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TECHNICAL NOTE

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STATIC STABILITY TESTS IN THE LANGLEY 24-INCH HYPERSONIC ARC TUNNEL ON A BLUNTED CONE AT A MACH NUMBER OF 20

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SUMMARY

An experimental investigation has been conducted in the Langley 24-inch hypersonic arc tunnel to determine the static longitudinal characteristics for a blunted 9° semivertex angle cone at a Mach number of 20 at angles of attack from -2.5° to 12.5°. The model with a spherical-segmented nose and a truncated conical base was a 1/7-scale Scout payload. The investigation comprised the first force tests made in the Langley 24-inch hypersonic arc tunnel. This facility is an arc-heated, hypervelocity, blowdown (hotshot) wind tunnel. For operation during the present tests, nitrogen, initially confined in a reservoir, was heated and pressurized to approximately 3,000° K and 750 atmospheres by generating an electric arc in the reservoir. The heated gas then expanded through a conical nozzle to the test section and into a vacuum chamber.

A compilation of the data of the present tests with other wind-tunnel data at Mach numbers of 6.8, 9.6, 17, 17.3, and 24 is presented. An analysis of the experimental results showed that for all Mach numbers from 6.8 to 24 (except the free-flight tests at a Mach number of 17 at angles of attack up to about 4°), the model was longitudinally stable about the 44-percent body-length station. The normal-force coefficient generally decreased slightly with increasing Mach number. Mach number had small effects on the center-of-pressure location which tended to be approximately at the 50-percent body-length station.

INTRODUCTION

A current project, Scout, which is in support of the space research program, concerns the investigation of the thermodynamic effects of the upper atmosphere on a high-velocity vehicle. In an effort to determine the static longitudinal stability characteristics of the Scout payload configuration, several hypersonic wind-tunnel tests were made.

The Scout payload configuration consisted of a spherical segmented nose followed by a short cylindrical section and a 9° semivertex angle cone with a truncated conical base.

The tests at a Mach number of 20 were conducted in the Langley 24-inch hypersonic arc tunnel. Normal-force and pitching-moment data were obtained at angles of attack ranging from -2.5° to 12.5°. In addition, some data from tests made in other wind tunnels at Mach numbers of 6.8, 9.6 (both unpublished results), 17, 17.3, and 24 (refs. 1, 2, and 3, respectively) are presented herein.

SYMBOLS

The normal-force and pitching-moment coefficients are referred to the body axes, and the reference center of moments is located at 44-percent body-length station.

A	maximum body cross-sectional area, sq in.
C_m	pitching-moment coefficient, $\frac{\text{Pitching moment}}{qAd}$
C_N	normal-force coefficient, $\frac{\text{Normal force}}{qA}$
$\frac{dC_m}{dC_N}$	rate of change of pitching-moment coefficient with normal-force coefficient
d	maximum body diameter, in.
M	Mach number
p	pressure, lb/sq in.
q	dynamic pressure, lb/sq in.
R	Reynolds number
T	temperature, $^{\circ}$K
t	tunnel run time, milliseconds
v	velocity, ft/sec
x/l	center-of-pressure location from nose of model
α	angle of attack, deg
ρ	density, amagat units (a relative scale referred to density at 0° C and 1 atmosphere of pressure; for nitrogen, 1 amagat = 0.00242 lb-sec^2/ft^4)

Subscripts:

1	free-stream condition ahead of normal shock
t,1	reservoir condition
t,2	stagnation condition behind normal shock

MODEL

The model tested in this investigation consisted of a spherical segmented nose followed by a short cylindrical section and a 9° semivertex angle cone as shown in figure 1. The configuration is terminated by a truncated 40° half-angle conical base section. A photograph of the model is shown in figure 2. The model tested at a Mach number of 20 was designed to feature a light, strong structure. The light weight was required to maintain low moments of inertia because relatively short tunnel run time necessitated rapid balance response. The blunt-nosed conical section of the model, constructed of magnesium, had a 0.020-inch wall thickness, and the conical base was made of balsa wood. The complete model weighed about 0.1 pound.

APPARATUS

The tests at a Mach number of 20 were conducted in the Langley 24-inch hypersonic arc tunnel. This facility is an arc-heated, hypervelocity, blowdown wind tunnel, and it is essentially the same in design and operation as the hotshot tunnel described in reference 4. A schematic diagram and a photograph of the present tunnel are shown in figures 3 and 4, respectively. The major components of the tunnel include a two-million-joule capacitor electrical-energy storage system with a charging unit, an arc-heated reservoir with a volume of approximately 100 cubic inches, a 10° total-angle conical nozzle varying in diameter from 0.100 inch at the throat to 24 inches at the test section, an approximate 200-cubic-foot vacuum chamber, and a vacuum-pump system.

A two-component, internal, high-frequency response, strain-gage balance was used to obtain normal-force and pitching-moment data on the model. A photograph of the balance is shown in figure 5. This balance was designed with frequency response of about 1,000 cps which is considerably higher than the conventional wind-tunnel balance. The support system reduced the natural frequency to approximately 350 cps. The high-frequency response was necessitated by the short tunnel run time of about 20 to 50 milliseconds. The electrical signal from the balance is transmitted through a 20-kilocycle carrier system and a low-frequency galvanometer element to a consolidated oscillograph recorder.

A single-pass, Z-arrangement schlieren system with a continuous light source and a Fastax movie camera was used for each run. The camera speed was approximately 4,000 frames per second during a run.

A description of the Langley 11-inch hypersonic tunnel for which the unpublished tests are presented herein can be found in reference 5. A calibration of the tunnel at Mach numbers of 6.8 and 9.6 for air is contained in reference 6.

TESTS AND ACCURACY

For the present tests the arc chamber was charged initially with nitrogen to a pressure of approximately 1,000 lb/sq in. The nozzle, test section, and vacuum chamber were evacuated to a pressure of approximately 5 microns of mercury. Then about 700,000 joules of electrical energy at approximately 4,500 volts were released across the main electrodes in the arc chamber. This energy heated and pressurized the nitrogen to approximately 3,000° K and 750 atmospheres. The heated gas then vaporized or burst the Mylar diaphragm near the throat and expanded through the conical nozzle to the test section and vacuum tank. In the test section a quasi-steady flow was established with a Mach number of approximately 20 for about 20 to 50 milliseconds.

At the present time, a very limited range of test conditions has been realized in the Langley 24-inch hypersonic arc tunnel. However, the facility has a large potential capabilities envelope for simulation of Reynolds numbers and Mach numbers which are presented in figure 6.

Prior to the present tests, a calibration of the tunnel was made in which the initial reservoir pressure, reservoir pressure after the arc discharge, and pitot pressures on a survey rake in the test section were measured. Then, with these conditions, all other reservoir and free-stream thermodynamic properties were determined by using the data-reduction program from reference 7. This method is based on nitrogen in equilibrium. From the calibration data, a Mach number of 20 ± 0.5 was determined for an 8-inch-diameter test-section core at tunnel axial stations where test models would be located.

In calculating the test-section conditions for the present tests, arc-chamber pressure was measured and a corresponding average pitot pressure was obtained from the calibration data. Typical results are listed in table I. A typical oscillograph pressure record is shown in figure 7(a).

A strain-gage-balance oscillograph record is presented in figure 7(b) which shows the normal-force and pitching-moment traces during a run. Values are read by averaging the envelope of each trace.

Two typical schlieren photographs of the model at angles of attack of 0° and 5° are presented in figure 8. In these photographs, the bow wave around the model can be seen.

Uncertainties involved in repeatability of balance and readability of the oscillograph records caused maximum probable inaccuracies in C_N of ±0.016 and in C_m of ±0.005 for the Mach number 20 data. The angle of attack was set within ±0.1°.

RESULTS AND DISCUSSION

Experimental normal-force and pitching-moment coefficients for angles of attack from -2.5° to 12.5° on a blunt-nosed cone have been obtained at Mach number 20 for the present investigation and have been compiled with other wind-tunnel data of Mach numbers 6.8, 9.6, 17, 17.3, and 24. These test results are presented in figures 9 to 12. For this same Mach number range, the center-of-pressure location and $\frac{dC_m}{dC_N}$ slopes for the model are shown in figure 13. Reynolds numbers for all the tests are given in table II. In analyzing the results, no attempt was made to show the effects of the different test media on the aerodynamic characteristics of the configuration.

