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AERODYNAMIC CHARACTERISTICS OF SEVERAL FLEXIBLE DECELERATORS AT MACH NUMBERS FROM 1.8 TO 2.5

M. L. Homan

ARO, Inc.

Per AF letter dtd 16 October 1974 signed William O. Cole

January 1971

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AERODYNAMIC CHARACTERISTICS OF SEVERAL FLEXIBLE DECELERATORS AT MACH NUMBERS FROM 1.8 TO 2.5

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FOREWORD

The work reported herein was done at the request of the Air Force Flight Dynamics Laboratory (AFFDL), Air Force Systems Command (AFSC), under Program Element 62201F, Project 6065, Task 606505.

The results of tests presented 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 F40600-71-C-0002. The test was conducted on October 27 and 28, 1970, under ARO Project No. PS0138, and the manuscript was submitted for publication on December 18, 1970.

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This technical report has been reviewed and is approved.

George F. Garey	Joseph R. Henry
Lt Colonel, USAF	Colonel, USAF
AF Representative, PWT	Director of Test
Directorate of Test	

ABSTRACT

A test was conducted in the Propulsion Wind Tunnel (16S) to determine the aerodynamic performance of four types of decelerators. Data were obtained at Mach numbers from 1.8 to 2.5 at free-stream dynamic pressures from 80 to 200 psf. Increasing the Mach number resulted in a decrease in the steady-state drag coefficient and an increase in the dynamics of the cross parachutes. At Mach number 2.5, increasing the free-stream dynamic pressure resulted in a decrease in the dynamics and an increase in the steady-state drag coefficient of the Supersonic X parachute.

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I. ILLUSTRATIONS

NOMENCLATURE

C_{D_p}	Decelerator drag coefficient, drag force/$q_\infty S$
$C_{D_{p_i}}$	Mean decelerator drag coefficient value of each cell in the statistical analysis program, drag force/$q_\infty S$
D	Forebody diameter, 1.4683 ft
N	Total number of drag coefficient data samples used in the statistical analysis program
N_i	Number of drag coefficient data samples in each cell of the statistical analysis program
$(N_i)_{max}$	Maximum number of drag coefficient data samples in any cell of the statistical analysis program
q_∞	Free-stream dynamic pressure, psf
S	Decelerator reference area, sq ft Standard cross parachute, 10-ft diameter (reefed), 45.8304 sq ft Modular cross parachute, 10-ft diameter (reefed), 45.8304 sq ft Standard cross parachute, 3.5-ft diameter, 5.6151 sq ft Supersonic X parachute. 9.6214 sq ft Hemisflo parachute, 6-ft nominal diameter (reefed), 28.2740 sq ft 80-deg conical balloon, 21.6480 sq ft
X	Axial location of the decelerator, downstream of the forebody base, positive downstream, ft

σ	Standard deviation of the distribution of drag coefficient data determined from the statistical analysis program
Relative Dynamic Parameter	Ratio of the 95-percent confidence level interval, expressed as drag coefficient interval, of a distribution of drag coefficient data to the average drag coefficient value as determined from the statistical analysis program

SECTION I
INTRODUCTION

The purpose of this test program was to determine the drag and stability characteristics of four types of aerodynamic decelerators in supersonic flow. The decelerators investigated were an 80-deg conical balloon, a Hemisflo parachute, a Supersonic X parachute, and three cross parachutes. The decelerators were suspended from a strut-mounted forebody such that the decelerator-forebody separation distance could be remotely varied by a winch-cable system. Data were obtained at Mach numbers from 1.8 to 2.5 at free-stream dynamic pressures from 80 to 200 psf.

SECTION II
APPARATUS

2.1 TEST FACILITY

Propulsion Wind Tunnel (16S) is a closed-circuit, continuous-flow wind tunnel currently capable of being operated at Mach numbers from 1.70 to 4.75. The tunnel can be operated over a stagnation pressure range from about 200 to 2300 psfa, depending upon Mach number. The test section stagnation temperature can be controlled through an approximate range from 100 to 620°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 Ref. 1. A sketch showing the forebody location and the decelerator support system in Tunnel 16S is presented in Fig. 1, Appendix I.

2.2 TEST ARTICLES

2.2.1 Model Forebody and Deployment System

The decelerators tested during this investigation were deployed from a strut-mounted forebody with base bleed (approximate open area to plenum was 1 sq in.) resulting from the cable arrangement used to vary X/D. Dimensions of the forebody are presented in Fig. 2, and a wind tunnel installation photograph of the forebody is shown in Fig. 3.

