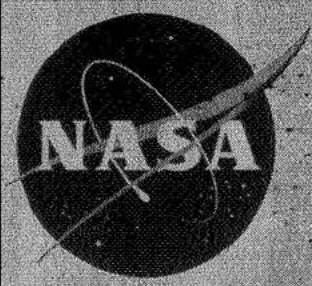


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TECHNICAL MEMORANDUM

X-660

EFFECTIVENESS OF TWO FLAP CONTROLS ON A MERCURY
TYPE CAPSULE AT A MACH NUMBER OF 15 IN THE
AMES HYPERSONIC HELIUM TUNNEL

By Thorval Tendeland and B. Douglas Pearson, Jr.

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Moffett Field, Calif.

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EFFECTIVENESS OF TWO FLAP CONTROLS ON A MERCURY
TYPE CAPSULE AT A MACH NUMBER OF 15 IN THE
AMES HYPERSONIC HELIUM TUNNEL*

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SUMMARY

X63-10145
The trim effectiveness of two types of control flaps was measured at a Mach number of 15 and a Reynolds number of 1.8 million (based on maximum diameter). The two flaps were: (1) a flat surface perpendicular to the model axis at the juncture between the spherical segment front face and the conical afterbody, and (2) a "conical" flap which was an extension, in the forward direction, of the conical afterbody. The ratios of flap area to model frontal area were 0.049 and 0.047 for the flat and conical flaps, respectively. The measured shock-wave shapes for the basic capsule at angles of attack are compared to predicted shapes. A brief description of the wind tunnel and the nozzle flow characteristics at $M = 15$ also is presented.

Results indicate that for approximately equal ratios of flap area to frontal area the conical flap had the greater trim effectiveness. Force and moment coefficients for the basic capsule and for the capsule with the flat flap were adequately predicted by theory. Force and moment coefficients measured in helium at a Mach number of 15 agreed well with those measured in air at Mach numbers of 3.3 and 5.5. The largest difference was in drag coefficient which in helium was approximately 7 percent lower than in air. Measured shock-wave shapes agreed with estimated shapes in the nose region at angles of attack from 0° to -15° .

Author

INTRODUCTION

The advantages of generating lift on a vehicle entering the earth's atmosphere from a space flight mission are well known (e.g., refs. 1 and 2). The ability to generate lift has become generally accepted as

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a requirement for manned spacecraft and a number of investigations have been conducted to evaluate various devices to trim capsules in a lifting attitude. In reference 3, the use of center-of-gravity offset was investigated as a means of trimming a Mercury type capsule; while in reference 4 a study was made of the effectiveness of aerodynamic controls consisting of flaps attached at the juncture of the spherical forebody and the conical afterbody of a Mercury type capsule. Reference 4 also gives data obtained in a wind tunnel at $M = 3.3$ and in a ballistic range at $M = 5.5$. The purpose of the investigation reported herein was to provide data at a higher Mach number (namely $M = 15$ in helium),¹ for two of the control arrangements investigated in reference 4 and to compare the helium results with the air data and predicted values. The tests were conducted in a new hypersonic helium tunnel at a free-stream Reynolds number of 1.8 million (based on maximum model diameter). A brief description of the helium tunnel and the nozzle flow characteristics at $M = 15$ is presented.

SYMBOLS

A_F	area of flap
d	model diameter
C_D	drag coefficient, $\frac{\text{drag}}{qS}$
C_L	lift coefficient, $\frac{\text{lift}}{qS}$
C_m	pitching-moment coefficient, $\frac{\text{pitching moment}}{qSd}$
$\frac{L}{D}$	lift-drag ratio
C_p	pressure coefficient
l	length of flap
M	free-stream Mach number
p_{t1}	stagnation pressure

¹The adequacy of test data obtained in helium atmospheres to assess the characteristics of vehicles at hypersonic speeds has been discussed in reference 5.

p_{t2}	pitot pressure
q	free-stream dynamic pressure
q'	local dynamic pressure
R	free-stream Reynolds number per inch
r	helium purity, percent by volume
S	reference area, $\frac{\pi d^2}{4}$
y	distance from test section center line, normal to the flow
α	angle of attack, referenced to body center line
γ	ratio of specific heats of gas
δ	angle between free-stream flow vector and the tangent to the capsule surface
θ	angle of rotation of impact survey rake
μ	angle between local flow vector and the tangent to the flap surface

WIND TUNNEL

Description

The hypersonic helium tunnel is a closed-circuit blowdown tunnel and is shown schematically in figures 1 and 2. The major components are as follows: (1) a high-pressure reservoir for helium storage at 6,000 pounds per square inch, (2) a heater filled with cast-iron pebbles to maintain a constant stagnation temperature of about 70° F during a test, (3) four interchangeable contoured nozzles which provide Mach numbers of 8, 15, 20, and 26, (4) a 20-inch diameter test section equipped with interchangeable curved or flat glass optical windows for flow visualization, (5) a model support which consists of a position feedback system actuated by hydraulic power and controlled electrically by a programmer through an angle-of-attack range from +30° to -15°, (6) a straight, constant diameter diffuser, (7) two spheres for low-pressure storage with a total volume of 447,000 cubic feet, (8) a reciprocating helium compressor consisting of two parallel vacuum cylinders followed by a series of seven compression cylinders, (9) a helium purifier in which helium gas is cooled by means of subcooled liquid nitrogen to condense the impurities, (10) a Beckman model 210 data acquisition system. The tunnel can be operated approximately once every 2 hours. To obtain high compression ratios to start

the tunnel flow, the circuit upstream of the nozzle is prepressurized to a value higher than the operating stagnation pressure. Tunnel flow is then started by means of a quick-opening valve located upstream of the nozzle. Stagnation pressures are controlled to within 1 percent of the desired value by means of a stagnation pressure controller. Helium purity during tunnel operation is approximately 99.4 to 99.5 percent by volume.

Preliminary investigations of tunnel starting problems indicated that for flat-faced models, supersonic flow could be established in the test section only if the model diameter were less than 1-1/2 inches. To permit the testing of larger models, a "flow starting spike" is placed ahead of the model while the tunnel is started and stopped (see fig. 2). During the test period, the spike is retracted upward into the boundary layer along the wall. As well as allowing testing of flat-faced models as large as 3 inches in diameter, the spike arrangement reduces axial forces on the models to tolerable limits (reduction amounted to 50 percent of starting value).

Nozzle Flow Characteristics

To evaluate stream properties a survey of total pressure was made in the test section. The results of surveys using the Mach number 15 nozzle are shown in figure 3. Plotted in this figure is the ratio of pitot pressure to stagnation pressure as measured on horizontal and vertical diameters normal to the flow (i.e., $\theta = 0^\circ$ and 90° , respectively). Data are shown for two stagnation pressures at four longitudinal stations in the test section, spaced 7 inches apart (see fig. 2 for station locations). Pitot-pressure surveys were made with a 15-tube total-pressure rake which was positioned at the desired test-section station by means of suitable extensions between the rake and the model support. Pressures were measured with strain-gage-type pressure transducers. Pitot-pressure data were corrected for real gas effects by the method given in reference 6. These corrections were in the order of 2 to 3 percent. The helium purity was approximately 99.4 percent for all but one test. The 0.6-percent contamination was due to air and its effect on measured pitot pressures was estimated from results given in reference 7 to be in the order of 1 percent. Since this is a small error, no corrections for impurities were made to the data.

As may be noted from figure 3 the ratio of p_{t2}/p_{t1} was fairly constant for a distance of approximately 5 inches on either side of the test section, indicating a test core approximately 10 inches in diameter. Therefore with a 20-inch-diameter test section the boundary layer is approximately 5 inches thick. The approximate boundary-layer edge is denoted in this figure as the intersection of straight lines faired through the data. Values of p_{t2}/p_{t1} on the horizontal and vertical



diameters were in good agreement and did not vary appreciably between stations 0 and 14. At station 21 values of p_{t2}/p_{t1} near the center line were less than those at the outer extremity of the core and less than those measured at the other three stations.

