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RESEARCH MEMORANDUM

PRELIMINARY INVESTIGATION OF A CONICAL SPIKE INLET IN COMBINATION WITH A VERTICAL-WEDGE AUXILIARY INLET AT MACH NUMBER 1.9

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NATIONAL ADVISORY COMMITTEE
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SUMMARY

An experimental investigation of a fixed-area spike-type-nose inlet in combination with a vertical-wedge auxiliary inlet was conducted in order to determine the combined-inlet performance. Data were obtained at a free-stream Mach number of 1.9 and zero angle of attack.

Air flow from the spike inlet and an additional 17 percent obtained from the scoop inlet were combined with a drop in critical pressure recovery from 0.86 to 0.81. The drop in pressure recovery was attributed to mismatching of the two inlets arising from a difference in their critical total-pressure recoveries. In terms of inlet-engine matching, however, the pressure recovery of the spike inlet operating at a specified corrected air flow increased with the scoop open, for example, from 0.69 to 0.81. The radial total-pressure profiles at the diffuser exit were changed from 6-percent distortion without scoop flow to about 17-percent distortion with scoop air flow.

INTRODUCTION

The use of variable auxiliary air intakes for improving off-design performance of inlet-engine combinations at subsonic and low supersonic speeds is established in references 1 and 2 for normal-shock-type inlets. Basically the system avoids supercritical main-inlet operation by admitting enough additional air through an auxiliary inlet to enable the engine to match at critical inlet-flow conditions. Similar performance gains may feasibly be obtained with a high-performance auxiliary scoop.

Twin-duct systems wherein two identical high-performance inlets feed a single duct are in common use. However, before auxiliary inlet systems can be considered for supersonic speeds, knowledge is needed of the effects of discharging into a common duct two air flows obtained from different-size or -geometry inlets having the same or different pressure-recovery capabilities.

The present investigation evaluated performance characteristics of a fixed-area 30°-spike-type-nose inlet in combination with a rectangular fixed-area vertical-wedge-type scoop at a free-stream Mach number of 1.9 and zero angle of attack. Pressure-recovery, mass-flow and flow-stability characteristics of the combined systems were obtained.

SYMBOLS

The following symbols are used in this report:

A	area
h	boundary-layer splitter-plate height above main body surface
h/δ	ratio of boundary-layer splitter-plate height to boundary-layer thickness
L	subsonic-diffuser length
m	mass flow
$\frac{m_a}{m_0}$	mass flow ratio, $\frac{\text{mass-flow auxiliary scoop}}{\rho_0 V_0 A_{c,a}}$
$\frac{m_3}{m_0}$	mass-flow ratio, $\frac{\text{total diffuser-exit mass flow}}{\rho_0 V_0 A_c}$
P	total pressure
$\frac{\Delta P}{P_3}$	radial total-pressure distortion in vertical plane at diffuser-discharge, $\frac{(P_{max.} - P_{min.})}{P_{av,3}}$
r	radius measured from centerline of main inlet
V	velocity
w	weight flow
$\frac{w\sqrt{\theta}}{\delta A}$	corrected rate of weight flow per unit diffuser discharge area
x	longitudinal section
δ	ratio of local total pressure to static pressure of NACA standard atmosphere at sea level; boundary-layer thickness

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ρ mass density of air

θ ratio of total temperature to static temperature of NACA standard atmosphere at sea level

Subscripts:

a auxiliary scoop

av average

c capture area of cowling

x longitudinal station

0 free stream

1 main inlet, station 4 in. from cowl lip

2 auxiliary-scoop discharge into main diffuser, station 12.5 in. from cowl lip

3 diffuser-exit discharge (engine face) at constant-diameter section, station 33.8 in. from cowl lip

Pertinent areas and dimensions:

A_c spike-inlet capture area defined by cowl lip, 11.83 sq in.

$A_{a,c}$ inlet capture area of auxiliary scoop defined by cowl lip and boundary-layer splitter-plate area, 2.17 sq in.

$A_{a,2}$ flow area of auxiliary-scoop subsonic-diffuser exit, 1.93 sq in.

A_3 flow area of main-diffuser discharge (engine face), 10.18 sq in.

L_1 spike-inlet subsonic-diffuser length, 17 in.

L_2 auxiliary-scoop subsonic-diffuser length, 5.7 in.

R radius at diffuser discharge, 1.8 in.

APPARATUS AND PROCEDURE

The model shown installed in the Lewis 18- by 18-inch Mach number 1.9 wind tunnel (fig. 1) consisted of a single-shock vertical-wedge scoop mounted on the outer cowl surface of a 30°-half-angle single-conical-shock-nose inlet (fig. 2). Projection of the 30°-half-angle nose cone was selected so that the conical shock would intersect the cowl lip at a Mach number of 2.5. The average slope of the cowl lip was nearly alined with the local flow behind the conical shock at a free-stream Mach number of 2.5, and the cowl lip included angle was maintained slightly below the maximum detachment angle for the local flow behind the cone shock at a free-stream Mach number of 1.9. Coordinates of the cowl and centerbody appear in table I. The rectangular auxiliary scoop was located approximately 1.3 inlet diameters downstream of the nose-inlet entrance.