Normal-Force Coefficient

Variation of normal-force coefficient with angle of attack for a blunt-nosed cone in the Langley 24-inch hypersonic arc tunnel at Mach number of 20 with nitrogen as the flow medium is shown in figure 9. All data points were read at a tunnel run time of 25 milliseconds. It can be seen, however, in figure 10 where the data were read every 2 milliseconds from 15 to 35 milliseconds that the effects of time on C_N are small. In general, for a particular angle of attack, the normal-force coefficient decreased slightly as Mach number increased (see figs. 11 and 12).

Pitching-Moment Coefficient

Variation of pitching-moment coefficient with angle of attack at a Mach number 20 is presented in figure 9. Pitching-moment-coefficient data, like normal-force-coefficient values, were read at a run time of 25 milliseconds and as shown in figure 10 varied only slightly with run time. At Mach numbers of 6.8, 9.6, 17.3, 20, and 24 the pitching-moment coefficient (fig. 11) indicates that the model was longitudinally stable about the 44-percent body-length station. However, the free-flight tests at Mach number of 17 showed a region of slight static instability about the 44-percent body-length station up to an angle of attack of about 4°. Since absolute values of the pitching-moment coefficient were small for the tested angles of attack, small or no Mach number effects (see fig. 12) were observed within the accuracy of the data.

Center-of-Pressure Location and Stability Derivative

The center-of-pressure location and the longitudinal-stability derivative $\frac{dC_m}{dC_N}$ are plotted against Mach number for several angles of attack in figure 13. The data indicate that the Mach number had small effects on the center-of-pressure location and that the center-of-pressure location tended to be approximately at the 50-percent body-length station. For most Mach numbers the $\frac{dC_m}{dC_N}$ values became more negative with increasing angle of attack. It is clear from the $\frac{dC_m}{dC_N}$ plot that for most Mach numbers the model was stable through the angle-of-attack range of the tests.

CONCLUSIONS

Wind-tunnel tests have been made on a blunt-nosed cone at Mach numbers of 6.8, 9.6, 17, 17.3, 20, and 24. An analysis of these tests has led to the following conclusions:

1. At Mach numbers from 6.8 to 24 (except the free-flight tests at Mach number of 17 at angle of attack up to about 4°), the model was longitudinally stable about the 44-percent body-length station for angles of attack from -2.5° to 12.5°.

2. The normal-force coefficient generally decreased slightly with increasing Mach number.

3. Mach number had small effects on the center-of-pressure location which tended to be approximately at the 50-percent body-length station.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., August 22, 1962.

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3. Henderson, Arthur, Jr.: Recent Investigations of the Aerodynamic Characteristics of General and Specific Lifting and Nonlifting Configurations at Mach 24 in Helium, Including Air-Helium Simulation Studies. Presented at the Specialists' Meeting on the High Temperature Aspects of Hypersonic Flow (Rhode-Saint-Genese, Belgium) AGARD, Apr. 1962.

4. Perry, R. W., and MacDermott, W. N.: Development of the Spark-Heated, Hypervelocity, Blowdown-Tunnel Hotshot. AEDC-TR-58-6, ASTIA Doc. No. AD-157138, Arnold Eng. Dev. Center, June 1958.

5. McLellan, Charles H., Williams, Thomas W., and Bertram, Mitchel H.: Investigation of a Two-Step Nozzle in the Langley 11-Inch Hypersonic Tunnel. NACA TN 2171, 1950.

6. Bertram, Mitchel H.: Boundary-Layer Displacement Effects in Air at Mach Numbers of 6.8 and 9.6. NASA TR R-22, 1959. (Supersedes NACA TN 4133.)

7. Grabau, Martin, Humphrey, Richard L., and Little, Wanda J.: Determination of Test-Section, After-Shock, and Stagnation Conditions in Hotshot Tunnels Using Real Nitrogen at Temperatures From 3000 to 4000° K. AEDC-TN-61-82 (Contract No. AF 40(600)-800 S/A 24(61-73)), Arnold Eng. Dev. Center, July 1961.

TABLE I.- LANGLEY 24-INCH HYPERSONIC ARC TUNNEL TEST CONDITIONS

[t = 25 msec]

α, deg	$p_{t,1}$, lb/sq in.	$\rho_{t,1}$, amagat	$T_{t,1}$, °K	p_1, lb/sq in.	ρ_1, amagat	V_1, ft/sec	q_1, lb/sq in.	M_1	R, per ft
-2.5	11,300	61	3,200	0.17×10^{-2}	0.66×10^{-3}	9,100	0.46	20	0.22×10^{6}
0	10,700	61	3,000	.16	.66	8,800	.44	20	.24
2.5	11,400	63	3,100	.17	.68	9,000	.46	20	.24
2.5	11,200	62	3,100	.17	.67	9,000	.46	20	.23
5.0	10,800	61	3,000	.16	.66	8,900	.44	20	.24
7.5	13,100	61	3,700	.21	.66	9,900	.54	19	.19
10.0	11,400	61	3,200	.17	.65	9,100	.46	20	.22
12.5	10,700	61	3,000	.16	.66	8,800	.43	20	.24
12.5	10,600	61	3,000	.16	.66	8,800	.43	20	.24

TABLE II.- SOURCE AND CONDITIONS OF COMPILED DATA

M_1	R, per ft	Model base diameter, in.	Test medium	Source
6.8	2.04×10^{6}	2.509	Air	Langley 11-inch hypersonic tunnel (unpublished)
9.6	1.20	2.509	Air	Langley 11-inch hypersonic tunnel (unpublished)
17	100.00	.401	Air	Ames supersonic free-flight wind tunnel (ref. 1)
17.3	1.00	1.606	Nitrogen	Chance Vought hypervelocity wind tunnel (ref. 2)
20	.23	2.867	Nitrogen	Langley 24-inch hypersonic arc tunnel (present)
24	3.42	2.509	Helium	Langley 22-inch helium tunnel (ref. 3)

