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STATIC-STABILITY CHARACTERISTICS OF THE ALARR BOOSTER AND THE EFFECT OF THE PAYLOAD WAKE ON A FULL-SCALE BALLUTE AT SUPERSONIC SPEEDS

T. M. Perkins and T. R. Brice
ARO, Inc.

February 1966

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ARO, Inc.

FOREWORD

This work was done at the request of the Air Force Special Weapons Center (AFSWC), Air Force Systems Command (AFSC), under System 921A, Project 9087.

The results of the tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup and Parcel, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), AFSC, Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. The tests were conducted on November 1, 15, and 17, 1965, under ARO Project No. PS0611, and the manuscript was submitted for publication on January 27, 1966.

This technical report has been reviewed and is approved.

Francis M. Williams
Major, USAF
AF Representative, PWT
DCS/Test

Jean A. Jack
Colonel, USAF
DCS/Test

ABSTRACT

Investigations were conducted in the 16-ft supersonic wind tunnel of the Propulsion Wind Tunnel Facility to determine the drag and stability characteristics of a ballute deployed in the wake of a full-scale Air Launch, Air Recoverable Rocket (ALARR) payload. The ballutes were deployed at Mach numbers 0.55 and 2.00 to 3.00 and exhibited excellent deployment and inflation characteristics. Force data were obtained on a 0.6-scale model of the ALARR booster with a modified speed brake at Mach numbers from 1.80 to 3.00. The booster with speed brake was statically stable in pitch for all Mach numbers tested

CONTENTS

ILLUSTRATIONS

NOMENCLATURE

A_B	Ballute area (nominal), $\frac{\pi D_B^2}{4}$, ft^2
A_b	Base area, $\frac{\pi D_b^2}{4}$, ft^2
C_A	Total axial-force coefficient, $\frac{\text{measured axial force}}{q_\infty S}$
$C_{A,b}$	Base axial-force coefficient, $\left(\frac{p_\infty - p_b}{q_\infty}\right)\frac{A_b}{S}$
$C_{A,F}$	Forebody axial-force coefficient, $C_A - C_{A,b}$

C_D	Ballute drag coefficient, $\frac{\text{measured drag}}{q_\infty A_B}$
C_m	Pitching-moment coefficient referenced to center of gravity (see Fig. 3), $\frac{\text{measured pitching moment}}{q_\infty SD}$
C_{m_α}	Rate of change of pitching-moment coefficient with angle of attack $(dC_m/d\alpha)_{\alpha=0}$, per degree
C_N	Normal-force coefficient, $\frac{\text{measured normal force}}{q_\infty S}$
C_{N_α}	Rate of change of normal-force coefficient with angle of attack $\left(\frac{dC_N}{d\alpha}\right)_{\alpha=0}$, per degree
D	Reference diameter of booster model, 0.867 ft
D_B	Ballute diameter (nominal), 2.18 ft
D_b	Booster base diameter, 0.562 ft
d	Reference diameter of payload, 1.44 ft
L/d	Payload-ballute separation distance in payload reference diameters
M_∞	Free-stream Mach number
p_b	Static pressure at base of booster model, psf
p_{t_∞}	Free-stream stagnation pressure, psf
p_∞	Free-stream static pressure, psf
q_∞	Free-stream dynamic pressure, $0.7\, p_\infty M_\infty^2$, psf
Re/ft	Reynolds number per foot, $\frac{V_\infty}{\nu_\infty}$
S	Model cross-sectional reference area, $\frac{\pi D^2}{4}$, ft^2
V_∞	Free-stream velocity, ft/sec
x_{cp}	Center-of-pressure location in model reference diameters (D), negative aft of moment reference, C_m/C_N
x_{np}	Neutral-point location in model reference diameters (D), negative aft of moment reference, $(dC_m/dC_N)_{\alpha=0}$

α	Angle of attack, corrected for balance and sting deflections, positive nose up, deg
ν_∞	Free-stream kinematic viscosity, ft^2/sec

SECTION I
INTRODUCTION

The Air-Launch, Air Recoverable Rocket (ALARR) is designed to take atmospheric samples at altitudes above 60,000 ft. After completion of the sampling cycle, the payload is explosively separated from the booster, and the booster speed brake is deployed. After separation, a ballute is deployed from the payload to stabilize and slow the payload prior to deployment of a recovery parachute.

The present investigation was conducted in two phases. The purpose of Phase I was to determine the drag and stability characteristics of the ballute. For this purpose, a full-scale payload model was used. In one part of Phase I the ballute was suspended on a single line which could be reeled out to various lengths. The drag of the ballute was measured in this part. In the other part of Phase I the ballute was suspended on a fixed-length bridle which was attached to the payload at four points. For this part, only photographic data were obtained. The Mach numbers for Phase I were 0.55 and from 2.00 to 3.00. Comparative transonic data obtained with small scale models are available in Ref. 1.

The purpose of Phase II was to determine the effects of a modified speed brake on the drag and stability of the booster. In this phase a 0.6-scale model of the booster was tested at Mach numbers from 1.80 to 3.00 and angles of attack from -4 to 10 deg. Stability and drag data for the booster alone and with an earlier configuration of the speed brake are presented in Ref. 2.

SECTION II
APPARATUS

2.1 WIND TUNNEL

Tunnel 16S is a continuous flow, closed-circuit wind tunnel capable of operating from a stagnation pressure level of approximately 100 to 1800 psf. The test section is 16 ft square by 40 ft long. The Mach number range is from 1.65 to 3.20. A more detailed description of the tunnel and its calibration may be found in Ref. 3.

Schematics of the tunnel test section showing the ALARR payload and booster installations are presented in Figs. 1a and b. Photographs showing typical model installations in the test section are shown in Figs. 2a, b, and c.

2.2 TEST ARTICLES

Sketches of the full-scale payload, the ballute, and the 0.6-scale booster are presented in Figs. 3a, b, and c. The booster model was tested with a modified speed brake (Fig. 4) which had a cross-sectional area of 2.20 sq ft. Both the payload and booster were constructed of aluminum. The ballute, which was supplied by Goodyear Aerospace Company, was constructed principally of Viton rubber. In Phase I the position of the ballutes was varied from 2.6 to 8 payload diameters downstream of the payload base using a single suspension line and cable attached to an electric winch. The cable ran from the winch through the support strut and was conveyed through the model by a pulley system to a swivel and then to the ballute attachment point. The pulley and load-cell arrangement is shown in Fig. 3a. Also a four-point attachment bridle and riser line were utilized to deploy the ballute three diameters aft of the payload. A swivel was not employed in this configuration. The suspension arrangement for the fixed ballute is shown in Fig. 3b.

2.3 INSTRUMENTATION

For Phase I, the position of the movable ballute downstream of the payload was determined by a Selsyn transmitter attached to the electric winch. The drag of the ballute was measured with a load-cell located inside the model as shown in Fig. 3a. High speed motion picture cameras were used for visual coverage of all deployments.

For Phase II, a six-component, internal strain-gage balance was used to measure aerodynamic forces on the model. Base pressure measurements were obtained from a pressure transducer connected to two orifices located in the plane of the model base. The readout equipment for these measurements is described in Ref. 1.

SECTION III
PROCEDURE

3.1 TEST CONDITIONS

3.1.1 Phase I

Static and dynamic drag data were recorded for the ballute deployments obtained with the extendable riser at Mach numbers 2.00 and 2.50.

The ballutes were initially deployed three diameters behind the payload and then reeled out and in so as to obtain static drag data for payload-ballute separation distances in the range from 2.6 to 8.0 payload diameters. Static data were also obtained at M_∞ = 3.00 with the ballute already deployed from a previous Mach number. Tunnel conditions for the extendable riser ballute tests were:

M_∞	q_∞, psf	$(Re/ft) \times 10^{-6}$
2.00	201	0.84
2.51	205	0.80
3.01	200	0.87

For the fixed-length bridle and riser, deployments were made at the following conditions:

M_∞	q_∞, psf	$(Re/ft) \times 10^{-6}$
0.55	38	0.34
2.20	380	1.51
3.00	120	0.57

3.1.2 Phase II

Force data were obtained on the booster model with speed brake at Mach numbers from 1.80 to 3.00 and angles of attack from -4 to 10 deg. Stagnation pressures varied from 330 to 720 psf. The variations in Reynolds number per foot are shown in Fig. 5.

3.2 PRECISION OF MEASUREMENTS

The estimated precision of the test data for Phase I is as follows:

ΔM_∞	Δq_∞	ΔC_D
±0.005	±3 psf	±0.020

For the booster static-stability measurements, Phase II, the estimated uncertainties are:

M_∞	ΔC_N	ΔC_m	ΔC_A	$\Delta C_{A,b}$	$\Delta\alpha$, deg	ΔM_∞	Δp_{t_∞}, psf	$\Delta T_{t\infty}$, °F
2.00	±0.027	±0.019	±0.022	±0.007	±0.10	±0.005	±1.40	±5
2.50	±0.036	±0.040	±0.030	±0.008	±0.10	±0.005	±1.40	±5
3.00	±0.054	±0.060	±0.036	±0.021	±0.10	±0.005	±1.40	±5

The uncertainty quoted for Mach number is in reference to the ability to set and maintain a given tunnel Mach number. The variation in Mach number in the vicinity of the test articles is within ±0.02. The uncertainties quoted were determined by a statistical method based on a normal error distribution and a 95-percent confidence level.

