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MEMORANDUM

EFFECT ON INLET PERFORMANCE OF A COWL VISOR AND AN

INTERNAL-CONTRACTION COWL FOR DRAG REDUCTION

AT MACH NUMBERS 3.07 AND 1.89

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MEMORANDUM 3-18-59E

EFFECT ON INLET PERFORMANCE OF A COWL VISOR AND AN INTERNAL-CONTRACTION COWL FOR DRAG REDUCTION AT MACH NUMBERS 3.07 AND 1.89*

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SUMMARY

Two methods for reducing the external cowl angle, and hence the cowl pressure drag, were investigated on a two-dimensional model. One method used at both on- and off-design Mach numbers was the addition of a cowl visor that had the inner surface parallel to the free stream at 0° angle of attack. The other method investigated consisted in replacing the original cowl by a flatter cowl that also provided internal contraction. Both the visor and the internal-contraction cowl reduced the cowl pressure drag 64 percent or more. The visor had little effect on inlet performance at the design Mach number except to reduce the stability range slightly. At off-design, the visor caused an increase in critical pressure recovery.

INTRODUCTION

An important disadvantage of the all-external-compression inlets for high Mach number operation is the associated high cowl drag. For example, typical cowl pressure drags can be as large as 9 percent of the net engine thrust at Mach 3. Since the large drags result from the high cowl angles required with external-compression inlets, an obvious solution is the reduction of the effective cowl angle.

One method of reducing effective cowl angle is the addition of a visor-like extension, the visor having a small external angle and an inner surface parallel to the free stream at 0° angle of attack. The effect of the visor on inlet performance should be small for on-design operating conditions; off-design, however, the effects may be large. An investigation of shielded inlets is reported in reference 1, the purpose of the shields being to alleviate effects of angle of attack rather than to reduce the drag.

*Title, Unclassified.

An alternative method of reducing cowl angle is to redesign the inlet completely, reducing the amount of external compression (and hence the cowl angle) and adding internal compression to achieve the same total compression. The addition of internal contraction, however, causes starting problems at on-design operation.

An investigation has been conducted at the NASA Lewis Research Center to determine the effects on inlet performance of the two methods that were both designed to give about the same drag. Two visors were used on a two-dimensional model, one with a straight leading edge that spanned the entire inlet and the other with a pointed front and swept vertical sides. The pointed visor was used to reduce the pressure loads and weight. The visors were attached to a conventional two-dimensional cowl with a two-oblique-shock external-compression ramp. They were investigated at both on- and off-design Mach numbers over a range of mass flows and at angles of attack and yaw. The performance of this model with the basic cowl is reported in references 2 and 3.

The low-angle internal-contraction cowl was investigated with a variable external isentropic compression ramp at both on- and off-design Mach numbers. The on-design pressure-recovery data are not reported because mechanical difficulties made the data unusable. Cowls of this type have been reported before (ref. 4) for on-design operation. Data were taken over a range of mass-flow ratios and at angles of attack and yaw.

SYMBOLS

m mass flow

P total pressure

$\frac{\Delta P}{P}$ flow distortion parameter, $\frac{P_{max} - P_{min}}{P_{av}}$

Subscripts:

av average

max maximum

min minimum

0 conditions in free stream in capture area of inlet

2 compressor face

APPARATUS AND PROCEDURE

Models

Schematic diagrams of the models are shown in figure 1. The model with visor and two-shock ramp is shown in figure 1(a), while figure 1(b) shows the internal-contraction cowl with the isentropic ramp. The frontal area of the simulated compressor was 10.18 square inches. The ratio of cowl frontal area to compressor area for the basic cowl was 0.223 and for the internal-contraction cowl was 0.1485. The ratio of capture area to compressor area for the two-shock was 0.896, and for the isentropic was 1.092. Except for the cowl changes, this is the same model as used in references 2 and 3.

The two visors investigated were attached to the basic cowl with the two-oblique-shock ramp used as the external-compression surface. With a visor, it is difficult to spill air ahead of the inlet; therefore, it is necessary to take almost a full stream tube aboard. To do this, the ramps at Mach 3.07 were set at 15° and 30°, and those at Mach 1.89 were set at $5\frac{1}{2}^{\circ}$ and $20\frac{1}{2}^{\circ}$. These settings were found to give good performance in references 2 and 3. The effective cowl angle of both visors was 12° (fig. 2). The pointed visor had swept vertical sides with a 76° included angle, while the leading edge of the full visor covered the entire inlet and extended beyond the inlet on each side. The rear surface of both visors was set at 33°, an angle slightly higher than the 31° cowl angle. The visor extension was measured as the horizontal distance from the cowl leading edge to the lower rear edge of the visor.

The internal-contraction cowl was investigated with a flexible isentropic compression ramp as the external-compression surface. The ramp was positioned for either a Mach number 3.07 or 1.89 contour and had a total turn of 14.6° for Mach 1.89 (fig. 3). The cowl had an external angle of 15.2° and an internal angle of 8.8°.

Data Reduction

Pressure recovery and distortion were measured with a total-pressure rake at the simulated compressor inlet station. The mass flows were calculated from the choked exit area and the total pressure, measured with a 40-tube rake in front of a choked exit plug. Stability was determined using both the schlieren system and a static-pressure transducer at the compressor station. Flutter is defined as a local oscillation of the normal shock, while buzz is a very large oscillation. The cowl drag was calculated from static-pressure taps on the cowl and visor.

Tunnels

The investigations were conducted in the Lewis 18- by 18-inch tunnels having test-station Mach numbers of 3.07 and 1.89. The total temperature in both tunnels was 150° F, and a dewpoint of less than 0° F was maintained. The Reynolds numbers per foot were 1.79×10^6 and 3.14×10^6 in the Mach 3.07 and 1.89 tunnels, respectively.

RESULTS AND DISCUSSION

Cowl Drag

Cowl (and visor) pressure drags are compared in figure 4, using a ratio of cowl drag to ideal net thrust of an assumed Mach 3 engine. The drags were computed from measured pressures on the cowls and visors at supercritical operation and do not take into account any changes in pressure recovery, mass flow, or spillage between the visor and cowl. The basic cowl, which was the cowl used in references 2 and 3, had the inner side of the lip parallel to the entering flow from the external-compression ramps at the design Mach number. The measured drag coefficients of the basic cowl based on compressor frontal area were 0.18 and 0.205 at Mach 3.07 and 1.89, respectively. At Mach 3.07, both the internal-contraction cowl and the full visor had 74 percent less drag than the basic cowl. At Mach 1.89, the internal-contraction cowl had 70 percent and the full visor 64.5 percent less drag than the basic cowl.

The drag of the pointed visor was slightly higher than that of the full visor. This higher drag was caused by detached shock waves from the swept vertical sides of the pointed visor. These waves cannot be seen in figure 5, since they are parallel with the plane of the picture. The shock waves appearing to originate from the top middle of the visors during critical operation in figure 5 are caused by instrumentation from the visors that is outside of the capture area of the inlet and that did not affect either the inlet performance or pressure on the visors. A weak shock from the visor leading edge is a result of the fact that, although the inner side of the visor was alined with the free stream, no account was taken of the developing boundary layer. This shock or Mach wave is more apparent with the full visor but is also present with the pointed visor. At Mach 1.89, the ramp oblique shock interaction with the visor and the resulting reflected shock are visible in figures 5(c) and (d). The bridging between the shock from the internal-contraction cowl and the side fairings (fig. 5(e)) is caused by shock interaction with the boundary layer on the side plates.

Visored Cowls

<u>Performance at Mach 3.07</u>. - The performance of the basic two-shock inlet with boundary-layer bleed at the design Mach number of 3.07 is

presented in figure 6. The critical pressure recovery was 65 percent at a mass-flow ratio of 0.9. As can be seen, there was little flow between the visor and cowl at critical. The stable range at this point was about 0.1 mass-flow ratio. Positive angle of attack caused large decreases in pressure recovery and mass flow, whereas negative angle of attack caused small increases. At large positive angles of attack, there was no stability; but at large negative angles there was more stability than at 0°. Distortions without the visors were less than 10 percent at all times; and, since the distortions of the visor configurations followed these same trends at Mach 3.07, they are not shown in the following figures.

