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EXPERIMENTAL INVESTIGATION OF A MACH 5 ISENTROPIC SPIKE INLET AT AND BELOW DESIGN SPEED

By Leonard E. Stitt and Richard J. Flaherty

Lewis Research Center
Cleveland, Ohio

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TECHNICAL MEMORANDUM X-4

EXPERIMENTAL INVESTIGATION OF A MACH 5 ISENTROPIC SPIKE INLET AT AND BELOW DESIGN SPEED*

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SUMMARY

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An isentropic spike inlet designed for maximum external compression at Mach 5.0 was investigated over a range of Mach numbers at zero angle of attack. At the design point a peak total-pressure recovery of 43 percent was obtained, compared with a theoretical maximum of 50 percent. The corresponding cowl pressure drag coefficient was 0.04, based on maximum cross-sectional area. At Mach numbers lower than 2.5, boundary-layer separation behind the bow shock resulted in low total-pressure recoveries; for example, 75 percent at Mach 1.91 compared with a theoretical maximum of $99\frac{1}{2}$ percent. Also near Mach 2.0, the cowl-plus-additive-drag coefficient was at its maximum, 0.47, based on maximum cross-sectional area.

Author

INTRODUCTION

A program has been completed at the NASA Lewis Research Center in which the performance of various inlet types at Mach 5.0 has been obtained. The performances of (1) a two-dimensional external plus internal compression inlet and an axisymmetric isentropic-spike inlet with cylindrical cowl and dump diffuser, and (2) an all-internal conical compression inlet are presented in references 1 and 2, respectively.

This report presents the zero angle-of-attack performance of an isentropic spike inlet designed for maximum external compression at Mach 5.0. As a fixed-geometry configuration, this inlet was also investigated at Mach numbers down to 1.0 primarily to evaluate analytical methods for obtaining off-design performance: mass-flow ratio, total-pressure recovery, and additive drag. The inlet featured a low cowl projected area ($A_C/A_{max} = 0.20$) boundary-layer bleed at the throat, and a short subsonic diffuser.

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*Title, Unclassified.

SYMBOLS

A	area
C_D	drag coefficient
C_p	pressure coefficient
M	Mach number
m	mass-flow rate
P	total pressure
p	static pressure
Re	Reynolds number
r	radius
T	total temperature
w	airflow
x	axial distance
y	distance normal to inlet axis
δ	ratio of total pressure to NASA standard sea-level pressure, $P_2/2116$ lb/sq ft
θ	ratio of total temperature to NASA standard sea-level temperature, $T_2/519^\circ$ R

Subscripts:

a	additive
c	cowl
i	inlet capture
max	maximum
s	spike
0	free stream

1 inlet-lip station

2 diffuser-exit station

Pertinent areas:

A_i 15.80 sq in.

A_{max} 19.65 sq in.

A_1 1.68 sq in.

A_2 4.27 sq in.

APPARATUS AND PROCEDURE

The model shown in figure 1 was designed for 99-percent total-pressure recovery through the initial shock followed by isentropic compression to an average Mach number of 2.52 at the inlet throat. Assuming a normal shock at Mach 2.52, the theoretical throat total-pressure recovery is about 50 percent. Both the spike contour (fig. 2) and the compression limit were computed by extending the results of reference 3 up to Mach 5.0. The subsonic diffuser had an initial equivalent 1° conical expansion followed by a 12° conical expansion to the survey-station area, which was sized to have a Mach number of 0.20 at a free-stream Mach number of 5.0.

The internal cowl lip angle of 14° was selected to keep the local flow deflection within 5° of the detachment value. The centerbody contour was designed so that no internal contraction resulted. With an initial lip angle of 18° the projected area of the external cowl was arbitrarily selected as 20 percent of the maximum cross-sectional area. The cowl drag coefficient, based on maximum cross-sectional area, was determined to be 0.035 from two-dimensional shock-expansion theory.

A boundary-layer bleed was located on the centerbody just downstream of a line from the lip, normal to the spike surface. This bleed was designed with a rounded lip since it would always be in subsonic flow with the inlet operating at critical conditions. The bleed air was ducted into the centerbody (fig. 2(c)) and back to the free stream through the hollow support struts (fig. 2(a)).

Mass-flow ratio was regulated by a remotely operated plug and was computed from a measured total-pressure recovery at the survey station and the assumption of isentropic flow to the choked exit area. Both spike and cowl pressure drag coefficients were obtained by integrating static pressure distributions on the surfaces.

The performance of this inlet at zero angle of attack was obtained over the following range of Mach numbers and Reynolds numbers, based on an inlet diameter of 4.48 inches:

Facility	Free stream Mach number, M_0	Reynolds number, Re, $\times 10^{-6}$
1- by 1-foot variable Mach number wind tunnel	4.97 4.05 3.43 2.94 2.43	1.07 1.48 1.08 1.57 1.62
18- by 18-inch supersonic wind tunnel	1.91	1.26
8- by 6-foot supersonic wind tunnel	1.98 1.48 1.00	1.79 1.85 1.72

RESULTS AND DISCUSSION

The mass-flow pressure-recovery characteristics of the fixed Mach 5.0 design are presented for a range of Mach numbers in figure 3. Significantly, an abrupt drop in total-pressure recovery occurred from Mach 2.43 to 1.98. The schlieren photographs of figure 4 indicate that this low recovery results from flow separation behind the bow shock on the spike surface. At Mach 1.91 (fig. 4(d)) the separated flow can be seen to fill the entire inlet throat, resulting in a peak recovery of only 75 percent, compared with a theoretical maximum of $99\frac{1}{2}$ percent. As the Mach number was progressively reduced below 1.91, the peak pressure recovery increased, but was always less than the normal shock value at the lower Mach numbers.