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Pertinent dimensions and coordinates of the auxiliary scoop are presented in figure 3. The auxiliary inlet had a fixed 16°-half-angle vertical precompression wedge with the leading edge and cowl sweep angle positioned so that the oblique shock would intersect the cowl lip at a free-stream Mach number of 2.40. This design condition was selected because no appreciable air flow would be required by the main inlet until it was operating at a Mach number of about 2.4. The normal wedge diffuser unit was set on a horizontal sweptback boundary-layer splitter plate. Boundary-layer removal for the auxiliary inlet was accomplished by means of spacers inserted between the main body surface and the splitter plate, while the scoop height (vertical distance between splitter plate and cowl) remained unchanged. The fixed area of the inlet was sized to capture approximately 20 percent of the main-diffuser (spike-inlet) air flow at a free-stream Mach number of 1.9. In effect, this scoop position represents a single operating condition for a variable-height auxiliary scoop inlet and is hereinafter referred to as the scoop-open position. A closed position of the scoop was obtained by removal of the auxiliary scoop. An additional auxiliary-scoop geometry was obtained by removing the scoop wedge, thus creating a normal-shock auxiliary inlet.

The area variations of the auxiliary-scoop and main-inlet diffusers are shown in figure 4 and represent the ratio of the local diffuser flow area to the maximum flow area. For each inlet, the ratio of inlet area to diffuser area at station 12.5 was kept nearly the same in order to satisfy conditions of equal static pressure and equal estimated total pressures for critical flow at a Mach number of 1.9. Scoop air flow entered the main diffuser slightly upstream of the diffuser discharge, station 12.5, through an opening in the main diffuser and at an angle of approximately 17° with the model longitudinal axis. There was a constant-area section of approximately 4.7 diameters between stations 17 and 33.8 for combining, or mixing, the auxiliary and main streams.

Mass-flow, pressure-recovery and schlieren data were recorded. Regions of inlet instability were determined from pressure-time records of the static-pressure variation in the diffuser-discharge chamber.

Total- and static-pressure measurements were made at the main-duct inlet (station 4) and at the diffuser-discharge chamber (station 33.8). The inlet rakes remained installed during the entire investigation. Total pressures at the diffuser discharge (or engine face, station 33.8) were area-averaged values. Static-pressure orifices were also located on the aft portion of the centerbody and along the walls of the auxiliary subsonic diffuser. Mass flow was computed from the area-averaged total pressures and the static pressures obtained at the diffuser discharge. Total-mass-flow ratio and the auxiliary-scoop mass flows were based on the free-stream capture area of the main inlet (spike entrance) and the auxiliary scoop, respectively. The amount of main-inlet air flow during scoop-open operation was obtained from a calibration of inlet mass flow as a function of throat rake readings. Scoop air flow was then determined as the difference between the diffuser inlet and exit mass flows. Auxiliary-scoop total pressure was estimated from mass flow, measured static pressure, and flow area in the small diffuser.

RESULTS AND DISCUSSION

Performance Characteristics

The total-pressure recovery, mass flow and corrected air flow of the open and closed auxiliary-scoop configurations are presented in figure 5 for two conditions of boundary-layer removal ($h/\delta = 1.0$ and 0). Characteristics with a low-performance scoop (obtained by removing the scoop vertical wedge) are also included in this figure.

From figure 5(a) it can be seen that opening the auxiliary scoop increased the mass flow over that of the basic inlet (closed scoop). With the closed scoop, a maximum inlet mass-flow ratio of 0.785 was obtained. Opening the scoop (with boundary-layer removal) increased the total air flow from 0.785 to about 0.92. Boundary-layer removal appeared to have little effect on the air flow obtainable. With the low-performance scoop (wedge removed) the fixed-inlet air flow was increased from 0.785 to 0.865. This mass-flow increase was only about one-half of that obtained with the wedge scoop and was primarily due to the internal contraction introduced by removing the wedge.

Critical pressure recovery of the fixed inlet was reduced with the additional auxiliary-scoop air flow. In figure 5(a), the increase in inlet air flow from 0.785 to 0.92 was accompanied by a decrease in critical pressure recovery from 0.86 to 0.81. This pressure-recovery decrease may be explained partly by mismatching of the two inlet air flows. Mismatching refers to the case in which the discharge static pressures of the two ducts are unequal for their respective critical-flow conditions. Because the total-pressure recovery of the auxiliary scoop (83 percent) was lower than that of the main diffuser (86 percent), and in order to maintain a balance of the static pressures at the junction of the two flows, the main diffuser had to operate supercritically at a reduced total-pressure recovery. This effect is presumably the major contributing factor that caused the reduction in the critical pressure recovery from closed-scoop to open-scoop conditions. Other effects that also contributed to the decreased pressure recovery are the angle at which the two flows joined and flow mixing losses. In order to attain low total-pressure loss due to angular injection, low injection angles are needed, as may be demonstrated by the mixing equations of reference 3.

Although boundary-layer removal improved auxiliary-inlet performance (fig. 5(b)), there was no apparent effect on combined pressure-recovery performance near critical-flow conditions (fig. 5(a)). Combined pressure-recovery performance with the wedge-removed scoop was seriously penalized because of the very low critical pressure recovery of this scoop.

It appears from the preceding discussion that, if two geometrically different inlets are of reasonably comparable performance, efficient discharge and mixing of the two air flows into a common duct may be achieved. It is significant to note that, in terms of inlet-engine matching, the pressure recovery of an undersize fixed inlet operating at a specified corrected air flow (i.e., 42, fig. 5(a)) may be increased from a value of 0.69 to a value of 0.81 with the scoop.

Opening the scoop greatly decreased the air-flow stability of the system. As shown in figure 5(a), with the scoop closed, no instability was obtained for the range of air flows investigated. However, with the scoop open, as the mass flow of the combined inlets was reduced, stable operation was possible only down to a mass-flow ratio of 0.84. Further reductions in mass flow caused the small scoop to buzz, which, in turn, induced main-inlet terminal-shock oscillation. This stability limit was about 8 percent higher than the maximum mass flow of the basic inlet.