The performance of the inlet with the pointed visor at Mach 3.07 is shown in figure 7 for several visor extensions. For visor extension ratios greater than 0.25, the pressure-recovery variations with mass flow are similar to those for the basic inlet. The levels, however, are about 0.05 lower for 0° angle of attack. This loss was probably caused by detached shock from the sides of the visor where the angle of 38° is larger than the detachment angle. The visor reduced the stability range to about 0.05 mass-flow ratio at an extension of 0.25 or larger, while there was no stability at 0.167 extension ratio. The negative angles of attack shown are the maximum at which the inlet would start.

Performance with the full visor (fig. 8) at 0° angle of attack was about the same as that without a visor. The range of stable operation was smaller; in fact, for the 0.229 extension ratio the full visor had no stable range. For angles of attack of greater magnitude than those of figure 8, the inlet would not start.

In general, the operating characteristics of the two visor types were similar in that both pressure recovery and mass flow decreased at negative angles of attack because of the shielding effect of the visor.

Off-design performance. - The performance at Mach 1.89 of the basic inlet, the pointed-visor inlet, and the full-visor inlet is presented in figures 9, 10, and 11, respectively. The critical pressure recovery with the pointed visor was 0.05 better than that of the basic inlet at 0° attack, while the increase with the full visor was up to 0.09 higher. This increase was a result of the reflected oblique shock from the visor (figs. 5(c) and (d)). At subcritical mass flows, the normal shock moves forward and cancels the reflected oblique shock, and the pressure-recovery advantages of the visored inlets decrease.

Stability was good with both visors (figs. 10 and 11). The stable range was 0.08 to 0.10 mass-flow ratio at 0° angle of attack, which was just slightly less than without the visors (fig. 9). Negative angles of attack increased this range to 0.25 to 0.30, but the range decreased at positive angles, the pointed visor decreasing more than the full visor.

The critical mass flow with both visors was about 4 percent less than it was for the basic inlet. The additional spillage to the sides and between the visor and cowl resulted from the higher pressure region behind the reflected shock.

Critical mass flow and pressure recovery always decreased at angles of attack because of the shielding effects on the inlet of either the compression ramp or the visor. Although the critical pressure recovery did decrease at angles of attack, it was still almost as high and in some cases higher than for 0° operation of the basic inlet. E-175

Off-Design Performance of Internal-Contraction Cowl

The data on the internal-contraction cowl, which was designed for Mach 3, are presented only at Mach 1.89 to show the off-design performance. On-design performance of a similar inlet has been reported previously (ref. 4). Because of the basic differences between the inlets, no attempt is made to compare them. Performance with throat bleed is presented in figure 12. The effect of bleed scoop-height ratio is shown in figure 12(a). At the ramp setting used, a full stream tube was captured. Critical pressure recovery increased for small bleeds as the boundary layer was removed. Critical distortion was high.

Performance at angles of attack and yaw is presented in figure 12(b). Pressure recovery and mass flow decreased at positive angles of attack and angles of yaw because of the shielding of the inlet by the ramp and side fairings, respectively. At negative angles of attack the pressure recovery increased because of the stronger oblique shock from the compression ramp, which resulted in a large total turn for the flow. The inlet had a large stable range at all positions.

SUMMARY OF RESULTS

Inlet performance with two methods of reducing cowl pressure drag was investigated. A method used at both on- and off-design Mach numbers of 3.07 and 1.89 was a visor on a conventional two-dimensional inlet. Both a pointed visor with swept vertical sides and a full visor with the leading edge wider than the inlet were used. The other method was a two-dimensional internal-contraction cowl. The following results were obtained:

1. Both the full visor and the internal-contraction cowl were equally effective in reducing the cowl pressure drag 74 percent at

Mach 3.07 and about 64 percent at Mach 1.89. The reduction caused by the pointed visor was slightly less.

2. Both visors at Mach 3.07 halved the stability range as compared with the basic inlet. The full visor caused no change in critical pressure recovery and distortion from the basic inlet, but the pointed visor did decrease critical recovery somewhat.

3. Both visors at Mach 1.89 increased critical recovery over the basic inlet, but the stability range remained the same. The visors reduced the critical mass-flow ratio about 0.04.

4. The internal-contraction cowl at Mach 1.89 had a critical recovery of about 92 percent. The stable range was large at all angles of attack and yaw.

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, December 29, 1958

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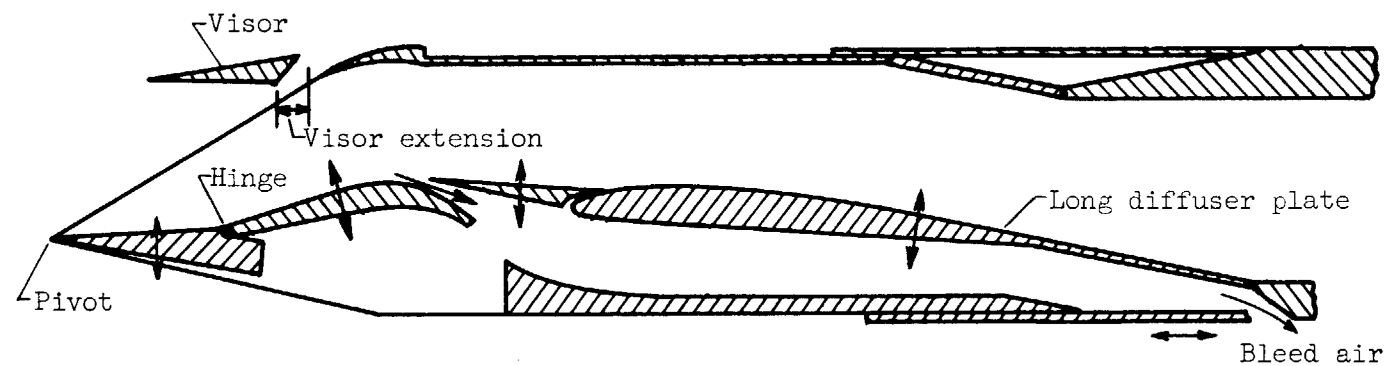
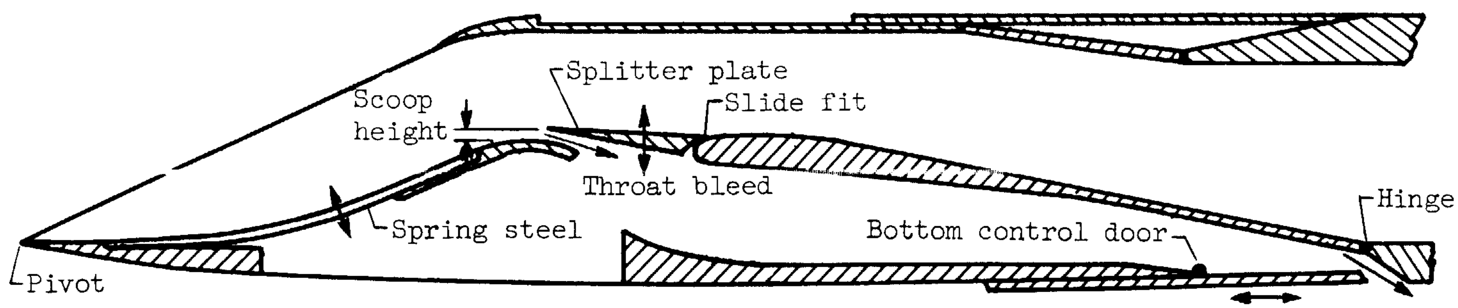
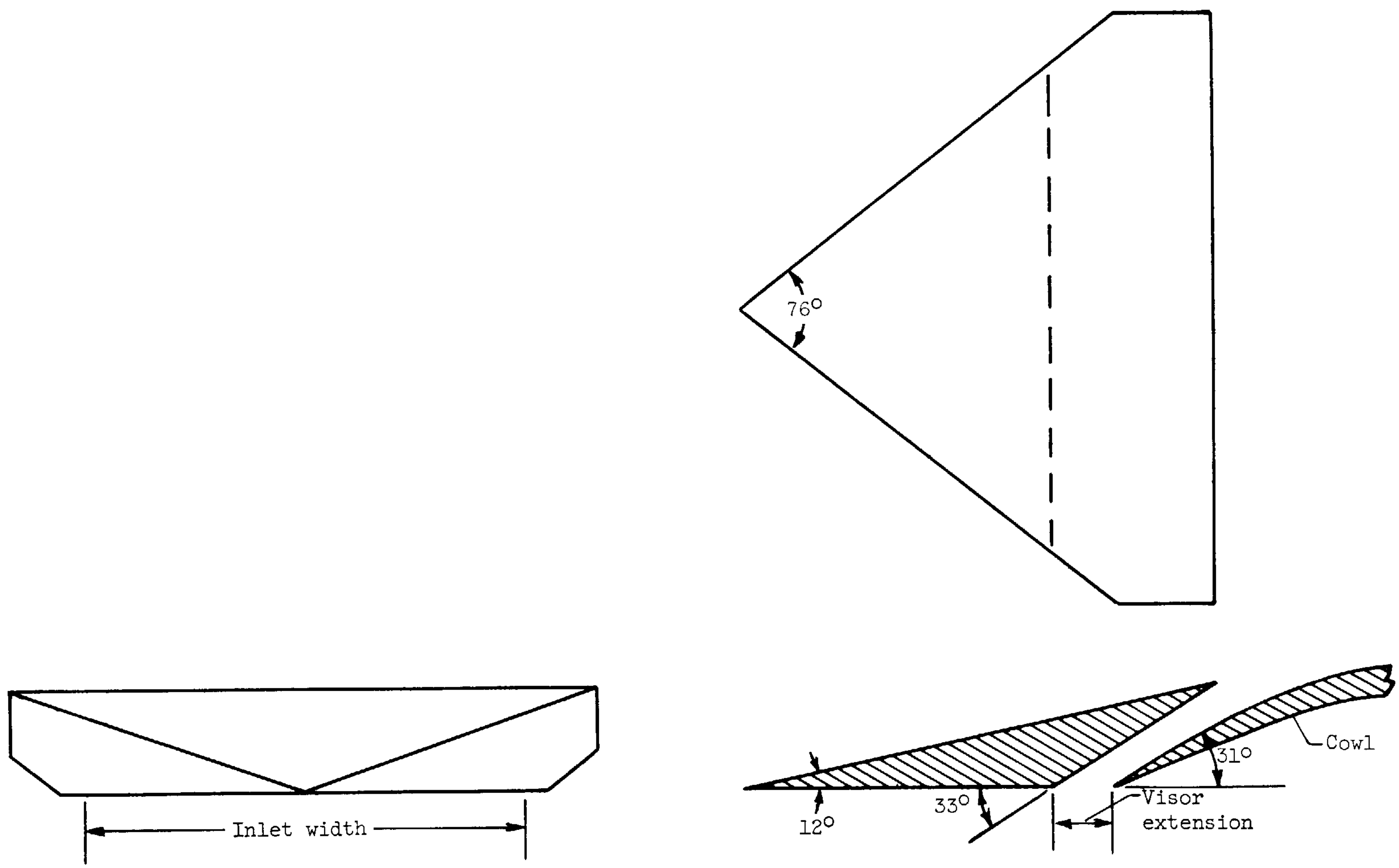