Some of the more important inlet parameters are summarized and presented as a function of Mach number in figure 5. A peak pressure recovery of 43 percent was obtained at Mach 4.97 compared with a limiting recovery of 50 percent. The peak recovery follows the theoretical curve down to about Mach 3.0 below which the flow separation on the spike results in low recoveries, as discussed previously.

Measured maximum mass-flow ratio (fig. 5(b)) is compared with a theoretical mass flow that was computed by applying the continuity equation between the free-stream and inlet throat, and hence does not account for any internal bleed flow. A supersonic recovery of 0.99 was assumed at the throat and the corresponding Mach number was computed using reverse Prandtl-Meyer flow expansion on the spike surface aft of the initial shock. When the flow detached from the external spike, the mass flow was computed in the same manner, assuming a Mach number of 1.0 at the throat and no loss across the detached wave. The disagreement between the measured and computed mass-flow ratio near Mach 2.0 was primarily a result of the low throat recovery when the external flow separated behind the bow wave.

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The critical corrected weight flow of this inlet increased only about 15 percent from Mach 5.0 to the transonic range (fig. 5(c)). A schedule of this type would match an engine with nearly constant weight-flow requirements, such as a ramjet.

Cowl pressure drag, which was computed at the peak pressure-recovery point, had a value of 0.04 at Mach 5.0, compared with a theoretical value of 0.035 from two-dimensional shock-expansion theory. The cowl drag remained constant down to Mach 3.0, then decreased with decreasing Mach number, becoming a thrust below Mach 2.0 because of the leading-edge suction. Cowl pressure distribution data (fig. 6) are included to indicate the level of the cowl pressure coefficient over the Mach number range.

Additive drag was computed by the method presented in reference 4; that is, from the change in momentum between the free stream and the inlet throat. The force on the spike centerbody was determined experimentally from an integration of the static-pressure distribution on the spike surface (fig. 7). The cowl-plus-additive-drag coefficient peaks at about Mach 1.8 at a value of about 0.47, based on maximum cross-sectional area. A total drag coefficient of 0.31 was obtained at Mach 1.0, indicating that the additive drag ($C_{D_a} = 0.47$) was only partially counterbalanced by the suction force on the cowl. Unpublished data obtained at Mach 1.0 in the NASA Lewis 8- by 6-foot tunnel gave similar results with a Mach 3.0 double-cone inlet.

SUMMARY OF RESULTS

The following results were obtained with an all-external compression isentropic spike inlet at zero angle of attack and Mach numbers from 5.0 to 1.0:

1. A peak total-pressure recovery of 43 percent was obtained at Mach 5.0, compared with a theoretical maximum of 50 percent. At the same Mach number the cowl pressure drag was 0.04, based on maximum cross-sectional area with a 20 percent cowl projected area.

2. At Mach numbers less than 2.50 the boundary layer separated behind the bow wave on the external spike. This separation resulted in low over-all total-pressure recovery; for example, 75 percent at Mach 1.91 compared with a theoretical $99\frac{1}{2}$ percent. The cowl-plus-additive-drag coefficient peaked in this region at a value of about 0.47 based on maximum cross-sectional area.

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Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, March 2, 1959

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1. Connors, James F., and Anderson, Leverett A., Jr.: Performance of an Axisymmetric External-Compression and a Two-Dimensional External-Internal Compression Inlet at Mach 4.95. NASA MEMO 12-18-58E, 1959.

2. Stitt, Leonard E., and Obery, Leonard J.: Performance of an All-Internal Conical Compression Inlet with Annular Throat Bleed at Mach Number 5.0. NACA RM E58E14, 1958.

3. Connors, James F., and Meyer, Rudolph C.: Design Criteria for Axisymmetric and Two-Dimensional Supersonic Inlets and Exits. NACA TN 3589, 1956.

4. Sibulkin, Merwin: Theoretical and Experimental Investigation of Additive Drag. NACA Rep. 1187, 1954. (Supersedes NACA RM E51B13.)