SECTION IV
RESULTS AND DISCUSSION

4.1 PAYLOAD WITH BALLUTE, PHASE I

The variation of the ballute drag coefficient with payload-ballute separation distance, L/d, is shown in Fig. 6. Figure 6 shows that the effect of separation distance on the drag of the ballute diminishes with increasing Mach number.

Since only movie camera data were taken for the fixed-length-riser ballutes (Fig. 3b) all drag data are for the ballutes with single suspension line and variable separation distance, L/d.

Deployment and inflation were successful in all instances. The ballute on the single extendable riser with an attached swivel was observed to spin at all Mach numbers, and the spin rate increased with Mach number. The ballute with four-point suspension and no swivel showed no tendency to spin.

4.2 BOOSTER MODEL, PHASE II

Figures 7 and 8 present the changes in normal-force and pitching-moment coefficients, respectively, with angle of attack. The variation of center-of-pressure location with angle of attack is presented in Fig. 9 along with neutral-point locations. The booster with modified speed brake (Fig. 4) was statically stable in pitch about its center of gravity from $M_\infty = 1.80$ to 3.00.

The variations of the static-stability parameter (C_{m_α}), the normal-force parameter (C_{N_α}), and the neutral-point location (x_{np}) with Mach number are presented in Figs. 10, 11, and 12, respectively.

The variations of the axial-force coefficients with angle of attack for Mach numbers from 1.80 to 3.00 are presented in Fig. 13. The axial-force coefficients are based on the area of the booster face without speed brake ($S = 0.69\ ft^2$). The total axial-force coefficients with the modified speed brake were approximately 2.6 times those obtained for the initial speed brake tested (Ref. 2) and 3.6 times those for the booster alone. Forebody and base axial-force coefficients at $\alpha = 0$ are plotted against Mach number in Figs. 14 and 15. The variation in $C_{A,F}$ with Mach number is small in the range of this test.

SECTION V
CONCLUSIONS

The following conclusions were derived from this test:

Phase I

1. The ballute with single-point suspension deployed well and inflated quickly but spun at a rate which increased as Mach number was increased.
2. The drag of the ballute generally decreased as it was positioned at greater distance downstream of the payload at Mach numbers of 2.00 and 2.50. At Mach number 3.0, the drag was invariant with ballute location.
3. The ballute with the four-point suspension and fixed riser length deployed and inflated satisfactorily at Mach numbers of 0.55, 2.20, and 3.00. No tendency to spin was shown at any of these Mach numbers.

Phase II

1. The total axial force of the booster with the modified speed brake was approximately 3.6 times greater than the total axial force of the booster alone at $M_\infty = 3.00$.
2. The booster with modified speed brake was statically stable in pitch about the indicated center-of-gravity position.

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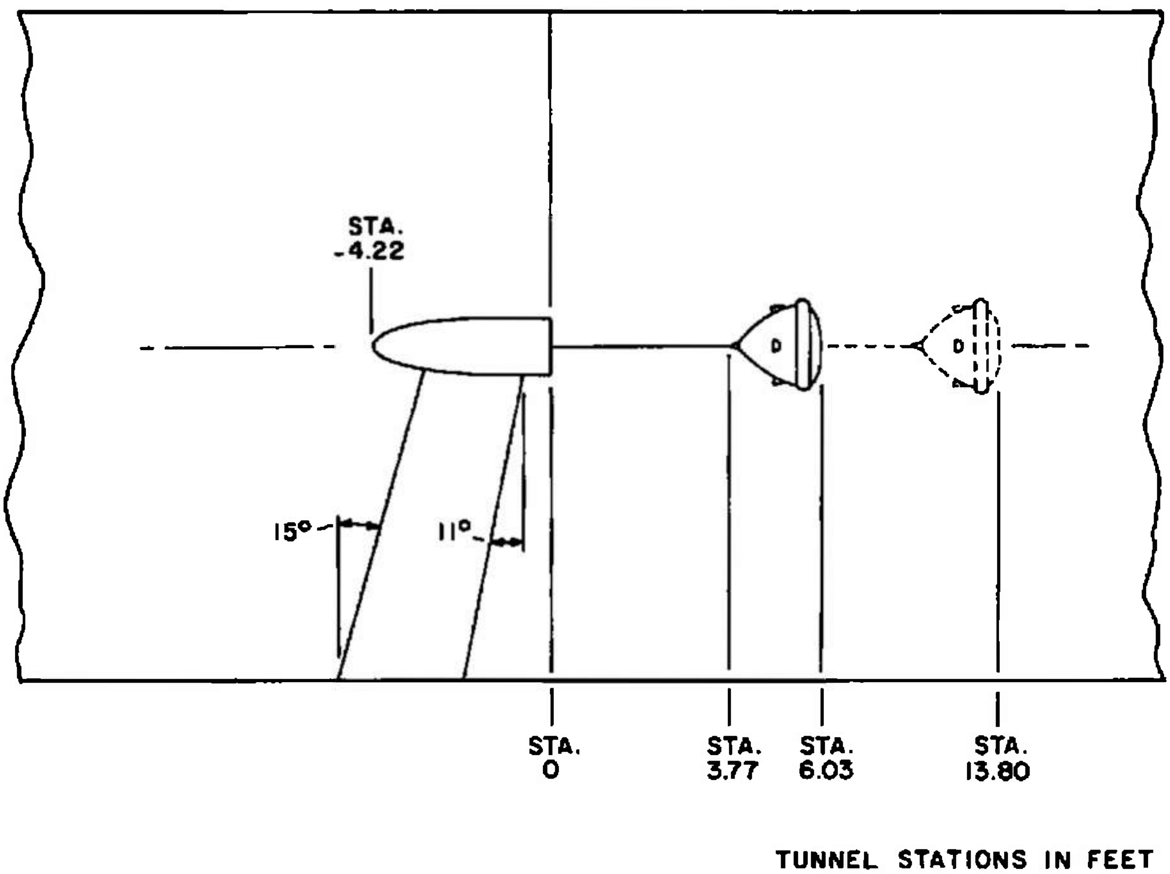
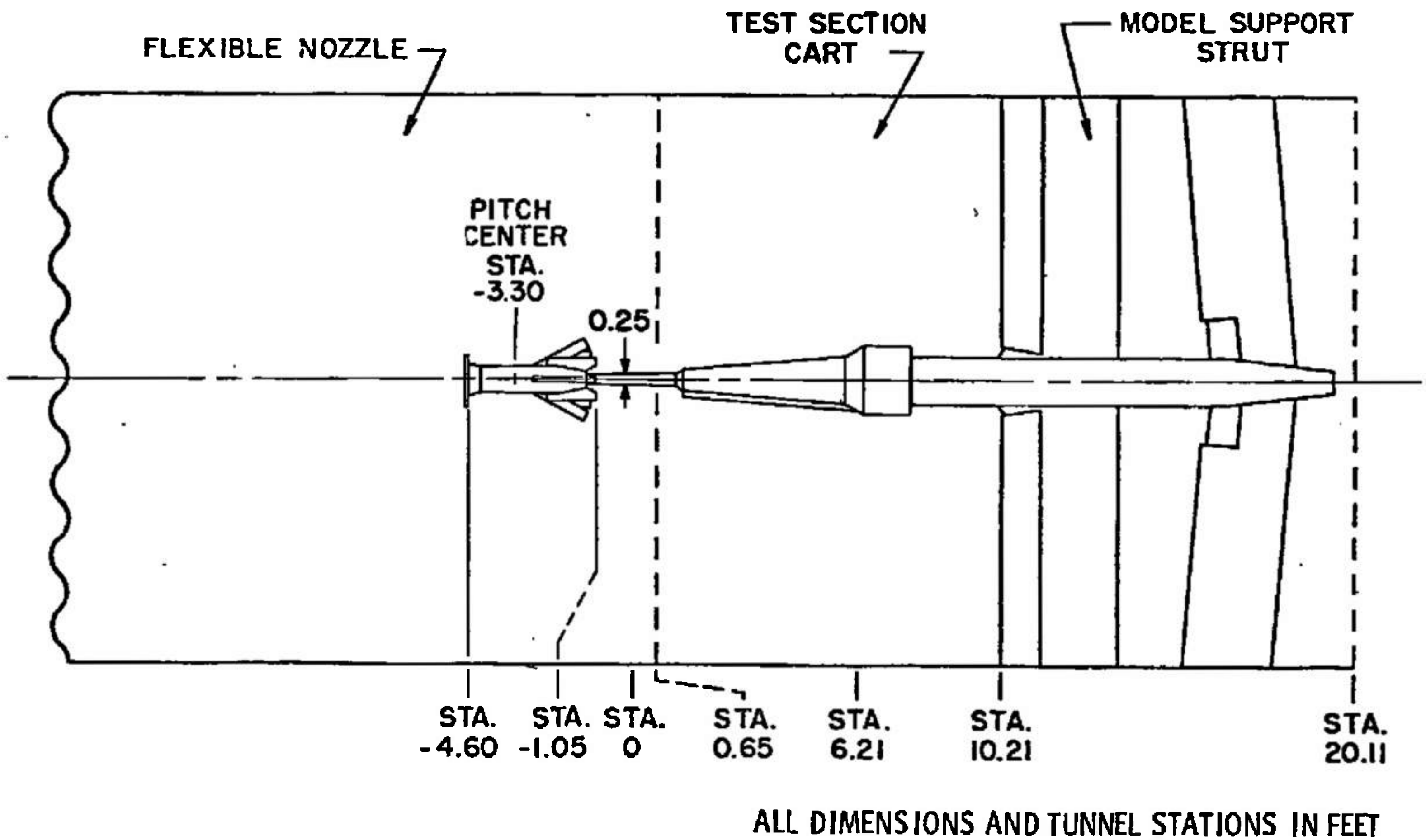
2. Perkins, T. M. and Brice, T. R. "Static Stability and Separation Characteristics of 0.6-Scale Models of the ALARR Payload and Booster at Supersonic Speeds." AEDC-TR-65-74 (AD461134), April 1965.