The decelerator pack was placed in the forebody storage compartment against a spring-loaded plate. Four restraining straps, connected together by a release pin, were used to hold the parachute pack against the spring-loaded plate. The retaining straps were released by a pyrotechnic-actuated pin release mechanism.

The position of the decelerator downstream of the forebody was remotely variable by means of a suspension line and cable attached to an electric winch. A sketch of the model and attachment system is shown in Fig. 4.

2.2.2 Decelerator Details

The 5.25-ft-diam 80-deg conical balloon was constructed of nylon cloth with a Viton® rubber coating. It had 16 inlets located under the burble fence and just forward of the equator. The dimensions of the conical balloon are shown in Fig. 5.

The cross parachute canopies were made of nylon cloth. Two standard "two band" type canopies, 10- and 3.5-ft diameter, and a 10-ft-diam modular "four band" type canopy were tested. Each cross parachute had webs between the band sides. The webs (called a "Belly Band") formed a complete circumferential canopy lip similar to a conventional circular parachute design. The 10-ft-diam cross parachutes were reefed to an inlet diameter of 2.706 ft. The dimensions of the cross parachutes are shown in Fig. 6.

The six-foot nominal-diameter Hemisflo ribbon parachute was tested with a reefed inlet diameter of 1.72 ft. The canopy was made with horizontal nylon ribbons and had eight gores with a geometric porosity of 14 percent. The dimensions are shown in Fig. 7.

A dimensioned sketch of the Supersonic X parachute is presented in Fig. 8, and the gore coordinates are presented in Fig. 9. The parachute was constructed of a relatively nonporous cloth with a single exit opening that controlled the airflow through the canopy. Results from a previous test of this parachute are reported in Ref. 2.

2.3 INSTRUMENTATION

The decelerator drag was measured by a 5000-lb-capacity, double-element load cell to within 10 lb. The readings were then corrected for the mechanical advantage of the pulley system (see Fig. 4). 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 provided visual coverage during testing. The position of the decelerator downstream of the forebody base was determined by a linear potentiometer.

The outputs from the load cell and linear potentiometer were digitized and code punched on paper tape for on-line data reduction. The load cell output was also recorded on magnetic tape by a high-speed digital recording system at a sampling rate of 1000 per second for off-line data reduction.

SECTION III
PROCEDURE

3.1 GENERAL

The decelerator pack, which consisted of a decelerator enclosed in a deployment bag, was packed in the forebody storage compartment before wind tunnel test operation was initiated. Once the prescribed test conditions were established, a countdown procedure was used to sequence data acquisition during parachute deployment. The deployment procedure consisted of activating the test section cameras and the high-speed digital recording system followed by firing a pyrotechnic squib in the release pin mechanism. Upon completion of the decelerator deployment sequence, steady-state drag loads were calculated by averaging the analog output from the load cell over 1-sec intervals. Motion pictures, steady-state drag, and dynamic drag data were obtained at each test Mach number.

The standard and modular-type cross parachutes, Hemisflo parachutes, and 80-deg conical balloon were deployed at Mach number 2.0, and the Supersonic X parachute was deployed at Mach number 2.5. After completion of data acquisition at the deployment test conditions, either the Mach number or the dynamic pressure was varied. The data cycle was repeated until the desired test data were obtained or until the parachute failed as determined by monitoring a television screen.

3.2 DRAG REDUCTION

Drag distribution parameters, such as average drag coefficient, standard deviation, skewness, and kurtosis, were calculated from the data recorded on the high-speed digital data recording system by a statistical analysis program (Ref. 3).

The decelerator drag data were reduced to coefficient form using the following areas: the surface area of the cross parachute canopy, the area of the Hemisflo parachute based upon the nominal diameter, and the area of the 80-deg conical balloon and Supersonic X parachute based upon the design projected diameter.

SECTION IV
RESULTS AND DISCUSSION

4.1 DECELERATOR STEADY-STATE PERFORMANCE

No steady-state data were obtained for the 80-deg conical balloon because of fabric failure during the inflation process.

