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AN INVESTIGATION OF VARIOUS TYPES OF DECELERATORS AT MACH NUMBER 2.8

D. A. MacLanahan, Jr.
ARO, Inc.

July 1966

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NOTICES

AN INVESTIGATION OF VARIOUS TYPES OF 1. DECELERATORS AT MACH NUMBER 2.8

2 Ballutes

3. Parachutes

1-15

D. A. MacLanahan, Jr.

ARO, Inc.

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FOREWORD

The work reported herein was done at the request of and for the Air Force Flight Dynamics Laboratory (AFFDL), Air Force Systems Command (AFSC), under Program Element 62405364, Project 6065, Task 606507.

The results of the test were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), AFSC, Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. The test was conducted from May 11 to 14, 1966, under ARO Project No. PS0656, and the manuscript was submitted for publication on June 23, 1966.

This technical report has been reviewed and is approved.

Theodore E. Workman
Major, USAF
AF Representative, PWT
DCS/Test

Leonard T. Glaser
Colonel, USAF
DCS/Test

ABSTRACT

A test was conducted in the 16-ft supersonic wind tunnel to obtain deployment and steady-state drag, inflation, and stability characteristics of a metal ballute, a cloth ballute, a cloth ballute with a burble fence, a parasonic parachute, and a hyperflo parachute. All decelerators were tested at a Mach number of 2.8 at a dynamic pressure of 120 psfa. The parachutes were also tested at Mach numbers of 2.9 and 3.0 at a dynamic pressure of 120 psfa. The data obtained show that a method of pre-inflation utilizing a methyl alcohol/water solution reduced the time required for the drag load to reach the steady-state value. This reduction of time permitted the metal ballute to attain full inflation.

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ILLUSTRATIONS

TABLE

NOMENCLATURE

A_e	Parachute exit area, sq ft
A_i	Parachute inlet area, sq ft
C_{D_o}	Decelerator drag coefficient, $F_D/q_\infty S_o$
F_D	Decelerator drag force
M_∞	Free-stream Mach number
p_i	Ballute internal pressure, psf
q_∞	Free-stream dynamic pressure, psfa
S_o	Decelerator drag-producing area a. Metal ballute, 19.635 ft^2 b. Cloth ballute with burble fence, 28.274 ft^2 c. Cloth ballute, 19.635 ft^2 d. Parachutes, 12.566 ft^2
T_i	Ballute internal temperature, °F
T_t	Free-stream total temperature, °F

SECTION I
INTRODUCTION

A test was conducted in the 16-ft supersonic tunnel (Propulsion Wind Tunnel, Supersonic (16S)) of the Propulsion Wind Tunnel Facility (PWT) to determine the steady-state drag, inflation, and stability characteristics of two types of aerodynamic decelerators in supersonic flows. The decelerators investigated during this test were three conical ballutes and two parachutes. All of the decelerators were tested at a nominal Mach number of 2.8 at a nominal free-stream dynamic pressure of 120 psfa. The parachutes were additionally tested at nominal Mach numbers of 2.9 and 3.0 at a free-stream dynamic pressure of 120 psfa.

SECTION II
APPARATUS

2.1 TEST FACILITY

Tunnel 16S is a closed-circuit, continuous flow wind tunnel currently capable of operating at Mach numbers from 1.65 to 3.20. The tunnel is capable of operating over a stagnation pressure range from about 350 to 1600 psfa, depending upon Mach number. The test section stagnation temperature can be controlled through an approximate range of from 150 to 430°F. The wind tunnel specific humidity is controlled by removing tunnel air and supplying makeup air from an atmospheric dryer. A more complete description of the facility and its operating characteristics is contained in the Test Facilities Handbook.[1]

2.2 TEST ARTICLE

2.2.1 Model Centerbody and Deployment System

The decelerators tested during this investigation were deployed from a strut-mounted centerbody. Dimensions of the centerbody are presented in Fig. 1, and the location of the centerbody in the wind tunnel is shown

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

in Fig. 2. The wind tunnel installation of the centerbody is shown in Fig. 3.

The ballutes were packed in the aft end of the centerbody and deployed with a drogue parachute. The parachutes were packed in the aft end of the centerbody on a spring-loaded plate. They were held against the plate by retaining straps which were released by a squib-fired release pin mechanism. A three-quarter rear view of a parachute packed in the aft end of the centerbody is shown in Fig. 4.

The ballute riser line was affixed to the centerbody by a cable with a load cell in series. The parachute riser line was similarly affixed to the centerbody, but a swivel was used to prevent twisting of the parachute suspension lines. A shear pin designed to protect the load cell was used to connect the riser line to the cable.

2.2.2 Decelerators

The decelerators tested were of three general types: ballutes, hyperflo parachute, and parasonic parachute. Specific construction details and photographs of the decelerators are shown in Figs. 5 through 9.

The 5-ft-diam metal ballute and the 5-ft-diam cloth ballute were constructed of woven stainless steel and Nomex®, respectively. These were 80-deg conical ballutes with four side-ram-air inlets. The dimensions of these ballutes are shown in Figs. 5a and b.

The 6-ft-diam cloth ballute was constructed of nylon. This ballute was an 80-deg conical ballute with four side-ram-air inlets with a 10 percent burble fence. The dimensions are shown in Fig. 5c, and a photograph is shown in Fig. 6.

An inflation device was incorporated in all of the ballutes. The normal inflation, made through the use of the four ram-air inlets, was augmented by the rapid vaporization of a methyl alcohol/water solution which was released inside the ballute upon deployment. At the internal pressure anticipated, the internal temperature was high enough to cause the alcohol/water solution to vaporize.

The 4-ft-diam parasonic parachute was constructed of nylon with a Dyna-Therm® coating on the canopy. This parachute had a mesh roof and skirt constructed of 0.25-in. webbing and 8.6-in.-wide fabric, respectively. The total porosity of this parachute was approximately 5 percent with an inlet-to-exit area ratio of 7.0. Further details and dimensions are shown in Fig. 7.

The 4-ft-diam hyperflo parachute was constructed of Nomex. Only the roof panel was coated with Dyna-Therm. This parachute had a mesh roof and skirt constructed of 0.25-in. webbing and 9.6-in.-wide fabric, respectively. The total porosity of the hyperflo parachute was approximately 5.6 percent. It had an inlet-to-exit area ratio of 7.0. Further details and dimensions are shown in Fig. 8, and a photograph is shown in Fig. 9.

2.3 INSTRUMENTATION

A 5000-lb capacity, double-element load cell was used to measure the drag load of the decelerators to within ±7 lb for the range of drag loads measured during these tests. A direct writing oscillograph was used to monitor the decelerator drag load during testing. Five motion-picture cameras and two television cameras, installed in the test section walls, were used to document and monitor these tests.

The internal pressure on the first two ballutes was measured with a model-mounted, 5-psid transducer. The internal pressure of the metal ballute was measured with a model-mounted, 15-psid transducer.

The internal temperature of the metal ballute was measured by Chromel®-Alumel® thermocouples.

SECTION III
PROCEDURE

A decelerator was packed in the aft end of the strut-mounted centerbody before the wind tunnel test operation was initiated. Once test conditions were established, the decelerator was ejected from the centerbody into the airstream. Motion pictures, dynamic drag data, dynamic pressure data, and dynamic temperature data were obtained during and after each deployment. Upon completion of the decelerator deployment sequence, a steady-state drag load was calculated by averaging the analog output signal from the strain-gage load cell over a 1-sec interval.

All of the decelerators were deployed at a nominal Mach number and free-stream dynamic pressure of 2.8 and 120 psfa, respectively. After deployment, additional data were obtained for the two parachutes at Mach numbers of 2.9 and 3.0. The centerbody was maintained at zero angle of attack and yaw for the entire test. A complete summary of the test conditions is presented in Table I.

SECTION IV
RESULTS AND DISCUSSION

Five decelerator deployments were made at a Mach number of 2.8 and a free-stream dynamic pressure of 120 psfa. Deployment and inflation data were obtained from all of the decelerators except the hyperflo parachute, which failed to completely separate from the deployment bag. A strap from the deployment bag encircled the riser lines during the entire test, thus causing the parachute to become partially reefed. Steady-state data were obtained for all decelerators at a Mach number of 2.8 and a free-stream dynamic pressure of 120 psfa. Additional data were obtained at Mach numbers 2.9 and 3.0 for both of the parachute configurations. A summary of the test results is presented in Table I.

4.1 DEPLOYMENT LOADS

Deployment of trailing aerodynamic decelerators generally creates two forces known as "snatch force" and "opening shock force." For wind tunnel testing of decelerators, the snatch force is defined as that force imposed on the centerbody by the deceleration of the mass of the decelerator from its velocity at line extension to zero velocity relative to the centerbody. The snatch force is followed closely by the opening shock force, which is defined as that force imposed on the centerbody by the sudden inflation of the decelerator at full line extension.