(a) Visor with two-shock ramp.



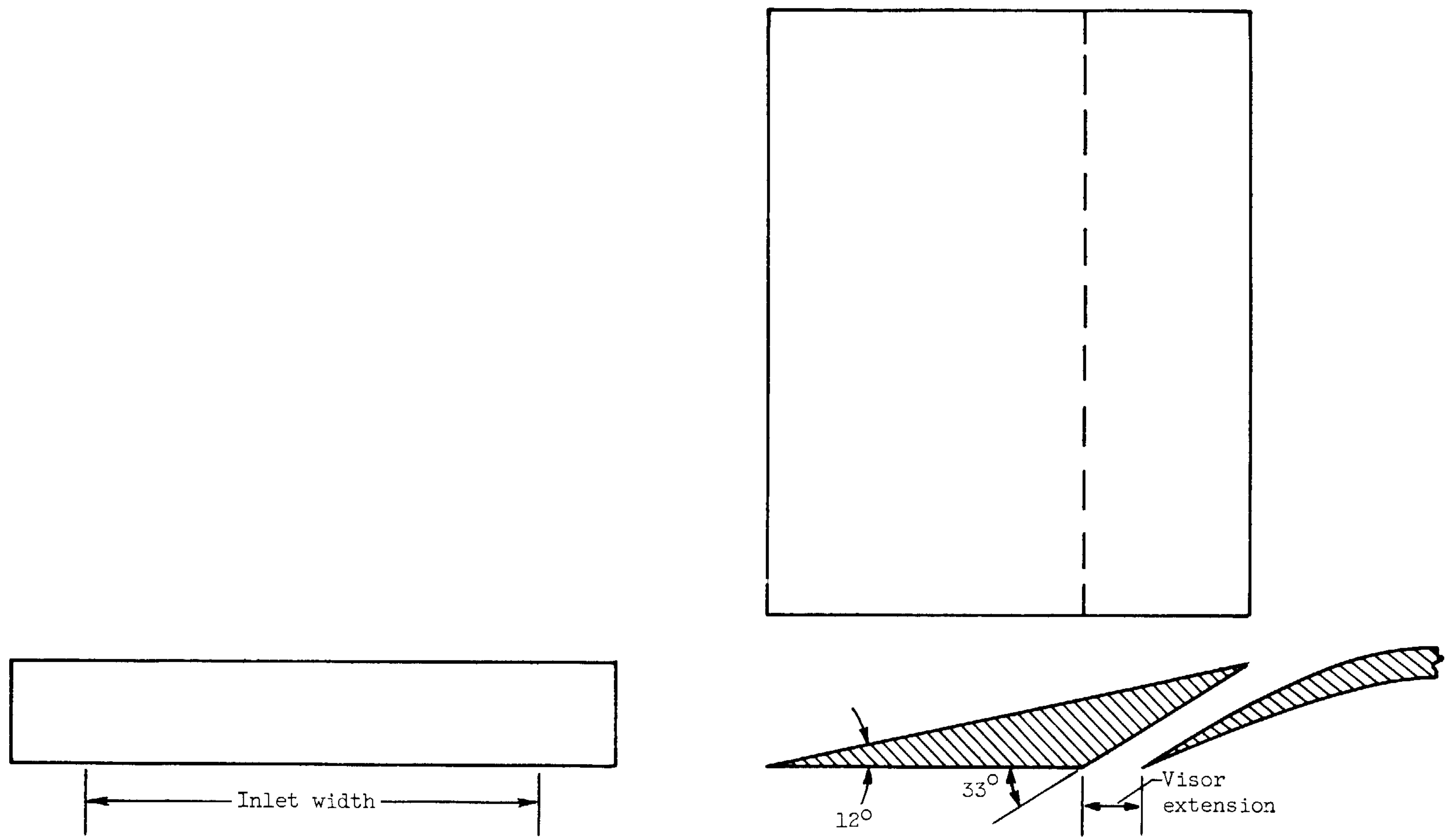
(b) Internal-contraction cowl with isentropic ramp.

Figure 1. - Schematic view of models.



(a) Pointed visor.

Figure 2. - Sketches of cowl visors.



(b) Full visor.

Figure 2. - Concluded. Sketches of cowl visors.