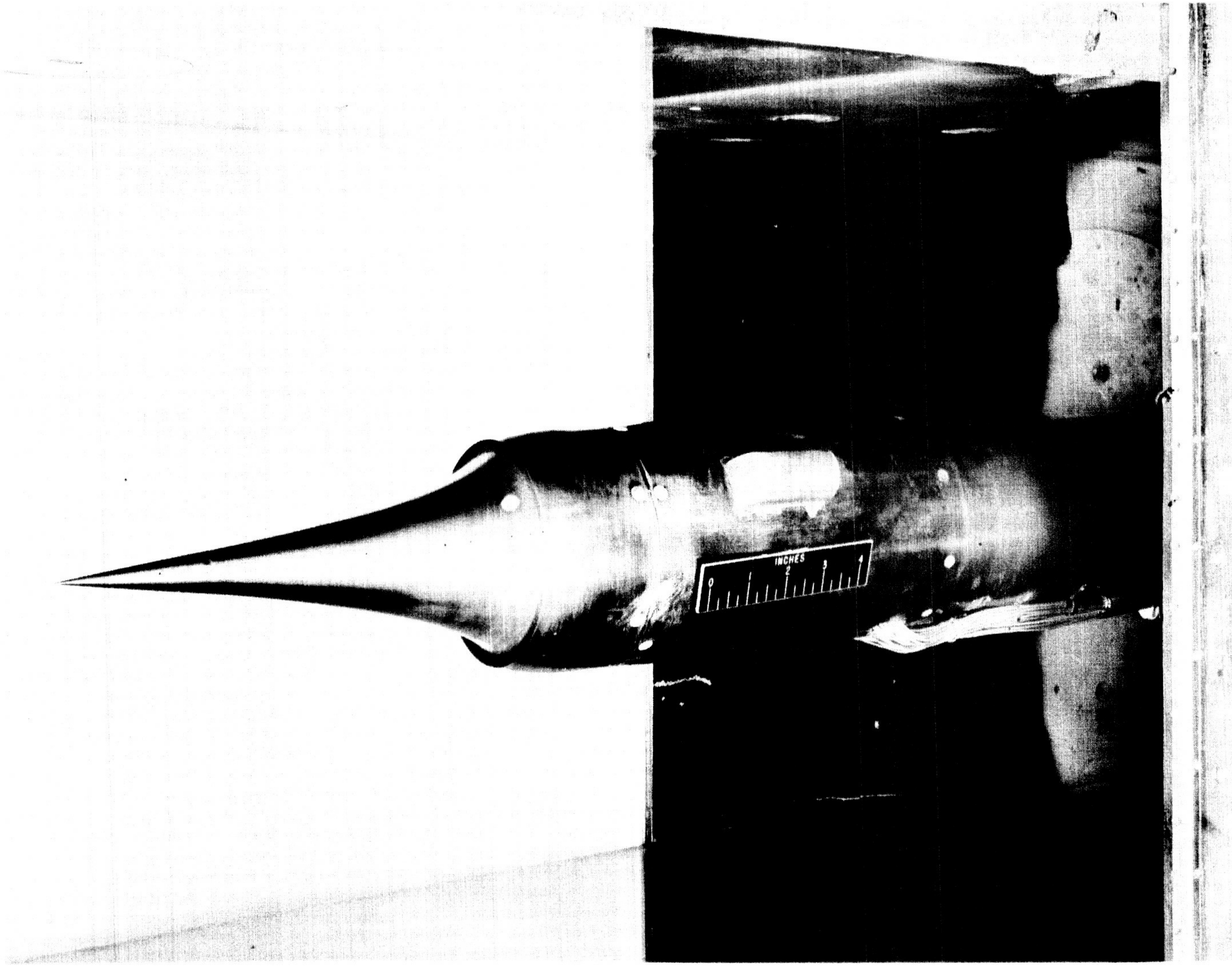

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Figure 1. - Mach 5.0 isentropic spike inlet model in 18- by 18-inch supersonic wind tunnel.

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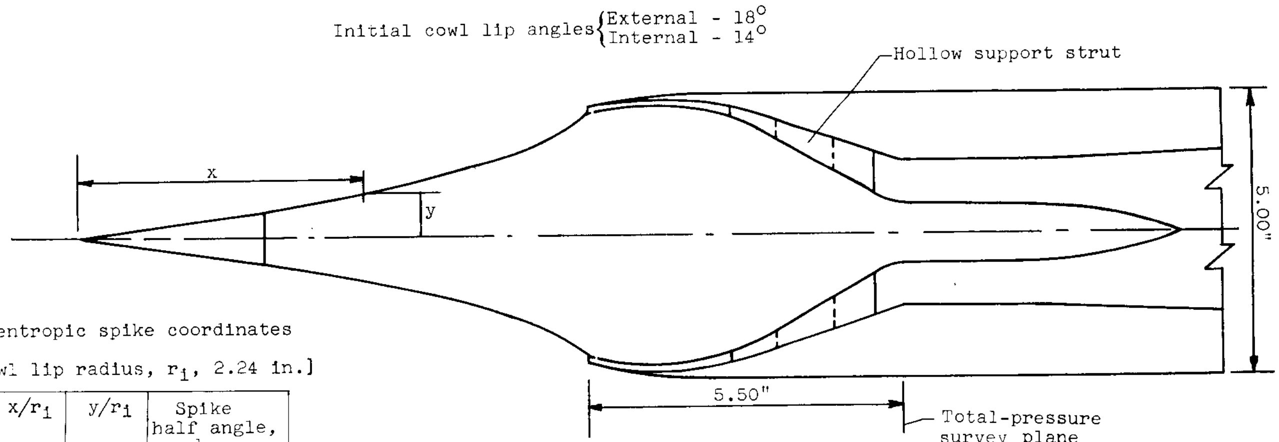
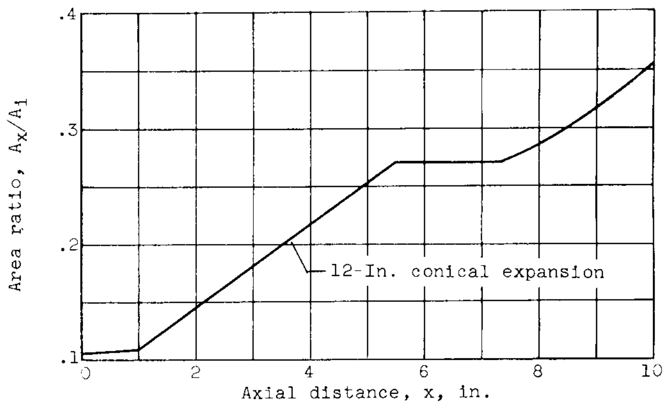


(a) General layout.