The snatch force and the opening shock force were found to vary considerably during each decelerator deployment since they are a function of the decelerator packing procedure. The deployment time histories are shown in Fig. 10.

The snatch force for the metal ballute, the cloth ballute, and the cloth ballute with a burble fence was 2200, 1140, and 1395 lb, respectively. The ballutes exhibited no opening shock force because a finite amount of time is required for inflation. The snatch and opening shock forces for the parasonic parachute were 930 and 650 lb, respectively.

4.2 STEADY-STATE LOADS

The drag coefficient for each of the aerodynamic decelerator configurations is presented in Table I. The drag coefficients for the ballutes at $M_\infty = 2.8$ varied from 0.689 to 0.733. The corresponding drag coefficients for the parasonic and hyperflo parachutes were 0.135 and 0.218, respectively. It is believed that the higher drag coefficient obtained with the hyperflo parachute was a result of parachute design. The hyperflo parachute has a larger inflated diameter than the parasonic parachute of the same area ratio and nominal diameter. The slightly higher porosity of the hyperflo parachute is another factor contributing to the higher drag coefficient. The effect of reefing (caused by incomplete deployment) of the hyperflo parachute should, however, decrease the drag loads.

The effect of Mach number on parachute drag coefficient is shown in Fig. 11. In the test range, the drag coefficient for the parasonic parachute shows little change with Mach number. The hyperflo parachute shows a decrease in drag coefficient with increasing Mach number.

4.3 INFLATION AND STABILITY CHARACTERISTICS

Photographic coverage obtained by motion-picture cameras permitted the determination of decelerator inflation and stability characteristics. The ballutes were equipped with a method of inflation utilizing a methyl alcohol/water solution to decrease the time required for inflation.

The cloth ballute and the metal ballute attained full inflation approximately 0.60 and 0.46 sec, respectively, after full line extension. The cloth ballute with a burble fence, being of a larger size, required about 0.77 sec to attain full inflation after full line extension. The fully inflated ballute exhibited no oscillation.

At similar test conditions, an identically sized cloth ballute with a burble fence from a previous test attained full inflation about 1.26 sec after full line extension. All inflatable metal ballutes previously tested at PWT have failed upon deployment.

Pressure-time and temperature-time histories for the metal ballute are shown in Fig. 12. This plot shows the temperature drop within the ballute caused by the vaporization of the alcohol/water solution with the corresponding rise in the internal ballute pressure.

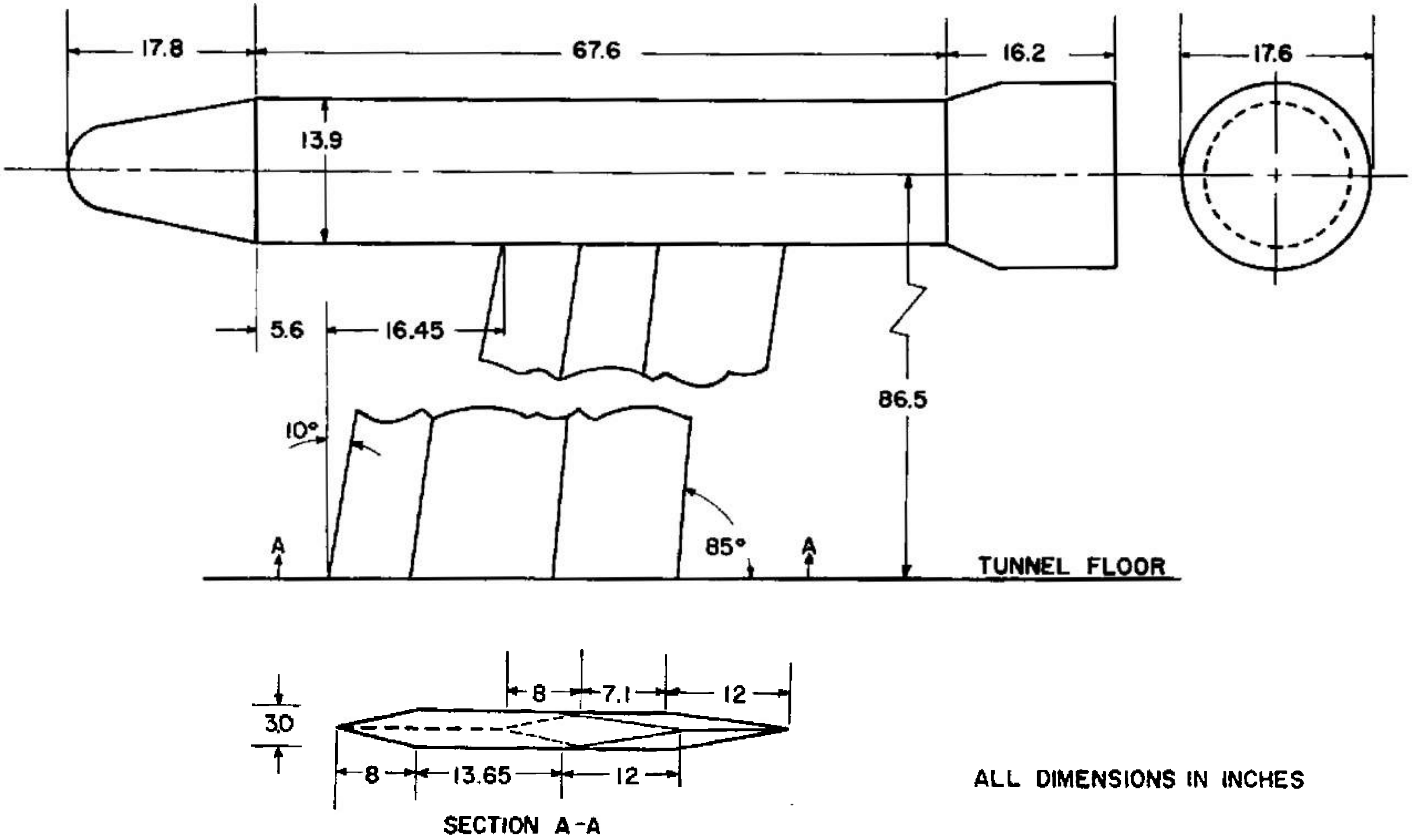
The parasonic parachute attained full canopy inflation approximately 0.015 sec after full line extension. The fully inflated canopy exhibited an oscillation of approximately ±7.0, ±4.5, and ±8.0 deg at Mach numbers 2.8, 2.9, and 3.0, respectively. This oscillation was in a plane that is perpendicular to the centerline of the centerbody. The frequency of oscillation was greatest at Mach number 3.0. The hyperflo parachute, once inflated, exhibited an oscillation of 17.0 deg at Mach number 2.8.

SECTION V
CONCLUDING REMARKS

Tests were conducted to obtain deployment, inflation, and stability characteristics of three ballutes and two parachutes. All decelerators were tested at Mach number 2.8 at a dynamic pressure of 120 psfa. The parachutes were also tested at Mach numbers of 2.9 and 3.0 at a dynamic pressure of 120 psfa.

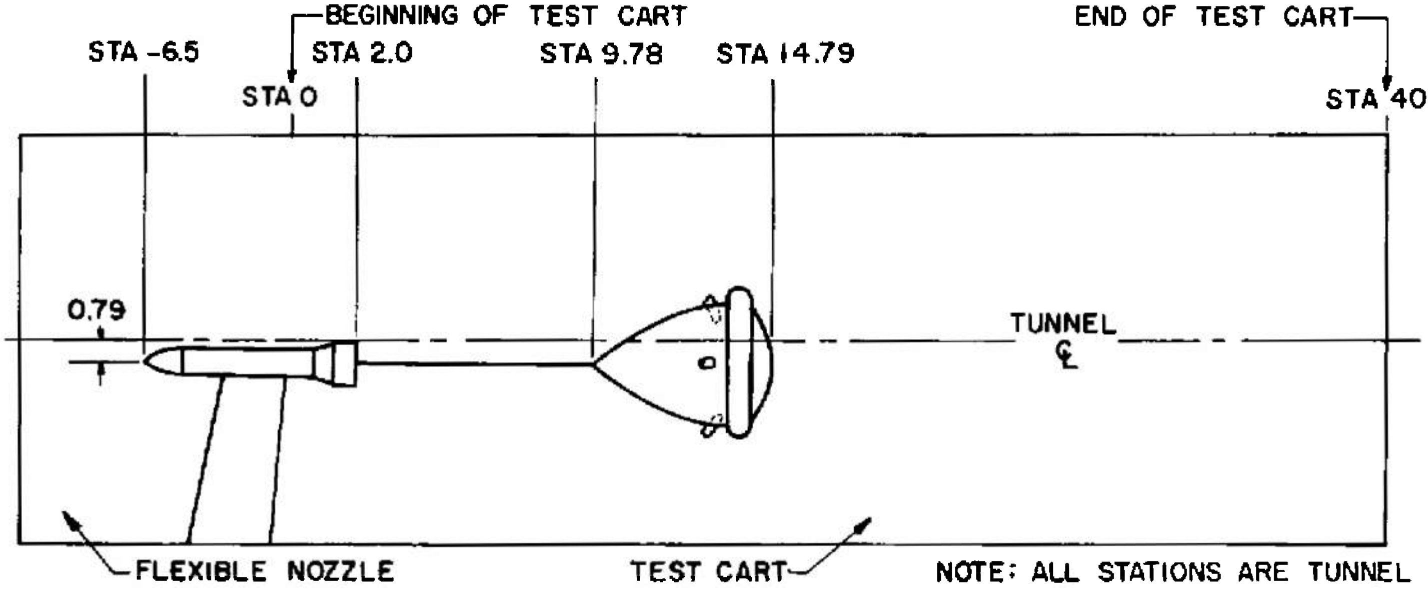
All of the ballutes inflated fully and exhibited excellent stability. Both parachutes exhibited some oscillation. The parasonic parachute showed better stability than the hyperflo parachute. The parasonic parachute was more stable for Mach numbers of 2.8 and 2.9 than for a Mach number of 3.0.