3. Test Facilities Handbook (5th Edition). "Propulsion Wind Tunnel Facility, Vol. 3." Arnold Engineering Development Center, July 1963.



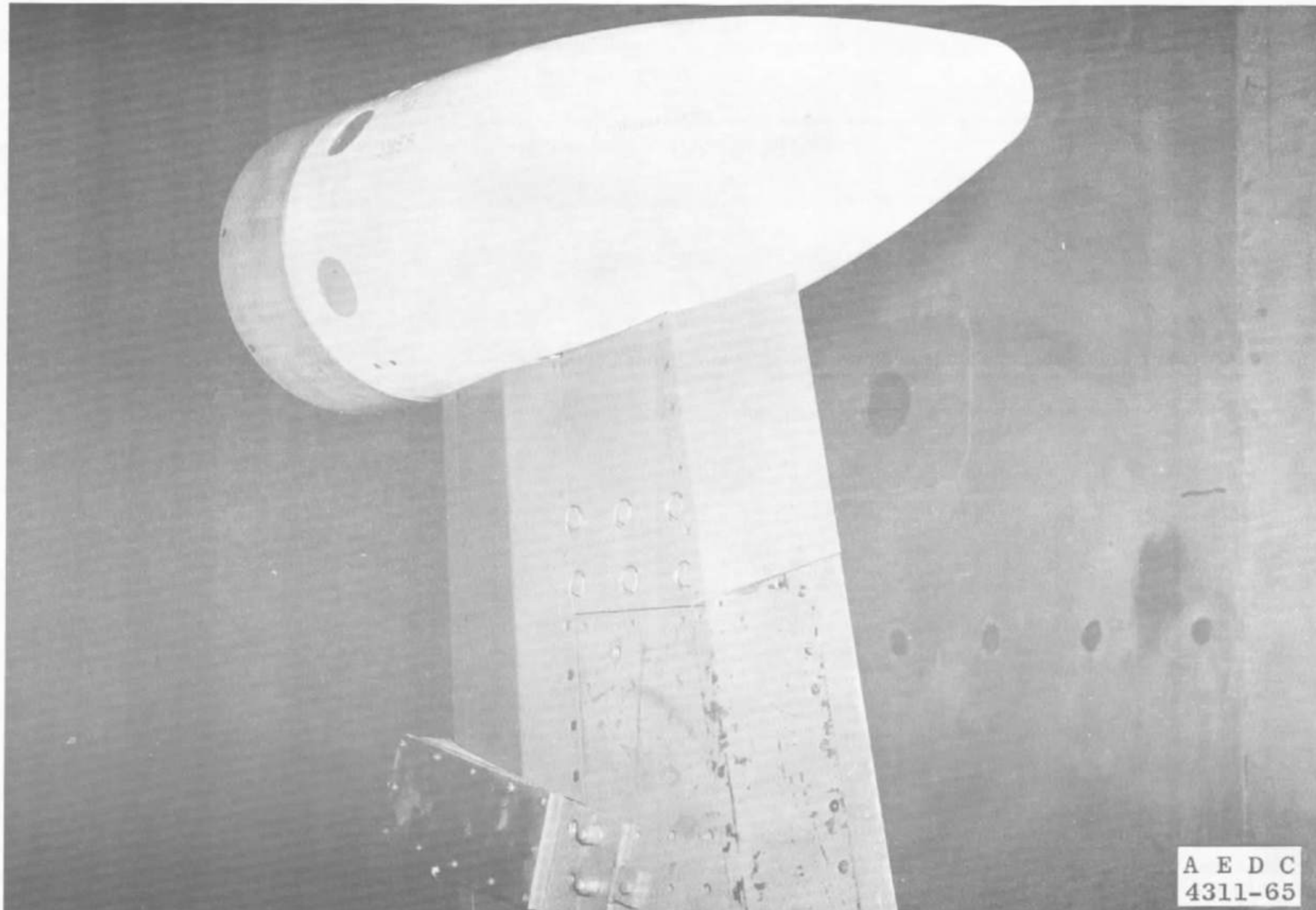
a. Payload with Ballute, Phase I

Fig. 1 Schematic of Tunnel 16S Test Section Showing Model Location



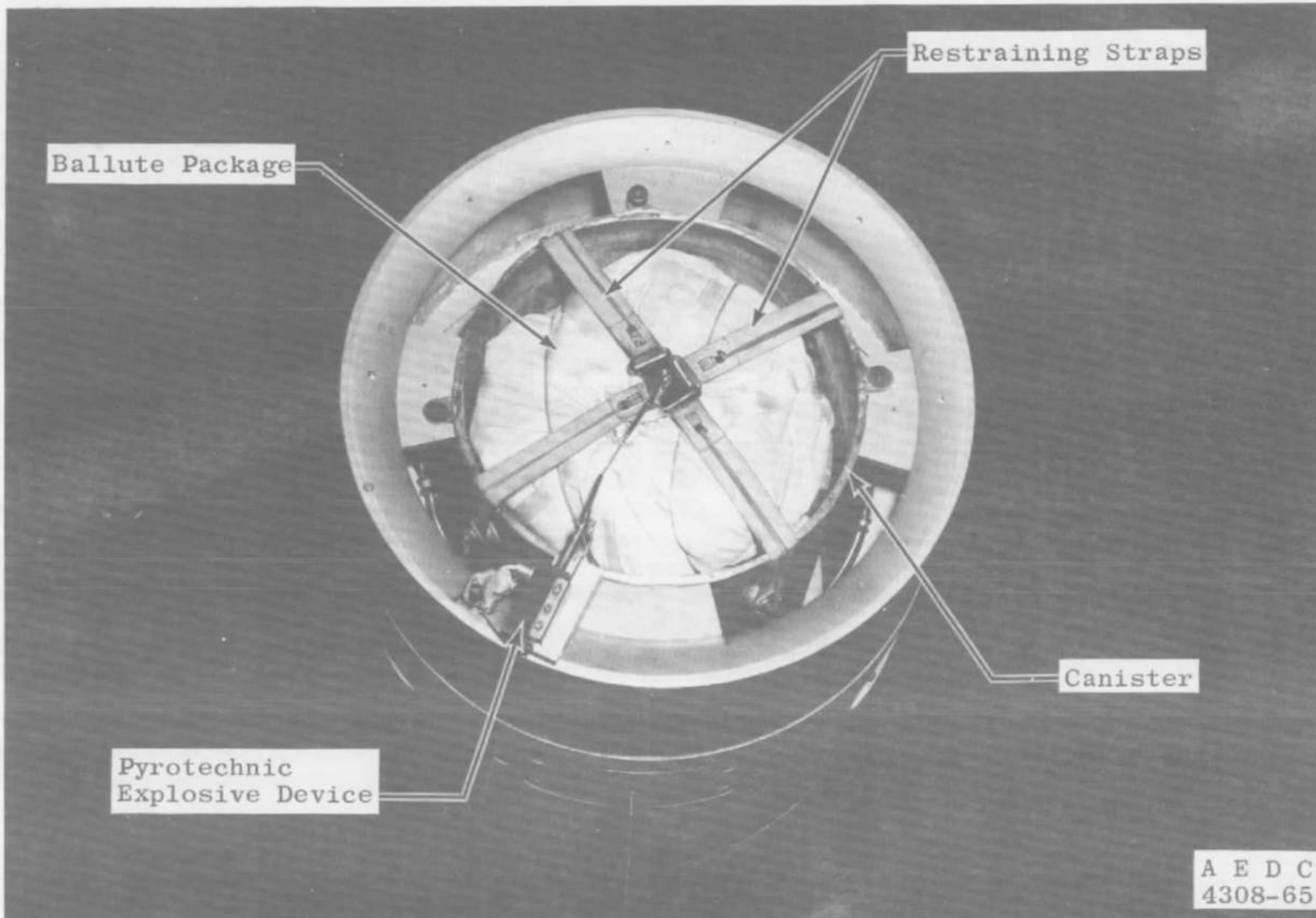
b. Booster with Modified Speed Brake, Phase II