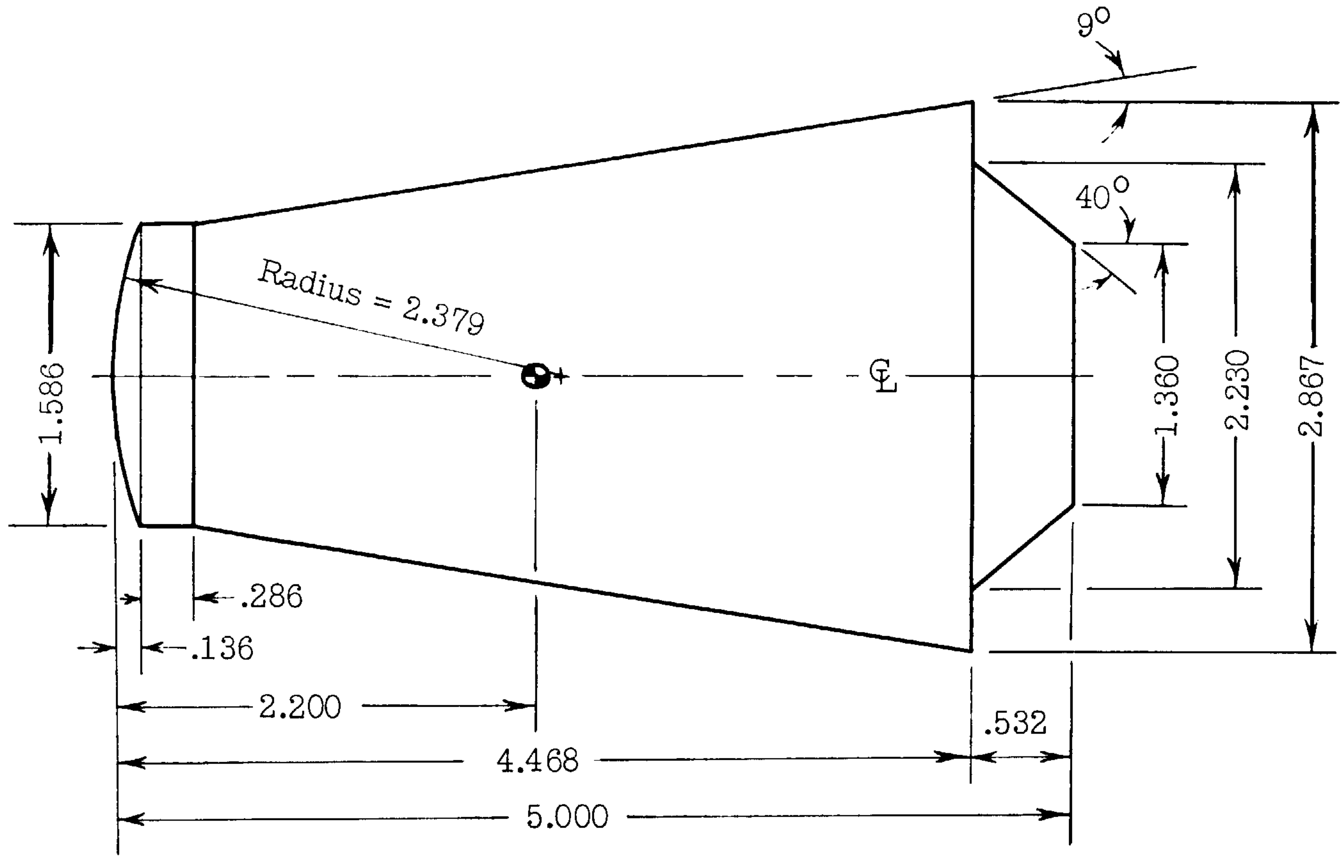


Figure 1.- Detail drawing of model. All dimensions are in inches unless otherwise noted.