In terms of small-scoop mass flow, the stability limit occurred at about 40 percent of its maximum air flow (fig. 5(b)). Inasmuch as this value represents a reasonably satisfactory stability limit, larger improvements in the over-all stability limits of the combination would not be anticipated unless the auxiliary inlet were completely stabilized. It should be pointed out that the stability margin obtained with the wedge scoop may be satisfactory with respect to engine throttling, because actual installation of this type of scoop assumes a variable-height design and the height of the scoop would be set so that operation would be at critical-flow conditions. Thus, variations in engine air flow would be reflected in scoop-height positioning. No stable subcritical mass flows were obtained with the low-performance scoop.

Below a combined mass-flow ratio of 0.76 (fig. 5(b)) the auxiliary scoop maintained reverse flow. The point at which reverse flow occurs may be predicted from one-dimensional flow analysis by assuming equal static pressures and knowing the difference in total pressures at the juncture of the ducts.

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Discharge Profiles

Auxiliary-scoop air flow changed the flow pattern at the diffuser exit (station 33.8) considerably. Varying the inlet flow conditions from supercritical to subcritical flow improves the air-flow distortions in the diffuser for either open- or closed-scoop positions (fig. 6). For all inlet flow conditions, however, opening the scoop decreased the local total-pressure recovery in the top quadrant of the diffuser. Apparently the 4.7-diameter constant-area section had little mixing effect. At critical inlet flow, the total-pressure probe nearest the wall $\left(\frac{r}{R} = 0.95\right)$ showed that the radial pressure variation changed from about 6-percent distortion with the scoop closed to a value of about 17 percent with the scoop open.

In conclusion, the auxiliary scoop appears to be a feasible means of inlet-engine matching. It could be competitive with the bypass and translating spike if integration of the scoop with the inlet-duct system on an airplane can be accomplished without introducing impractical design or weight problems and if internal and external performance is not penalized because of scoop geometry. Analysis of the data presented herein indicates that the improvement of engine thrust by matching with an auxiliary inlet is similar to that obtained with the bypass and translating spike. Before a full evaluation of this scoop-type system as a variable-geometry inlet is possible, however, additional experimental investigation is needed for a more representative auxiliary-scoop-type inlet that incorporates actual airplane installation and operating requirements.

SUMMARY OF RESULTS

An experimental investigation of a fixed-geometry spike-type-nose inlet in combination with a wedge-type auxiliary-scoop air intake was conducted in the Lewis 18- by 18-inch supersonic wind tunnel at a Mach number of 1.9 for a range of mass-flow ratio at zero angle of attack. The following results were obtained:

1. Use of an auxiliary wedge-type inlet allowed a mass-flow increase for the spike inlet of 17 percent. However, because of inlet mismatching, critical pressure recovery decreased from 0.86 to 0.81.

2. In terms of inlet-engine matching, the pressure recovery of the undersized spike inlet operating at a specified corrected air flow increased with the scoop, for example, from 0.69 to 0.81.

3. The total-pressure distortions were changed considerably by introducing additional air flow by means of the auxiliary scoop. At critical inlet flow, the radial distortions changed from about 6 percent with no scoop flow to about 17 percent with the scoop.

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Lewis Flight Propulsion Laboratory
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Cleveland, Ohio, August 3, 1955

REFERENCES

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2. Anderson, Warren E., and Scherrer, Richard: Investigation of a Flow Deflector and an Auxiliary Scoop for Improving Off-Design Performance of Nose Inlets. NACA RM A54E06, 1954.

3. Shapiro, Ascher A., and Hawthorne, W. R.: The Mechanics and Thermodynamics of Steady One-Dimensional Gas Flow. Jour. Appl. Mech., vol. 14, no. 4, Dec. 1947, pp. A317-A336.

TABLE I. - COORDINATES OF CENTERBODY AND COWL

Centerbody		Cowl		
Distance from cowl lip, in.	Radius, in.	Distance from cowl lip, in.	Internal radius, in.	External radius, in.
[a]-2.09		0	1.94	2.03
[a]-.2		.2	2.00	2.11
[a]0	1.20	.5	2.07	2.21
.2	1.30	1.00	2.18	2.38
.5	1.42	1.5	2.26	2.44
1.0	1.58	2.0	2.32	2.53
1.5	1.69	2.5	2.36	2.58
2.0	1.77	3.0	2.39	2.60
2.5	1.83	3.5	2.40	2.60
3.0	1.87	4.0	2.42	2.60
3.5	1.89	4.25	2.42	2.60
4.0	1.91			
4.5	1.91			
5.0	1.90			
5.5	1.87			
6.0	1.84			
6.5	1.79			
[a]7.0	1.73			
[a]17.5	1.21			
[a]13.0	.86			
[a]14.5	.70			
15.0	.63			
15.5	.53			
16.0	.41			
16.5	.26			
17.0	0			

[a]Followed by region of straight taper.