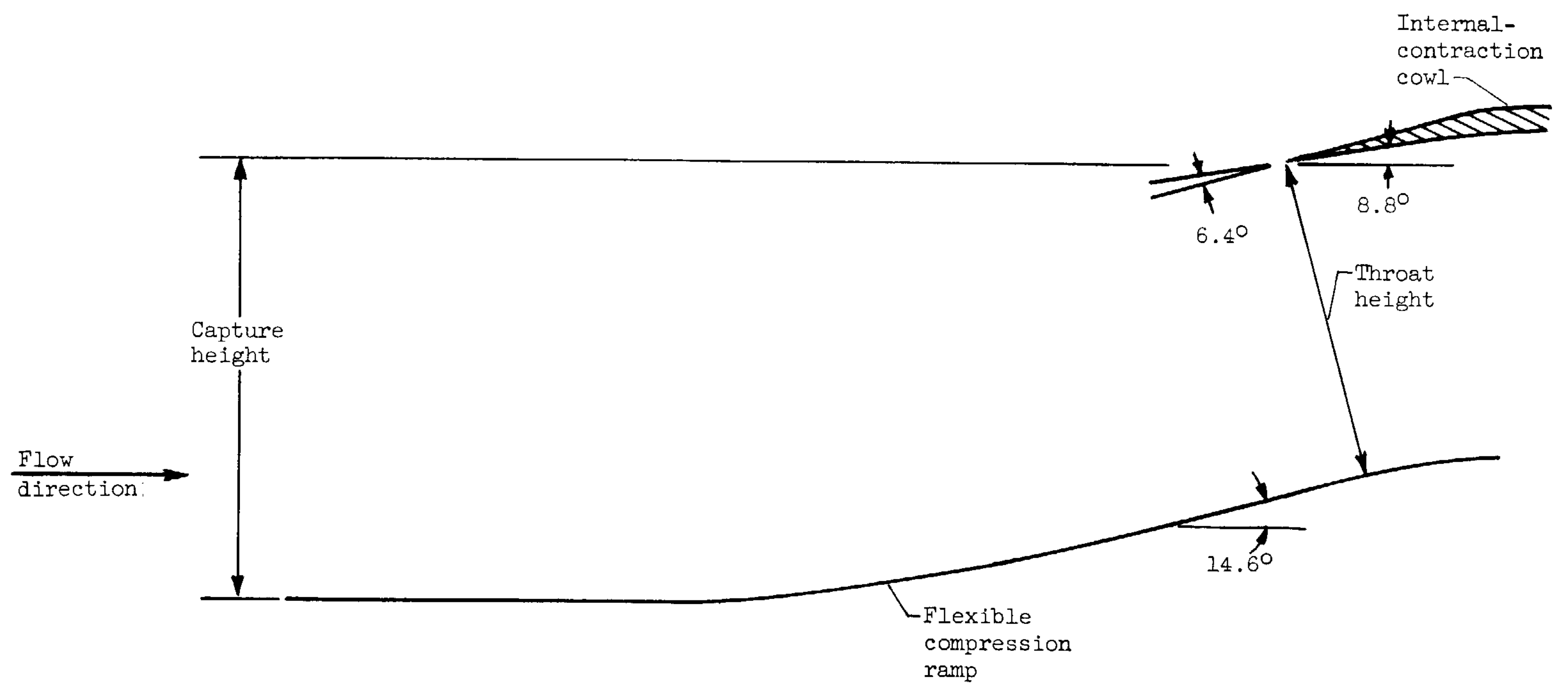
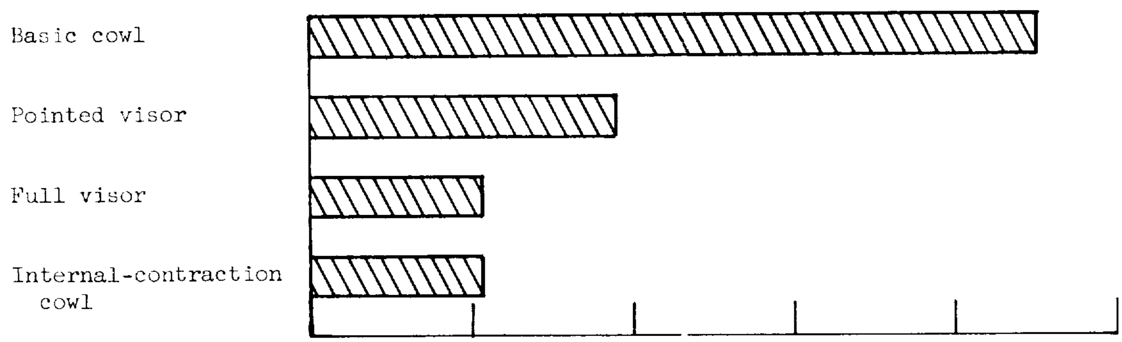
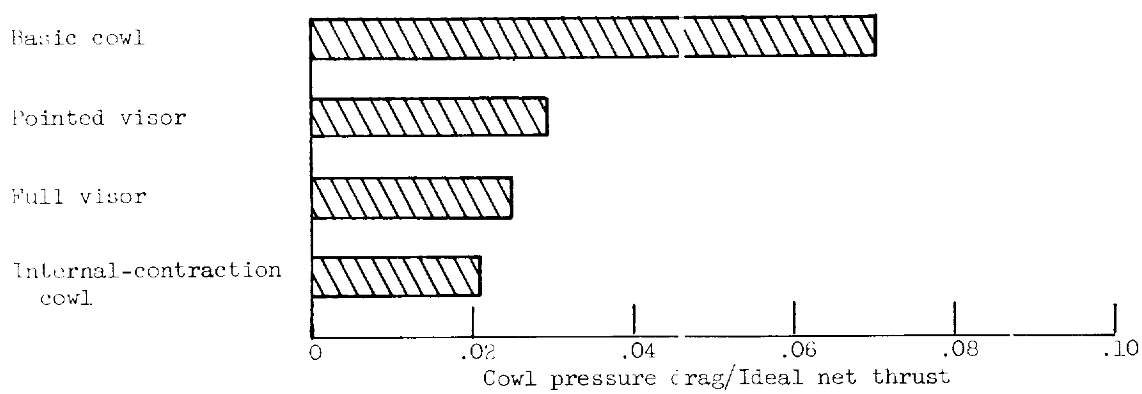


Figure 3. - Isentropic ramp, Mach 1.89 contour with internal-contraction cowl.



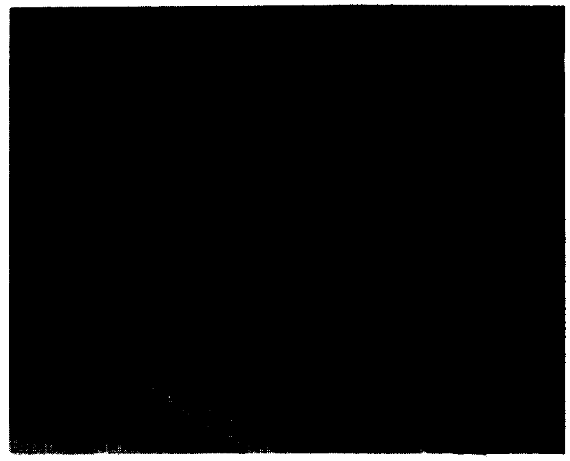
(a) Free-stream Mach number, 3.07.



(b) Free-stream Mach number, 1.89.

Figure 4. - Comparison of cowl drag.

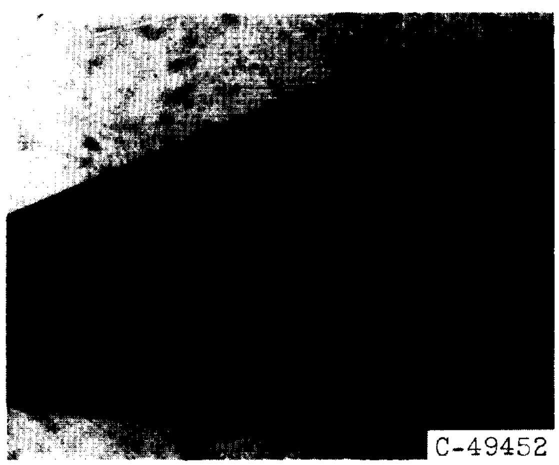
(a) Pointed visor at Mach 3.07.



(b) Full visor at Mach 3.07.

(c) Pointed visor at Mach 1.89.

(d) Full visor at Mach 1.89.



(e) Internal-contraction cowl at Mach 1.89.

Figure 5. - Schlieren photographs of models at critical operation.