Fig. 1 Concluded



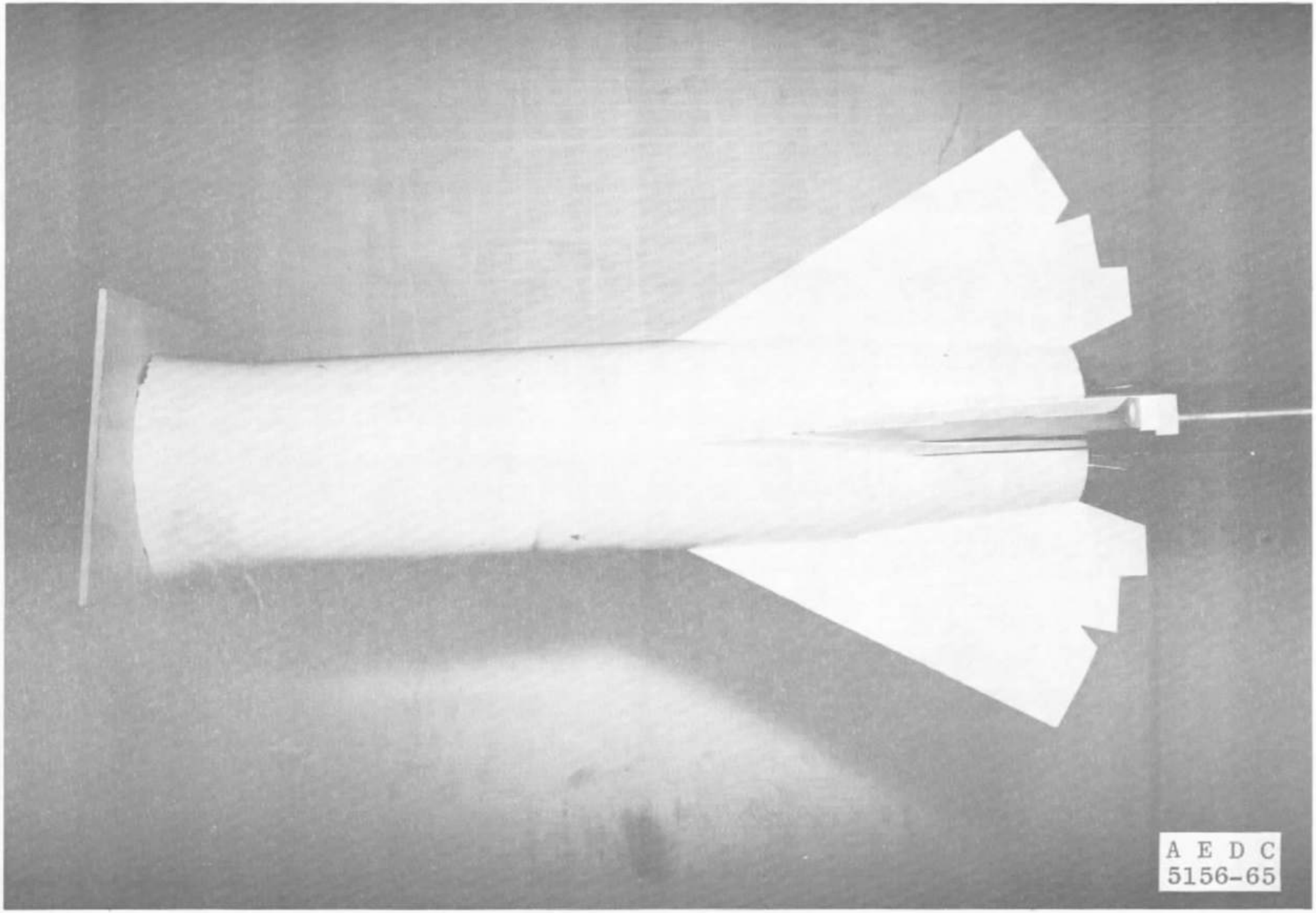
a. Payload

Fig. 2 Photographs of ALARR Models Installed in Tunnel 16S



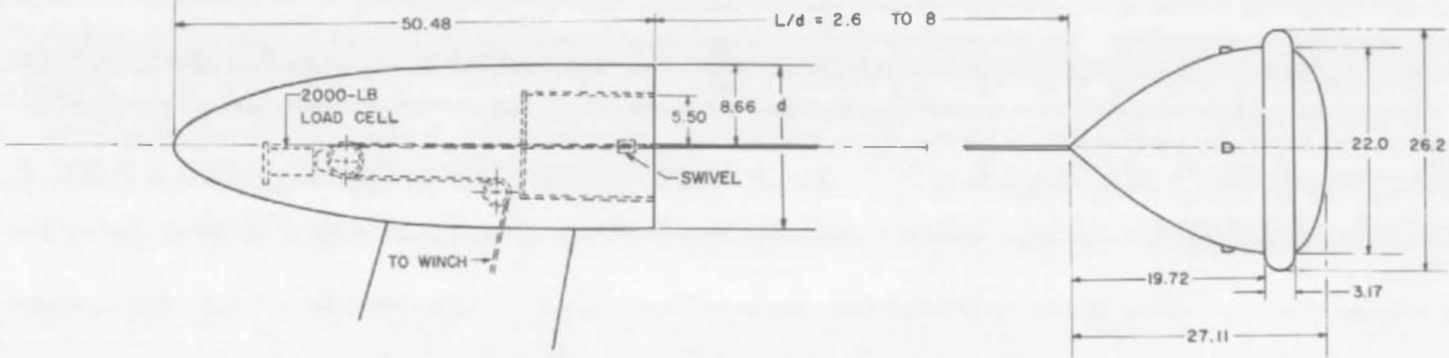
b. Ballute Package in Payload Base

Fig. 2 Continued

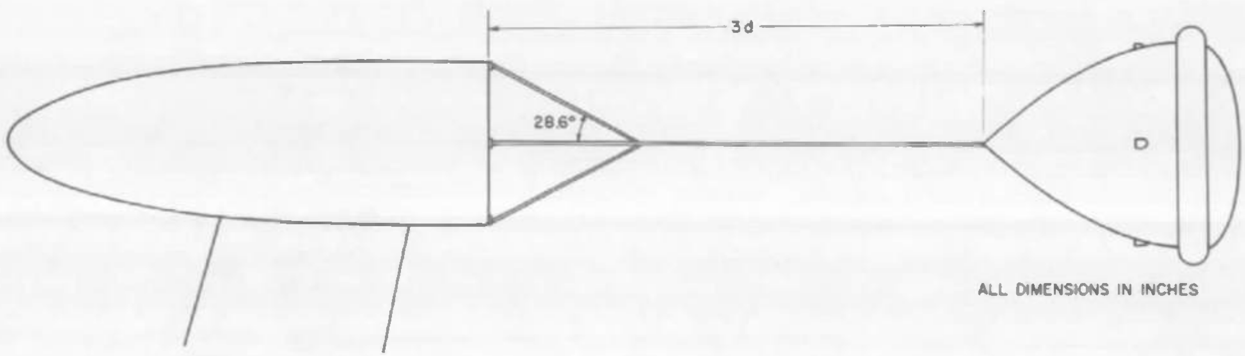


c. Booster with Modified Speed Brake

Fig. 2 Concluded

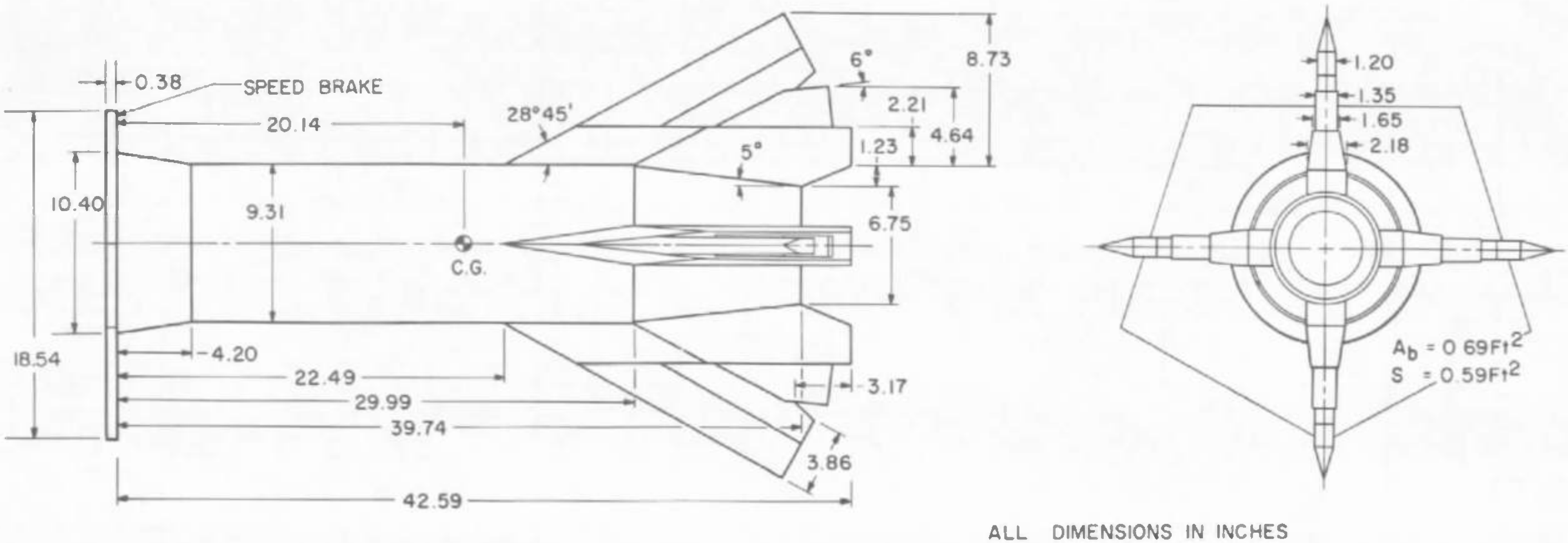