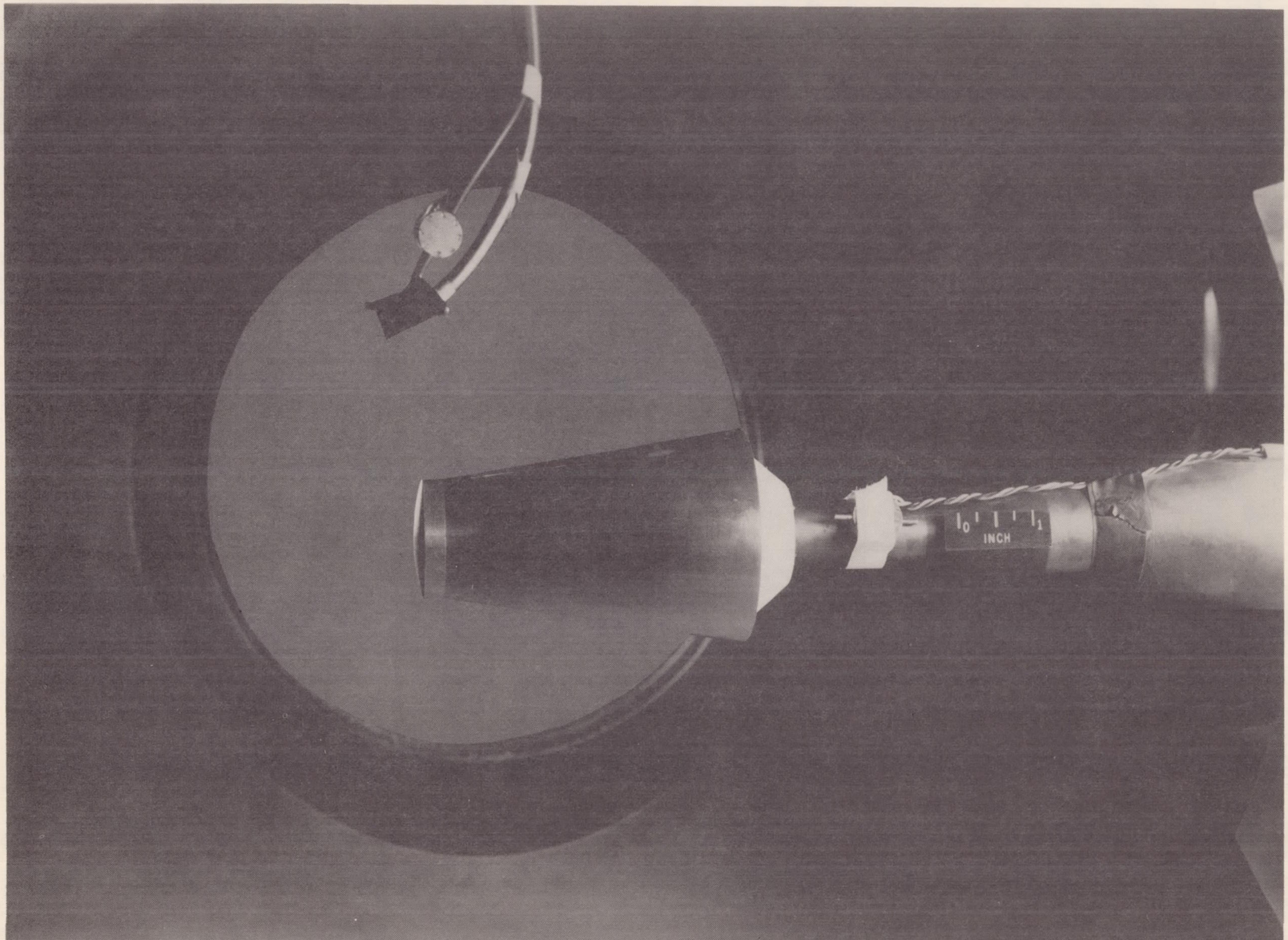


Figure 2.- Photograph of model in tunnel. L-62-308.1

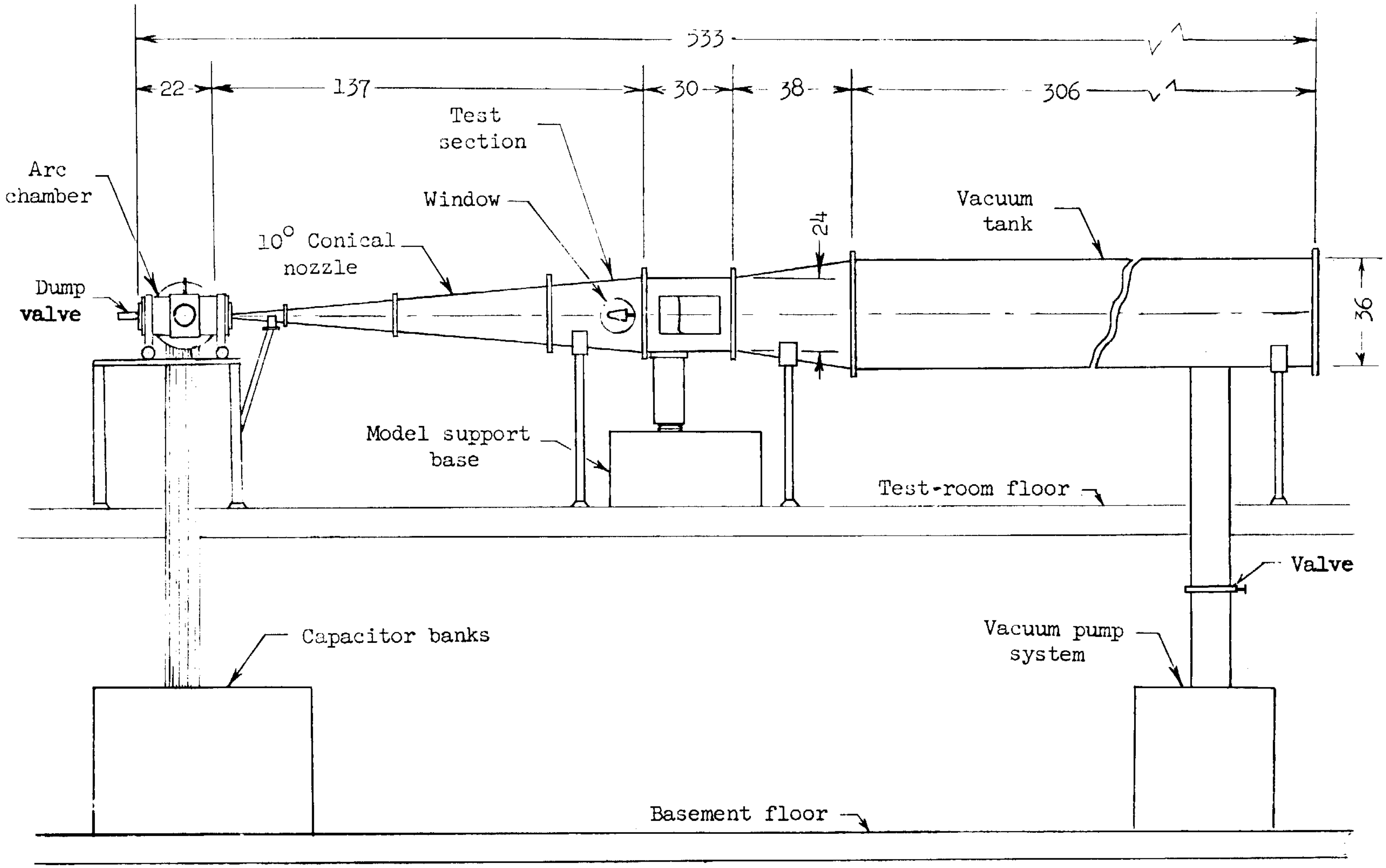
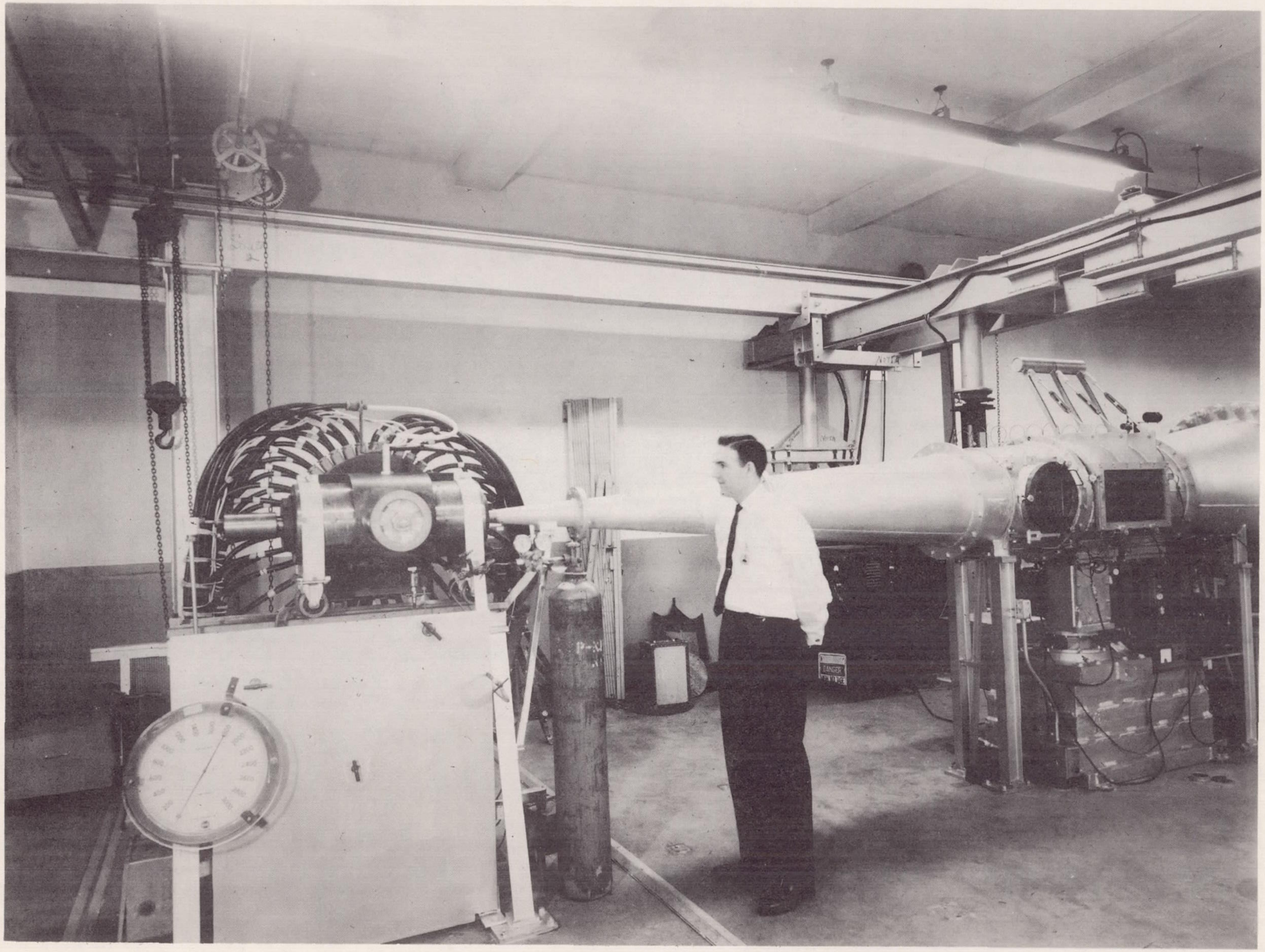
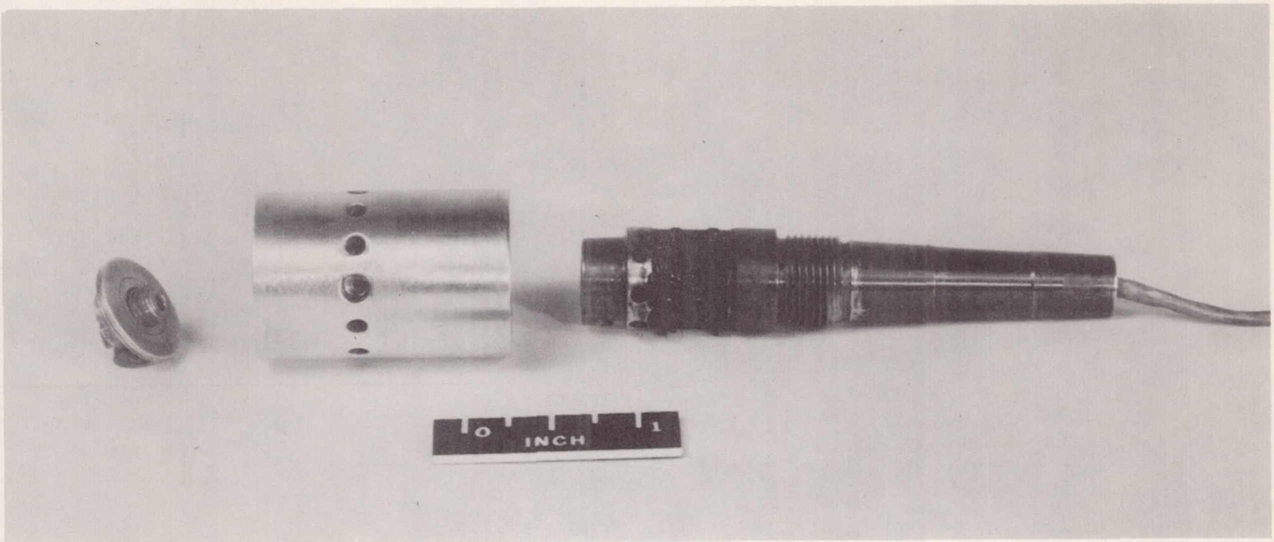


Figure 3.- Elevation view of the Langley 24-inch hypersonic arc tunnel with major components identified. All dimensions are in inches.