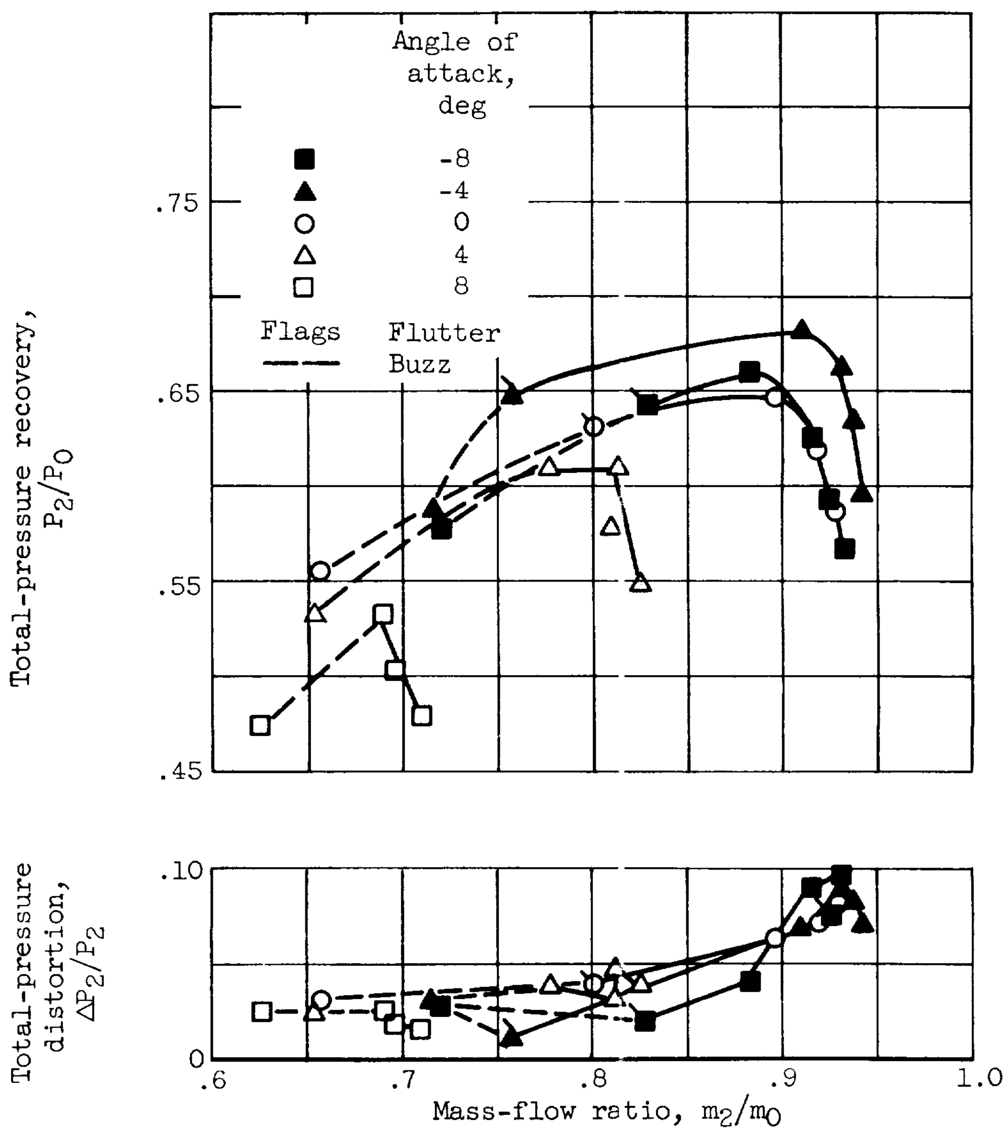
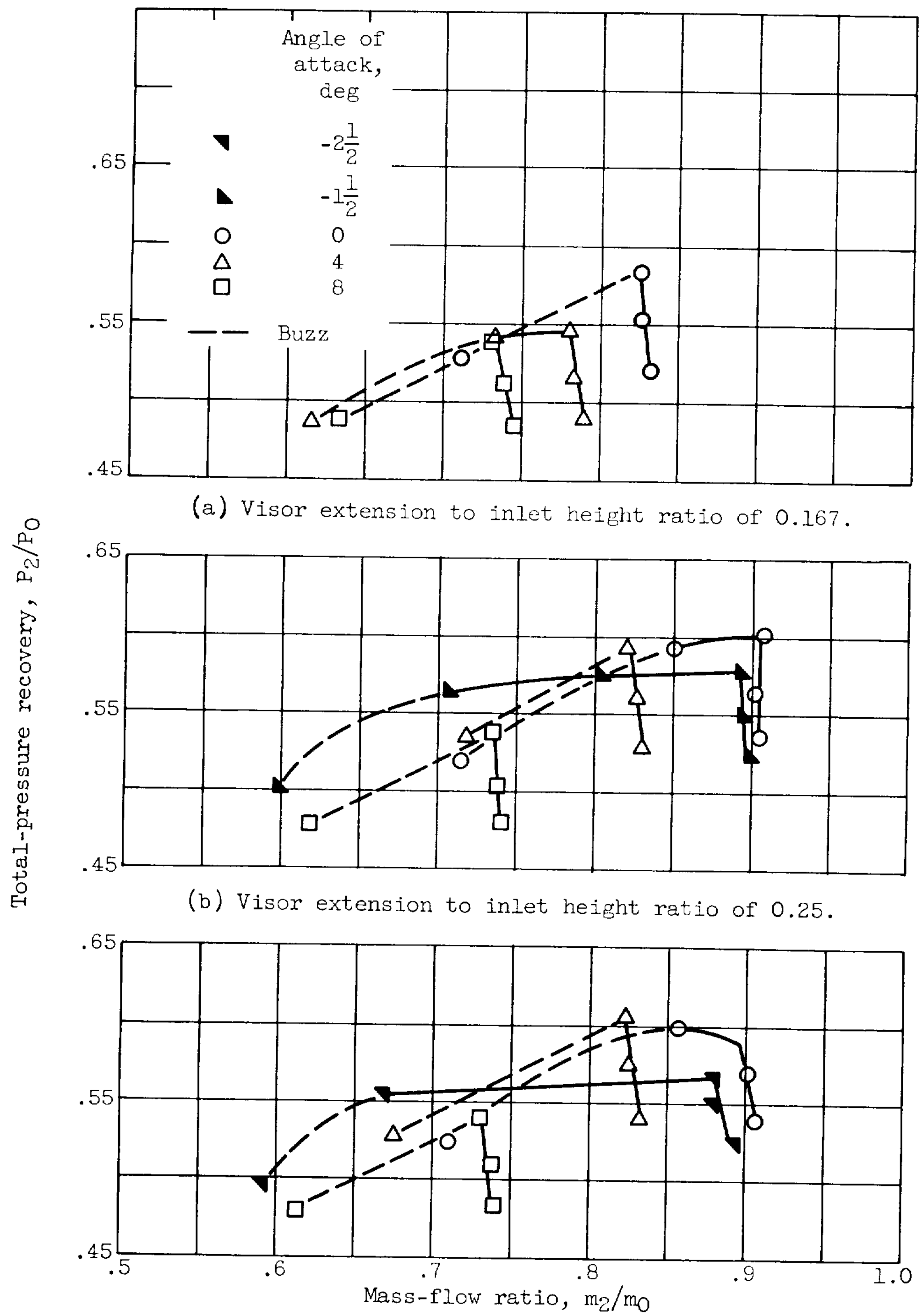


Figure 6. - Performance of basic two-shock inlet. Free-stream Mach number, 3.07.



(a) Visor extension to inlet height ratio of 0.167.

(b) Visor extension to inlet height ratio of 0.25.

(c) Visor extension to inlet height ratio of 0.333.

Figure 7. - Performance with pointed visor. Free-stream Mach number, 3.07.