a. Payload with Movable Ballute and Single Suspension Line



b. Payload with Fixed Ballute and Four-Point Suspension Lines

Fig. 3 Details of Models



c. Booster with Modified Speed Brake

Fig. 3 Concluded

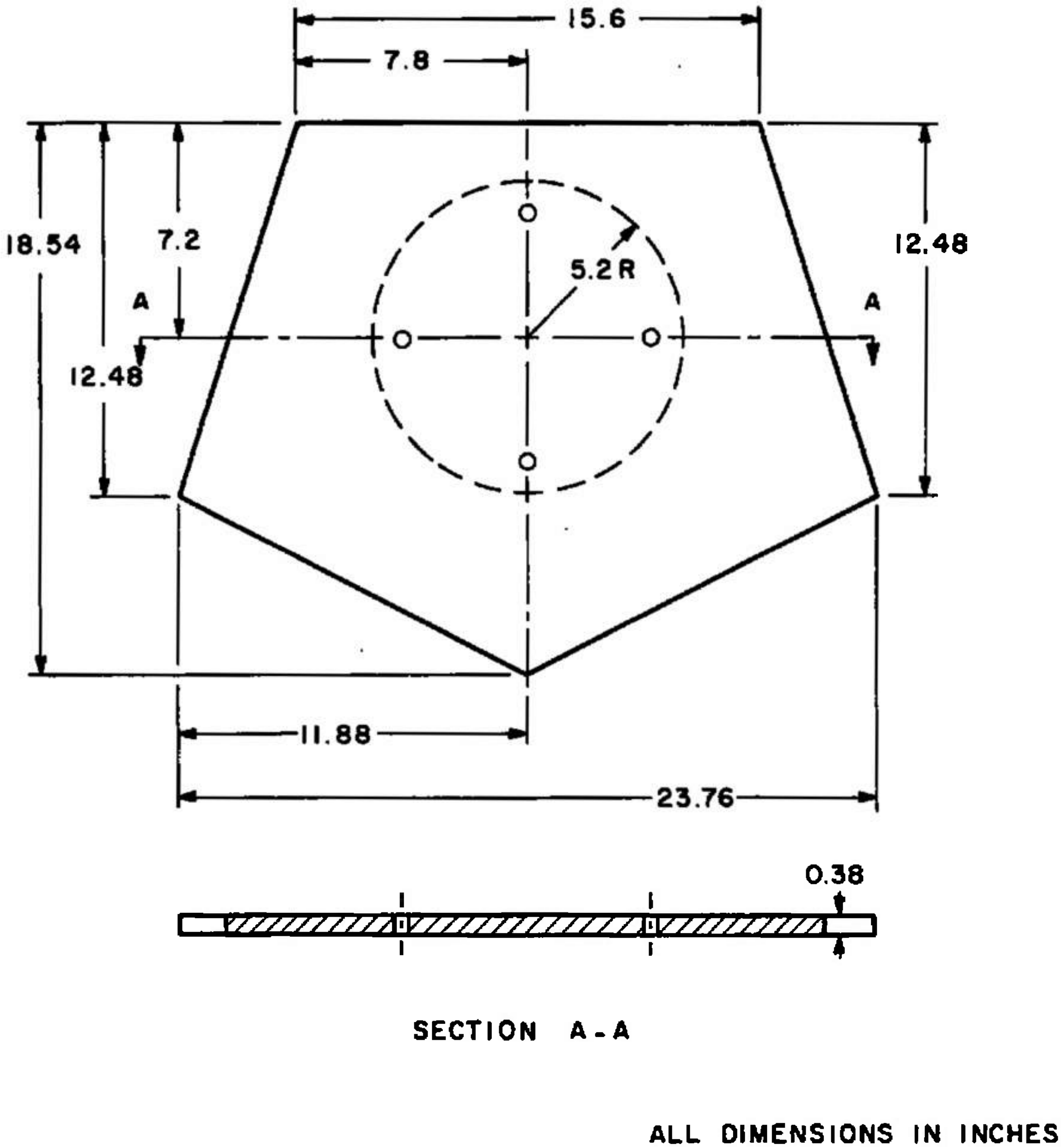


Fig. 4 Modified Speed Brake

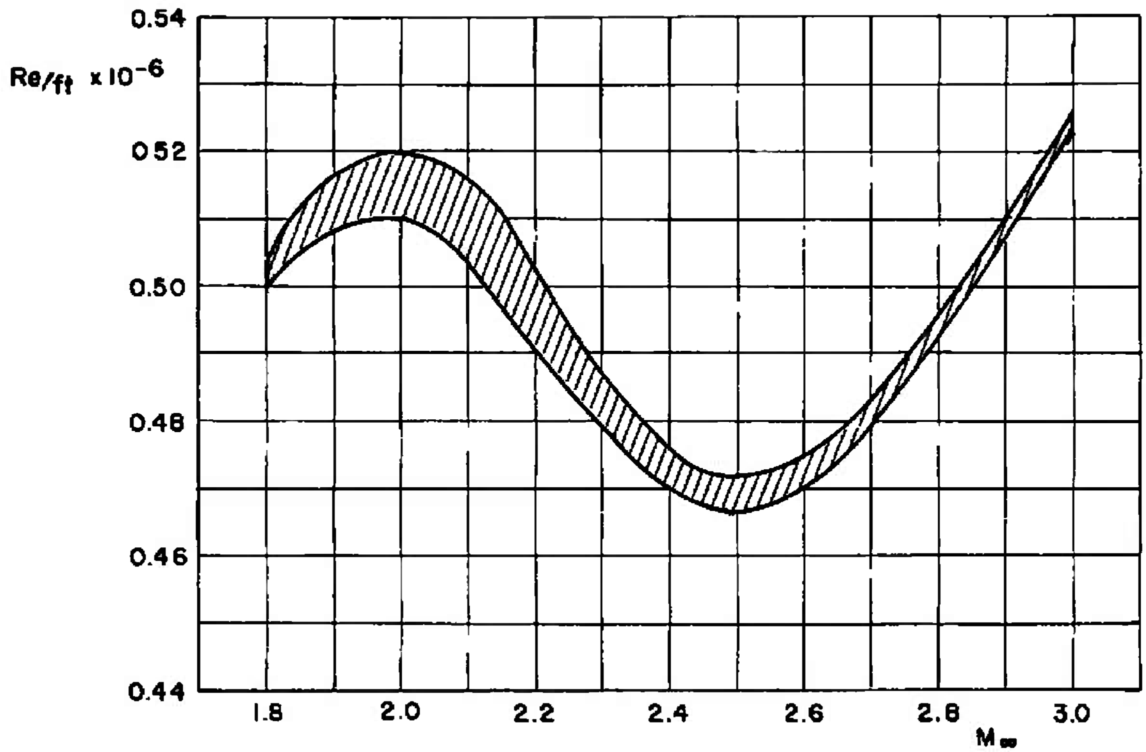


Fig. 5 Variation of Reynolds Number with Mach Number for Booster Phase (Phase II)