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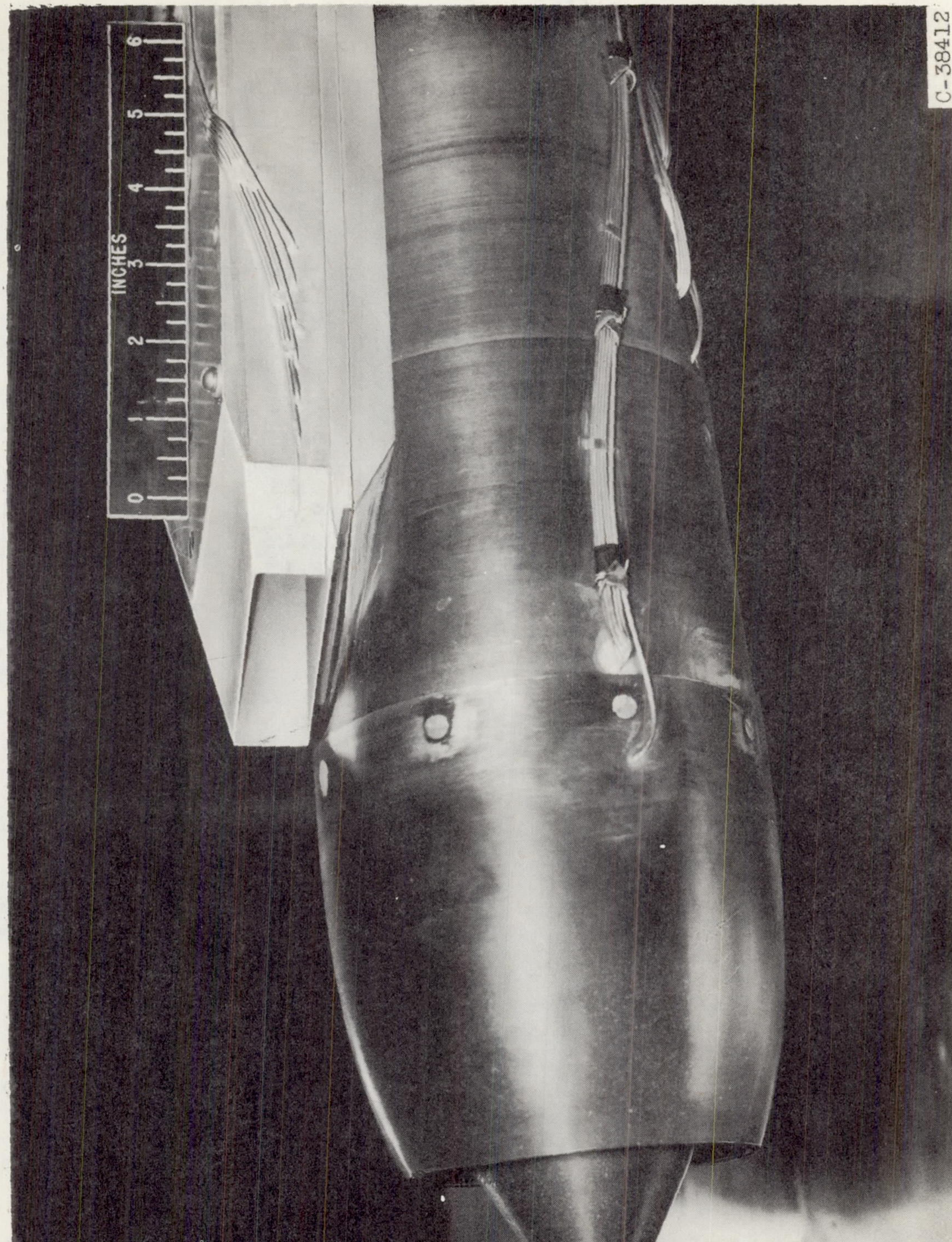


Figure 1. - Model installed in supersonic wind tunnel.