A pre-inflation method utilizing a methyl alcohol/water solution reduced the time required for the drag loads to reach the steady-state value. The reduction in time required for the ballute to inflate permitted the metal ballute to remain intact throughout deployment and inflation.



ALL DIMENSIONS IN INCHES

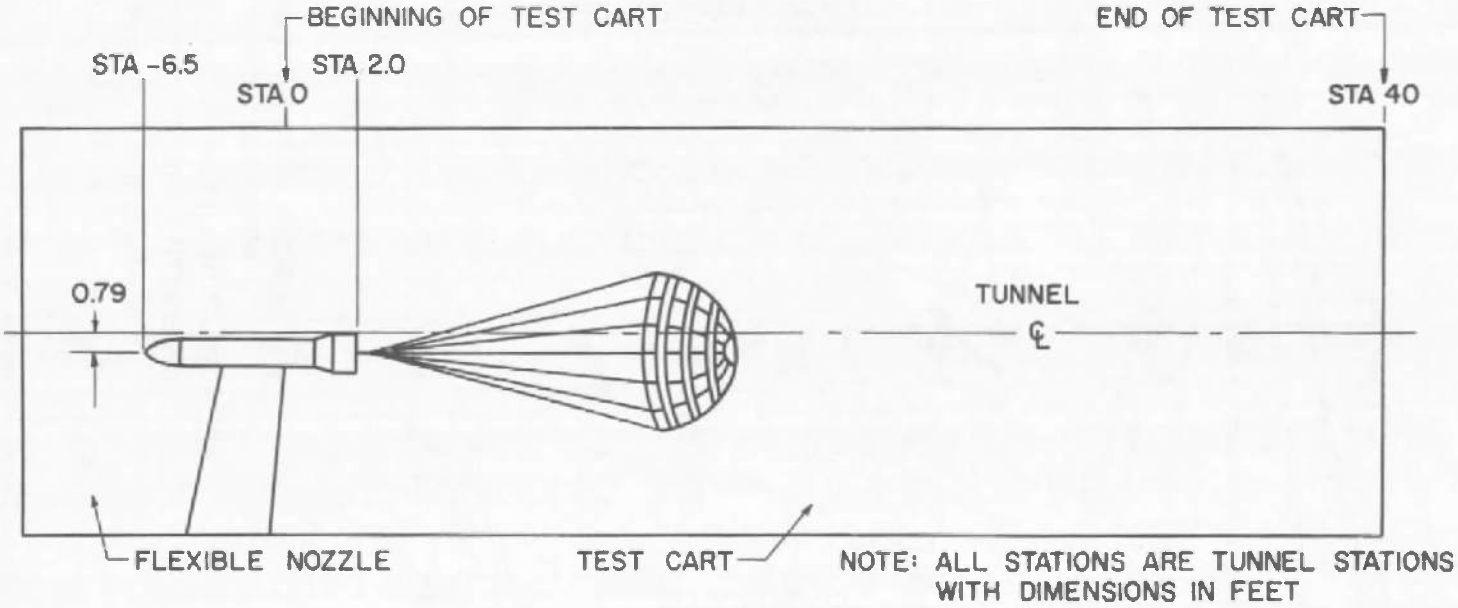
Fig. 1 Model Centerbody Dimensions



