/l_r = 0.02$, $\theta = 30^\circ$, and $\phi = 0^\circ$. 

(a) NPR = 3.0.
 Sidewall

\[ \delta_{\nu, p} = -20^\circ \]

\[ \delta_{\nu, p} = 0^\circ \]

\[ \delta_{\nu, p} = 20^\circ \]

\[ \delta_{\nu, y'} \]

\[ \delta_{y'} \]

\[ \delta_y \]

\[ \delta_p \]

\[ F_r/F_i \]

(b) NPR = 6.0.

Figure 26. Concluded.
Figure 27. Effect of yaw vectoring on internal pressures at various geometric pitch vector angles. NPR = 3.0; max sidewall; $x_r/l_r = 0.20; \theta = 30^\circ; \phi = 0^\circ$. 

(a) $\delta_{v,p} = 0^\circ$. 

$\delta_{v,y'}$ deg

- $0$
- $-30$

$p_r/p_t, j$

$x_p/l_r$
Figure 27. Continued.

(b) $\delta_{v,p} = -20^\circ$. 
(c) $\delta_{v,p} = 20^\circ$.

Figure 27. Concluded.
Figure 28. Effect of single yaw vectoring on nozzle performance at various geometric pitch vector angles. Max sidewall: \( x_r/l_r = 0.20; \theta = 30^\circ; \phi = 0^\circ \).
(δ_v,y)_I, deg  (δ_v,y)_r, deg
○ -30  -30
□ -30  0
◇ 0  -30

(b) δ_v,p = 20°.

Figure 28. Concluded.
Figure 29. Effect of hinge line inclination on nozzle performance at various geometric pitch vector angles. Max sidewall; $x_r/l_r = 0.20$; $\theta = 30^\circ$; and $\delta_{v,y} = -30^\circ$. 

(a) $\delta_{v,p} = 0^\circ$. 
(b) $\delta_{r,p} = -20^\circ$.

Figure 29. Continued.
Figure 29. Concluded.

(c) \( \delta_{v,p} = 20^\circ \).
Static Internal Performance of a Single Expansion Ramp Nozzle With Multiaxis Thrust Vectoring Capability

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Hampton, VA 23681-0001

National Aeronautics and Space Administration
Washington, DC 20546-0001

An investigation has been conducted at static conditions in order to determine the internal performance characteristics of a multiaxis thrust vectoring single expansion ramp nozzle. Yaw vectoring was achieved by deflecting yaw flaps in the nozzle sidewall into the nozzle exhaust flow. In order to eliminate any physical interference between the variable angle yaw flap deflected into the exhaust flow and the nozzle upper ramp and lower flap which were deflected for pitch vectoring, the downstream corners of both the nozzle ramp and lower flap were cut off to allow for up to 30° of yaw vectoring. The effects of nozzle upper ramp and lower flap cutout, yaw flap hinge line location and hinge inclination angle, sidewall containment, geometric pitch vector angle, and geometric yaw vector angle were studied. This investigation was conducted in the static-test facility of the Langley 16-Foot Transonic Tunnel at nozzle pressure ratios up to 8.0.