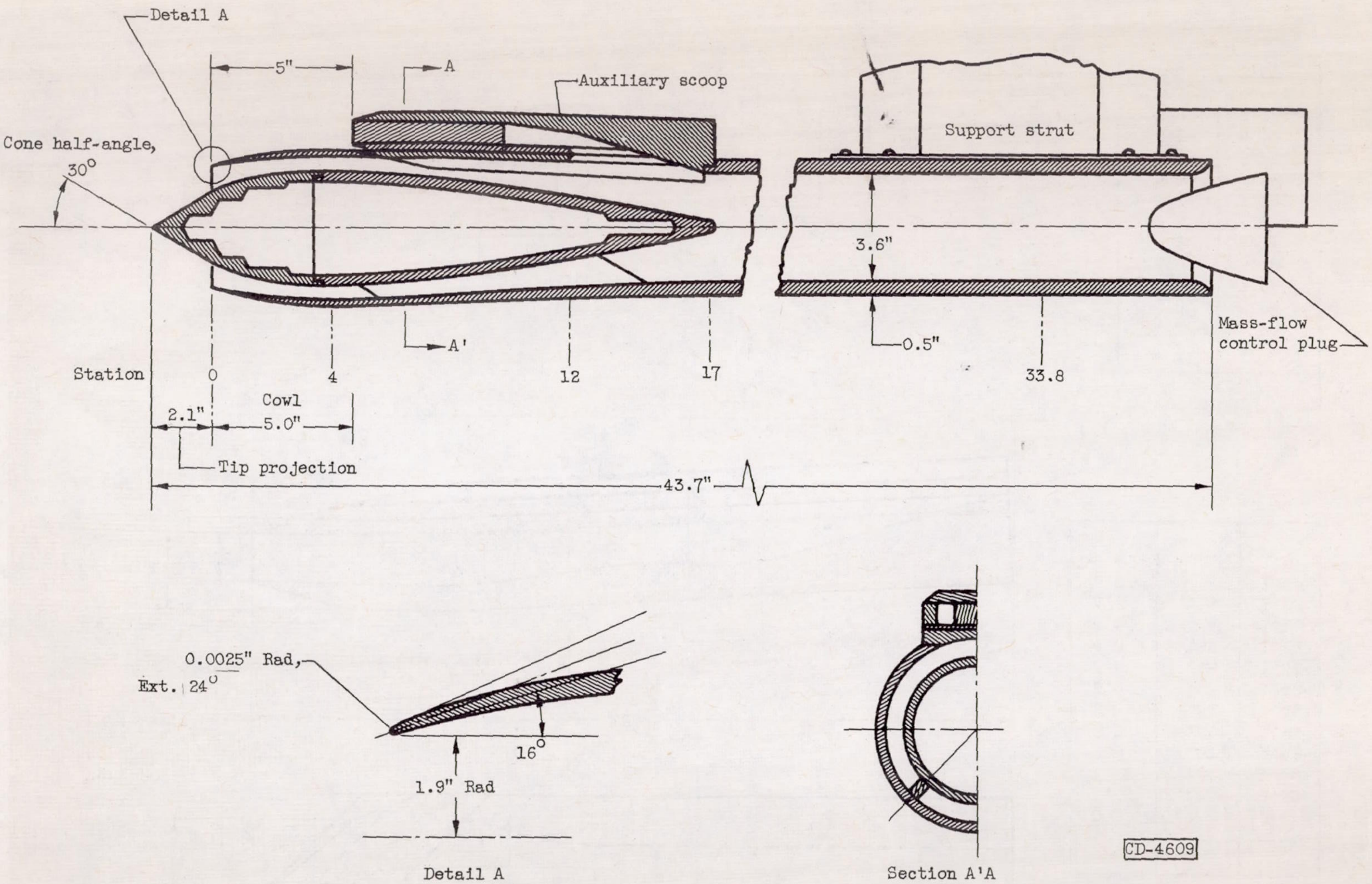
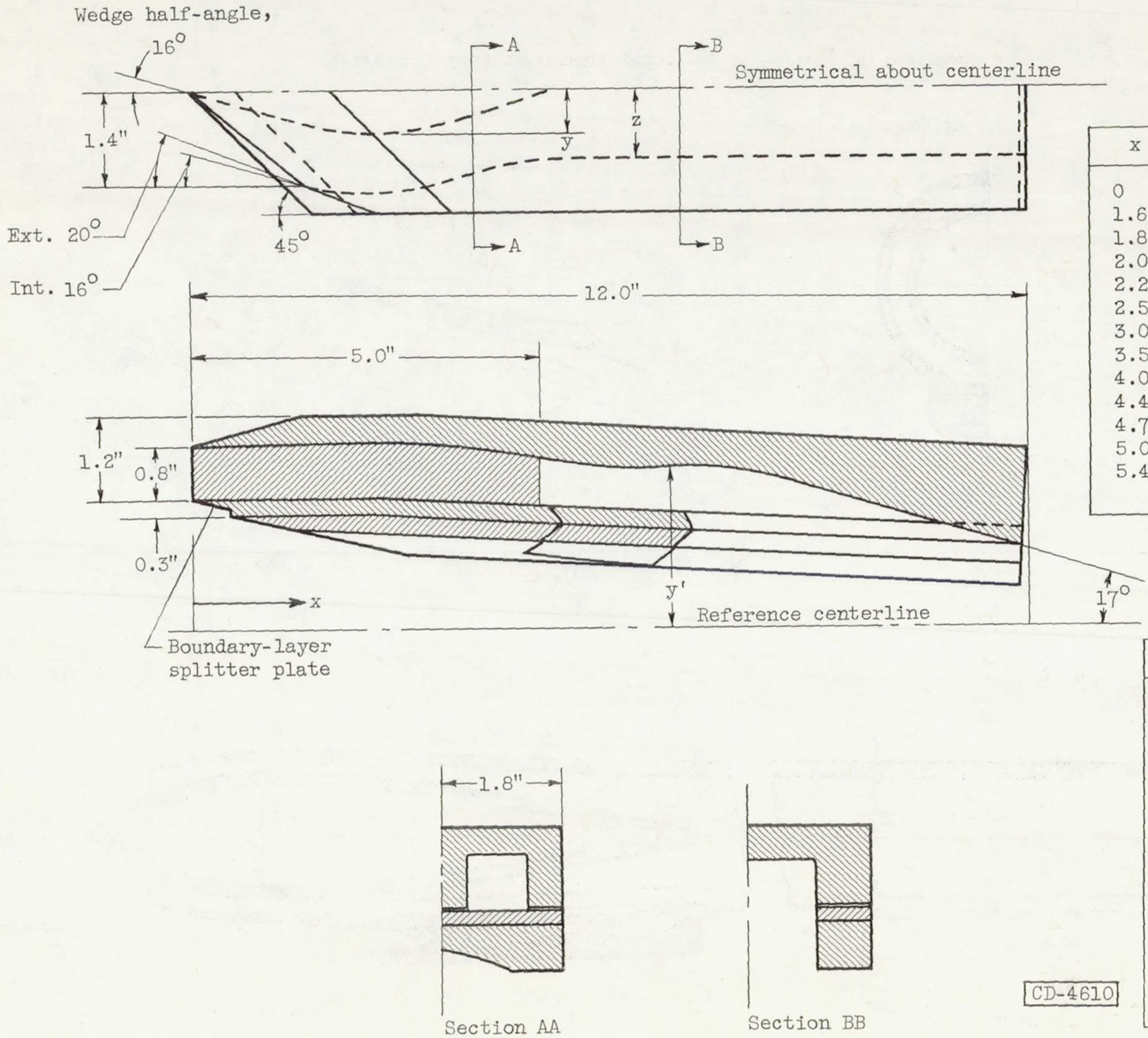


Figure 2. - Diagram showing principal dimensions of test model.



x	y	z
0	0	0
1.66	– –	1.35
1.89	.54	1.40
2.0	.57	1.42
2.2	.60	1.44
2.5	.62	1.46
3.0	.57	1.42
3.5	.48	1.33
4.0	.35	1.22
4.4	.24	1.11
4.7	.14	1.05
5.0	0	1.01
5.4	– –	1.0

x	y'
4.2	3.30
4.4	3.29
4.6	3.26
4.8	3.22
5.0	3.18
5.2	3.14
5.4	3.13
5.7	3.12
6.0	3.12
6.4	3.15
6.6	3.15
6.8	3.16
Straight section	
7.8	3.07

Figure 3. - Sketch and dimensions of auxiliary scoop.