Mach number as determined from the ratio of p_{t2}/p_{t1} (see ref. 8) are plotted in figure 4. Only a 3-percent reduction in Mach number is indicated in this figure as a result of a 50-percent reduction in Reynolds number. At the lower Reynolds number the thicker nozzle boundary layer caused a reduction in the effective test section area and thus reduced the Mach number. For the design Reynolds number of 0.744×10^6 per inch, the measured Mach number agrees well with the design Mach number of 15, indicating that the boundary-layer predictions calculated by means of reference 9 and used in the nozzle design were fairly accurate. At station 21 the increase in Mach number near the center line of the test section corresponds to the decrease in p_{t2}/p_{t1} noted in figure 3 at station 21.

No measurements were made to determine flow angularity in the test section. The constant and symmetrical Mach number distribution at stations 0, 7, and 14 suggests that the angularity of the flow is small. The change in stream angle along the center line was estimated from the change in Mach number between these stations and the resulting change in Prandtl-Meyer angle. (This approach is similar to that used in ref. 10.) The computed change in stream angle was in the order of 0.05° to 0.15° .

MODELS

The basic configuration was a body of revolution with a conical afterbody of 26.5° half-angle and a spherical-segment front face (see fig. 5). The face diameter was equal to the radius of the spherical segment. The moment center was 0.284 face diameters aft of the front face. Two models were tested in order to cover the desired angle-of-attack range ($+15^\circ$ to -60°). One model was rear-supported and one model was side-supported at 30° offset from the balance center line.

Two types of control flaps were tested with each model as shown in figure 5. The "flat" flap was a flat surface perpendicular to the model axis of revolution at the juncture between the front face and the afterbody. The "conical" flap was an extension, in the forward direction, of the conical afterbody. The ratios of flap area to model frontal area were 0.049 and 0.047 for the flat and conical flaps, respectively.

The model lift, drag, and pitching moment were measured at angles of attack from $+15^\circ$ to -60° by a flexure-type strain-gage balance (see fig. 6). The balance also served as the support sting for the models.





RESULTS AND DISCUSSION

Force and Moment Data

Values of C_m , C_L , C_D , and L/D for the basic capsule are shown in figure 7 for a test Reynolds number of 1.8 million (based on model diameter). In figure 8, values of C_m , C_L , C_D , and L/D are shown for the capsule equipped with flat and conical flaps. The base drag arising from the pressure difference between the free-stream static pressure and the static pressure measured at the cut-off base of the model was less than 1 percent of the measured drag and no adjustments for base drag were made to the data. For comparison with the helium results, data obtained in air at $M = 3.3$ and 5.5 for this shape (ref. 4) are also shown in these figures.

The helium data in figures 8(a) and 8(b) show that the conical flap trimmed the model ($C_m = 0$) at a somewhat more negative angle than did the flat flap. The trim angles were approximately -23° and -19° for the conical and flat flaps, respectively, and at these trim angles the lift-drag ratios were approximately 0.34 and 0.30.

For comparison with the experimental data, predicted force and moment coefficients are shown in figures 7 and 8. For the basic capsule (fig. 7) and for the capsule with a flat flap (fig. 8(a)) the predicted pressure coefficients were based on modified Newtonian theory (ref. 11) which considers pressures only on the surfaces facing into the stream. The following equations were used:

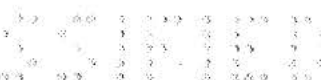
$$C_p = C_{p_{\max}} \sin^2 \delta \quad (1)$$

where

$$C_{p_{\max}} = \frac{\gamma + 3}{\gamma + 1} \left\{ 1 - \left[\frac{2}{(\gamma + 3)M^2} \right] \right\} \quad (2)$$

For helium at a Mach number of 15 and air at a Mach number of 3.3, values of $C_{p_{\max}}$ calculated from equation (2) are 1.75 and 1.76, which, for practical purposes, are equal. Therefore, force and moment coefficients predicted by modified Newtonian theory are the same for these helium and air conditions. For the model with the conical flap, force and moment coefficients are shown in figure 8(b). At angles of attack for which the local Mach number at the flap was less than 1 ($\alpha \lesssim -15.8^\circ$), impact pressure was used to predict pressure coefficients on the flap ($C_p = C_{p_{\max}}$); whereas, for a Mach number of more than 1 ($\alpha \gtrsim -15.8^\circ$), embedded Newtonian theory was used. The following equation (ref. 12) was used:





$$C_p = C_{p_{\max}} \sin^2 \delta + 2 \left(\frac{q'}{q} \right) \sin^2 \mu \quad (3)$$

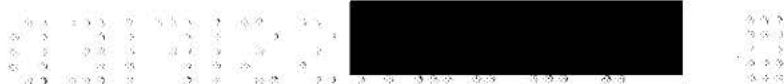
where δ is the angle between the free-stream flow vector and the tangent to the capsule surface at the flap location, and μ is the angle between the secondary shock and the surface of the model. For these tests, the secondary shock was assumed to be normal ($\mu = 90^\circ$). To determine the local value q' , the following assumptions were made concerning local flow conditions upstream of the flap: a total pressure corresponding to that downstream of a normal shock wave and a static pressure equivalent to the value predicted by Newtonian theory at the capsule surface.

The helium data for C_m , C_L , and L/D agree reasonably well with the theoretical data and with the air data over most of the angle-of-attack range for the capsule with or without the flaps. The largest discrepancy appears to be in values of C_D . At $\alpha = 0^\circ$ the model drag coefficients are approximately 7 percent lower than both the air data and the predictions. To further investigate the drag coefficients in helium, predictions of the flow field over the nose section of the capsule, without flaps and at zero angle of attack, were made by the method described in reference 13. The experimental shock-wave shape was used as an input condition in the calculation. Predictions of surface pressures by this method were then integrated over the surface of the nose section to determine the forebody drag coefficient. In the low density helium flow the forebody drag is essentially the total drag because afterbody pressures are negligible. The calculated value of C_D shown at zero angle of attack in figure 7 agrees well with the experimental helium data.

Shock-Wave Shapes

The knowledge of shock-wave shapes is helpful since it permits the prediction of local conditions in the flow field over the vehicle for many conditions. For example, as previously discussed, experimental shock-wave shapes can be used to calculate model surface pressures by the method given in reference 13; also the method described in reference 12 to predict pressure coefficients is based upon the shock-wave shape. Sample shadowgraphs of the models investigated are shown in figure 9. These photographs were taken through the curved windows of the test section. Therefore, all vertical measurements from the shadowgraphs had to be corrected to compensate for approximately a 10-percent error due to glass distortion. The correction factors were obtained from detailed calibrations of the windows and are believed to be accurate to 1 percent. The photographs (fig. 9) show the strong bow shock wave but because of the low test section density, details in the flow over the model are not visible.





Comparisons between measured and predicted bow shock waves for the basic capsule at 0° , -15° , and -30° angles of attack are shown in figure 10. Shock-wave patterns were predicted by the method of reference 14. This method can be used only for the capsule forebody between the sonic points which are assumed to be at the corner of the body or where the angle between the flow vector and the tangent to the surface is 45° . The method adequately predicts the shock-wave shape in the nose region in the angle-of-attack range from 0° to -15° , but for angles more negative than -15° , the prediction departs from the measured shapes near the test body corner.