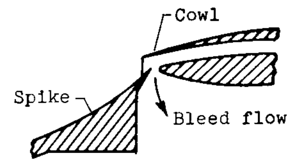
Isentropic spike coordinates

[Cowl lip radius, r_1, 2.24 in.]

x/r_1	y/r_1	Spike half angle, deg
0.0	0.0	8
1.457	.205	8
1.720	.251	--
2.051	.307	--
2.443	.383	--
2.656	.429	--
2.994	.511	--
3.246	.584	--
3.437	.648	--
3.560	.704	--
3.687	.753	--
3.768	.795	--
3.828	.831	--
3.873	.863	38
3.990	.958	38
3.956	1.000	Focal-point



(b) Subsonic diffuser area variation.



(c) Bleed detail.

Figure 2. - Isentropic spike inlet model details.

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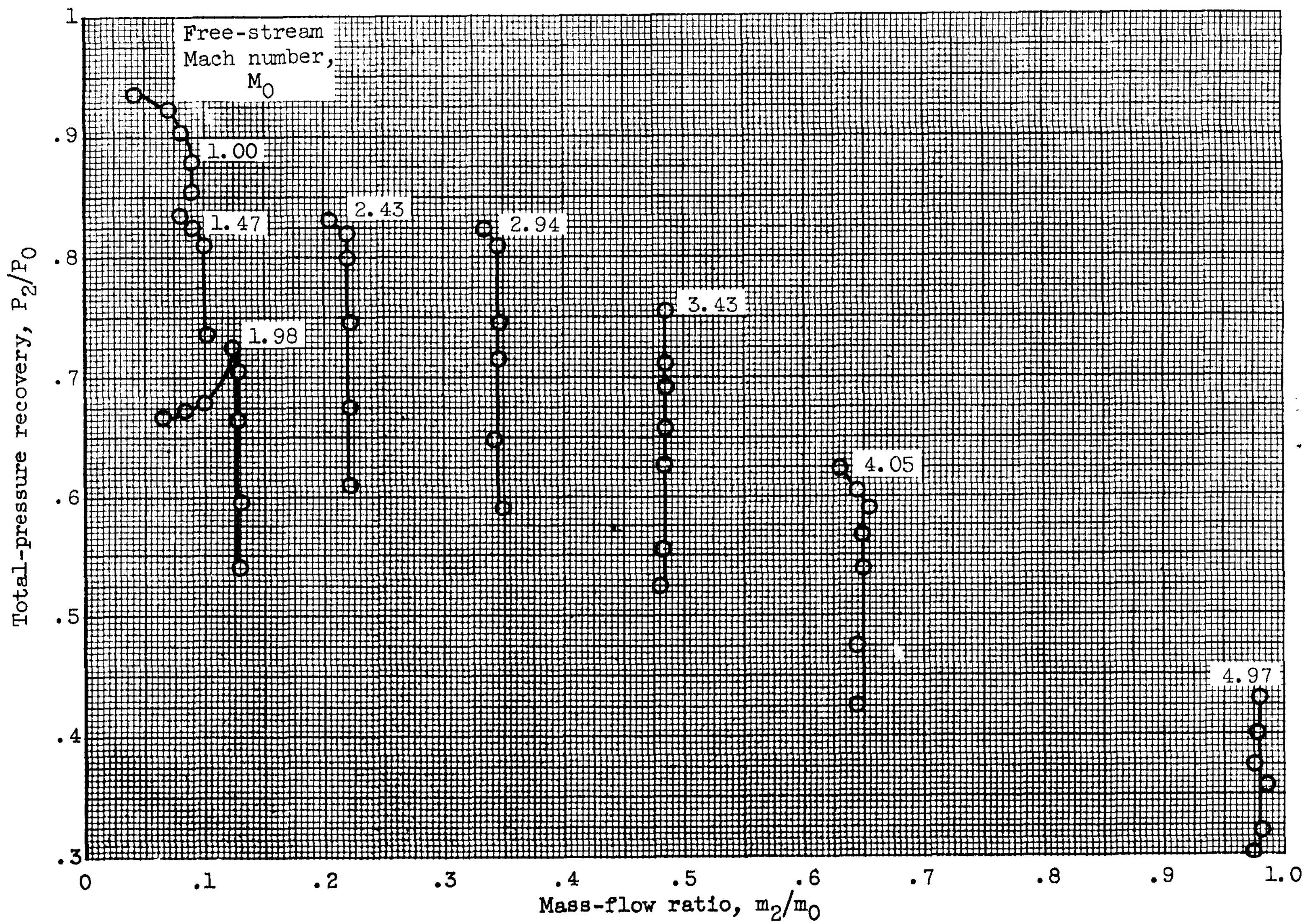

Figure 3. - Internal performance of isentropic spike inlet model.