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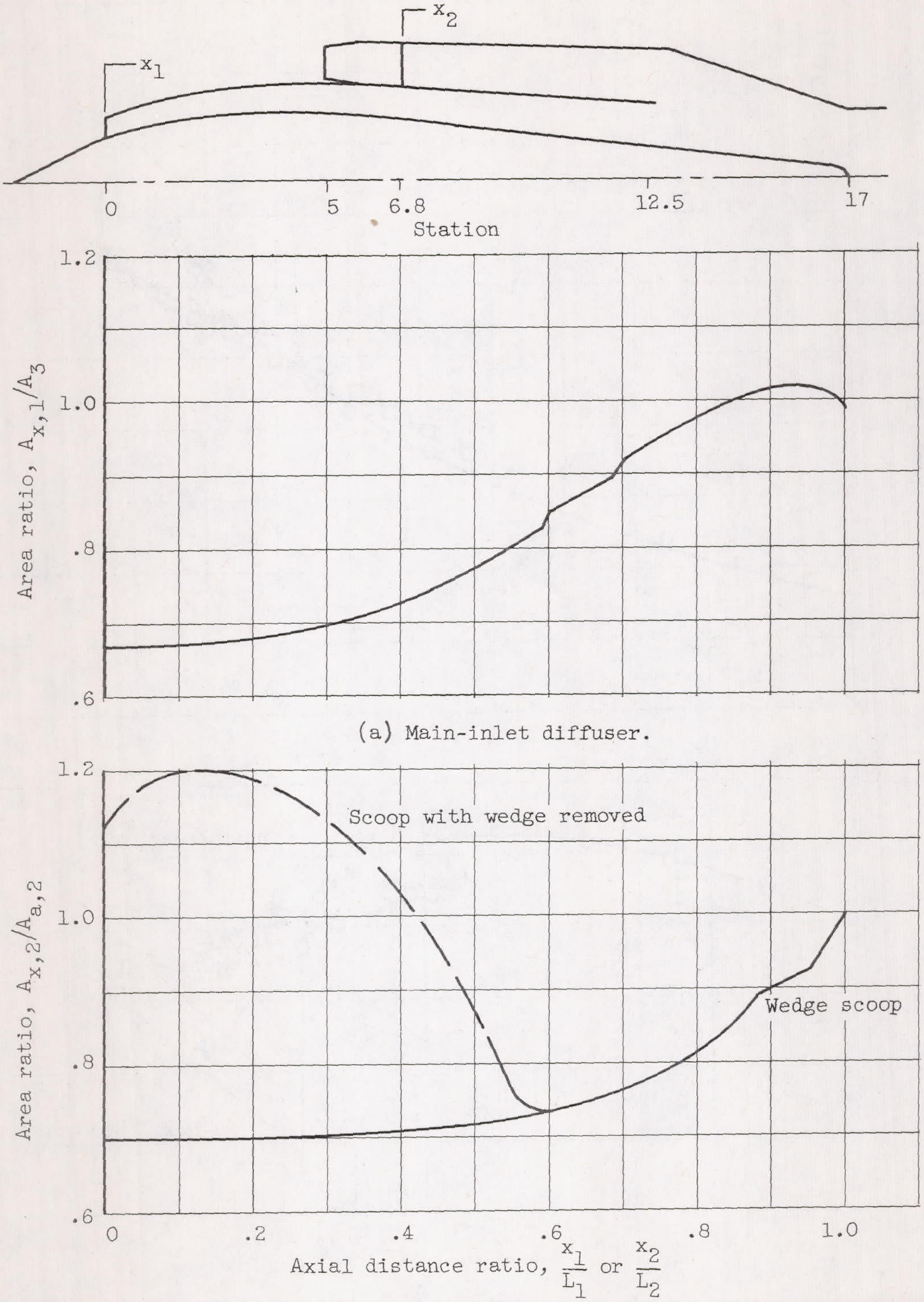

(a) Main-inlet diffuser.

(b) Auxiliary-scoop diffuser.

Figure 4. - Subsonic-diffuser area variations.