NOTE: ALL STATIONS ARE TUNNEL STATIONS
WITH DIMENSIONS IN FEET

a. Ballute

Fig. 2 Location of Model in Test Section



b. Parachute
Fig. 2 Concluded

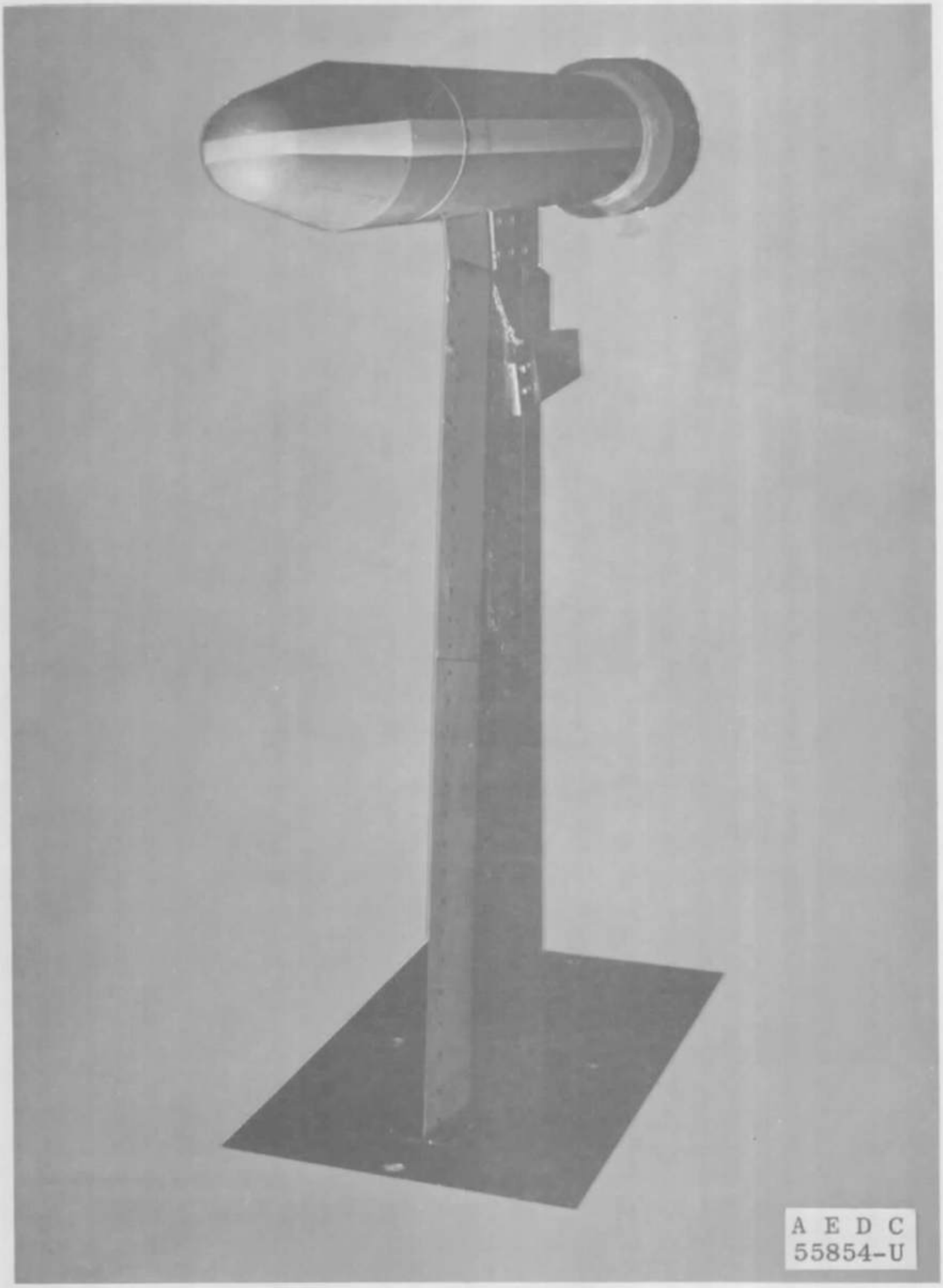


Fig. 3 Installation of Model Centerbody in Test Section

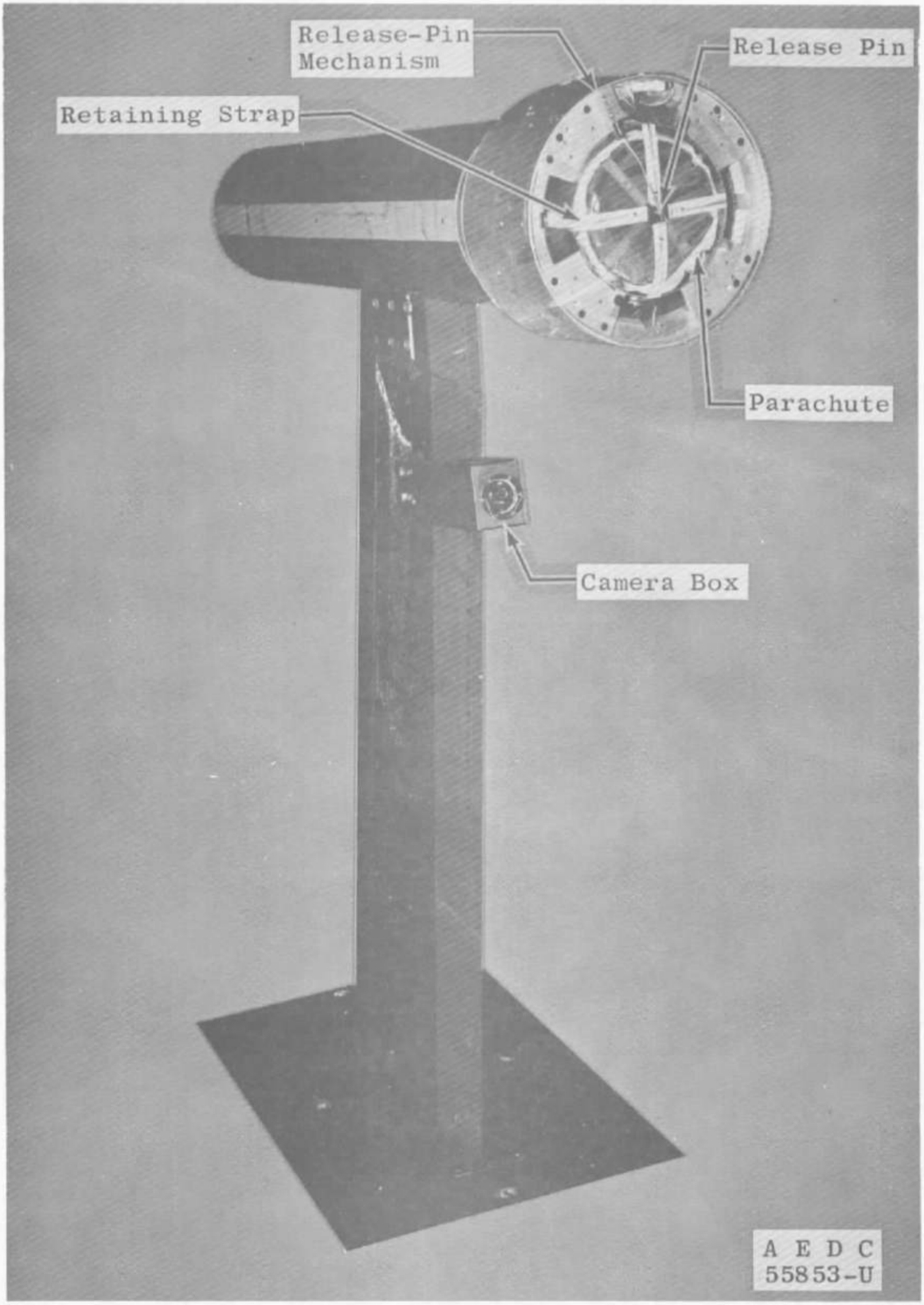
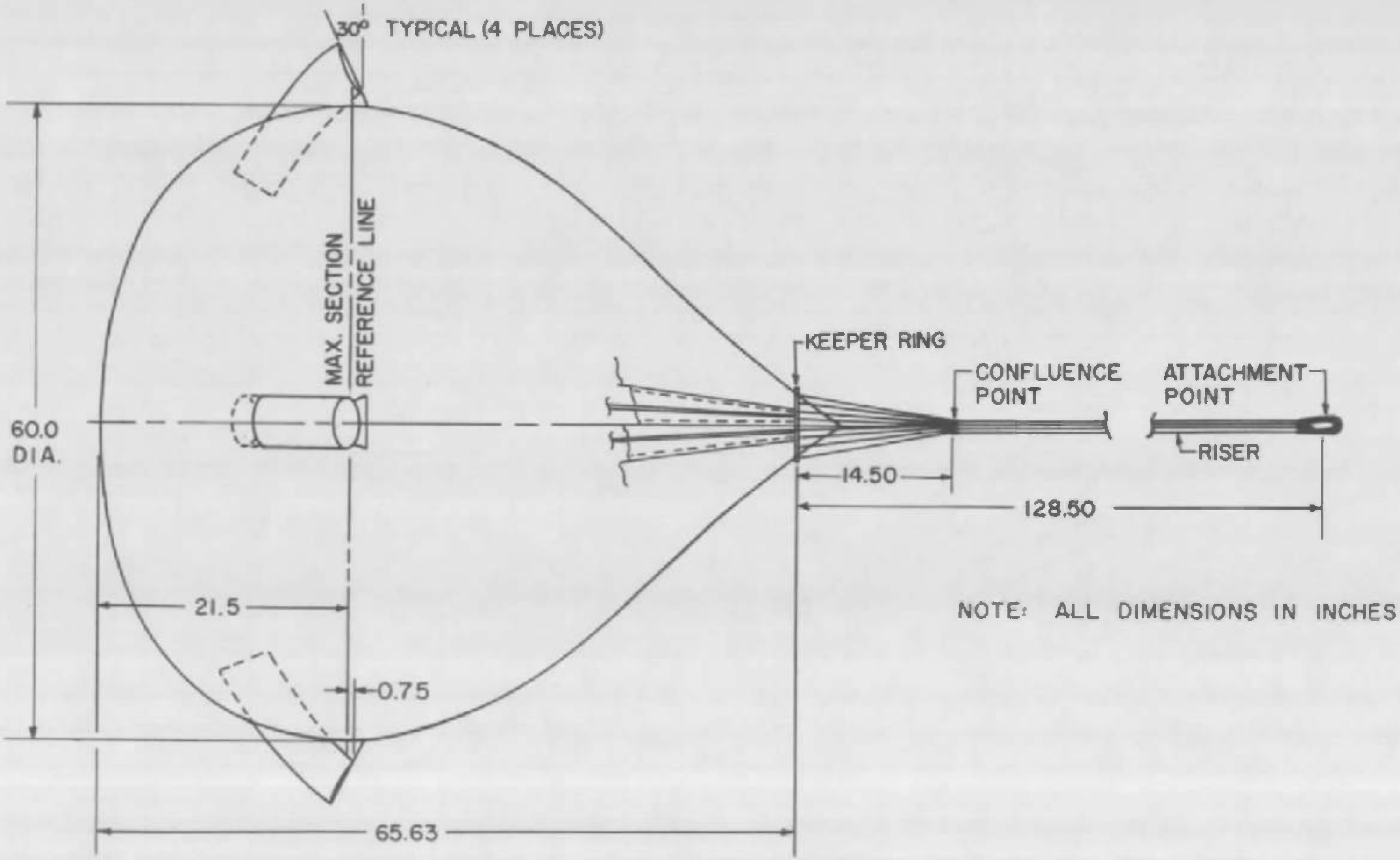
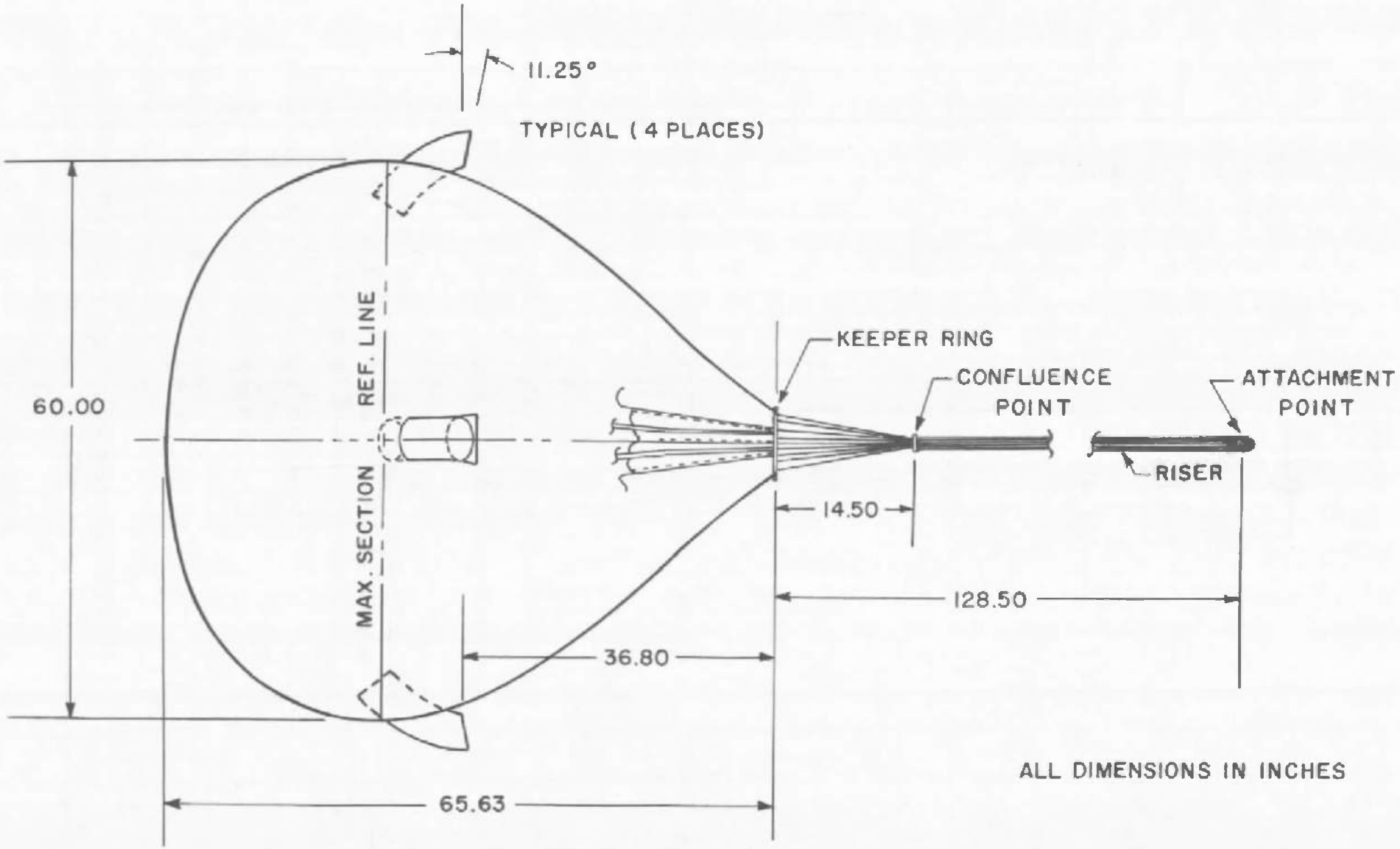