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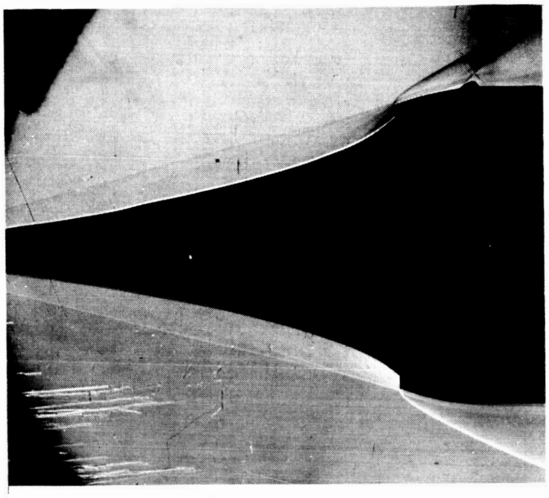
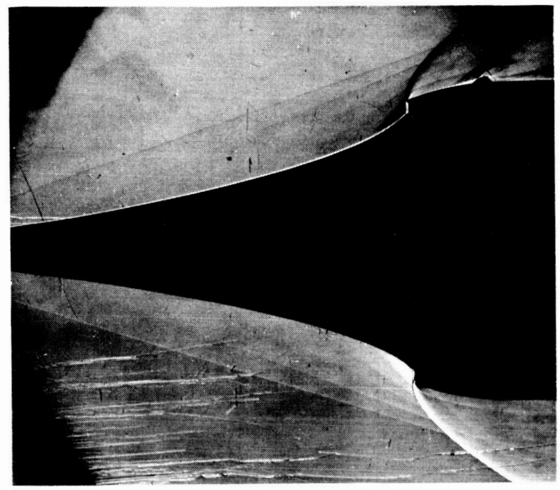
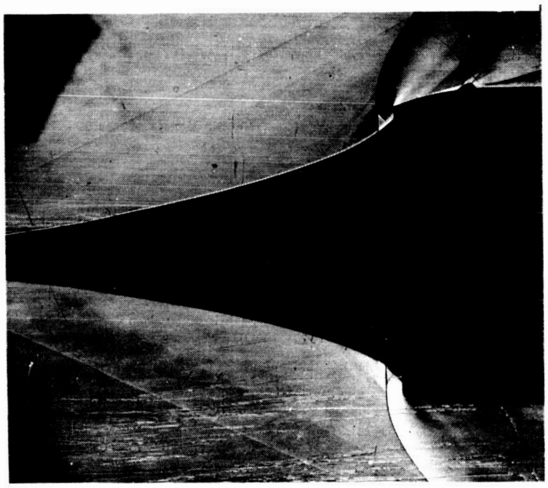


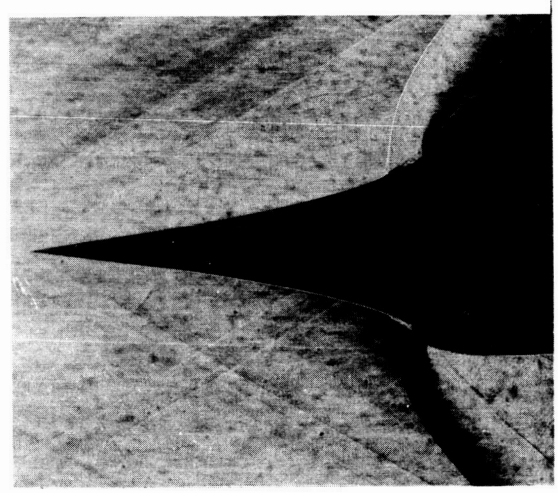
(a) Free-stream Mach number, M_0, 4.97.



(b) Free-stream Mach number, M_0, 3.43.



(c) Free-stream Mach number, M_0, 2.43.