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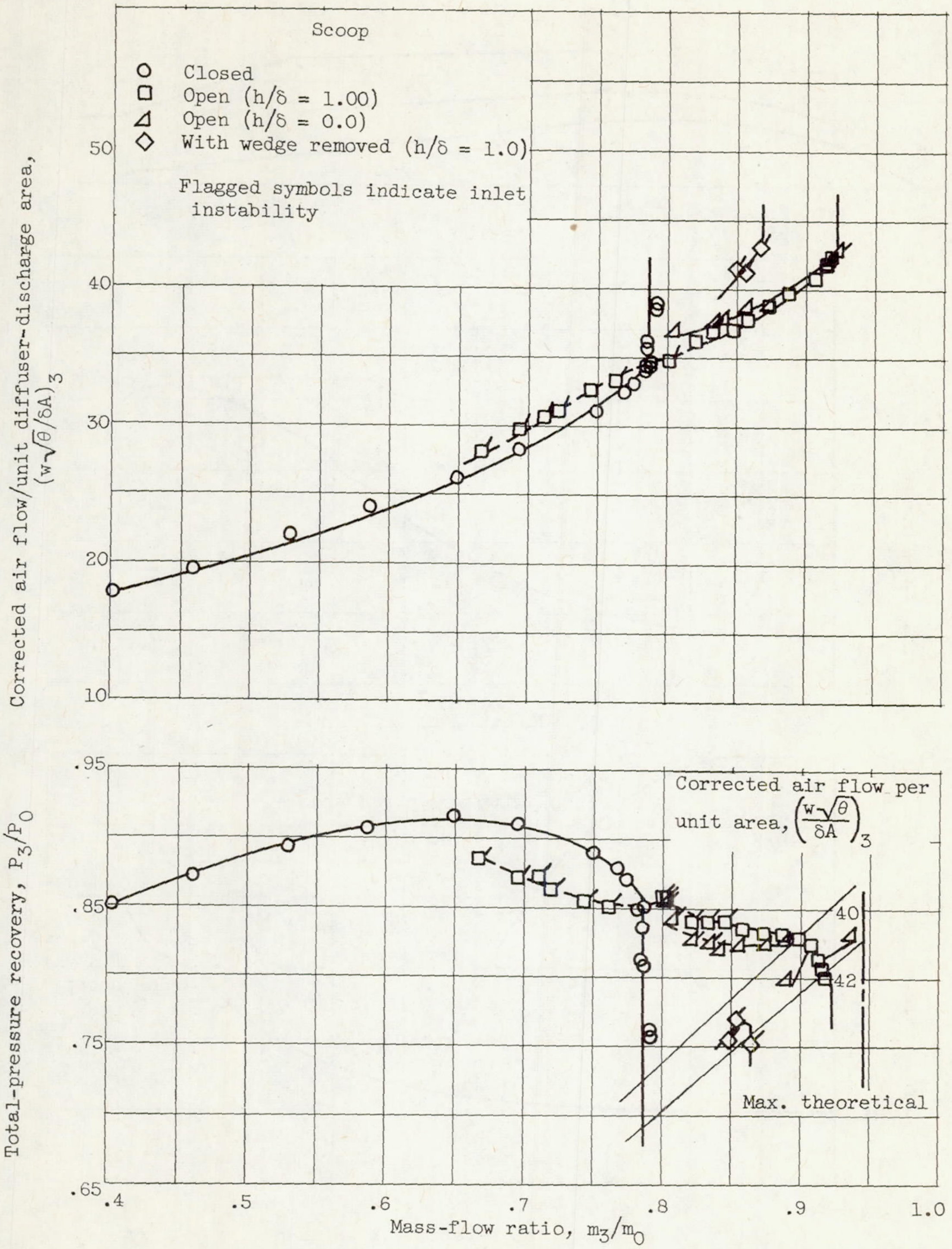

(a) Combined performance.

Figure 5. - Variation of inlet characteristics with mass-flow ratio. Mach number, 1.9; zero angle of attack.