Fig. 4 Three-Quarter Rear View of Model Centerbody

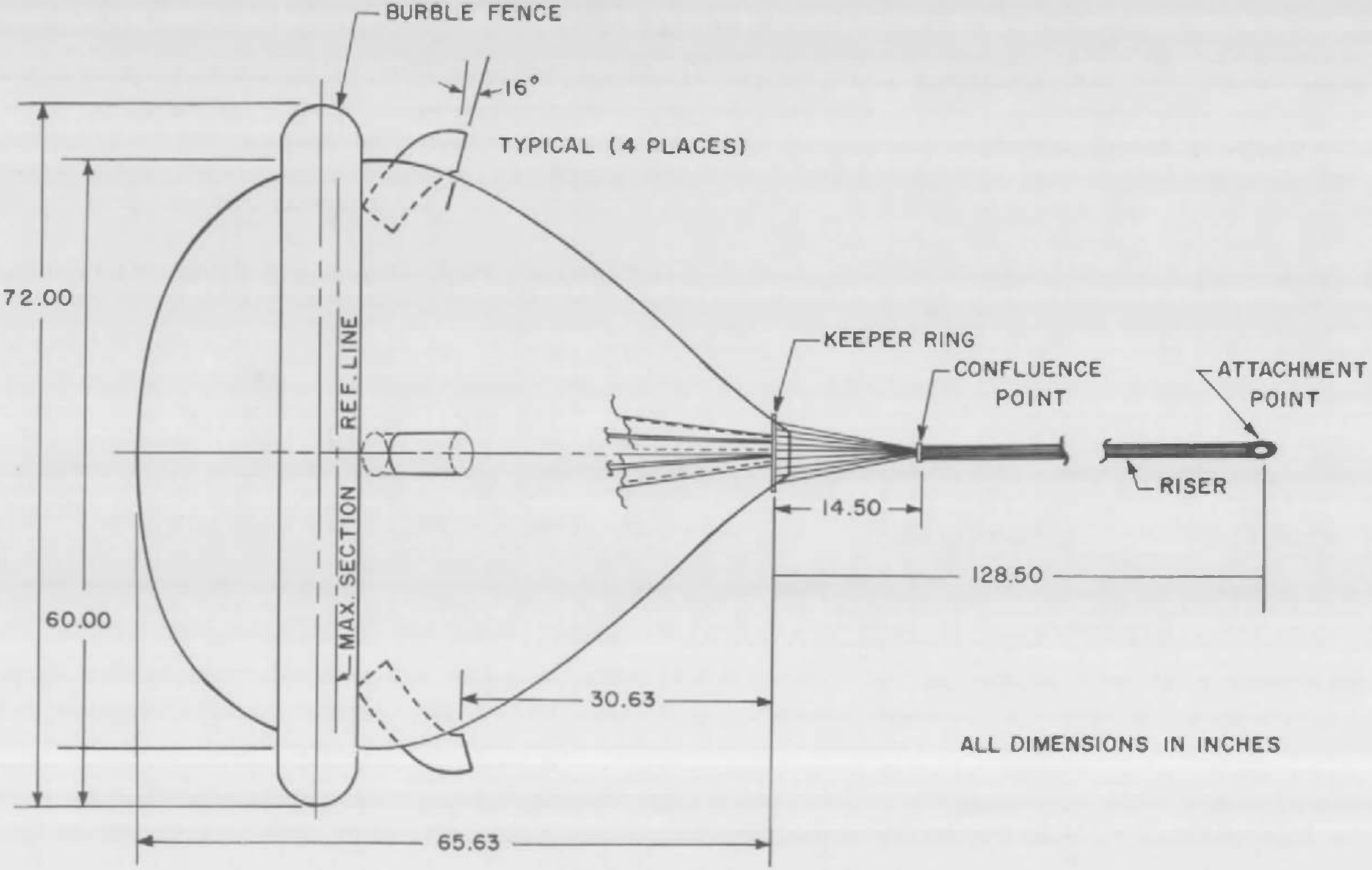


a. Metal Ballute

Fig. 5 Ballute Details



b. Cloth Ballute
Fig. 5 Continued



c. Cloth Ballute with Burble Fence
Fig. 5 Concluded

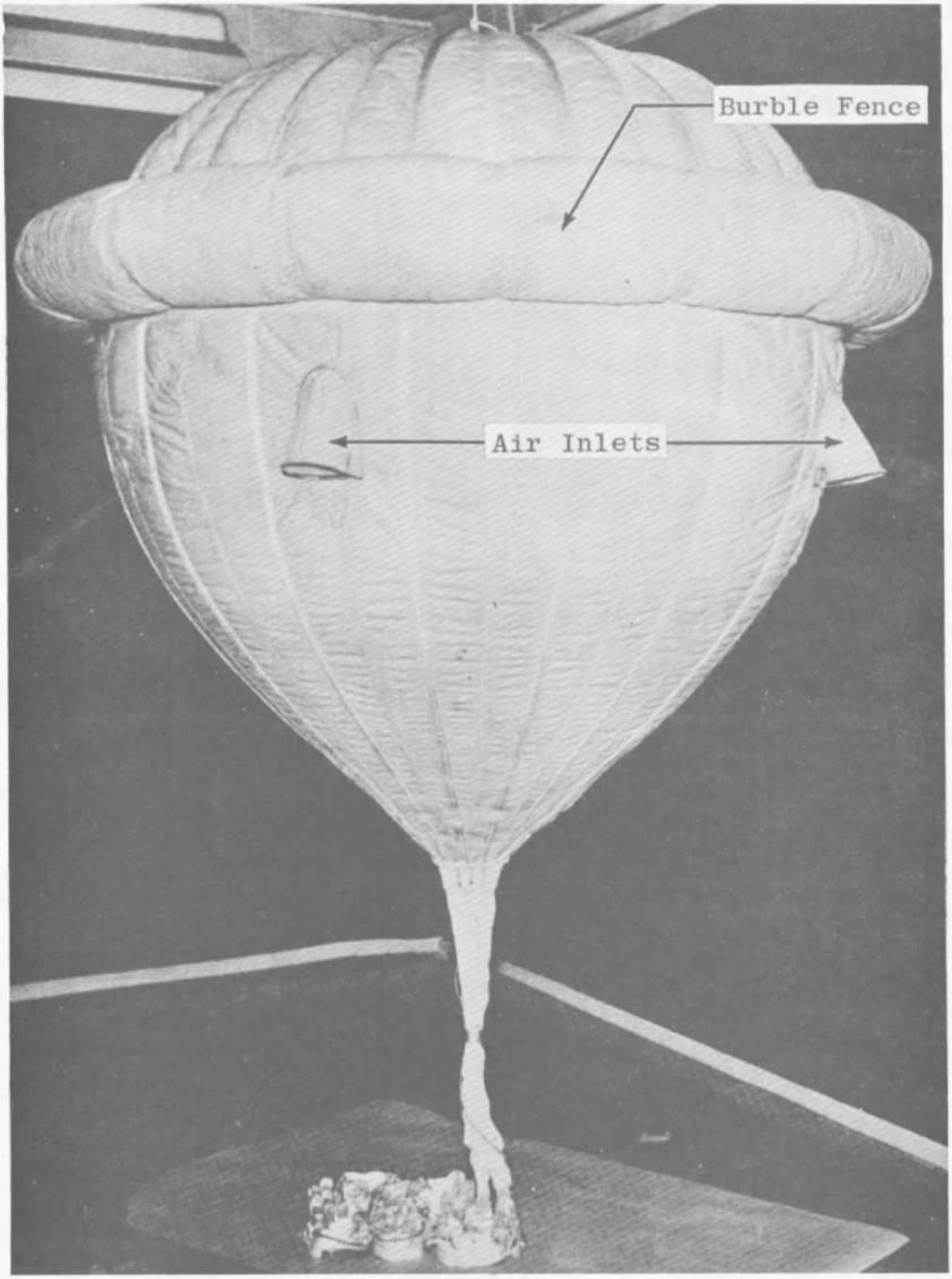
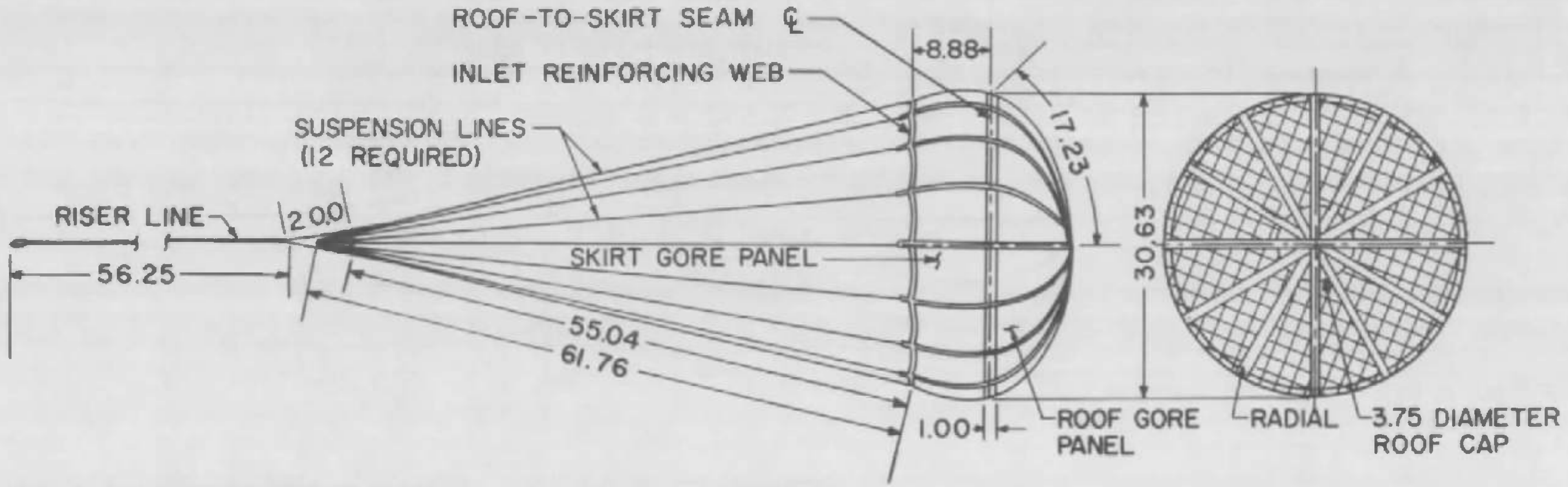


Fig. 6 Cloth Ballute with Burble Fence

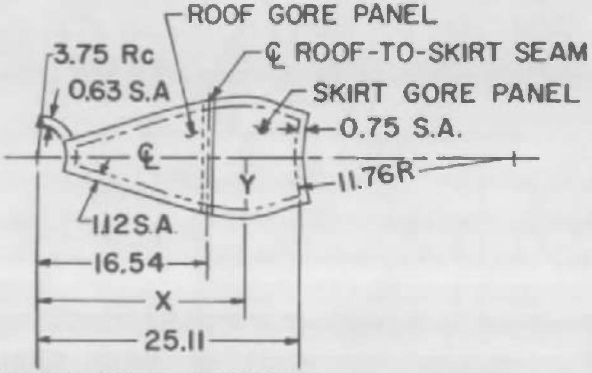