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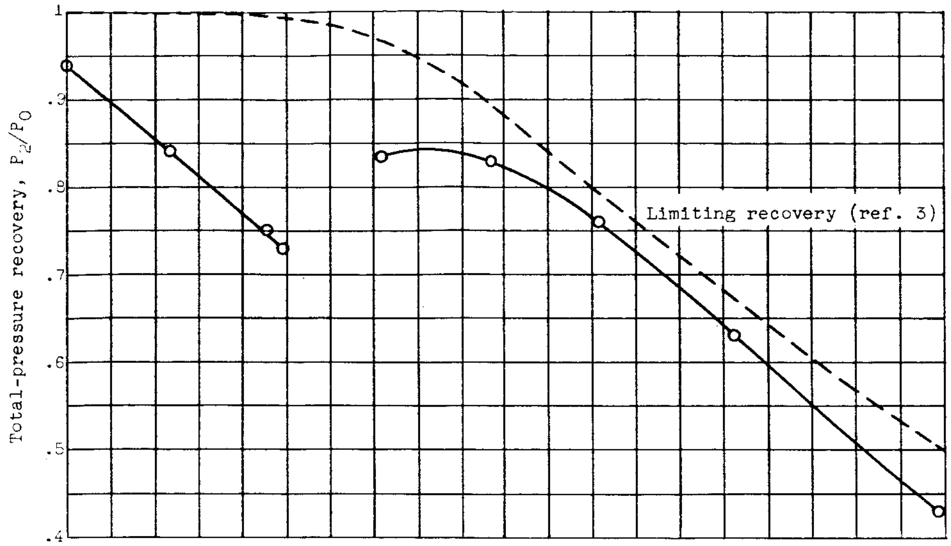
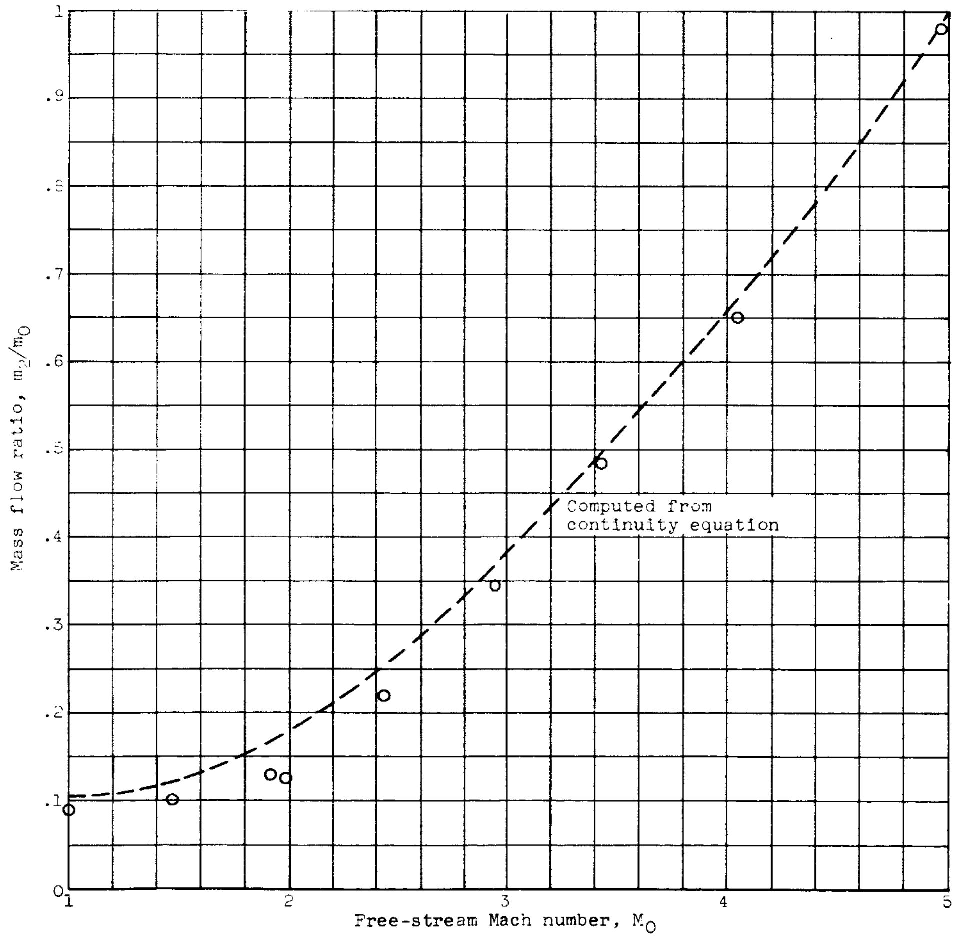
(d) Free-stream Mach number, M_0, 1.91.

Figure 4. - Isentropic spike inlet shock structure.



(a) Peak total-pressure recovery.



(b) Maximum mass-flow ratio.

Figure 5. - Performance of isentropic spike inlet model over a range of Mach numbers.

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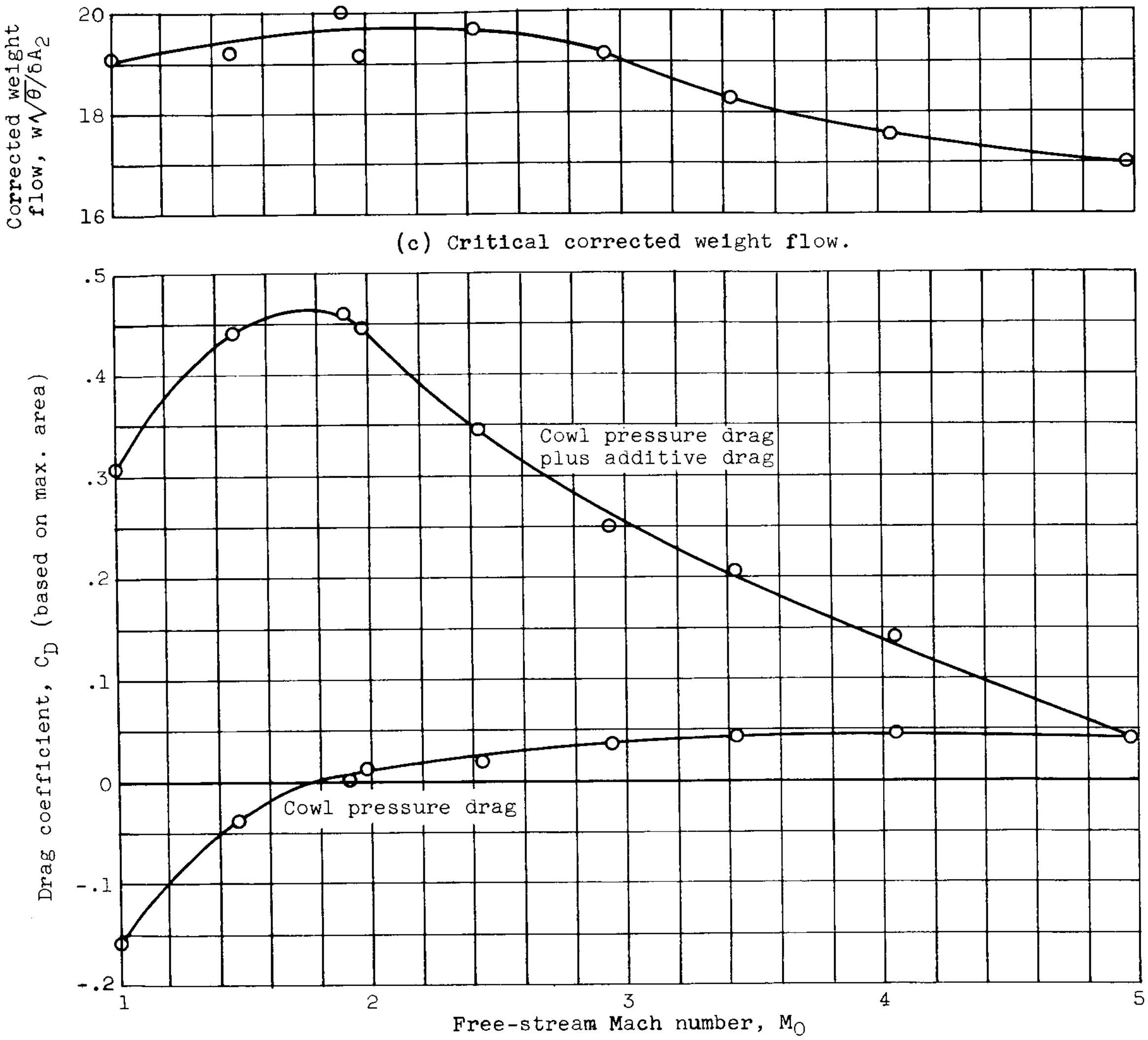