CONCLUSIONS

The measured and predicted aerodynamic characteristics have been presented for a Mercury type capsule with two types of control flaps. The tests were made in the Ames Hypersonic Helium Tunnel at a Mach number of 15 and a Reynolds number of 1.8 million (based on maximum diameter). Comparison of the data for the two types of flaps and comparison of the measured characteristics in helium with those obtained in air and with those predicted indicate that:

1. The conical flap had the greater trim effectiveness resulting in a trim angle of approximately -23° for a lift-drag ratio of about 0.34; the flat flap had a trim angle of -19° for a lift-drag ratio of 0.30.
2. Modified Newtonian theory predicted the effectiveness of the flat flap reasonably well; the effectiveness of the conical flap was predicted by assuming impact pressure on the flap and by an embedded Newtonian correction when the local flow exceeded a Mach number of 1.
3. Force and moment coefficients measured in helium at a Mach number of 15 agreed well with those measured in air at Mach numbers 3.3 and 5.5. The largest difference was in drag coefficient with the helium data approximately 7 percent low as compared to the air data.
4. Shock-wave shapes on the forebody of the basic capsule were predicted for angles of attack from 0° to -15° .

Ames Research Center

National Aeronautics and Space Administration

Moffett Field, Calif., Aug. 10, 1962

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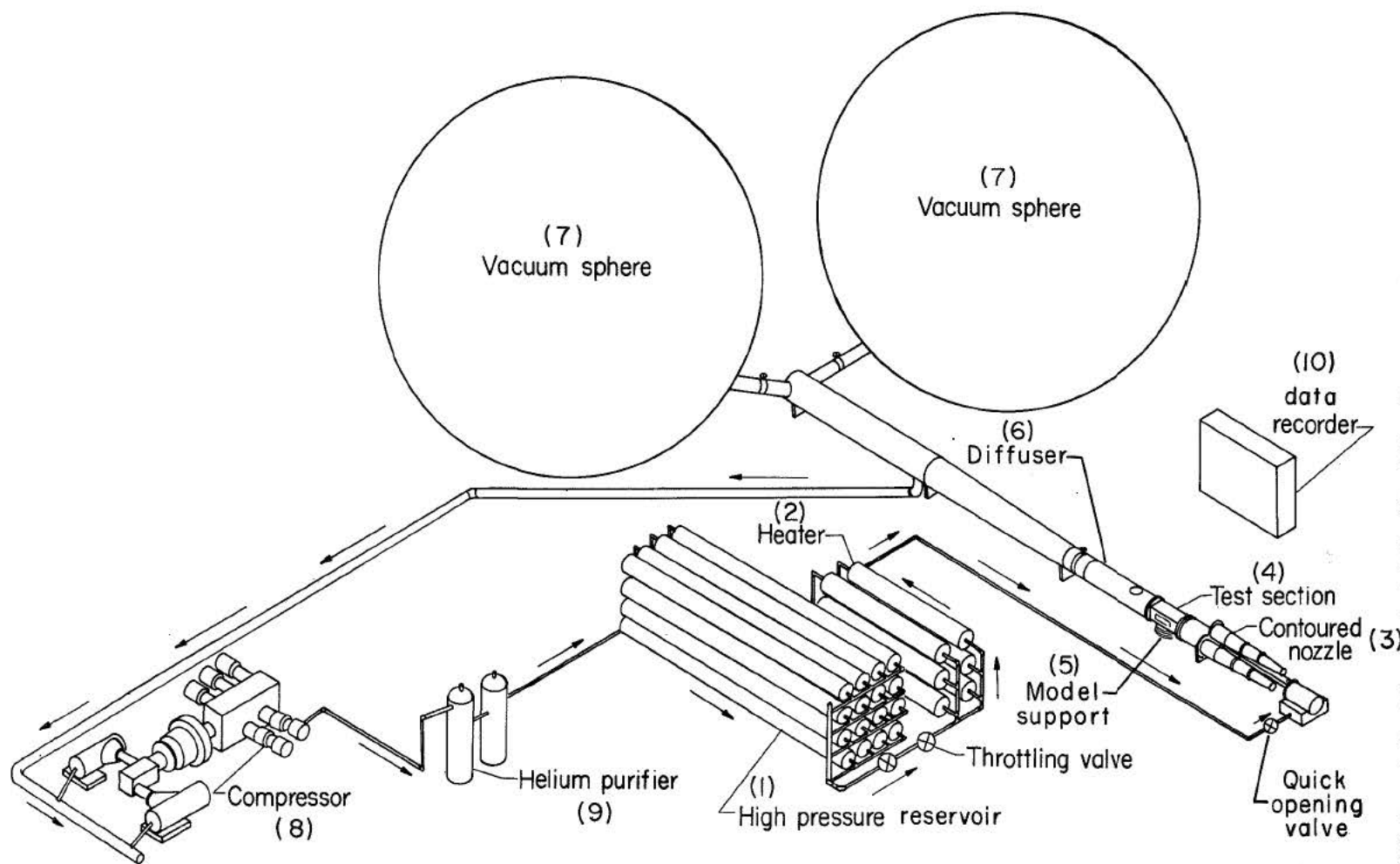


Figure 1.- Diagram of hypersonic helium tunnel.