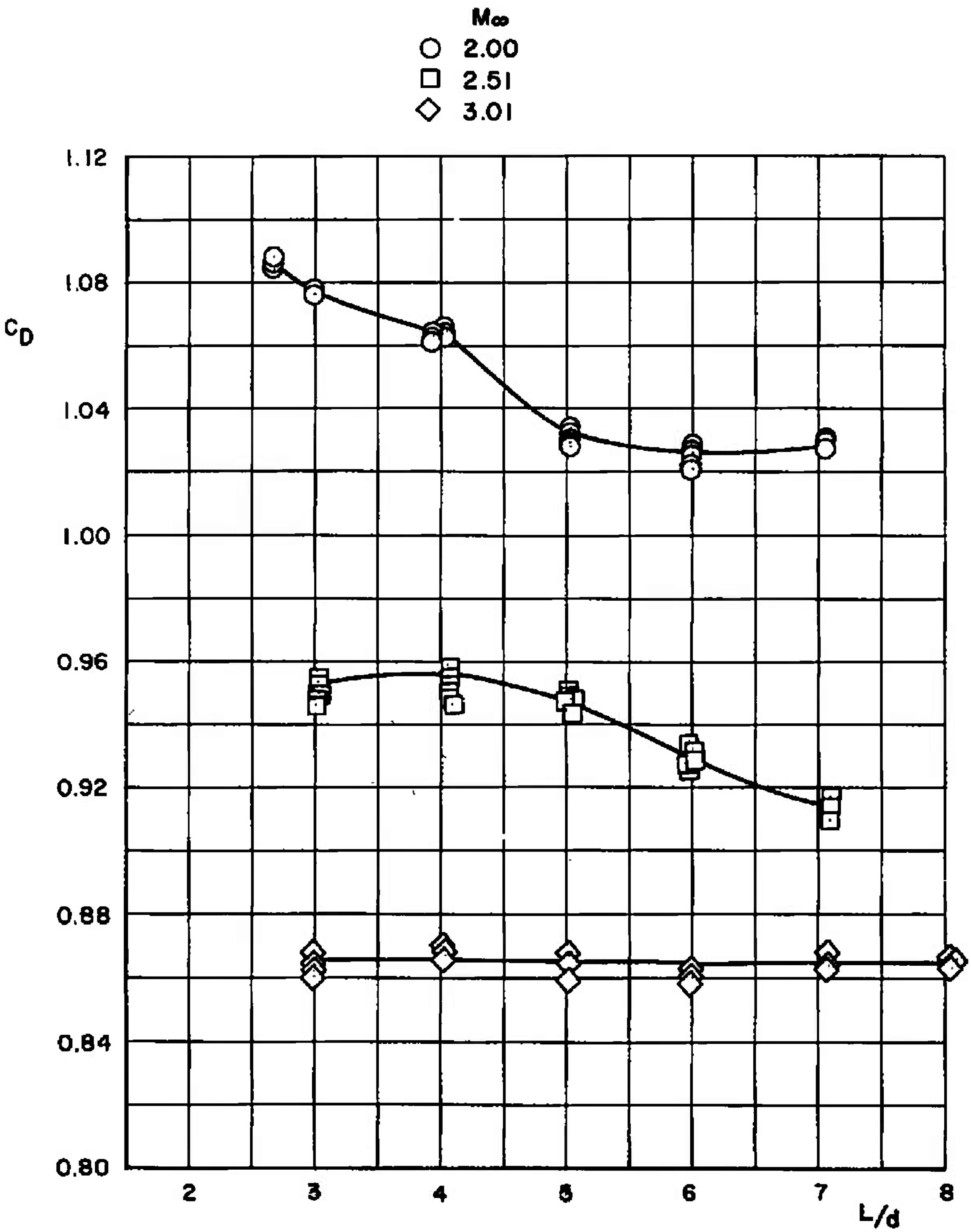


Fig. 6 Variation of Ballute Drag Coefficient with Payload-Ballute Separation Distance