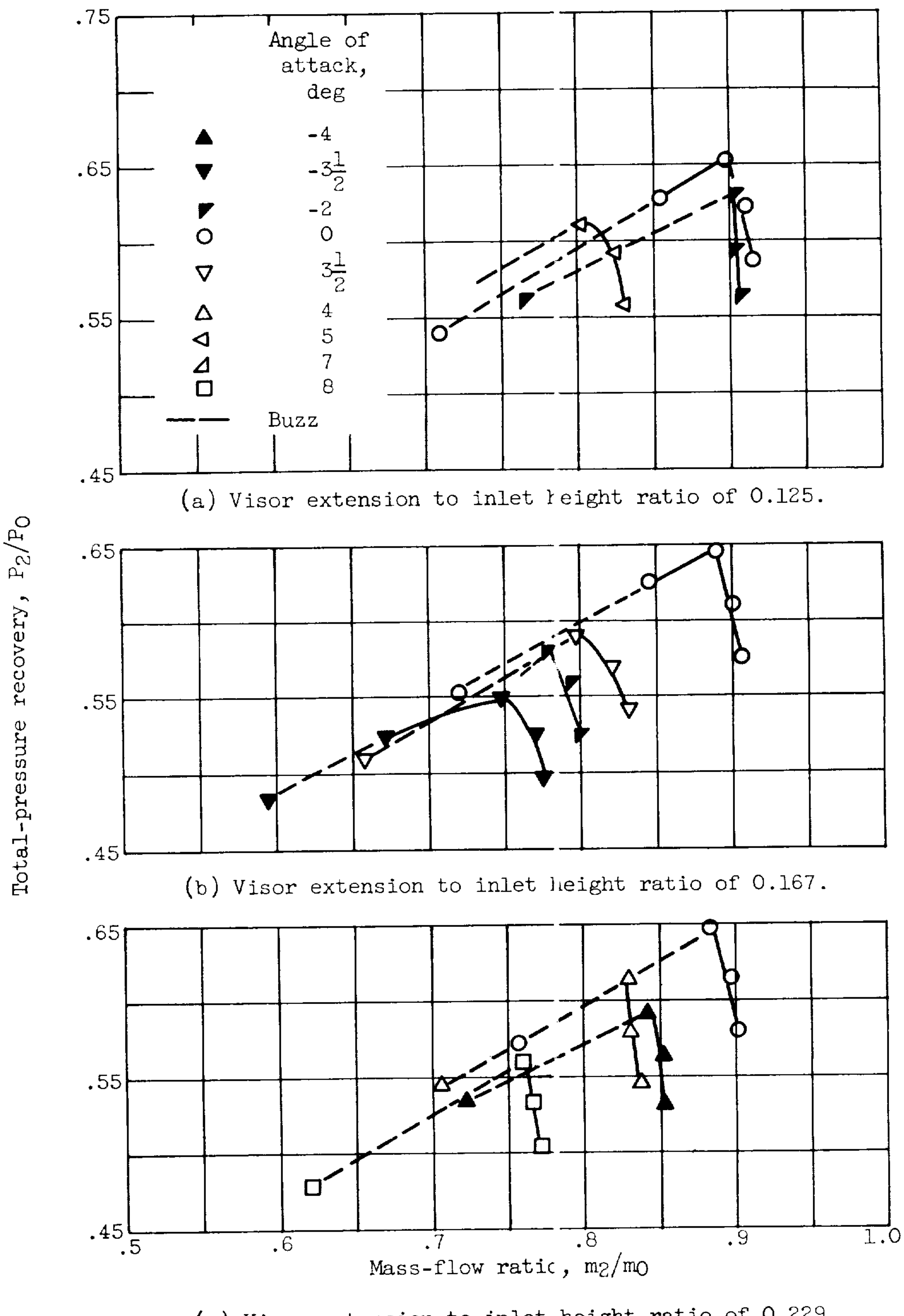


Figure 8. - Performance with full visor. Free-stream Mach number, 3.07.

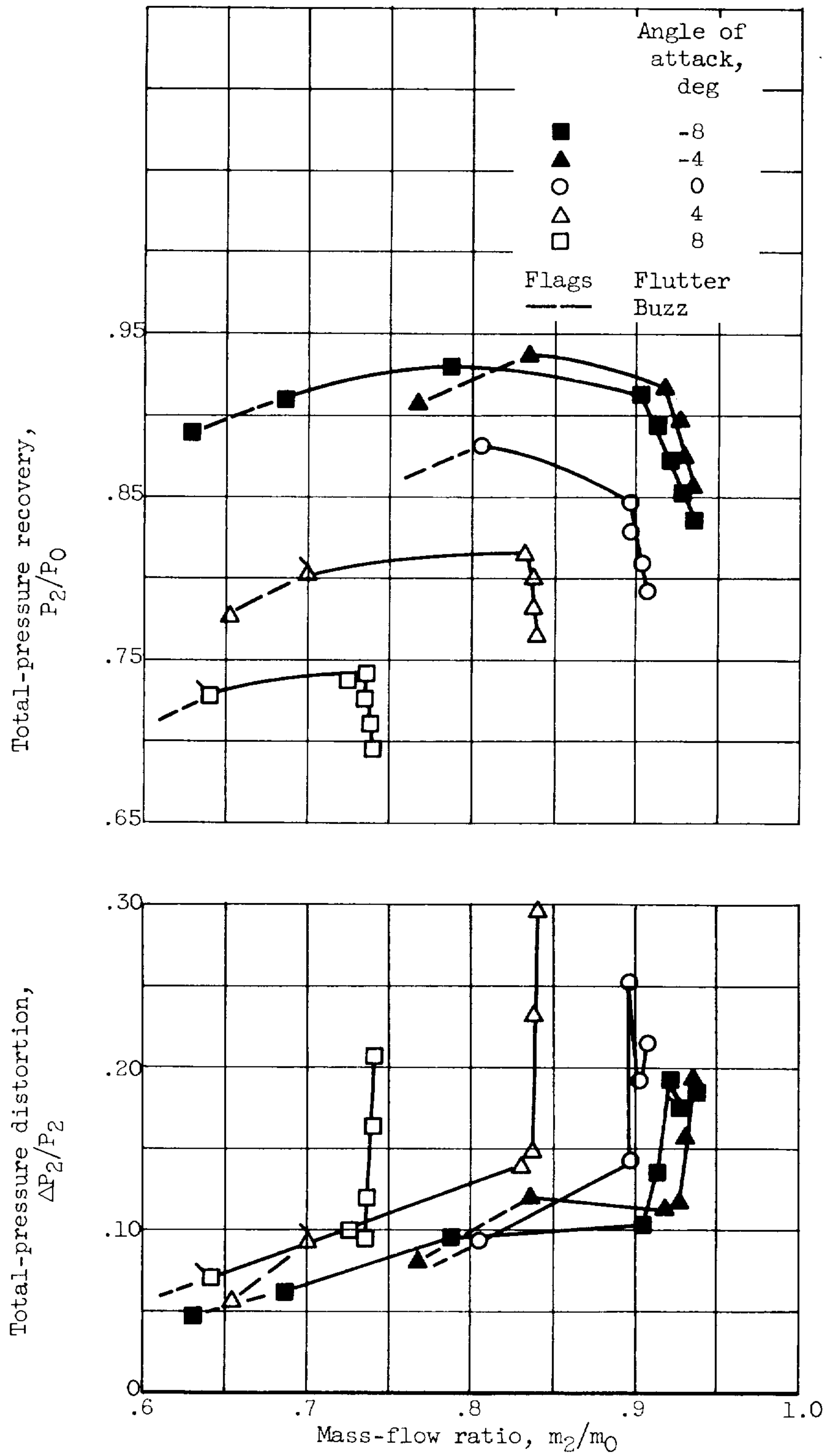
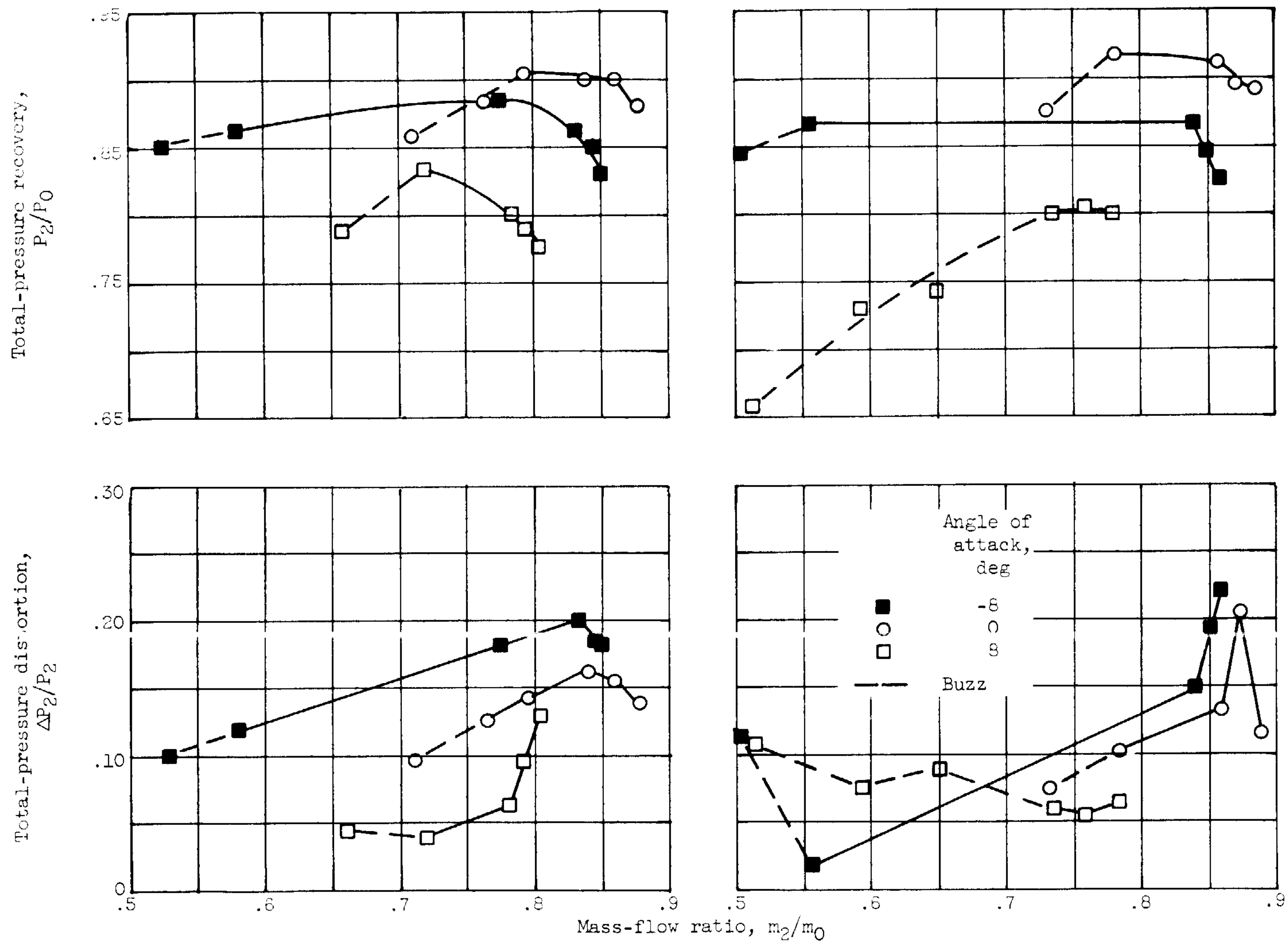
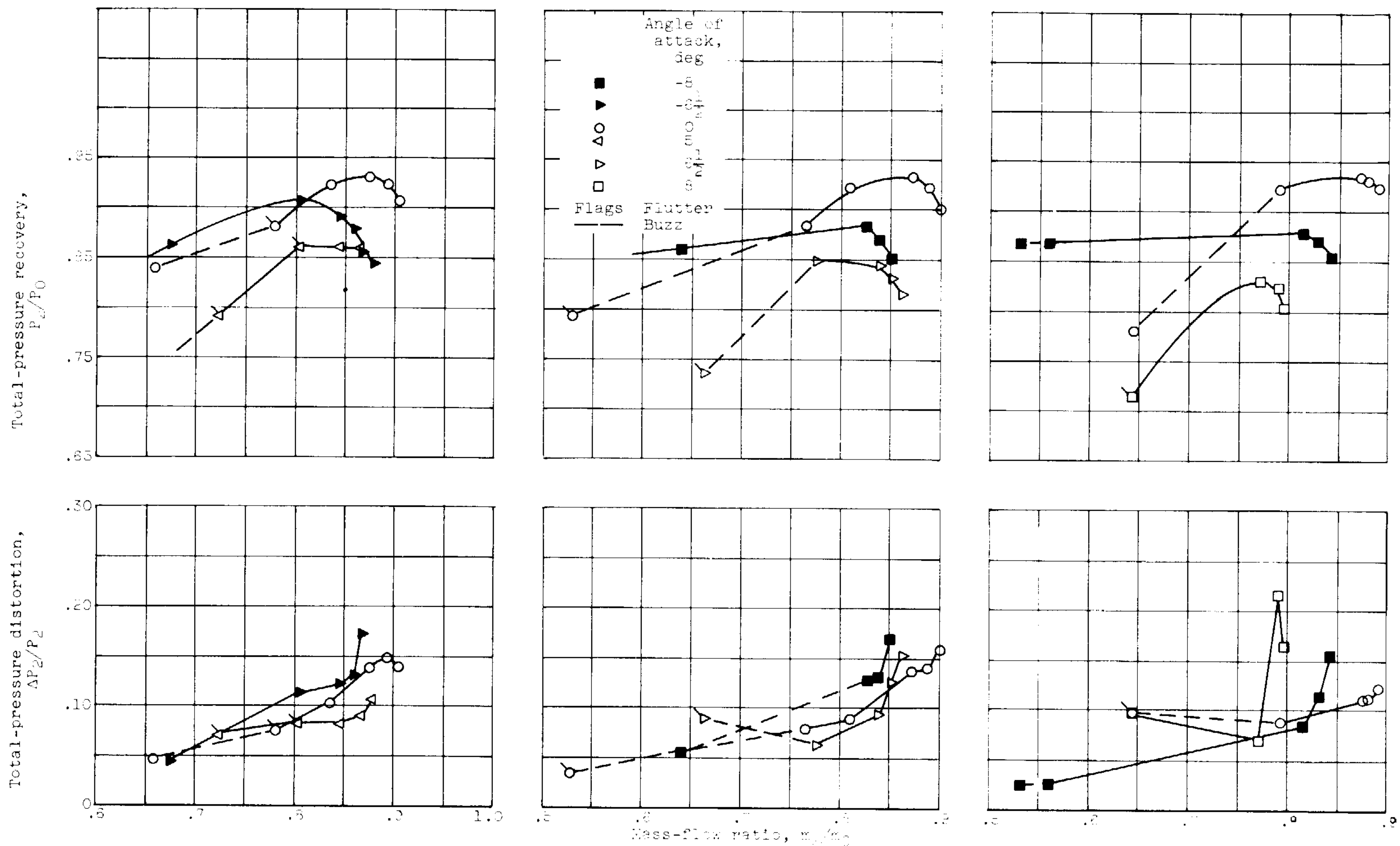