NOTE: ALL DIMENSIONS IN INCHES
S.A. = SEAM ALLOWANCE

DISTANCE AFT OF CENTERBODY BASE PLANE TO CONFLUENCE POINT = 3.25 FEET

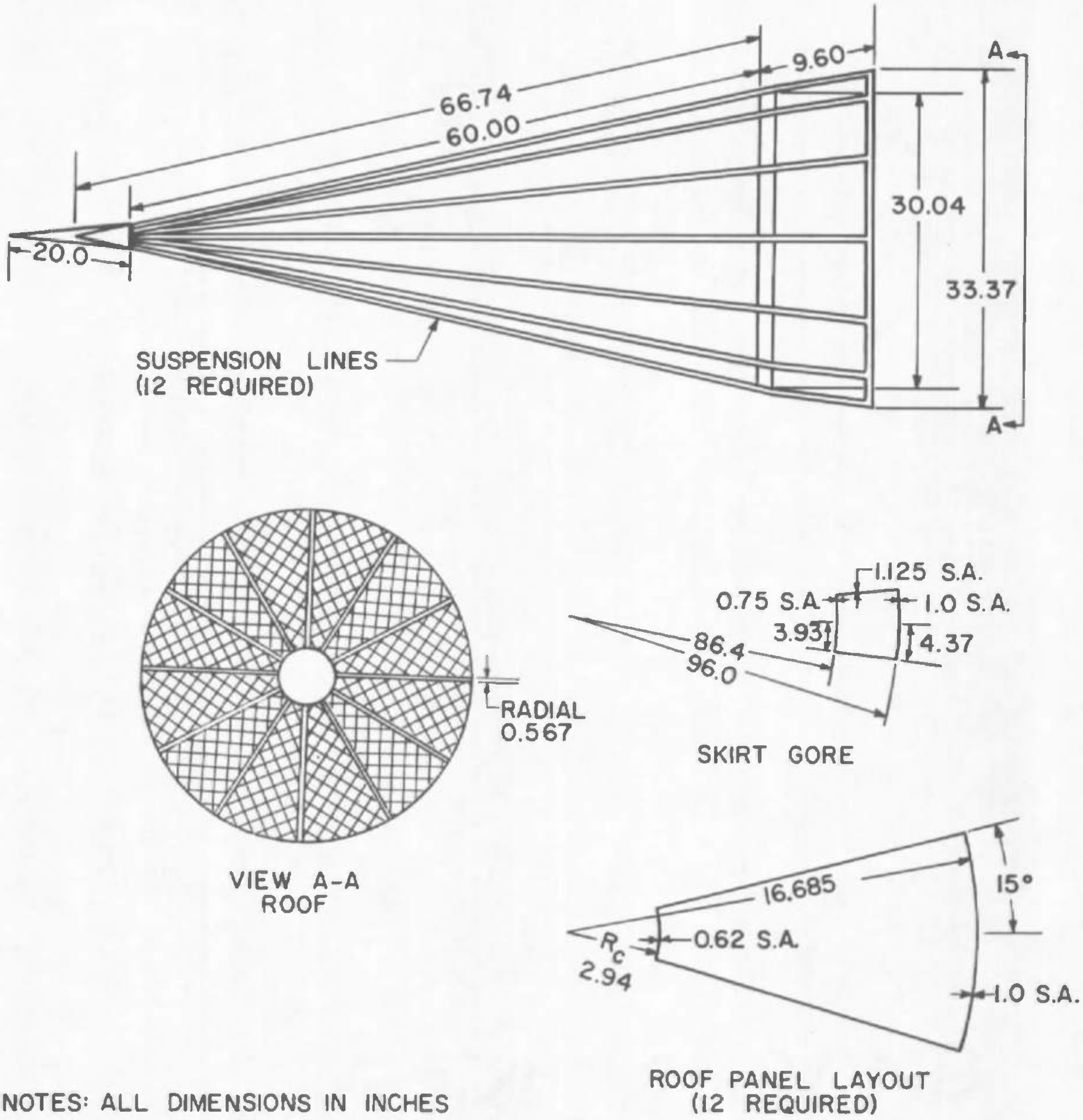
GORE COORDINATES

X	Y
0	0
3.06	0.84
6.12	1.70
9.19	2.60
12.25	3.52
15.32	4.36
16.54	4.59
18.38	4.84
20.03	4.91
21.44	4.78
22.16	4.56
22.94	4.24
23.46	3.97
24.00	3.71
24.53	3.58
25.11	3.57