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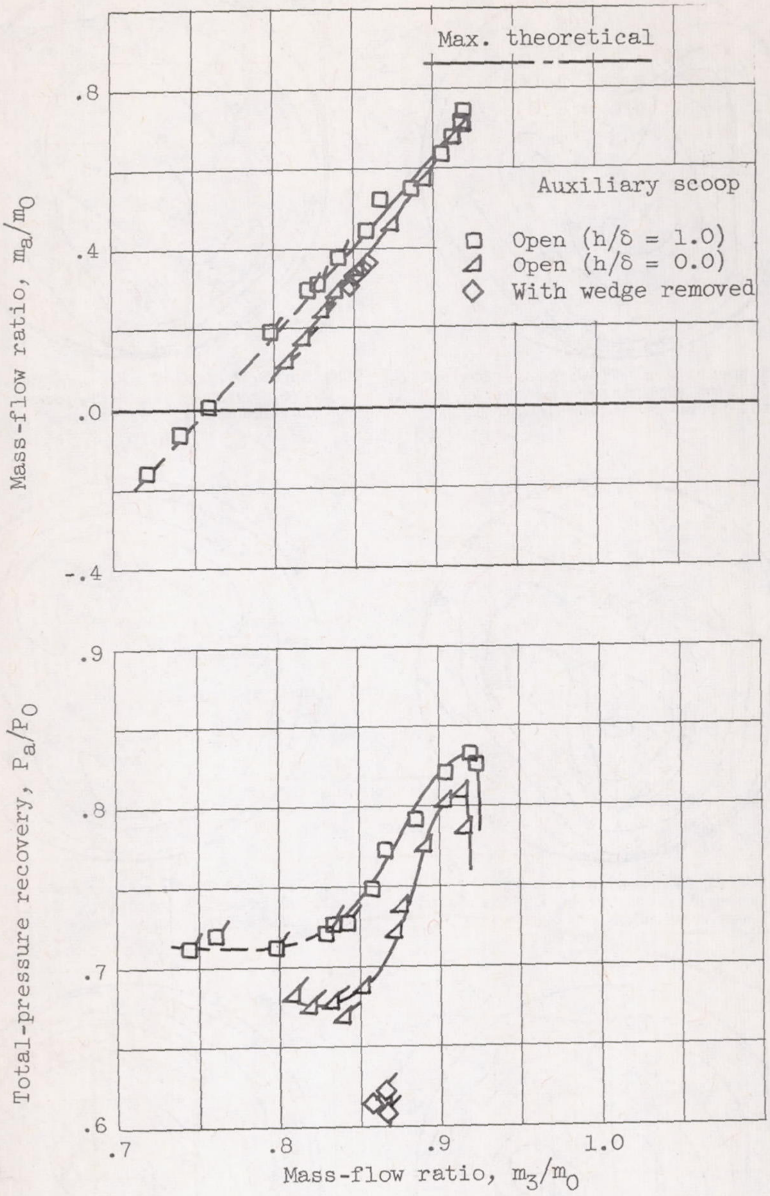
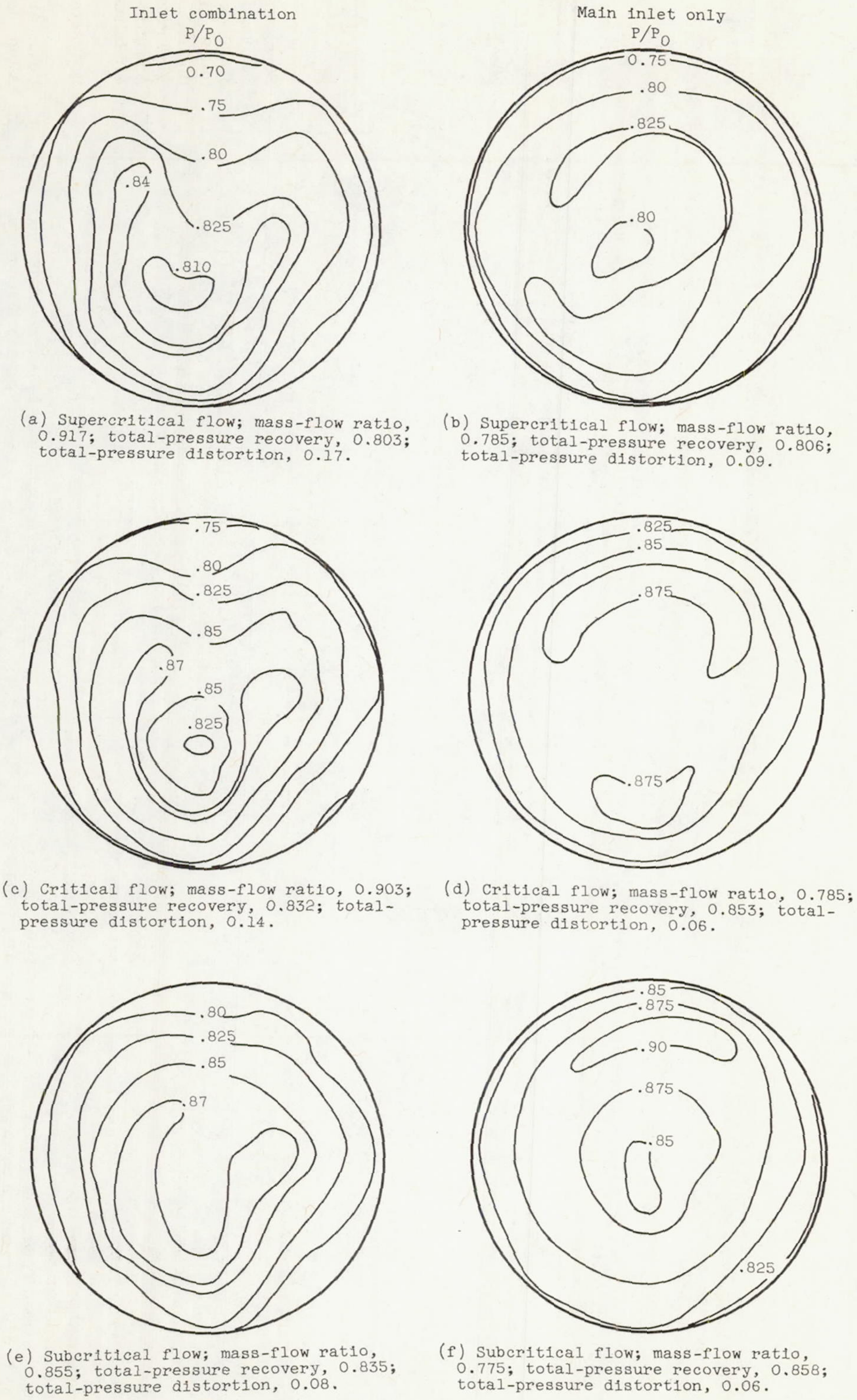


(b) Auxiliary-scoop performance.

Figure 5. - Concluded. Variation of inlet characteristics with mass-flow ratio. Mach number, 1.9; zero angle of attack.



(a) Supercritical flow; mass-flow ratio, 0.917; total-pressure recovery, 0.803; total-pressure distortion, 0.17.

(b) Supercritical flow; mass-flow ratio, 0.785; total-pressure recovery, 0.806; total-pressure distortion, 0.09.

(c) Critical flow; mass-flow ratio, 0.903; total-pressure recovery, 0.832; total-pressure distortion, 0.14.

(d) Critical flow; mass-flow ratio, 0.785; total-pressure recovery, 0.853; total-pressure distortion, 0.06.

(e) Subcritical flow; mass-flow ratio, 0.855; total-pressure recovery, 0.835; total-pressure distortion, 0.08.

(f) Subcritical flow; mass-flow ratio, 0.775; total-pressure recovery, 0.858; total-pressure distortion, 0.06.

Figure 6. - Total-pressure contours looking upstream at engine face for open- and closed-scoop positions. Free-stream Mach number 1.9; zero angle of attack; ratio of splitter-plate height to boundary-layer thickness, 1.00.

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