Figure 9. - Off-design performance of basic inlet. Free-stream Mach number, 1.89.



(a) Visor extension to inlet height ratio of 0.208. (b) Visor extension to inlet height ratio of 0.25.

Figure 10. - Off-design performance with pointed visor. Free-stream Mach number, 1.89.

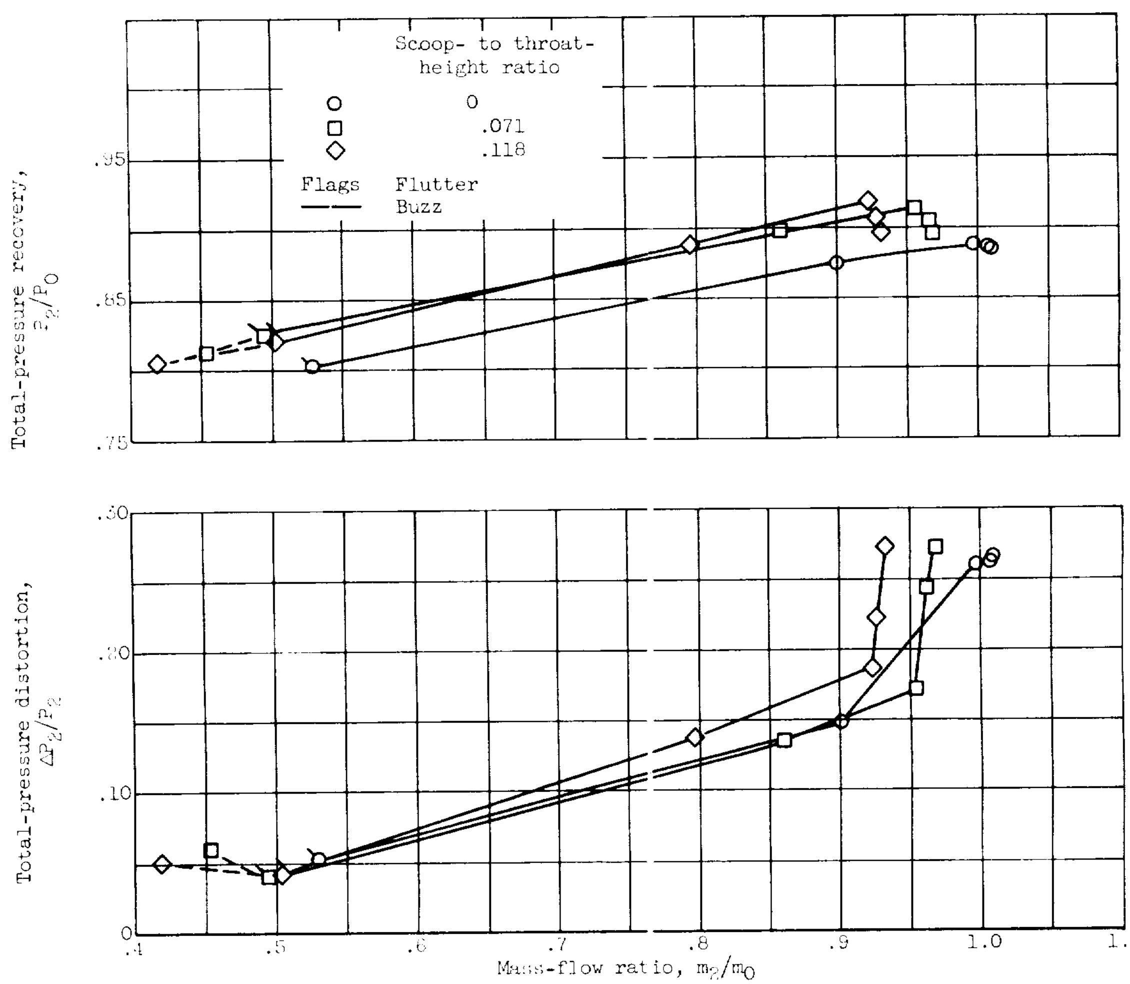


(a) Visor extension to inlet height ratio of 0.104.