(c) Critical corrected weight flow.

(d) External drag.

Figure 5. - Concluded. Performance of isentropic spike inlet model over a range of Mach numbers.

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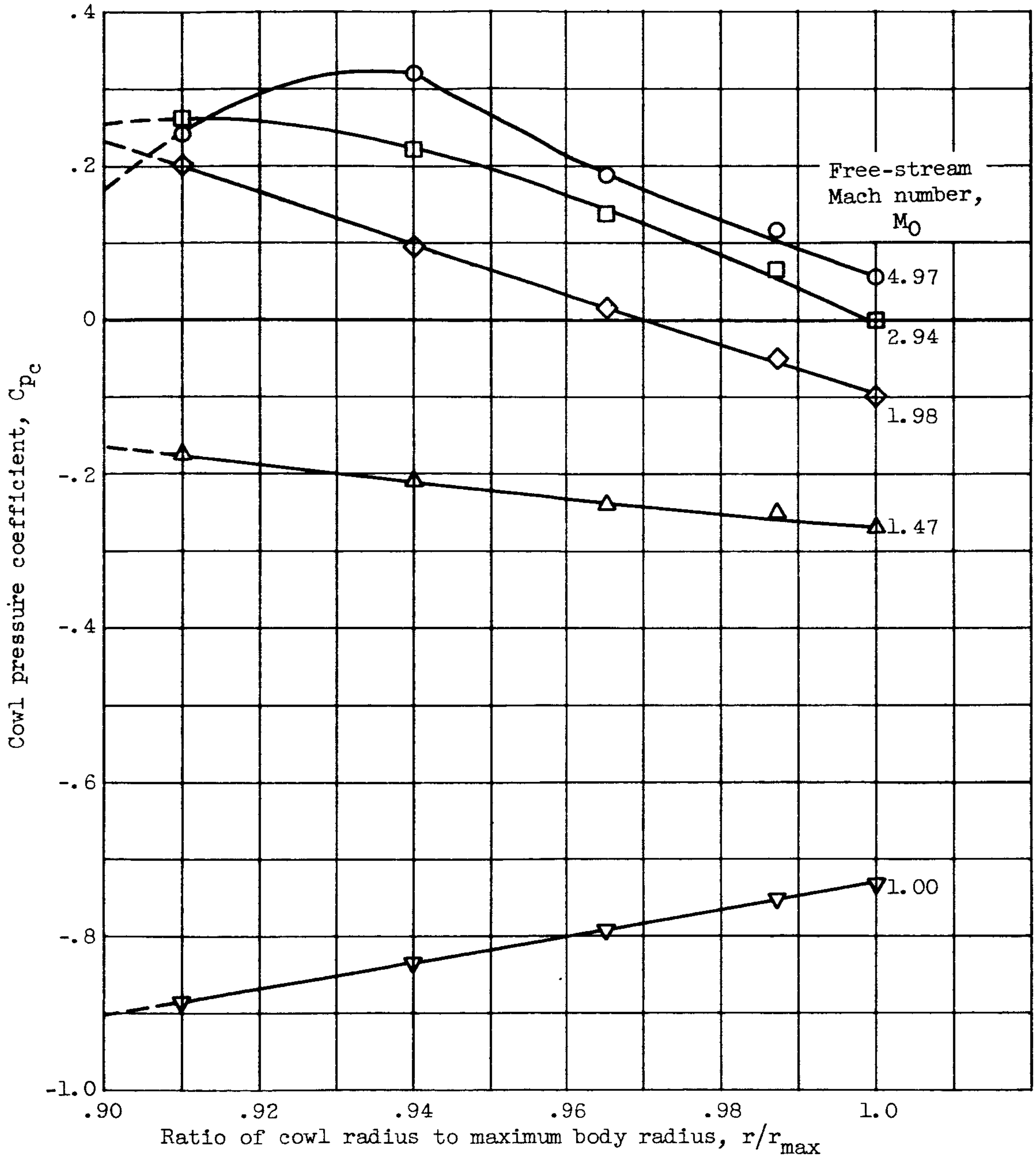

Figure 6. - Cowl pressure distributions for isentropic spike inlet model.