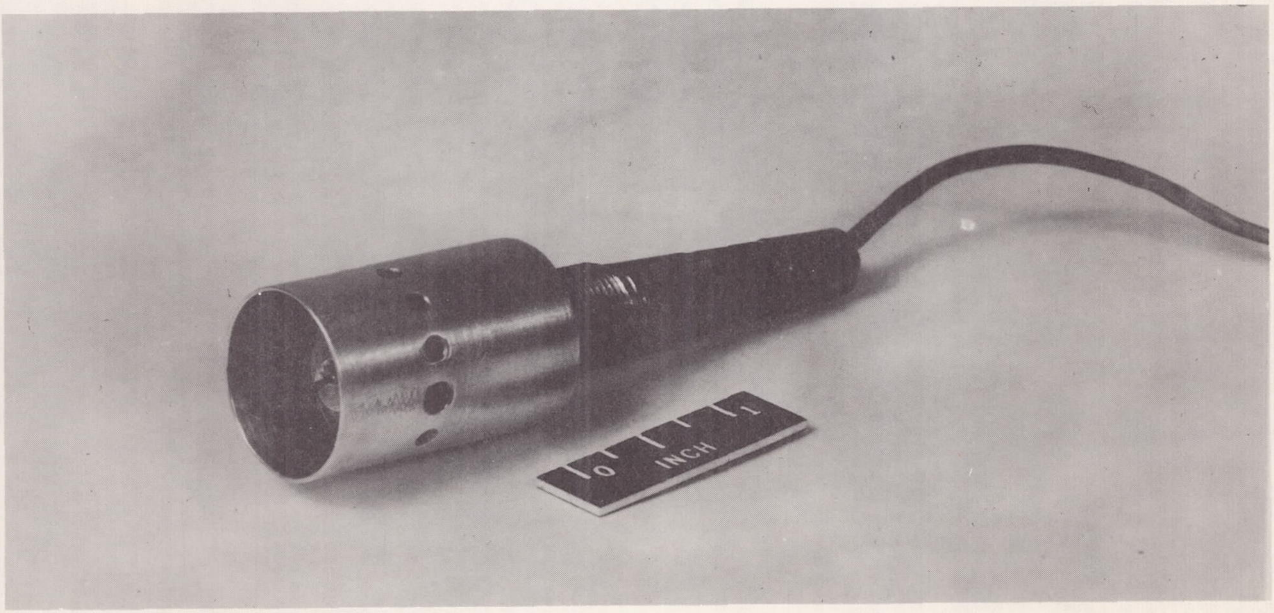


L-60-8526

Figure 4.- Photograph of the Langley 24-inch hypersonic arc tunnel (excluding the vacuum tank).



(a) Balance components. L-60-707



(b) Balance assembly. L-60-708

Figure 5.- Photograph of the two-component, strain-gage balance used for present test.

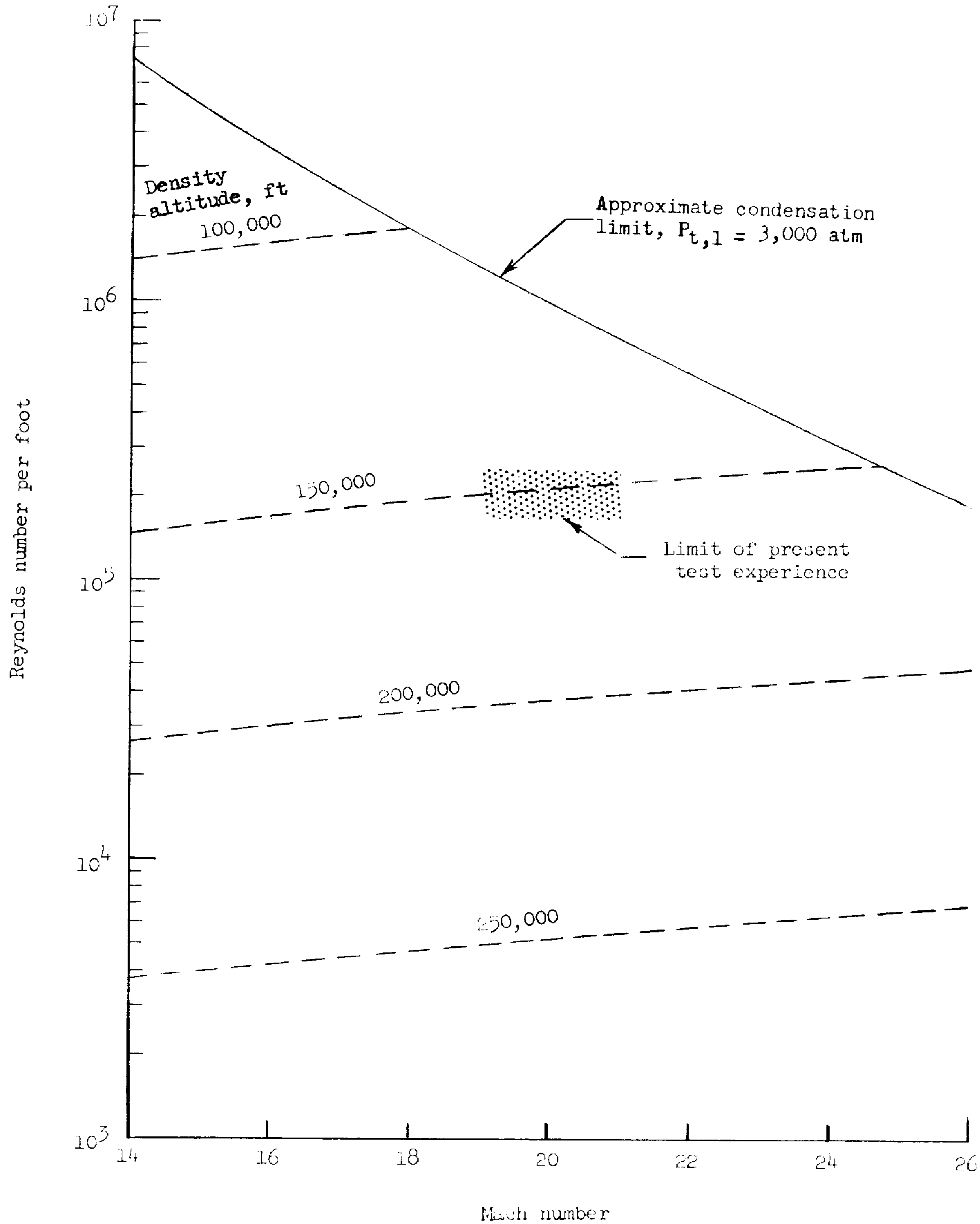
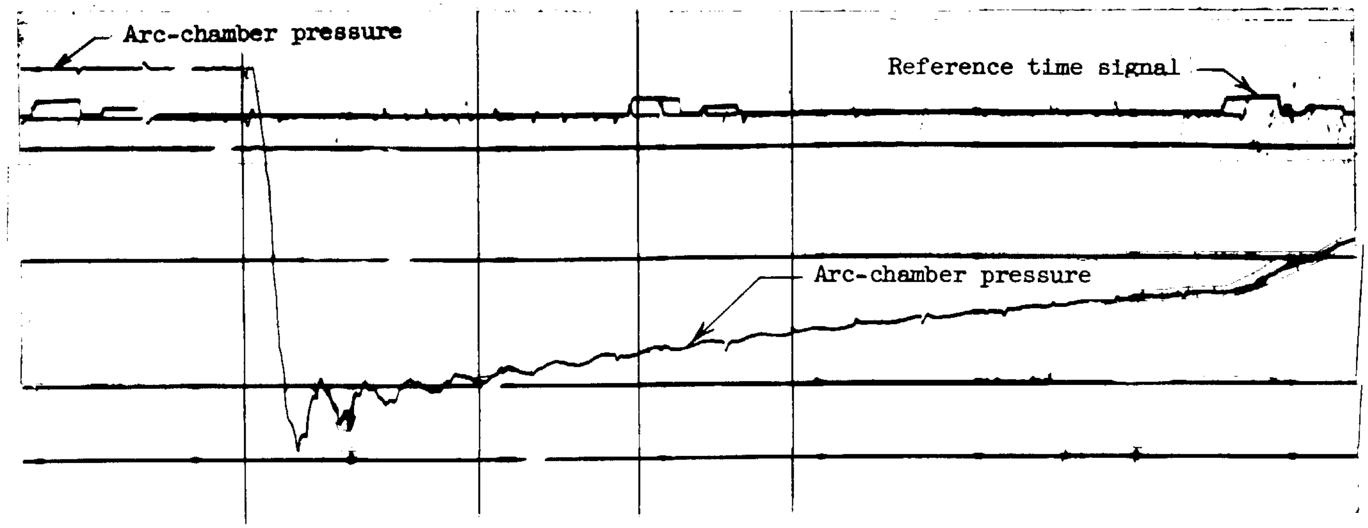
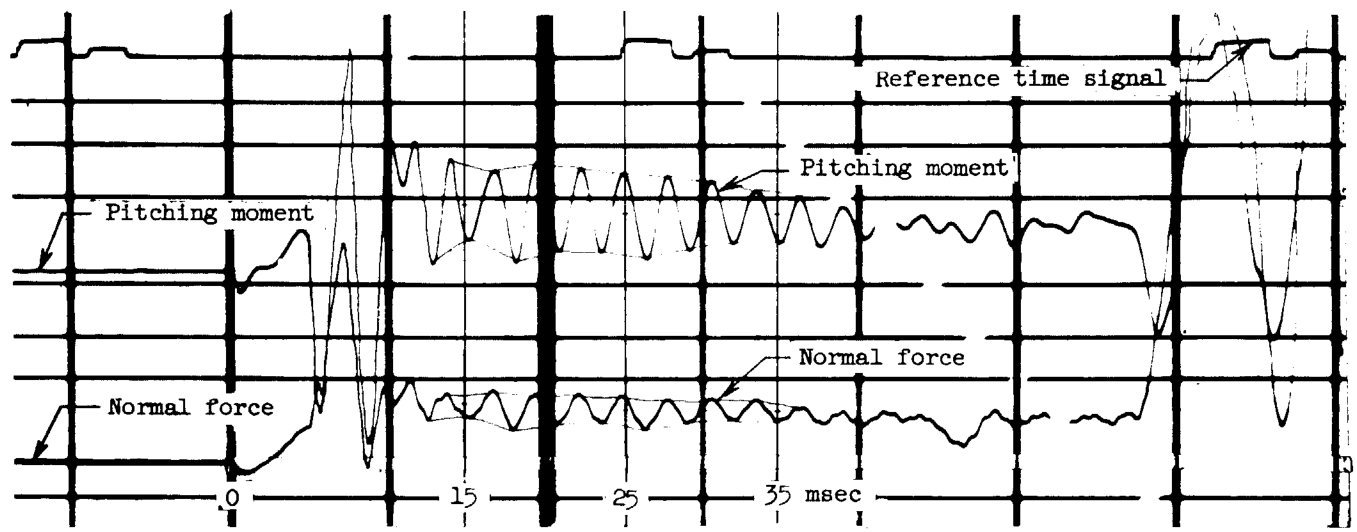