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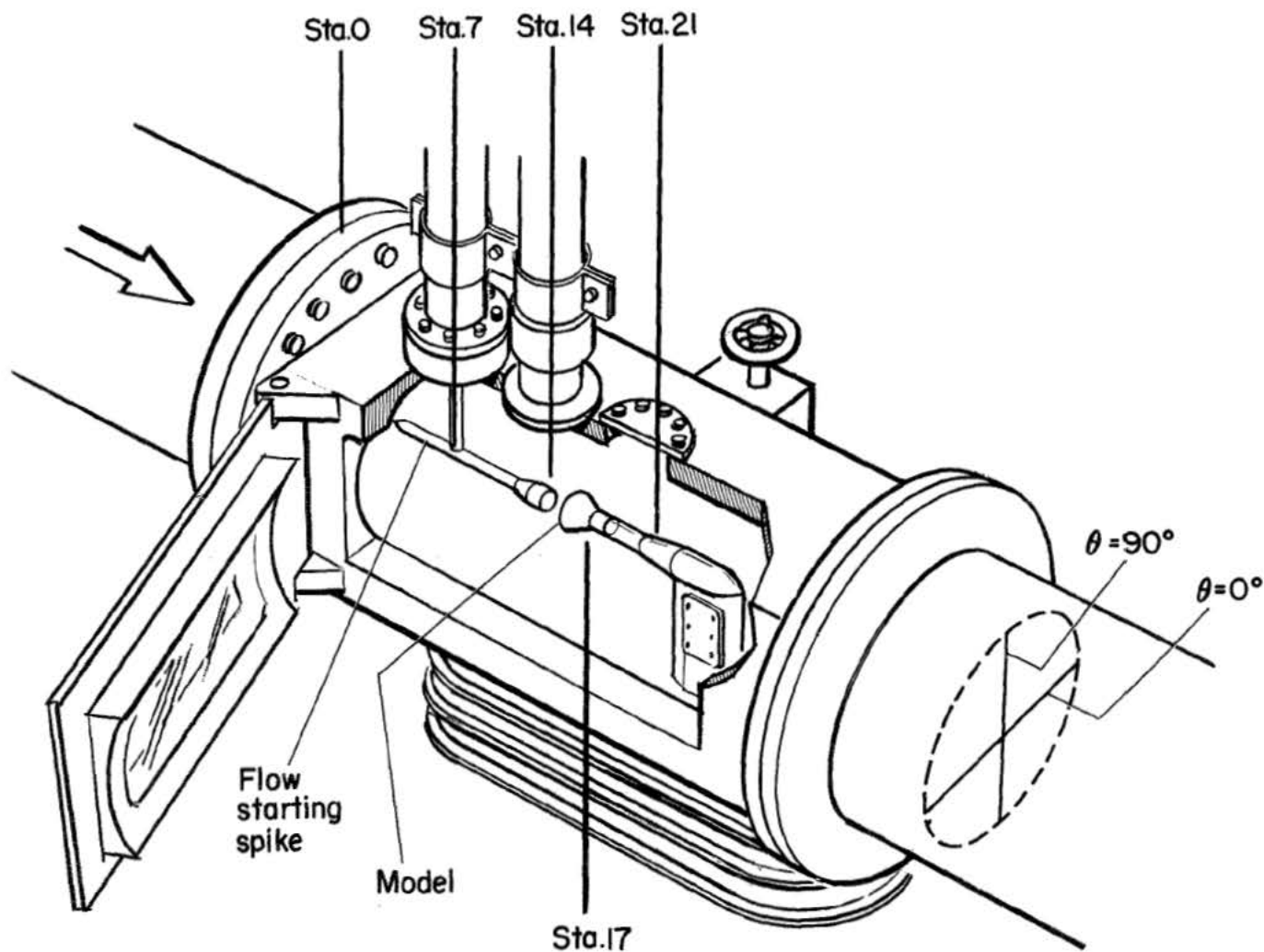
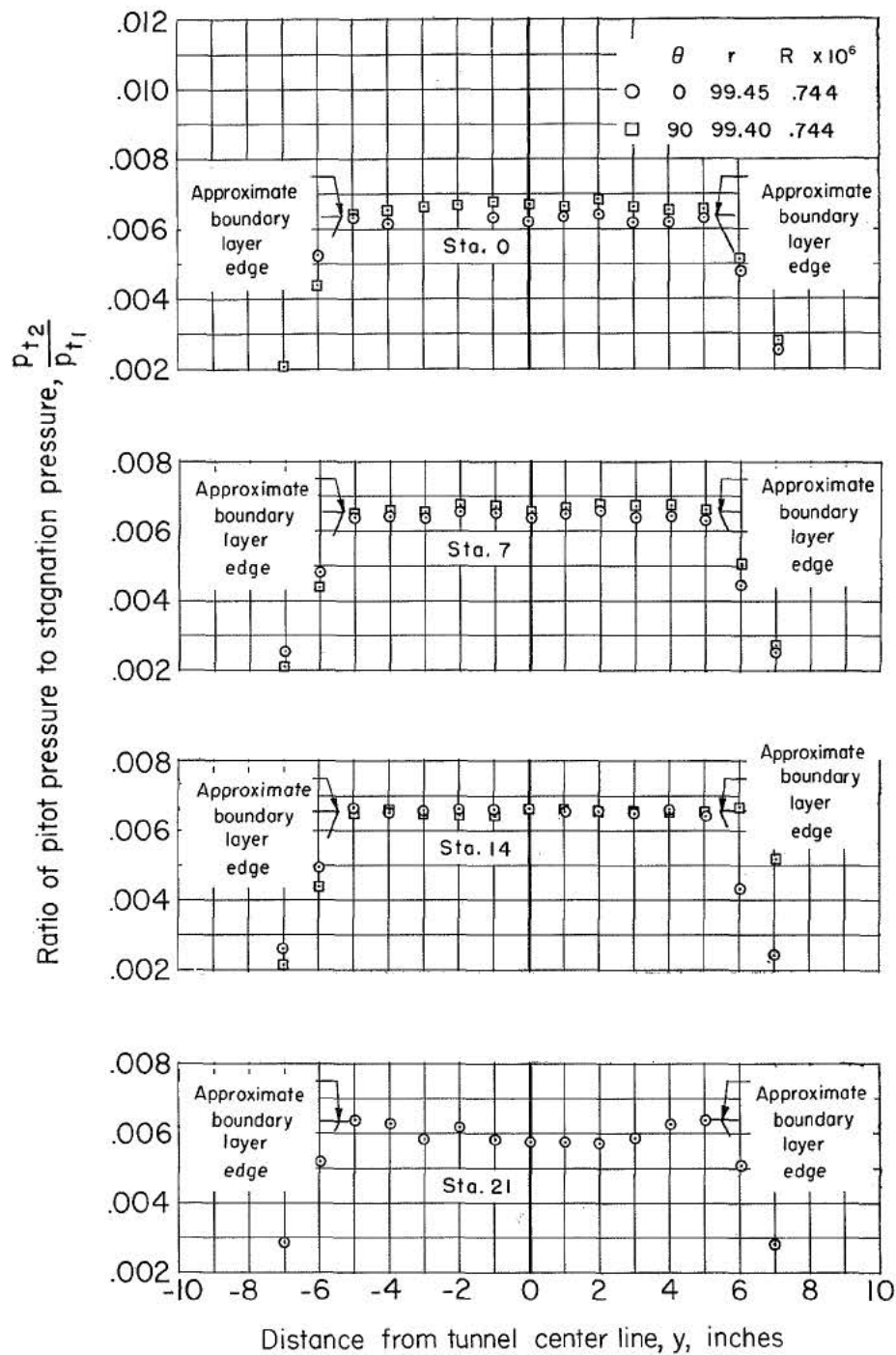
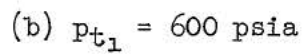


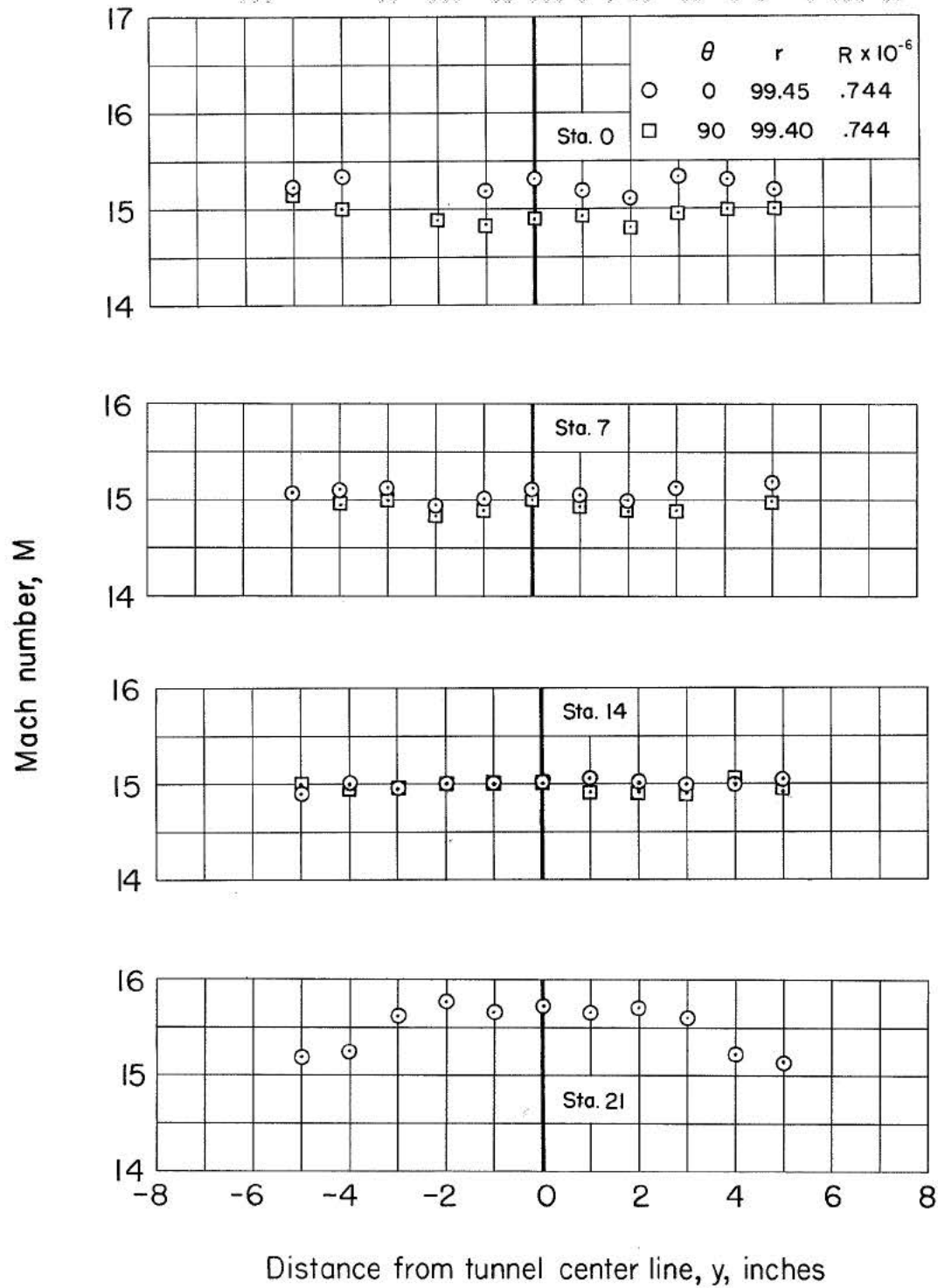
Figure 2.- Layout of the test section.