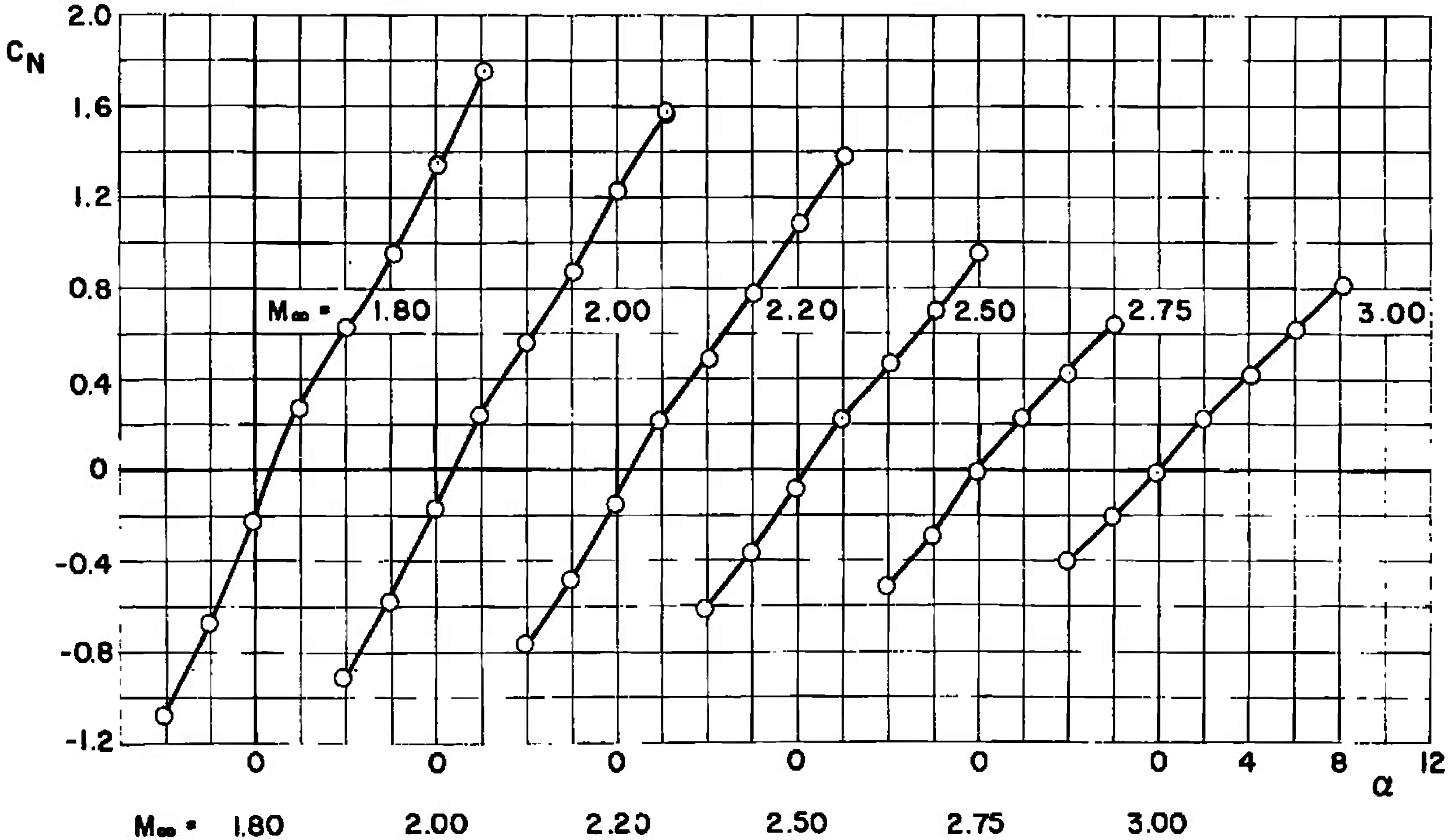


Fig. 7 Variation of Normal-Force Coefficient with Angle of Attack

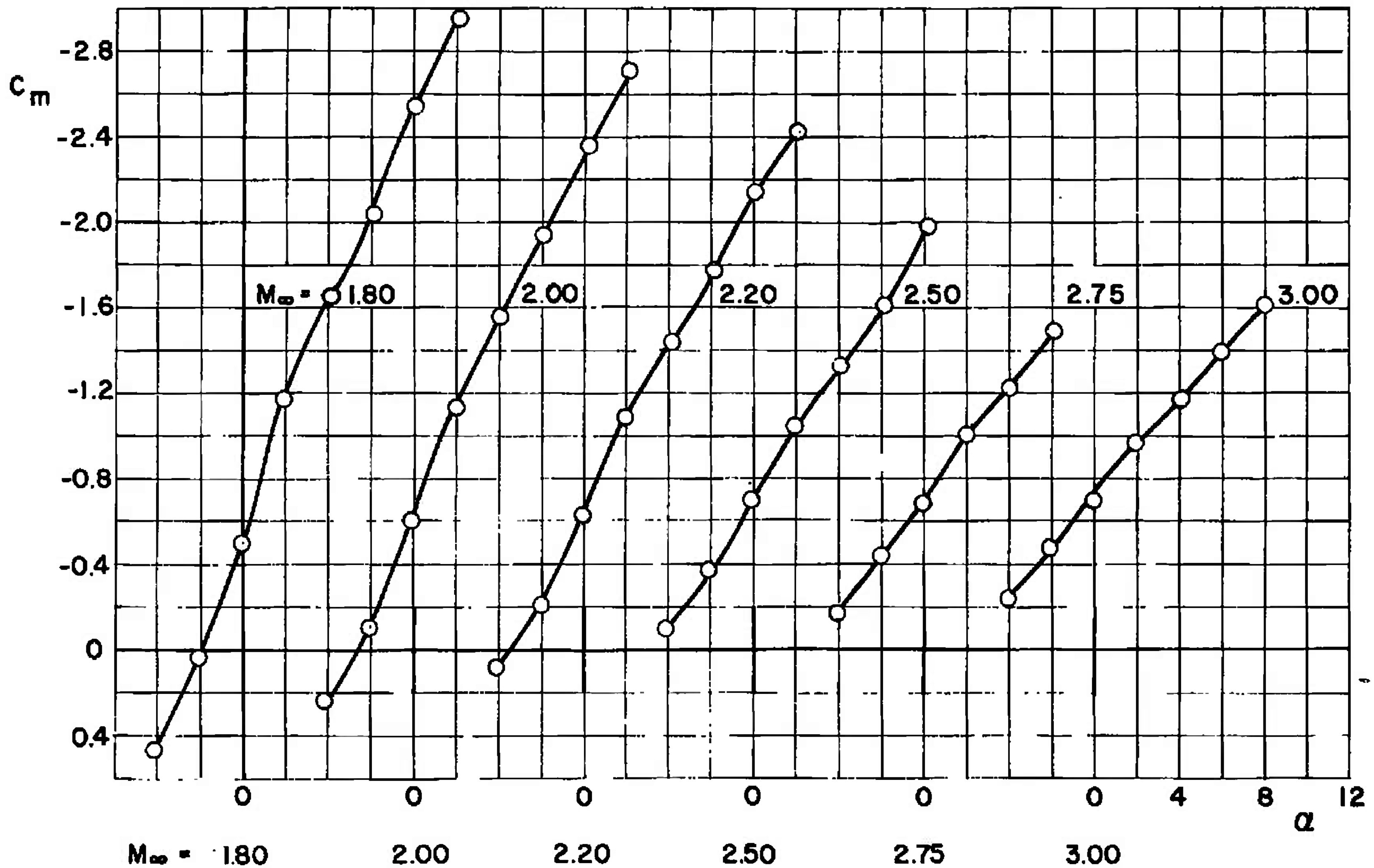


Fig. 8 Variation of Pitching-Moment Coefficient with Angle of Attack

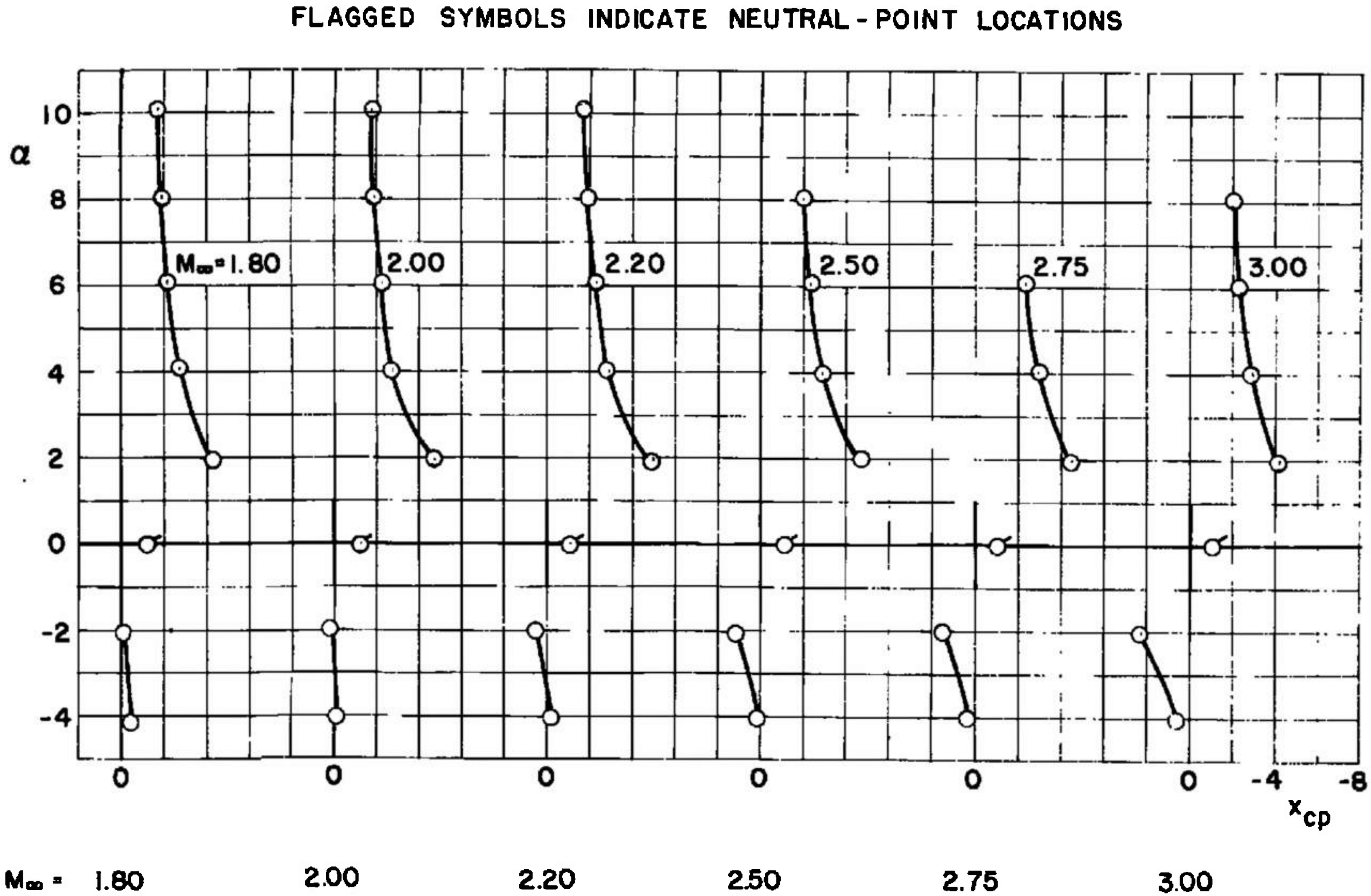


Fig. 9 Variation of Center-of-Pressure Location with Angle of Attack

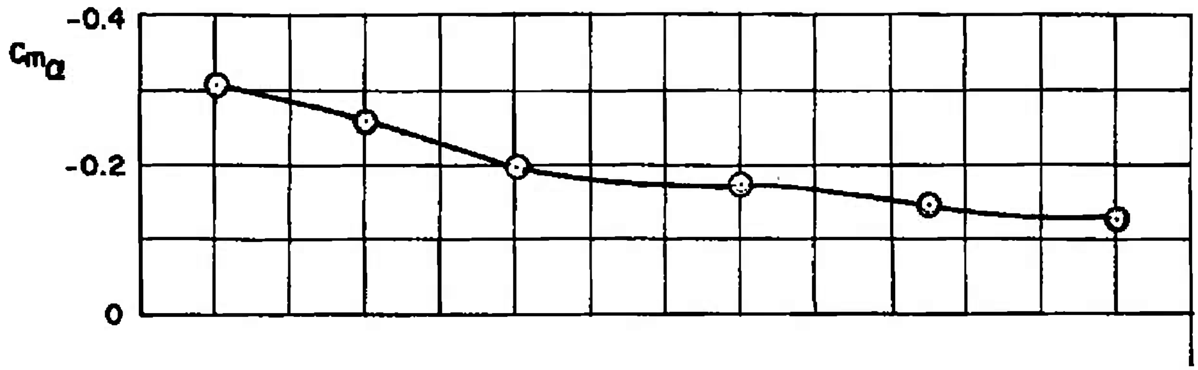


Fig. 10 Variation of the Rate of Change of Pitching-Moment Coefficient with Mach Number at $\alpha = 0$

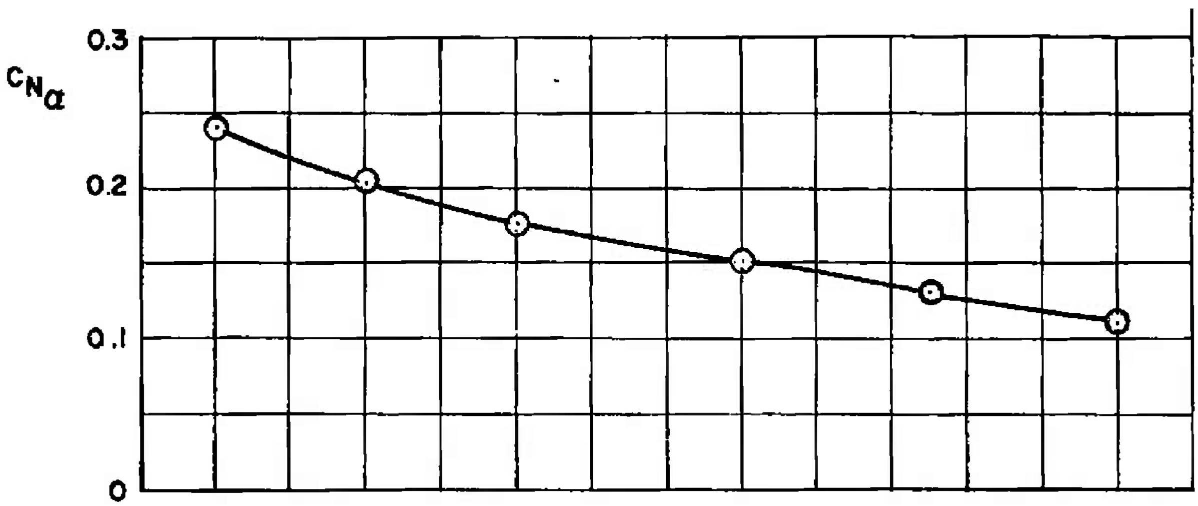


Fig. 11 Variation of the Rate of Change of Normal-Force Coefficient with Mach Number at $\alpha = 0$