Figure 6.- Potential capabilities envelope of the Langley 24-inch hypersonic arc tunnel for nitrogen.

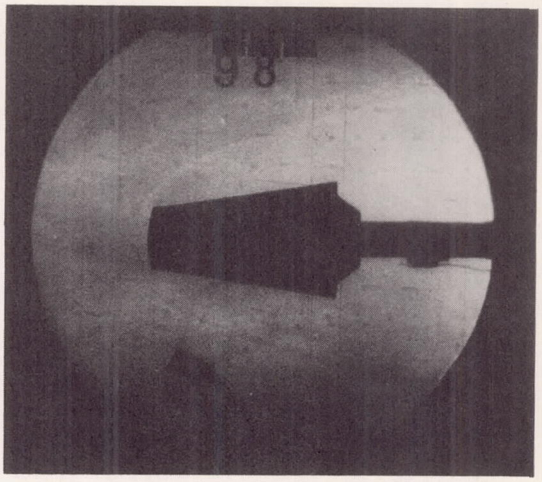


(a) Pressure record.

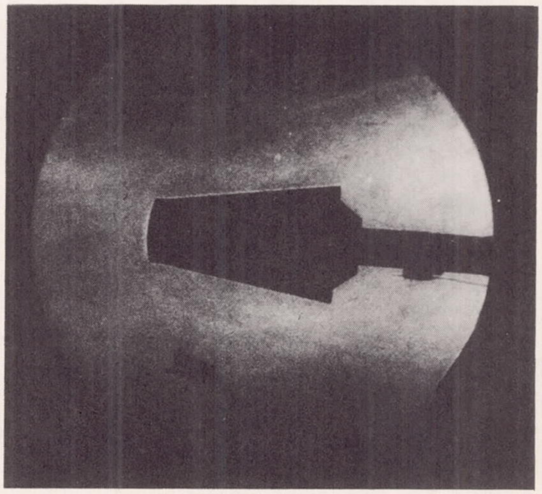


(b) Strain-gage balance record.

Figure 7.- Oscillograph records obtained in the Langley 24-inch hypersonic arc tunnel for a run with a blunt-nosed cone. $\alpha = 12.5^{\circ}$.



(a) $\alpha = 0^{\circ}$.



(b) $\alpha = 5^{\circ}$.

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Figure 8.- Typical schlieren photographs of model.

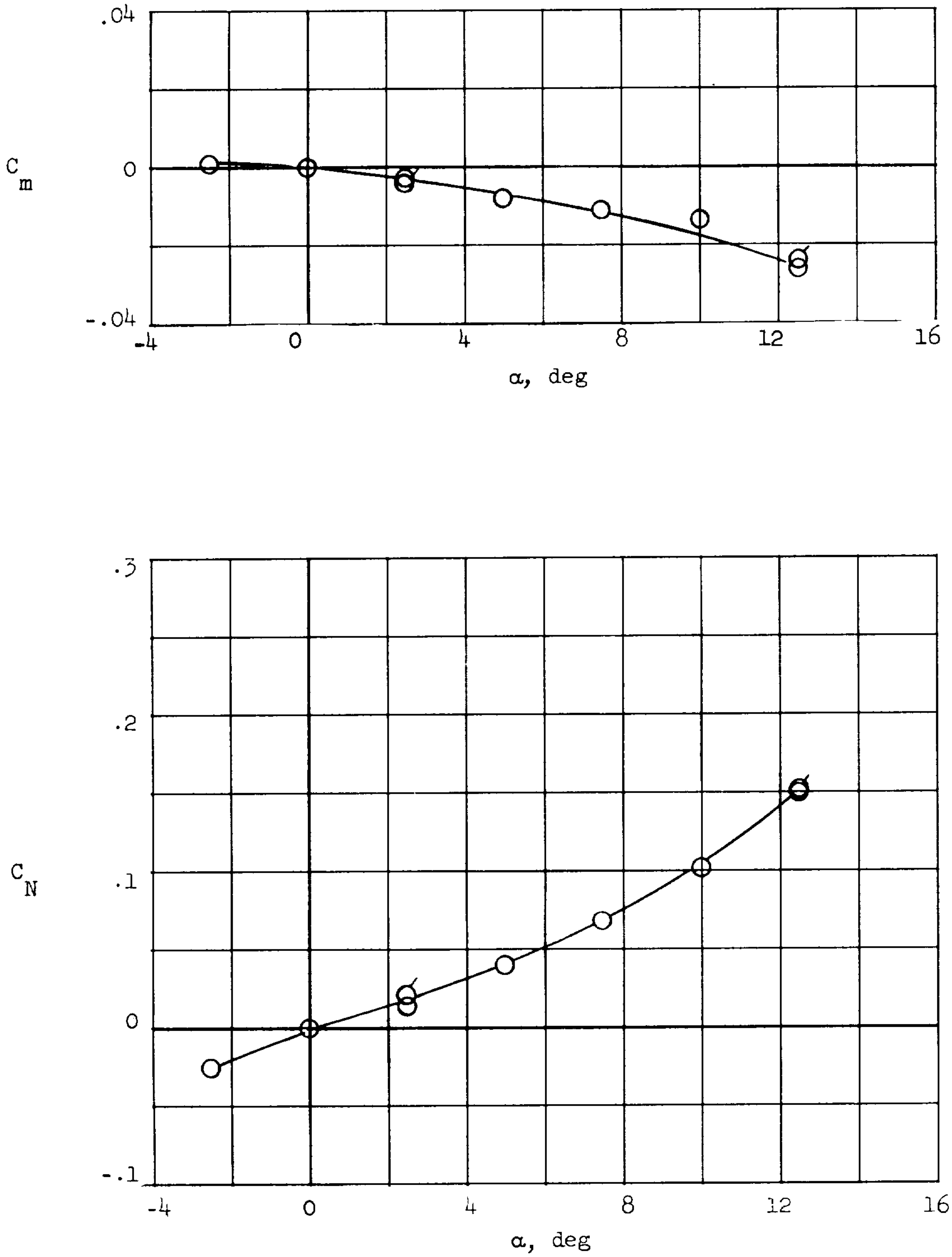


Figure 9.- Variation of pitching-moment coefficient and normal-force coefficient with angle of attack for a blunt-nosed cone in the Langley 24-inch hypersonic arc tunnel. $M_1 = 20$. Flagged symbols represent check points.