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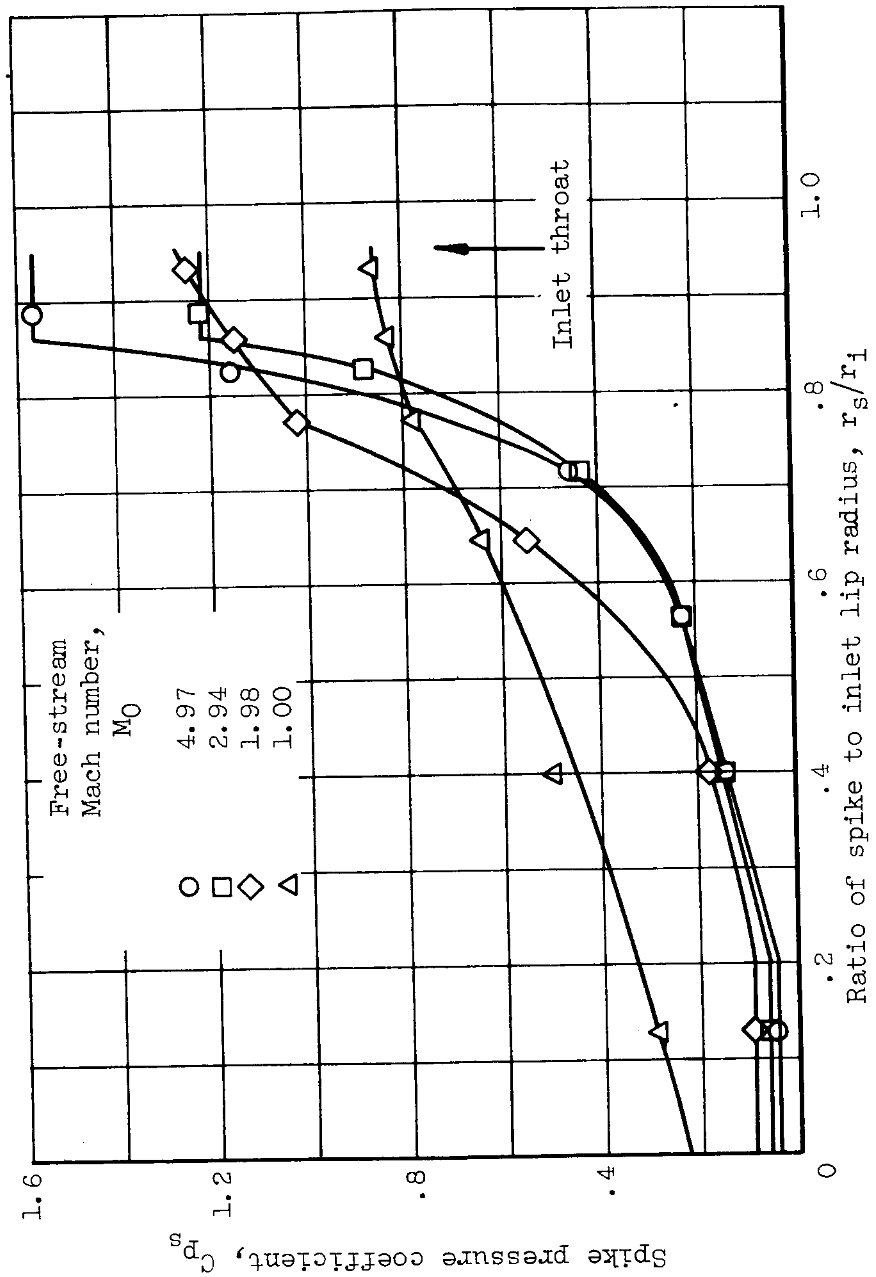

Figure 7. - Isentropic spike pressure distribution.

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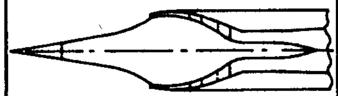
NOTES: (1) Reynolds number is based on the diameter of a circle with the same area as that of the capture area of the inlet.

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

INLET BIBLIOGRAPHY SHEET

Report and facility	Description			Test parameters				Test data				Performance		Remarks
	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	
CONFID. NASA TM X-4 1- by 1-ft variable Mach number wind tunnel		Isentropic	Flush slot bleed at inlet throat	4.97 4.05 2.94 1.98 1.00	1.07 1.48 1.57 1.79 1.72	0	0	√ √ √ √ √			√ √ √ √	0.43 .63 .83 .73 .94	0.98 .65 .35 .13 .09	Isentropic spike inlet designed for maximum external compression at Mach 5.0
CONFID. NASA TM X-4 1- by 1-ft variable Mach number wind tunnel		Isentropic	Flush slot bleed at inlet throat	4.97 4.05 2.94 1.98 1.00	1.07 1.48 1.57 1.79 1.72	0	0	√ √ √ √ √			√ √ √ √	0.43 .63 .83 .73 .94	0.98 .65 .35 .13 .09	Isentropic spike inlet designed for maximum external compression at Mach 5.0
CONFID. NASA TM X-4 1- by 1-ft variable Mach number wind tunnel		Isentropic	Flush slot bleed at inlet throat	4.97 4.05 2.94 1.98 1.00	1.07 1.48 1.57 1.79 1.72	0	0	√ √ √ √ √			√ √ √ √	0.43 .63 .83 .73 .94	0.98 .65 .35 .13 .09	Isentropic spike inlet designed for maximum external compression at Mach 5.0
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Bibliography

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