CANOPY GORE PATTERN
(12 REQUIRED)

Fig. 7 Parasonic Parachute Details



NOTES: ALL DIMENSIONS IN INCHES
S.A. = SEAM ALLOWANCE
RISER LINE LENGTH = 48.70 INCHES
DISTANCE AFT OF CENTERBODY
BASE PLANE CONFLUENCE
POINT = 2.63 FEET

Fig. 8 Hyperflo Parachute Details

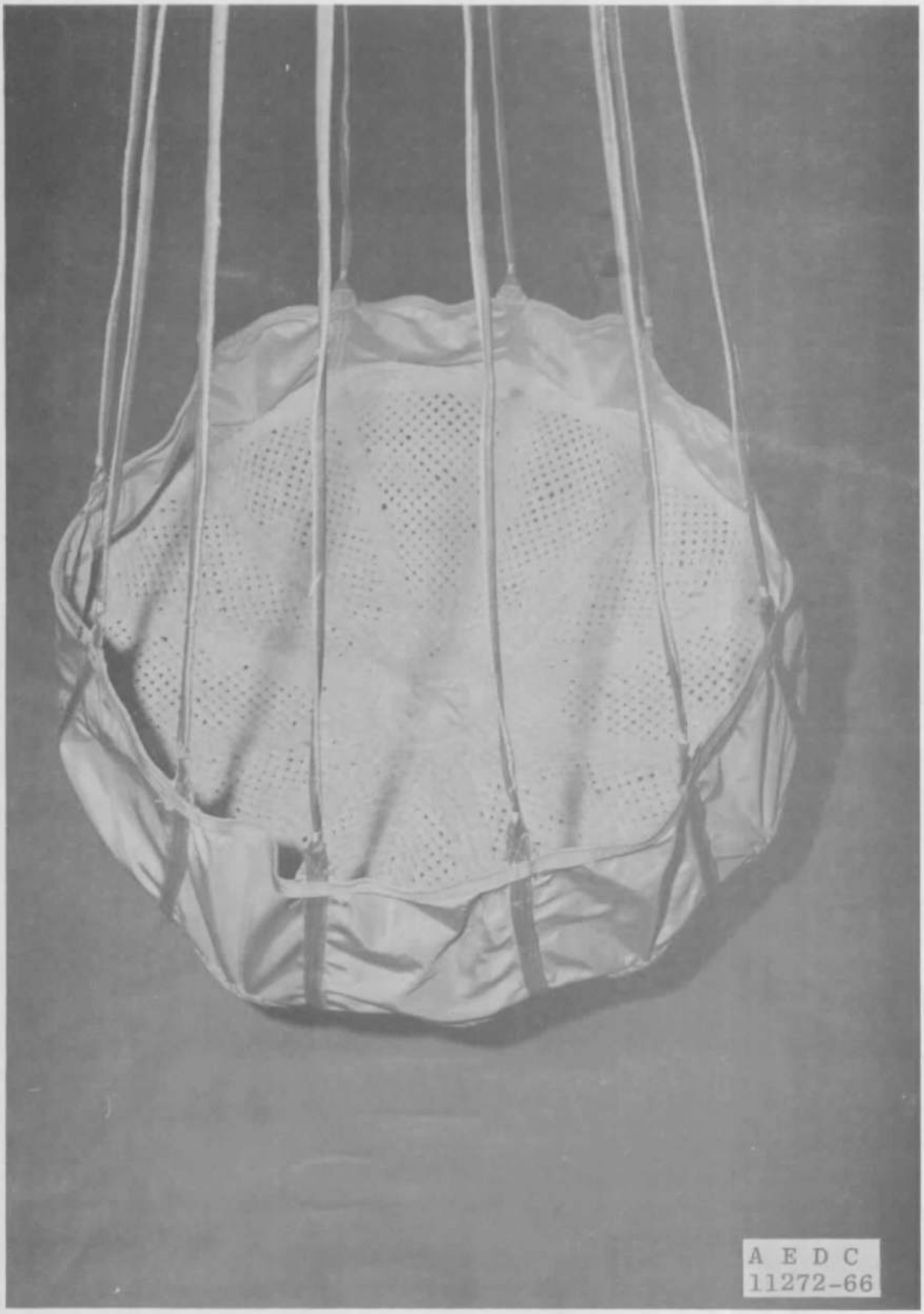
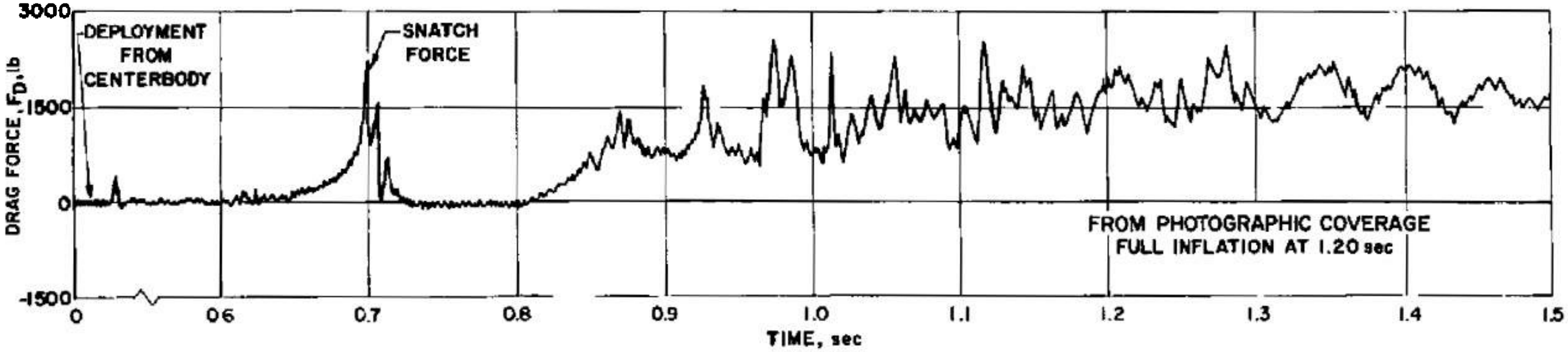
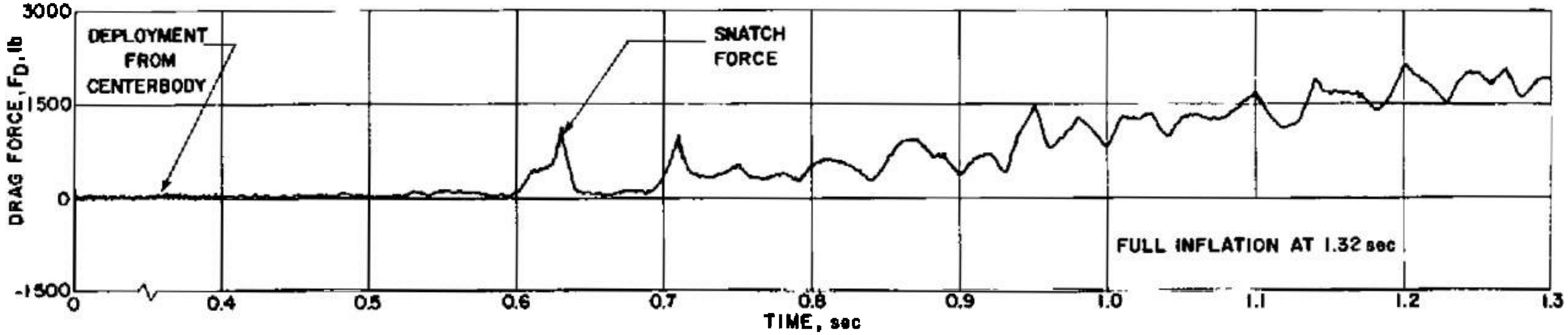