(a) $p_{t1} = 1200$ psia

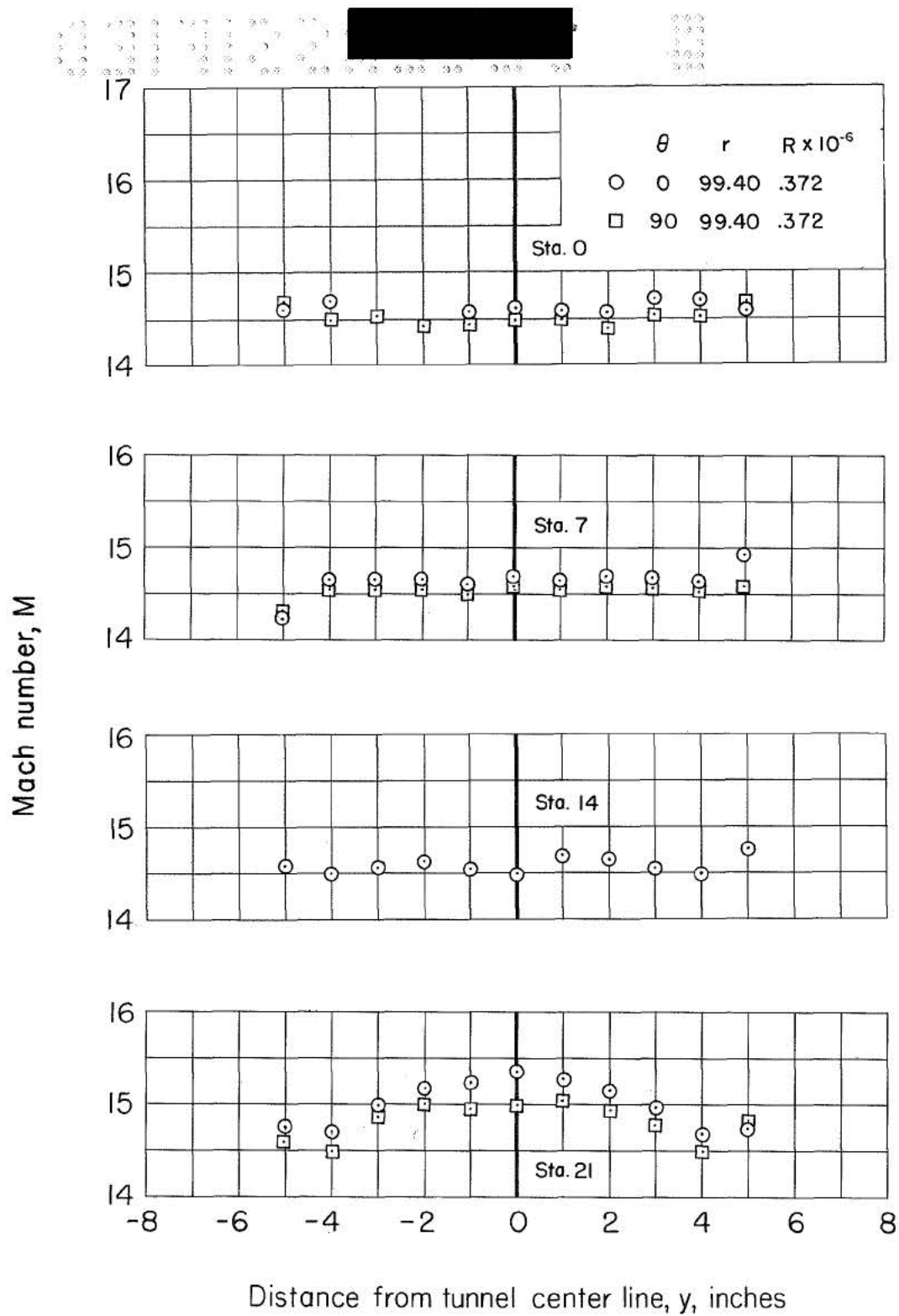
Figure 3.- Test-section pitot pressure distribution; nominal Mach number 15.





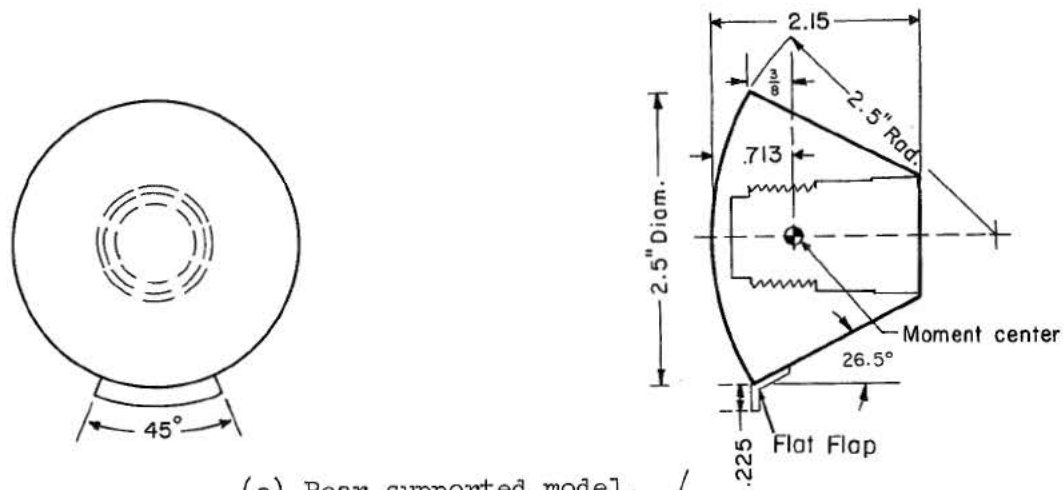
(a) $p_{t1} = 1200$ psia

Figure 4.- Test-section Mach number distribution.