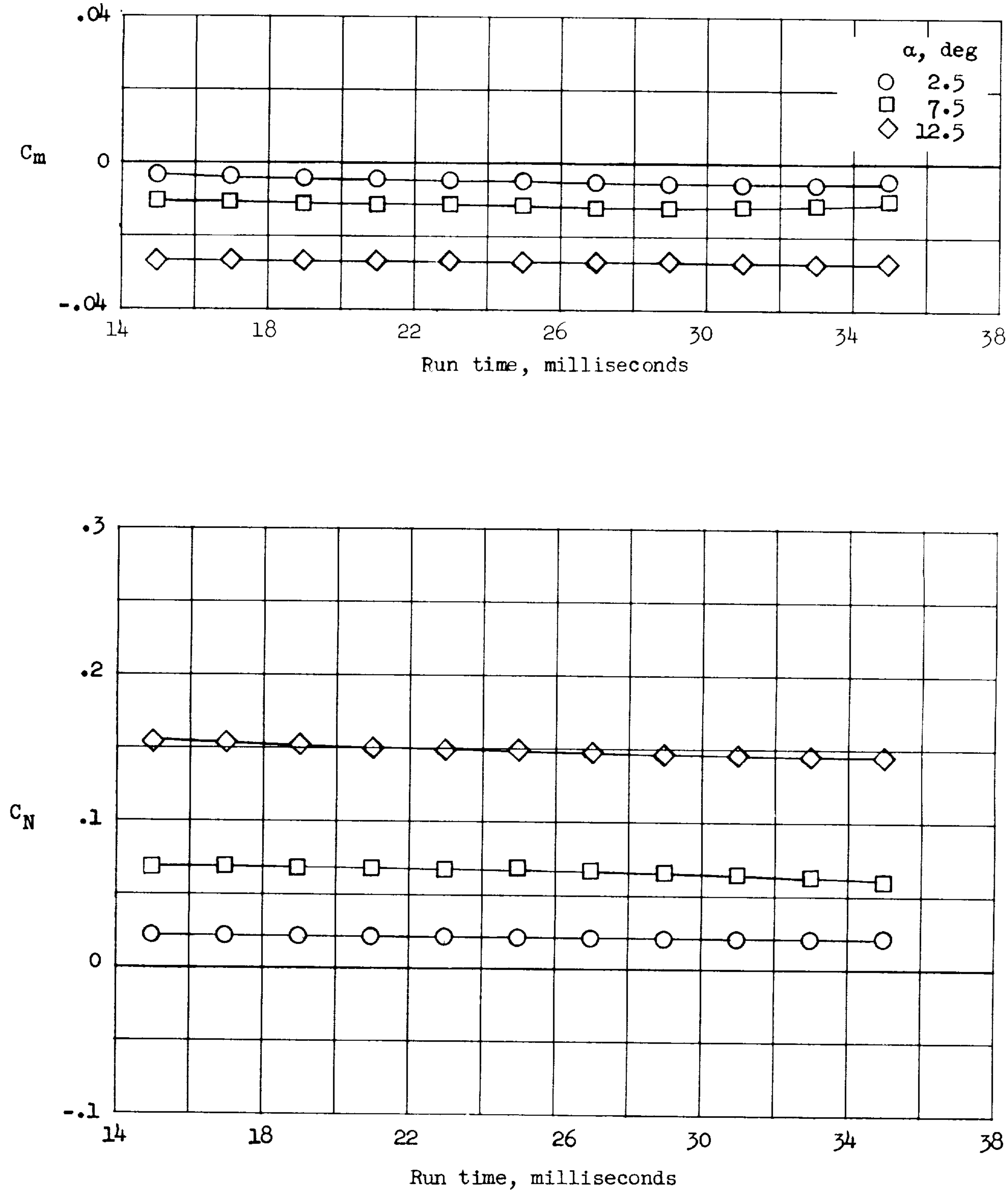


Figure 10.- Variation of normal-force and pitching-moment coefficients during runs in the Langley 24-inch hypersonic arc tunnel. $M_1 = 20$.

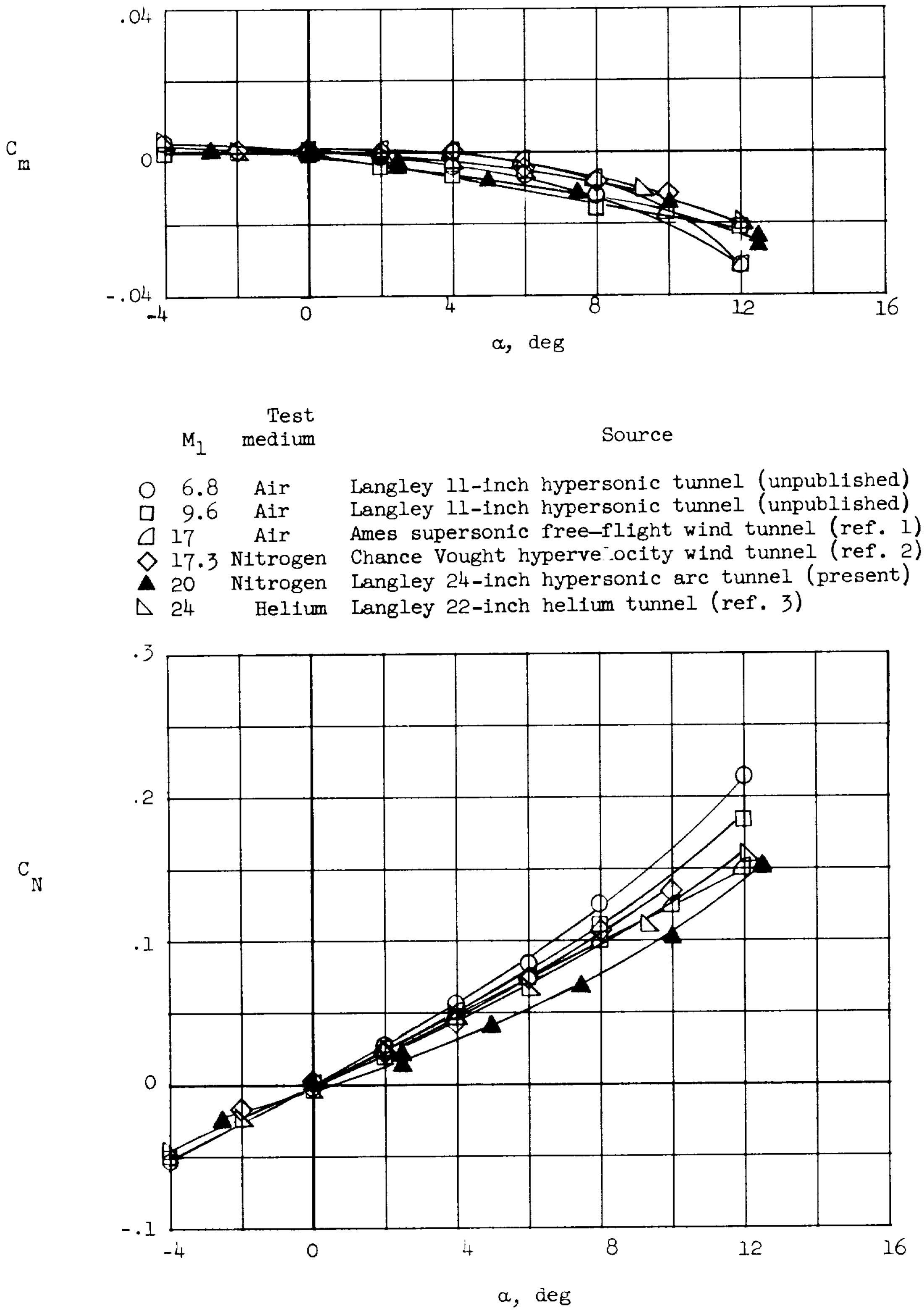


Figure 11.- Comparison of the longitudinal stability characteristics obtained on a blunt-nosed cone in several research facilities.