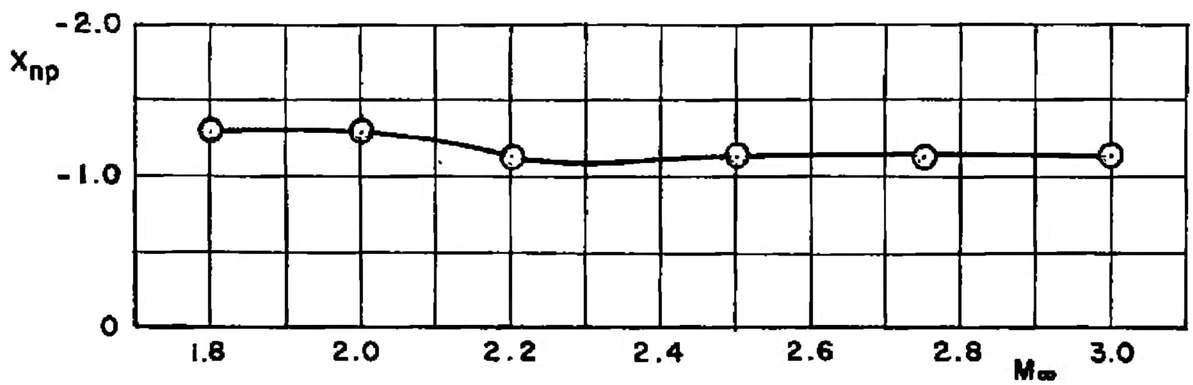


Fig. 12 Variation of Neutral-Point Location with Mach Number

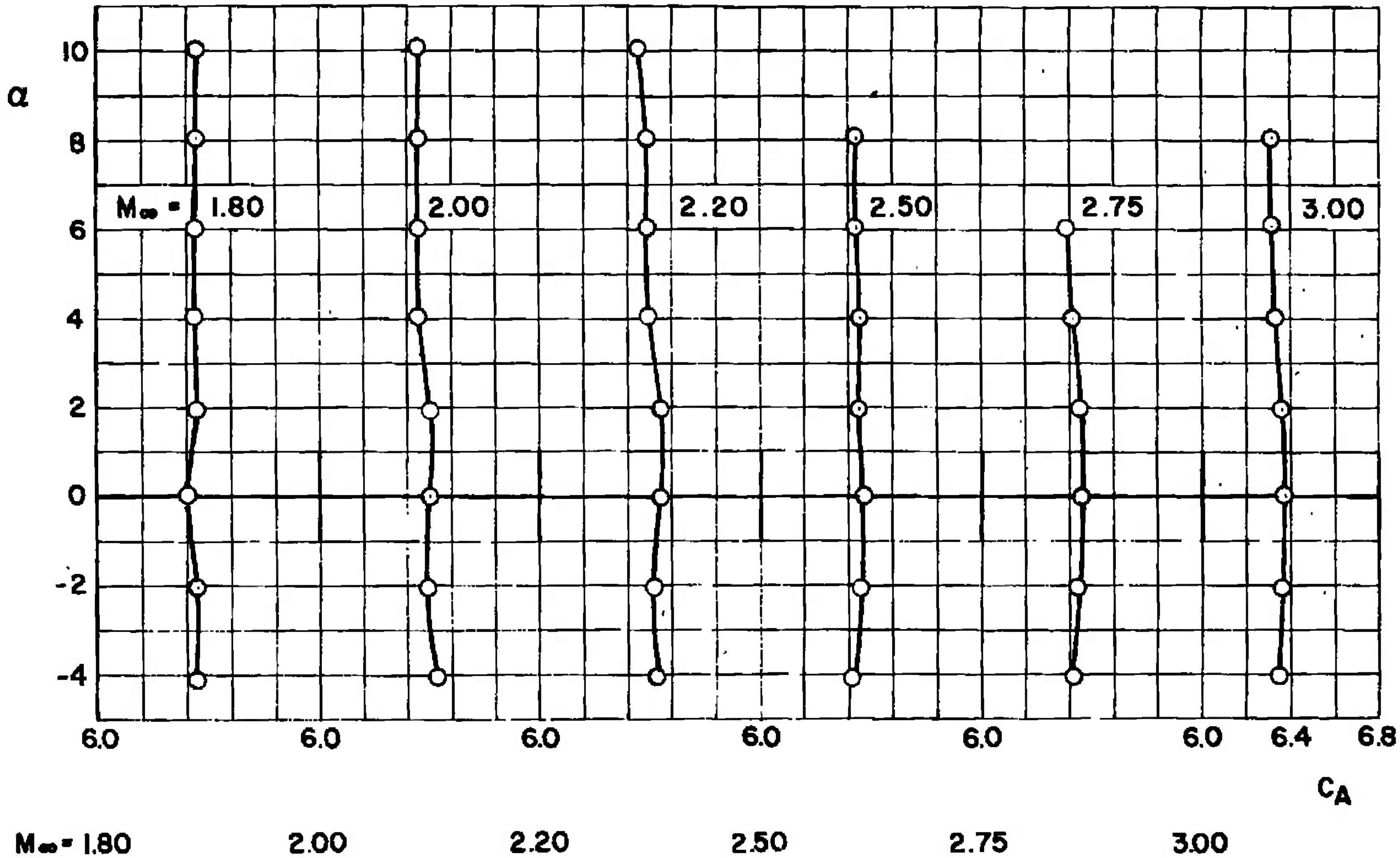


Fig. 13 Variation of Axial-Force Coefficient with Angle of Attack

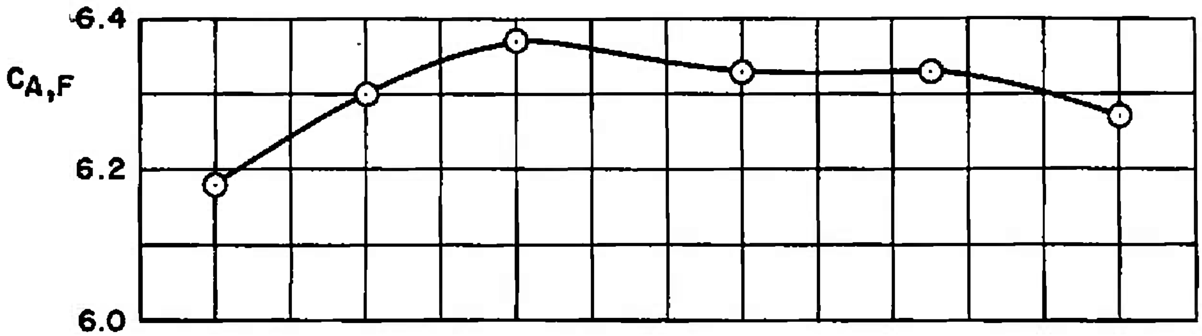


Fig. 14 Variation of Forebody Axial-Force Coefficient with Mach Number at $\alpha = 0$

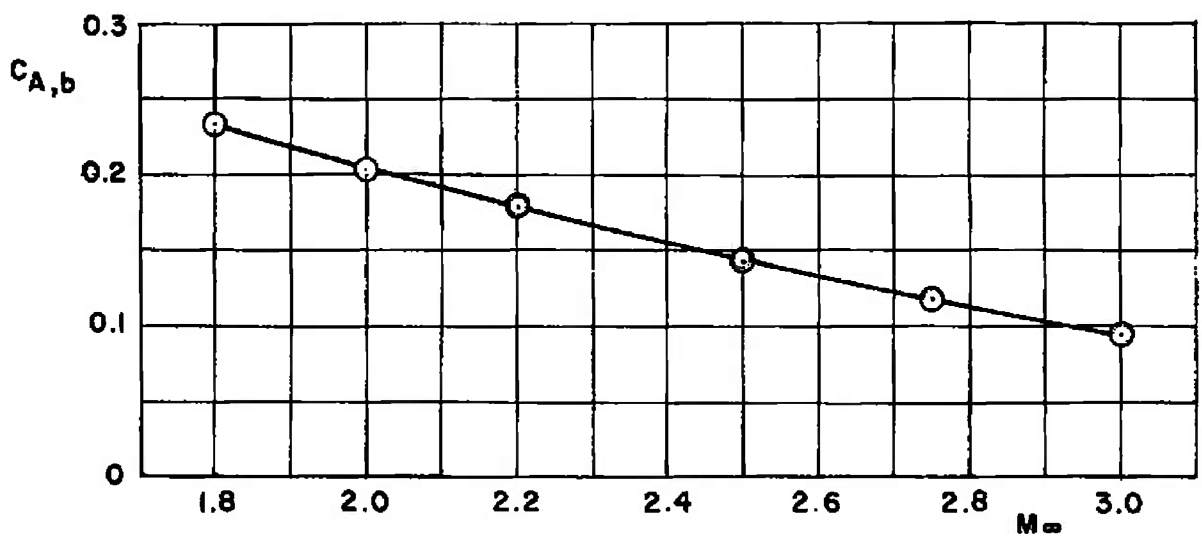


Fig. 15 Variation of Base Axial-Force Coefficient with Mach Number at $\alpha = 0$

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ALARR booster						
ballutes						
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