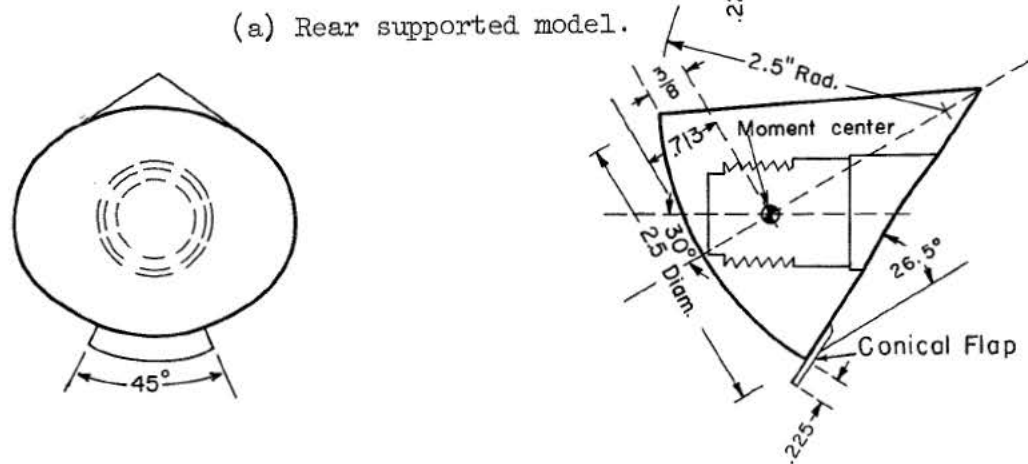


(b) $p_{t1} = 600$ psia

Figure 4.- Concluded.



(a) Rear supported model.



(b) Side supported model.

Figure 5.- Details of model and control flaps.

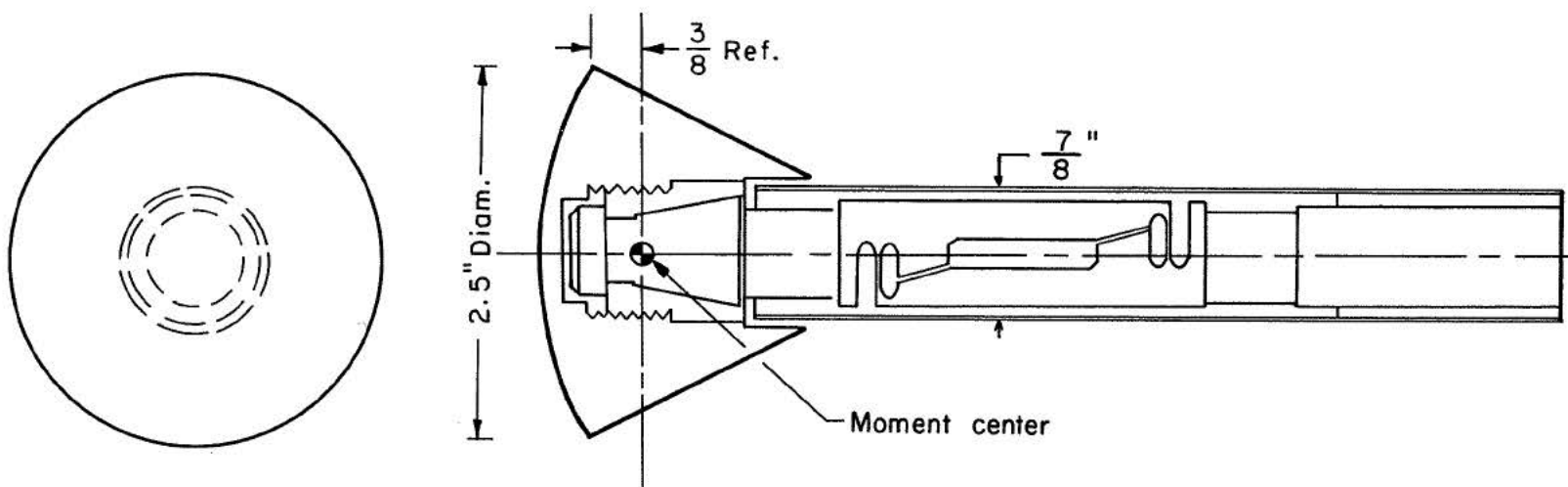


Figure 6.- Model support and force balance arrangement.