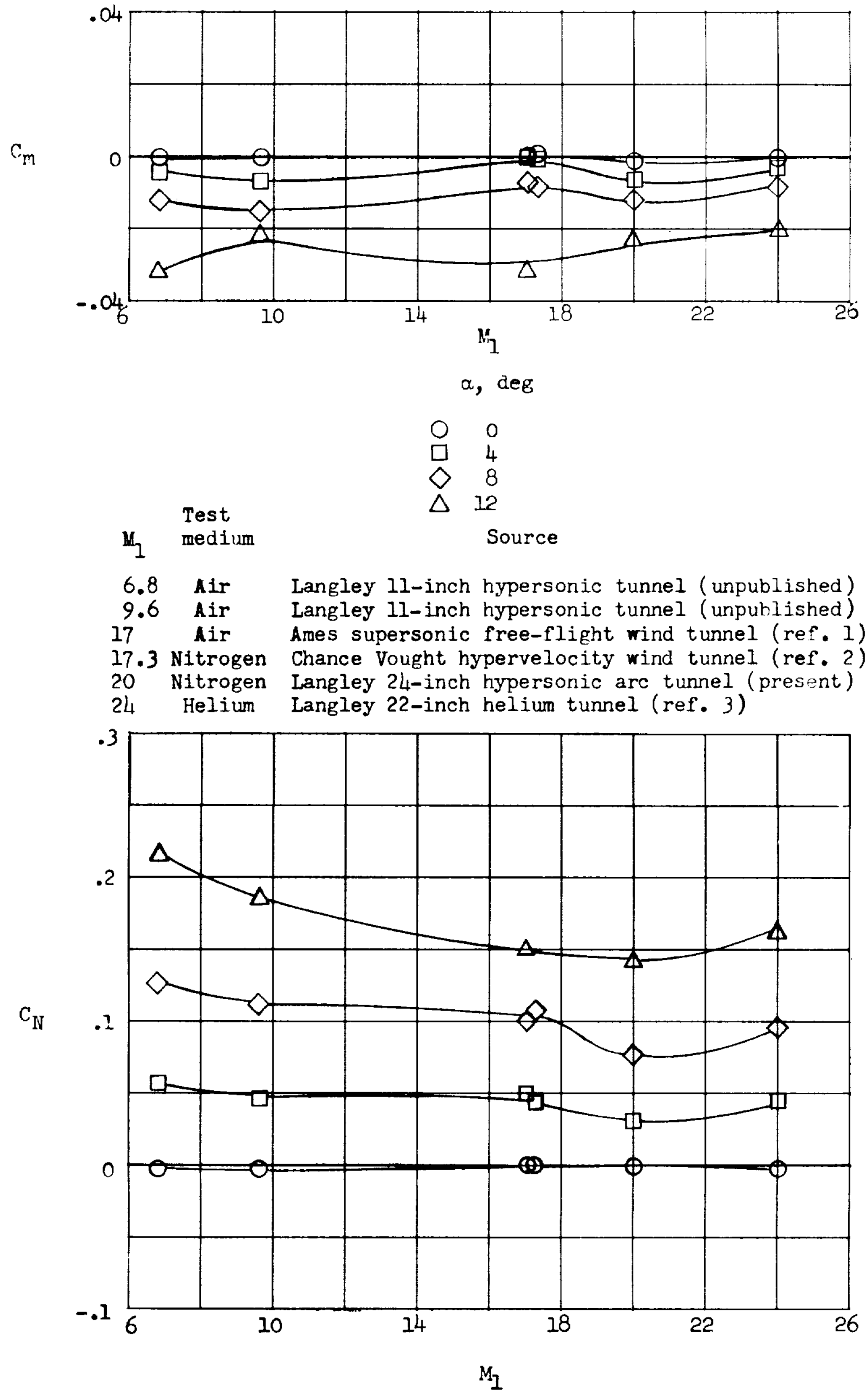
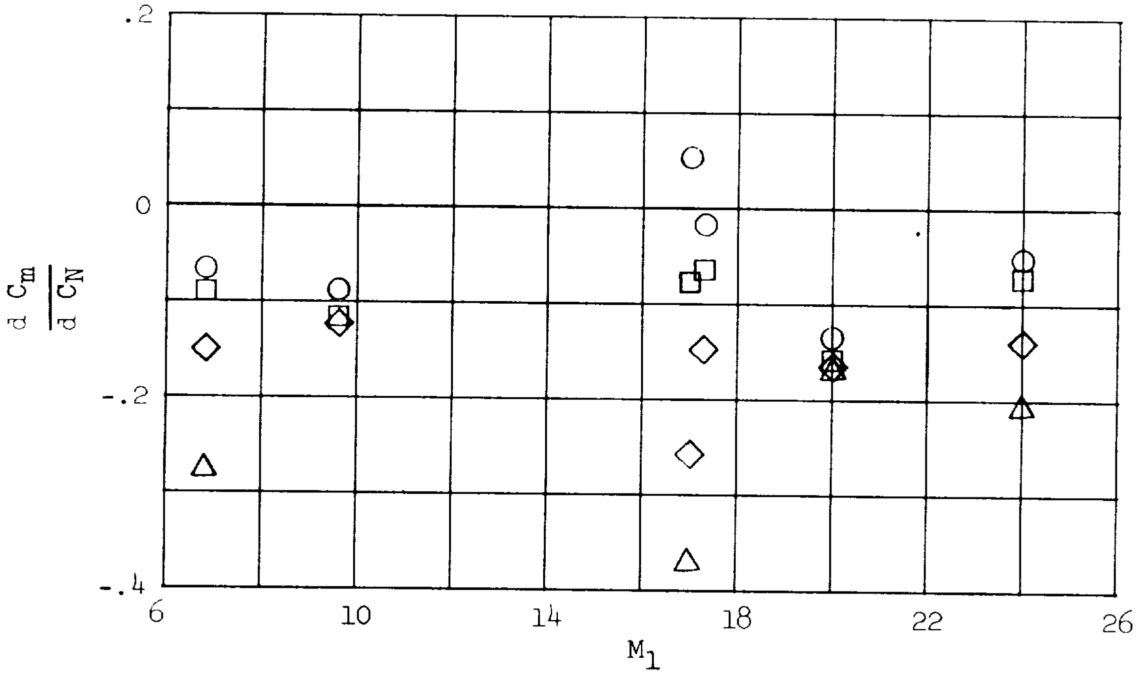


Figure 12.- Variation of pitching-moment and normal-force coefficients with Mach number.



α, deg

○ 0
□ 4
◇ 8
△ 12

M_1	Test medium	Source
6.8	Air	Langley 11-inch hypersonic tunnel (unpublished)
9.6	Air	Langley 11-inch hypersonic tunnel (unpublished)
17	Air	Ames supersonic free-flight wind tunnel (ref. 1)
17.3	Nitrogen	Chance Vought hypervelocity wind tunnel (ref. 2)
20	Nitrogen	Langley 24-inch hypersonic arc tunnel (present)
24	Helium	Langley 22-inch helium tunnel (ref. 3)

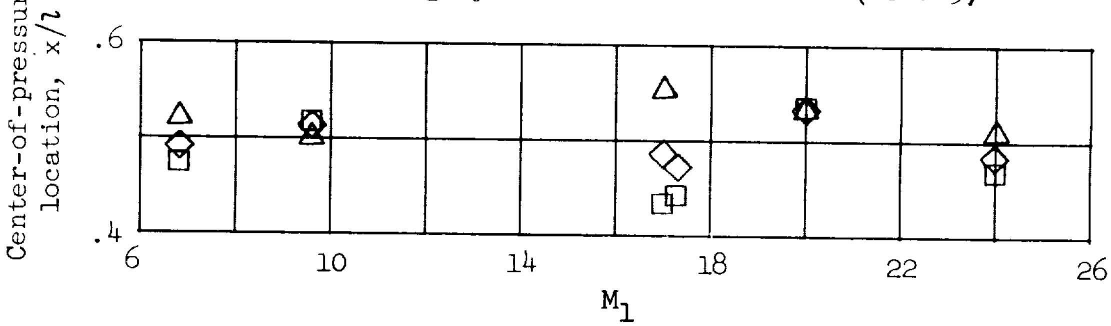


Figure 13.- Variation with Mach number of the longitudinal stability derivatives and the center-of-pressure location on a blunt-nosed cone.