Fig. 9 Hyperflo Parachute

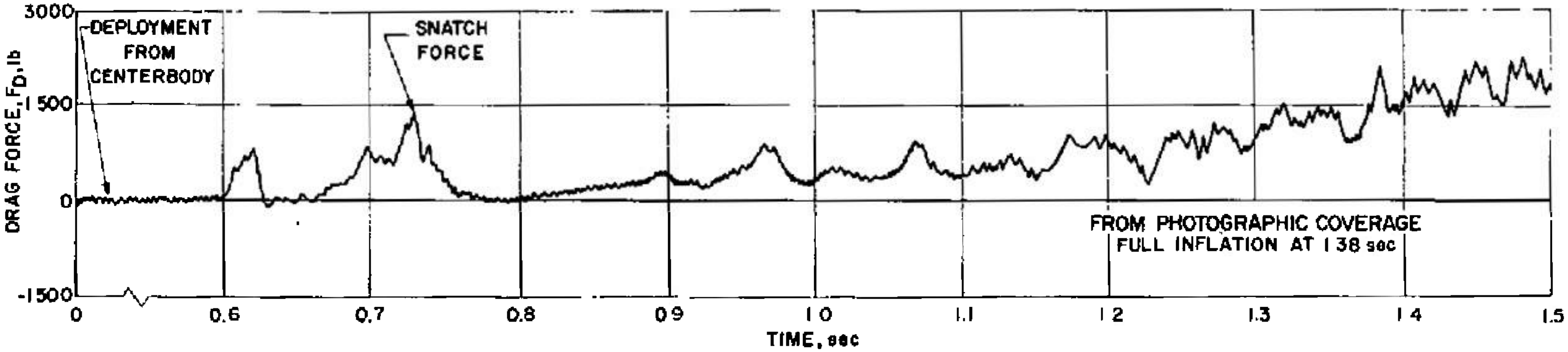


a. Metal Ballute

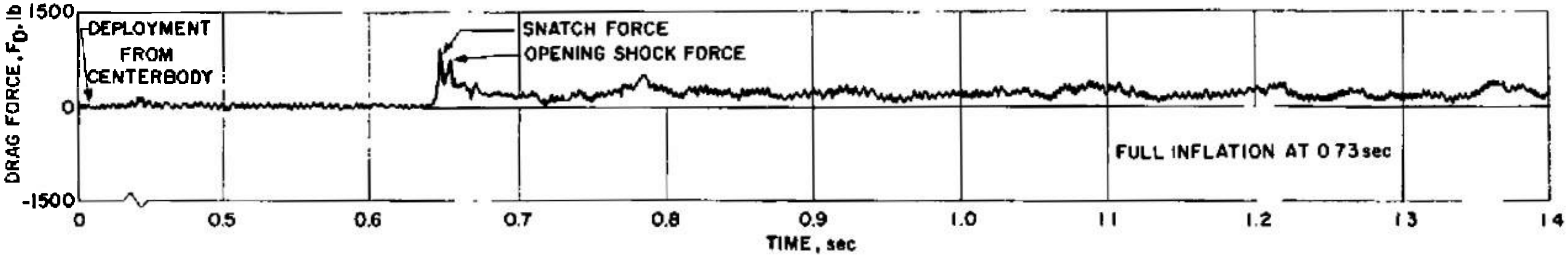


b. Cloth Ballute

Fig. 10 Decelerator Deployment Characteristics



c. Cloth Ballute with a Burble Fence



d. Parasonic Parachute

Fig. 10 Concluded

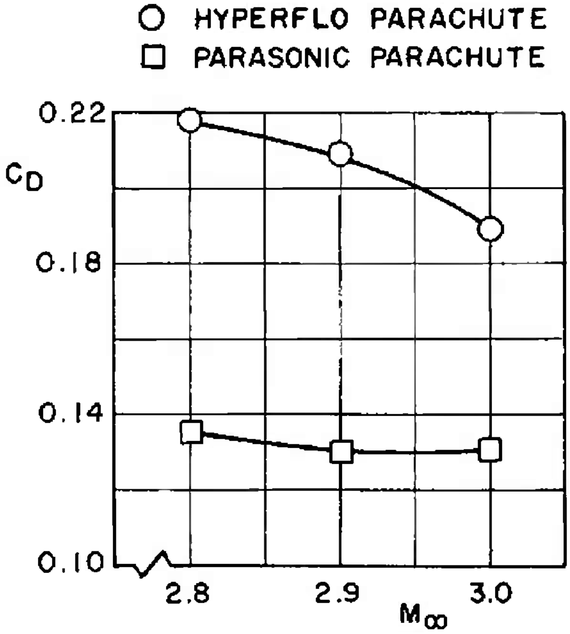


Fig. 11 Effect of Mach Number on Parachute Drag Coefficient

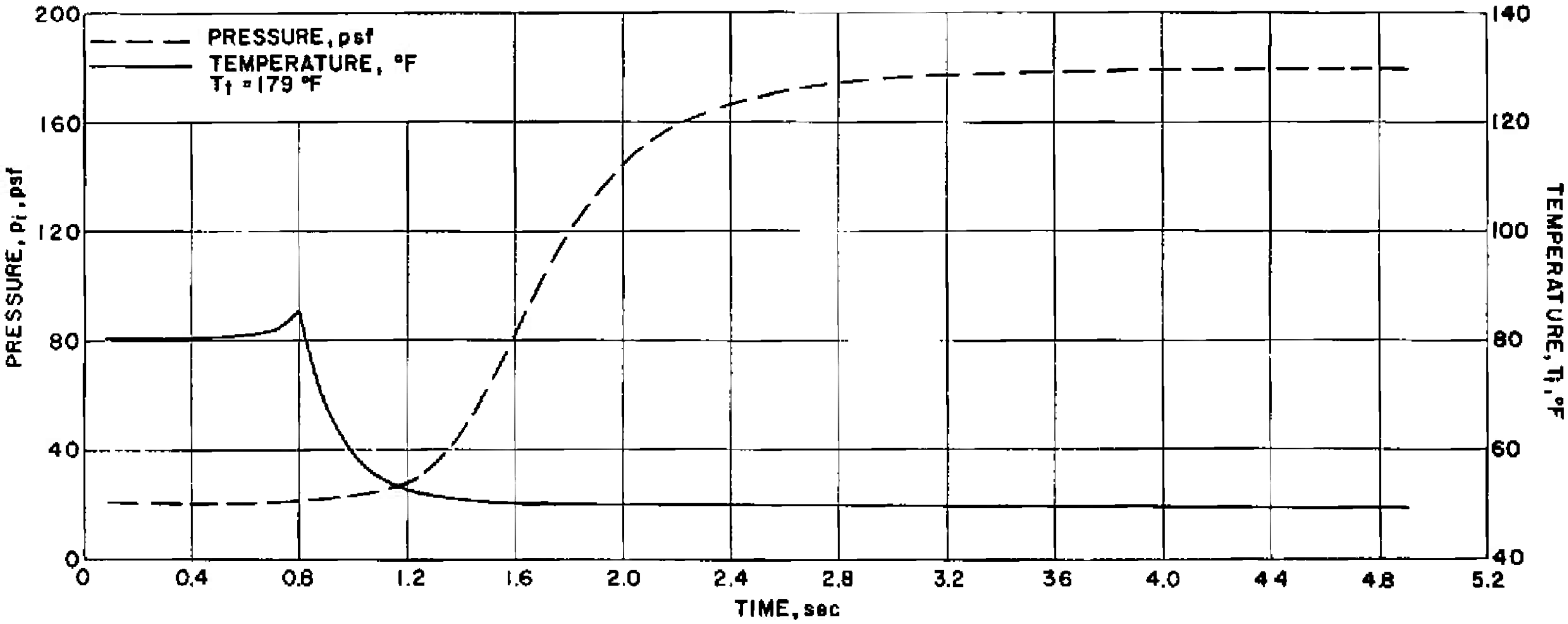


Fig. 12 Pressure-Time and Temperature-Time Histories for the Metal Ballute

TABLE I
SUMMARY OF TEST CONDITIONS AND RESULTS

Configuration	M_∞	q_∞, psfa	Decelerator Diameter, ft		Canopy Total Porosity, percent	C_{D_o}	Area Ratio, A_i/A_p	Maximum Angle of Oscillation about Base Attachment Point, ±deg*	Time from Deployment Initiation to Full Inflation, sec*	Time from Full Line Extension to Full Inflation, sec*
			Max.	Nom.						
Metal Ballute	2.8	120	5		-	0.718	-	0	1.20	0.40
Cloth Ballute with Burble Fence	2.8	120	6		-	0.689	-	0	1.38	0.77
Cloth Ballute	2.8	120	5		-	0.733	-	0	1.32	0.60
Parasonic Parachute	2.8	120		4	5.0	0.135	7.0	7.0	0.73	0.015
	2.9					0.130		4.5		
	3.0					0.131		8.0		
Hyperflo Parachute with Reefer	2.8	120		4	5.6	0.218	7.0	17.0	No deployment data obtained	
	2.9					0.209		-		
	3.0					0.188		-		

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*These data were obtained from photographic coverage.

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13 ABSTRACT

A test was conducted in the 16-ft supersonic wind tunnel to obtain deployment and steady-state drag, inflation, and stability characteristics of a metal ballute, a cloth ballute, a cloth ballute with a burble fence, a parasonic parachute, and a hyperflo parachute. All decelerators were tested at a Mach number of 2.8 at a dynamic pressure of 120 psfa. The data obtained show that a method of pre-inflation utilizing a methyl alcohol/water solution reduced the time required for the drag load to reach the steady-state value. This reduction of time permitted the metal ballute to attain full inflation.

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decelerators						
ballutes						
parachutes						
hyperflo						
parasonic						
drag						
inflation						
stability						
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