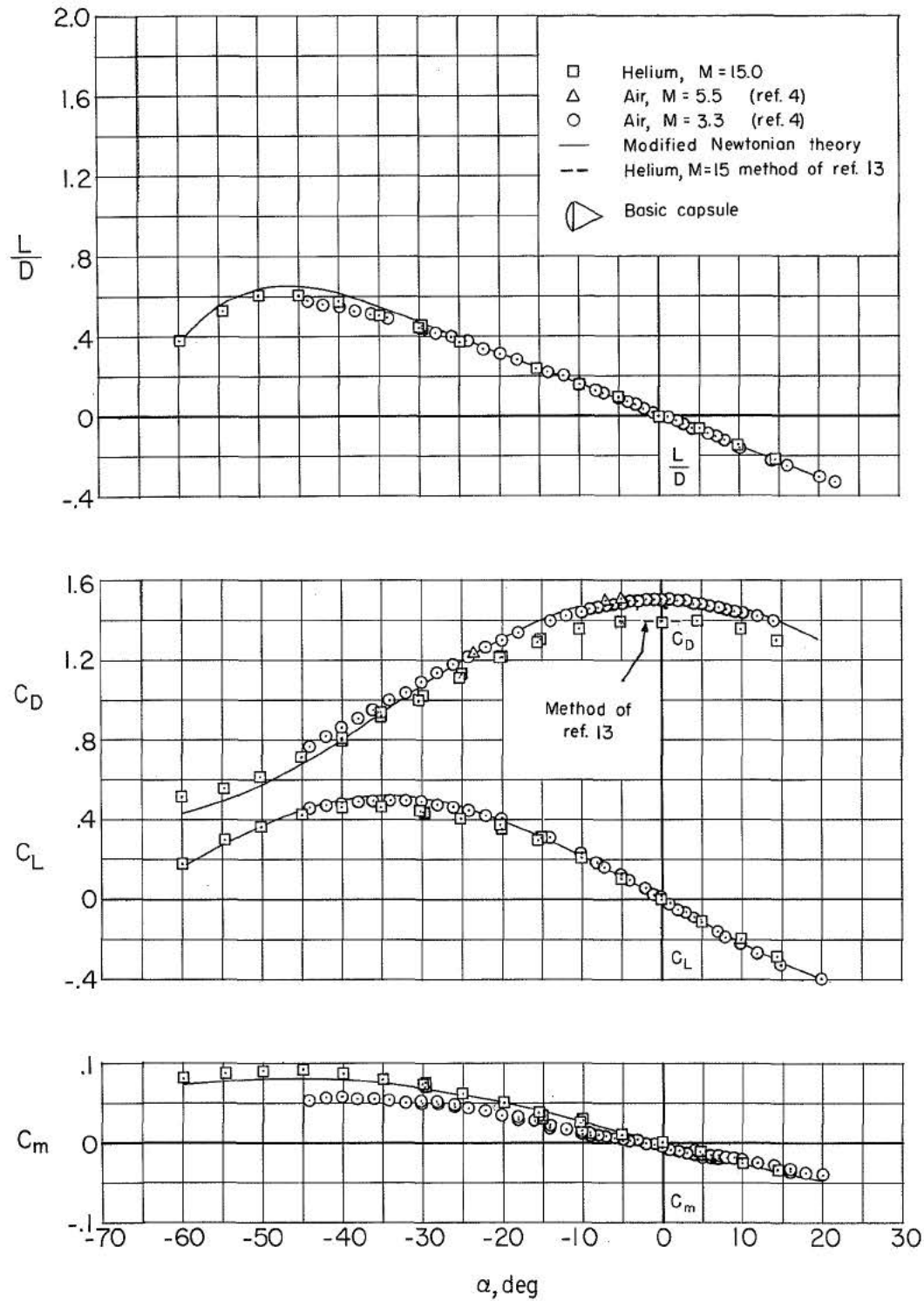
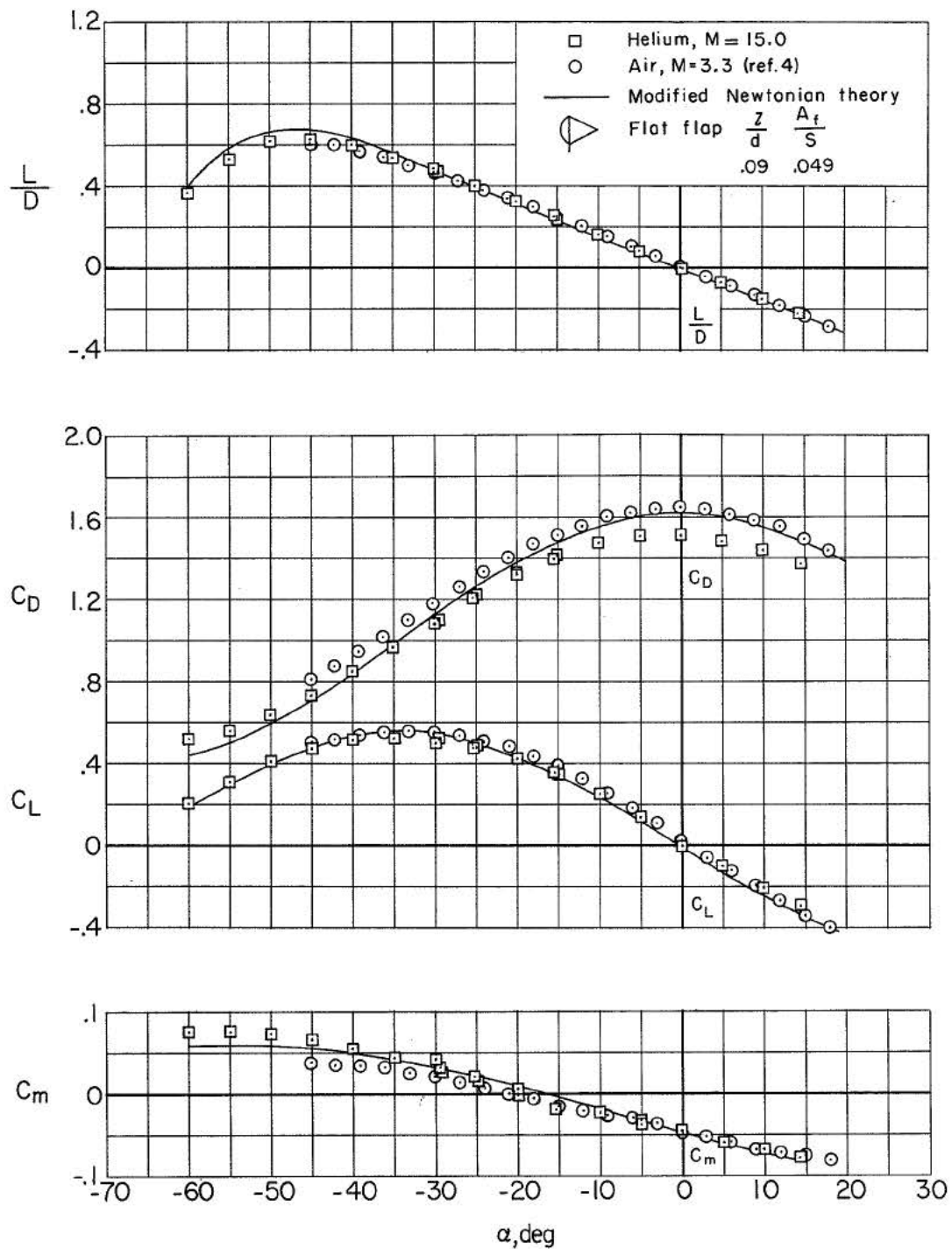
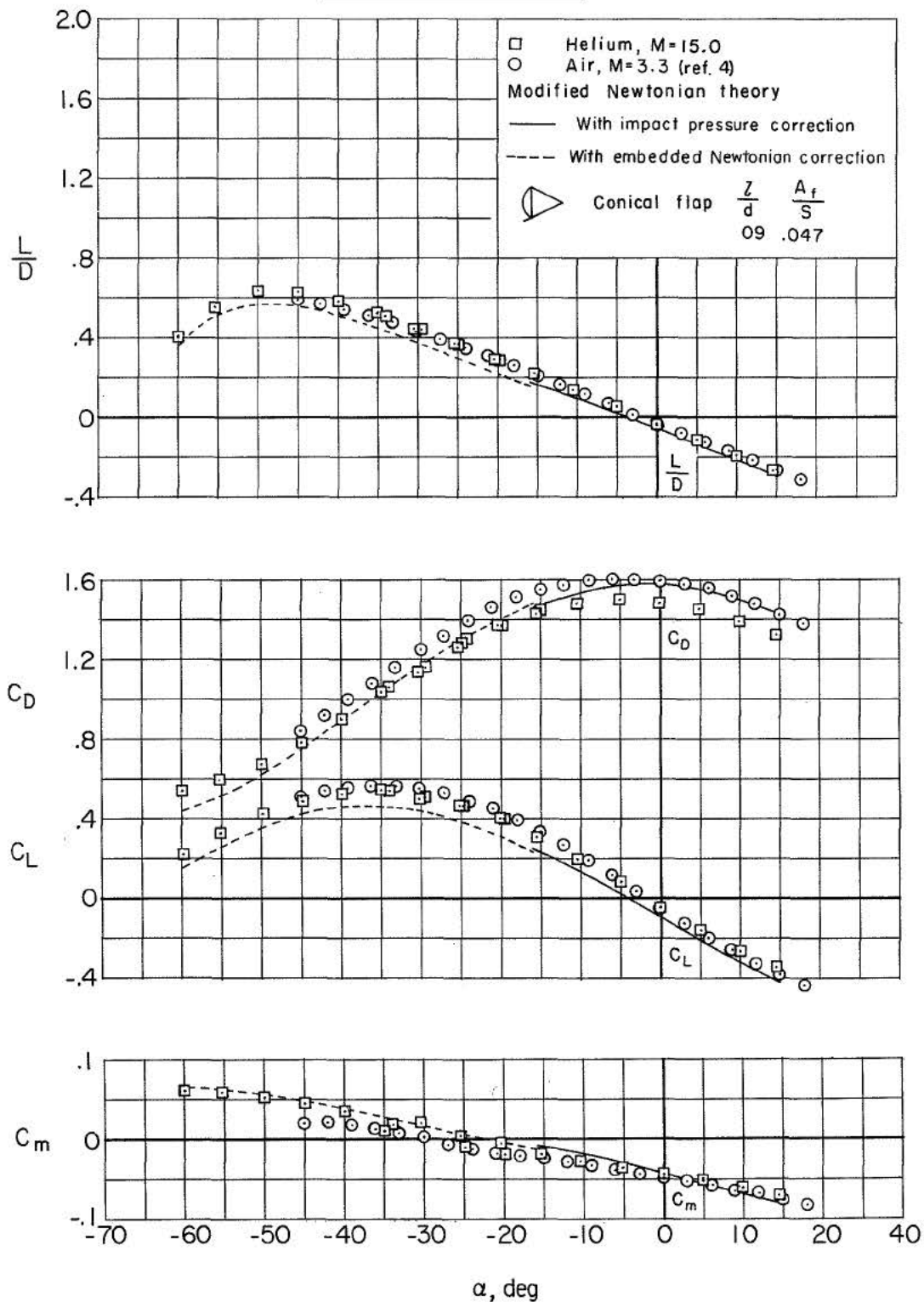


Figure 7.- Aerodynamic characteristics of the model as measured in helium and air.