(b) Visor extension to inlet height ratio of [illegible].

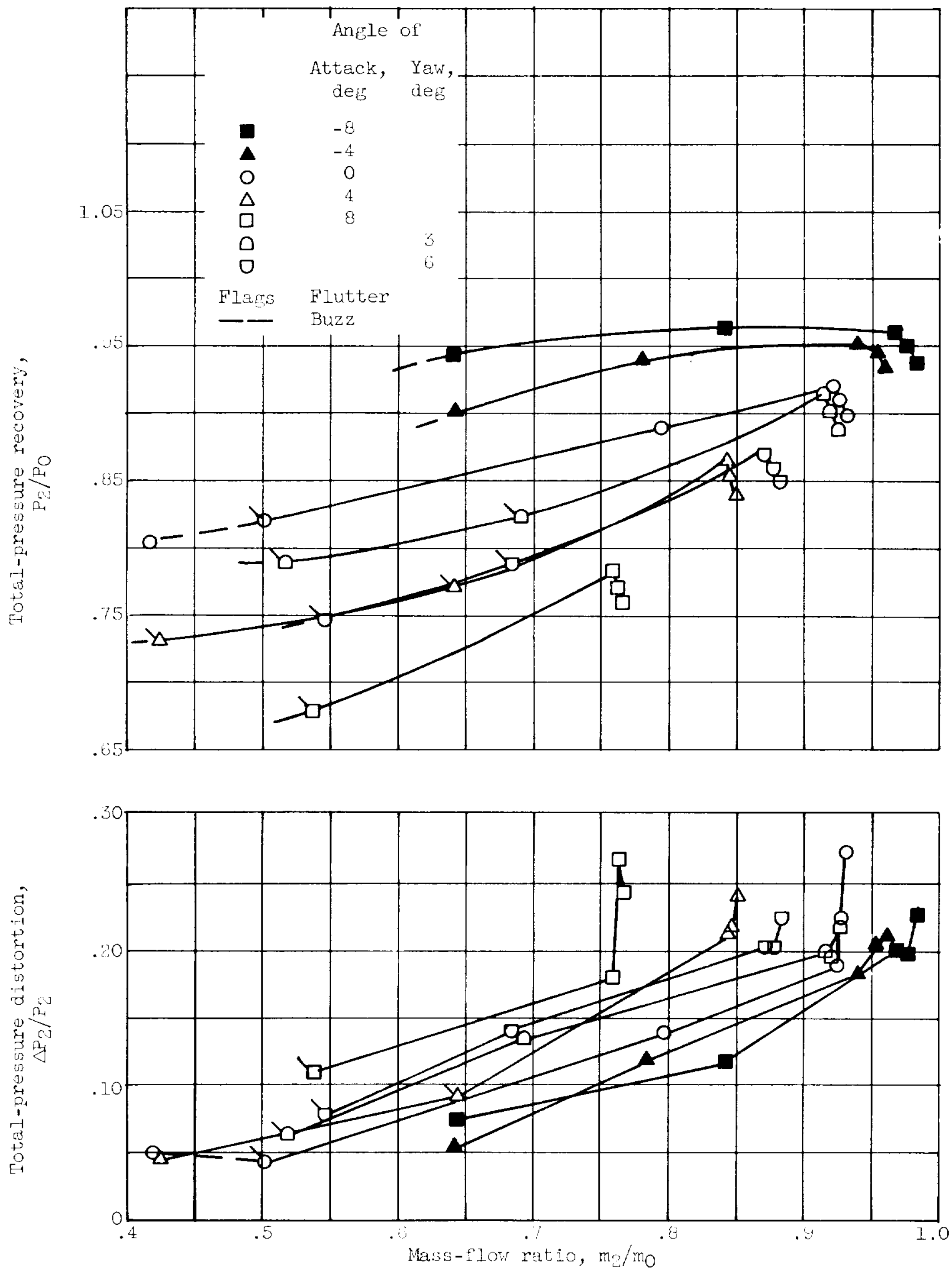
(c) Visor extension to inlet height ratio of [illegible].

Figure 11. - Off-design performance with full visor. Free-stream Mach number, [illegible].



(a) Variable throat bleed.

Figure 12. - Off-design performance with internal-contraction cowl and throat bleed. Free-stream Mach number, 1.89.



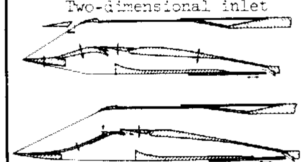
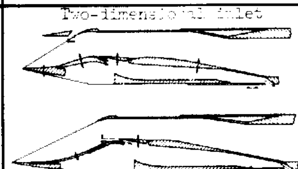
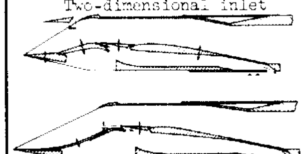
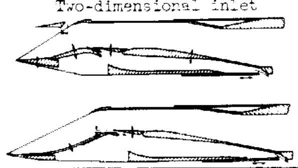
(b) Variable angles of attack and yaw.

Figure 12. - Concluded. Off-design performance with internal-contraction cowl and throat bleed. Free-stream Mach number, 1.89.

NOTES: (1) Reynolds number is based on the diameter of a circle with the same area as that of the capture area of the inlet.

(2) The symbol * denotes the occurrence of buzz.

INLET BIBLIOGRAPHY SHEET

	Description			Test parameters				Test data				Performance		
Report and facility	Configuration	Number of oblique shocks	Type of boundary-layer control	Free-stream Mach number	Reynolds number $\times 10^{-6}$	Angle of attack, deg	Angle of yaw, deg	Drag	Inlet-flow profile	Discharge-flow profile	Flow picture	Maximum total-pressure recovery	Mass-flow ratio	Remarks
CONFID. MEMO 3-18-59E Lewis 18- by 18-in. Mach 3.07 tunnel Lewis 18- by 18-in. Mach 1.89 tunnel	Two-dimensional inlet 	Isen-tropic or two oblique shocks	Throat ram scoop	3.07 1.89	Isentropic 0.575 2-S .538 Isentropic 0.97 2-S .907	+8 to -8	0 to 6	Cowl and visor drag only			√ √	0.68 .96	*0.60 to 0.94 *.42 to 1.00	Compares drag of different visors and cowls and their effect on inlet performance
CONFID. MEMO 3-18-59E Lewis 18- by 18-in. Mach 3.07 tunnel Lewis 18- by 18-in. Mach 1.89 tunnel	Two-dimensional inlet 	Isen-tropic or two oblique shocks	Throat ram scoop	3.07 1.89	Isentropic 0.575 2-S .538 Isentropic 0.97 2-S .907	+8 to -8	0 to 6	Cowl and visor drag only			√ √	0.68 .96	*0.60 to 0.94 *.42 to 1.00	Compares drag of different visors and cowls and their effect on inlet performance
CONFID. MEMO 3-18-59E Lewis 18- by 18-in. Mach 3.07 tunnel Lewis 18- by 18-in. Mach 1.89 tunnel	Two-dimensional inlet 	Isen-tropic or two oblique shocks	Throat ram scoop	3.07 1.89	Isentropic 0.575 2-S .538 Isentropic 0.97 2-S .907	+8 to -8	0 to 6	Cowl and visor drag only			√ √	0.68 .96	*0.60 to 0.94 *.42 to 1.00	Compares drag of different visors and cowls and their effect on inlet performance
CONFID. MEMO 3-18-59E Lewis 18- by 18-in. Mach 3.07 tunnel Lewis 18- by 18-in. Mach 1.89 tunnel	Two-dimensional inlet 	Isen-tropic or two oblique shocks	Throat ram scoop	3.07 1.89	Isentropic 0.575 2-S .538 Isentropic 0.97 2-S .907	+8 to -8	0 to 6	Cowl and visor drag only			√ √	0.68 .96	*0.60 to 0.94 *.42 to 1.00	Compares drag of different visors and cowls and their effect on inlet performance

Bibliography

NACA-C-8070(2-13-58)

These strips are provided for the convenience of the reader and can be removed from this report to compile a bibliography of NACA inlet reports. This page is being added only to inlet reports and is on a trial basis.