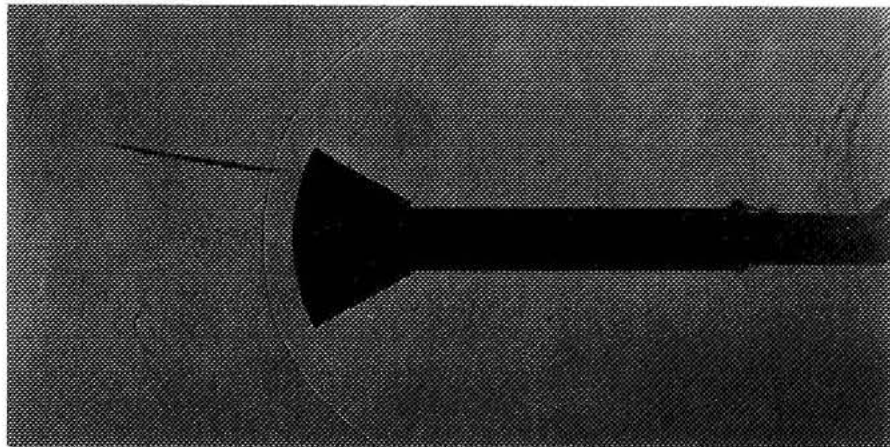
(a) Flat flap.

Figure 8.- Effect of flap shape on the aerodynamic characteristics of the model as measured in helium and air.

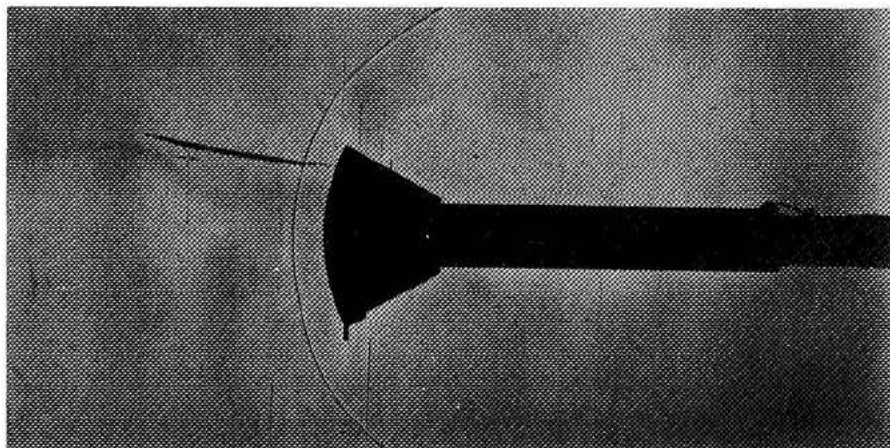


(b) Conical flap.

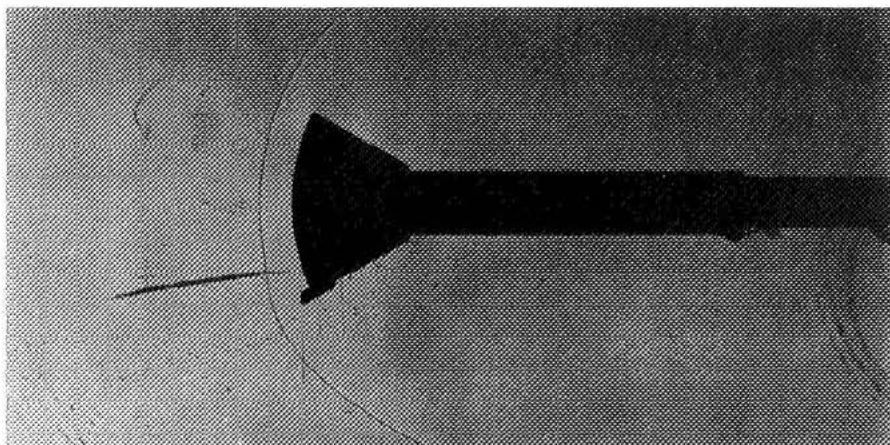
Figure 8.- Concluded.



(a) Basic capsule.



(b) Capsule with flat flap.



(c) Capsule with conical flap.

Figure 9.- Shadowgraph pictures of the models.

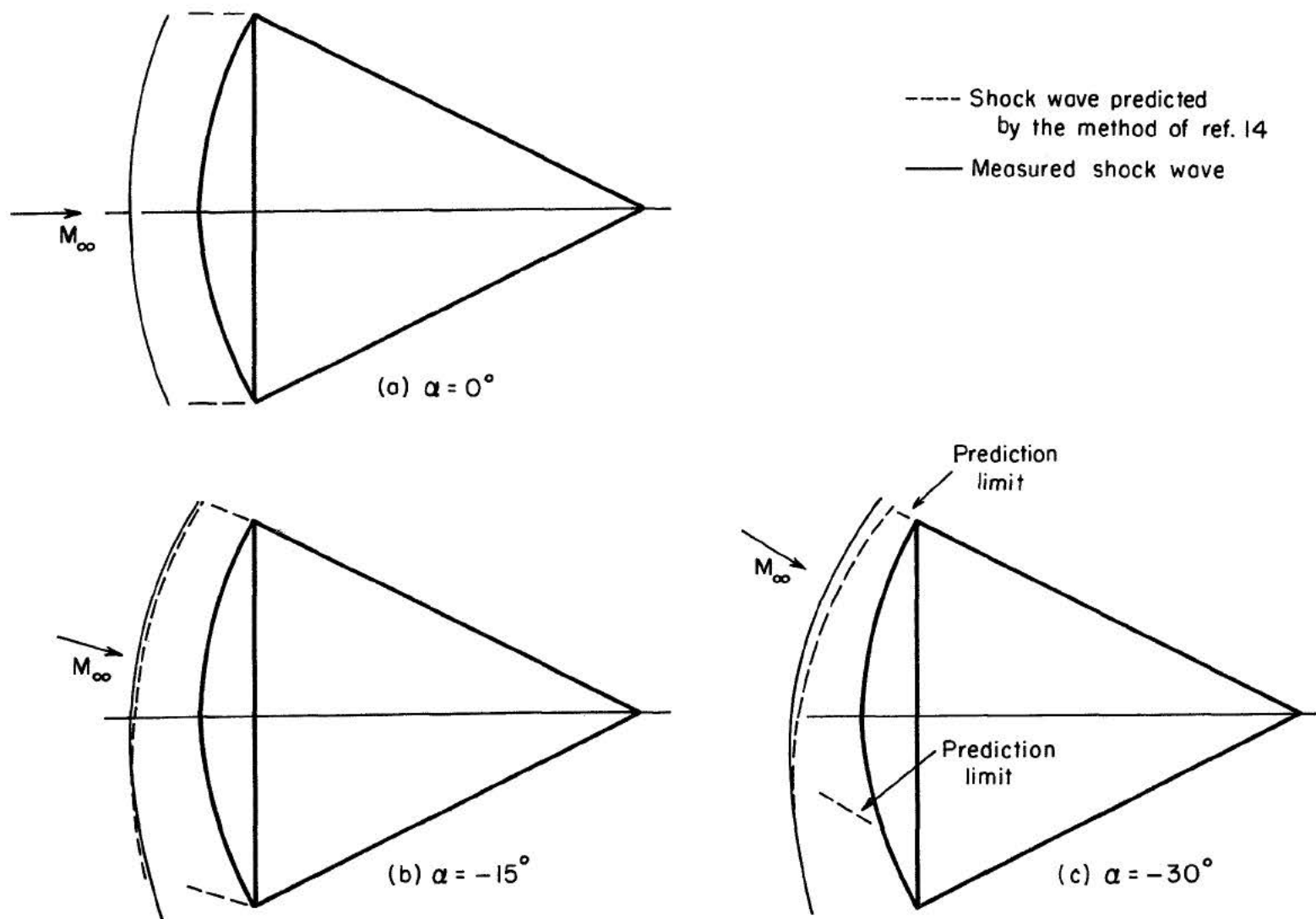


Figure 10.- Comparison of predicted and experimental shock wave shapes.

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