The variations in drag coefficient with Mach number for the cross and Hemisflo parachutes are shown in Fig. 10. The 10-ft-diam standard cross parachute had a slightly higher drag coefficient than did the 10-ft-diam modular cross parachute at Mach number 2.0. The 3.5-ft-diam standard cross parachute and the 10-ft-diam modular cross parachute drag coefficients decreased as Mach number increased. The drag coefficient of the Hemisflo parachute increased as Mach number increased, as shown in Fig. 10b. However, an apparent underinflation of the parachute as observed in the motion pictures caused the drag coefficient to be low at Mach number 1.8.

The variation in drag coefficient with dynamic pressure for the Supersonic X parachute at Mach number 2.5 is shown in Fig. 11. Increasing the free-stream dynamic pressure at Mach number 2.5 resulted in an increase in the drag coefficient of this parachute.

4.2 DECELERATOR DYNAMIC CHARACTERISTICS

The characteristics of the drag dynamics of each decelerator were determined from a statistical analysis program (Ref. 3). The statistical program reduces the data recorded by a high-speed digital data recording system at a sample rate of 1000 samples per second and calculates drag distribution parameters, average drag coefficient, standard deviation, skewness, and kurtosis. The drag distribution parameters are tabulated on the dynamic drag coefficient distribution sample plot presented in Fig. 12 and are summarized in Table I (Appendix II) for each decelerator. Also shown is the 95-percent confidence level interval which can be interpreted as representing a quantitative measurement of decelerator drag dynamics at a 95-percent confidence level. To compare drag dynamics of one decelerator with those of another decelerator, it is first necessary to divide the 95-percent confidence level interval, expressed as drag coefficient interval, by the average drag coefficient to obtain a relative drag dynamic level for each decelerator. This term will be referred to as the relative dynamic parameter, and its value is tabulated in Table I for each decelerator. The significance of the relative dynamic parameter can be discerned by explaining the drag dynamic characteristics of a decelerator having a Gaussian-type drag distribution when values of zero, unity, and two are assigned to the relative dynamic parameter. A value of zero implies no dynamics; a value of unity implies that the magnitude of dynamics about the average drag coefficient is equal to 50 percent of the average drag coefficient. A value of two implies that the magnitude of dynamics about the average drag coefficient is equal to 100 percent of the average drag coefficient. If the skewness parameter deviates from a value of zero, the drag dynamics are not symmetrical about the average drag coefficient. For skewness greater than zero, higher drag dynamics are encountered above the average drag coefficient; and for skewness less than zero, lower drag dynamics are encountered above the average drag coefficient.

The variation of the relative dynamic parameter with Mach number is shown in Fig. 13. The dynamics of the 10-ft-diam modular cross parachute and the 3.5-ft-diam standard cross parachute increased as Mach number increased. The dynamics of the Hemisflo parachute decreased as Mach number increased. However, the parachute was not fully inflated at Mach number 1.8.

The variation of the relative dynamic parameter with free-stream dynamic pressure for the Supersonic X parachute at Mach number 2.5 is shown in Fig. 14. The dynamics of the Supersonic X parachute decreased as the free-stream dynamic pressure increased.

SECTION V
SUMMARY OF RESULTS

Tests were conducted to obtain decelerator drag and stability characteristics of four types of decelerators deployed from a flared cylindrical forebody. The results of these tests may be summarized as follows:

1. The 80-deg conical balloon fabric failed during the inflation process.

2. For the 10-ft-diam modular cross parachute and the 3.5-ft-diam standard cross parachute, the drag coefficient decreased and the relative dynamic parameter increased as the Mach number increased.

3. At Mach number 2.5, increasing the free-stream dynamic pressure resulted in a decrease in dynamics and an increase in the steady-state drag coefficient of the Supersonic X parachute.

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1. Test Facilities Handbook (Eighth Edition). "Propulsion Wind Tunnel Facility, Vol. 5." Arnold Engineering Development Center, December 1969 (AD863646).

2. Homan, M. L. "Wake Properties Behind a Flared Cylindrical Forebody and Aerodynamic Characteristics of Several Flexible Aerodynamic Decelerators at Mach Numbers from 1.75 to 4.75." AEDC-TR-70-161 (AD870914), June 1970.

3. Galigher, Lawrence L. "Aerodynamic Characteristics of Ballutes and Disk-Gap-Band Parachutes at Mach Numbers from 1.8 to 3.7." AEDC-TR-69-245 (AD861437), November 1969.

APPENDIXES

I. ILLUSTRATIONS
II. TABLES

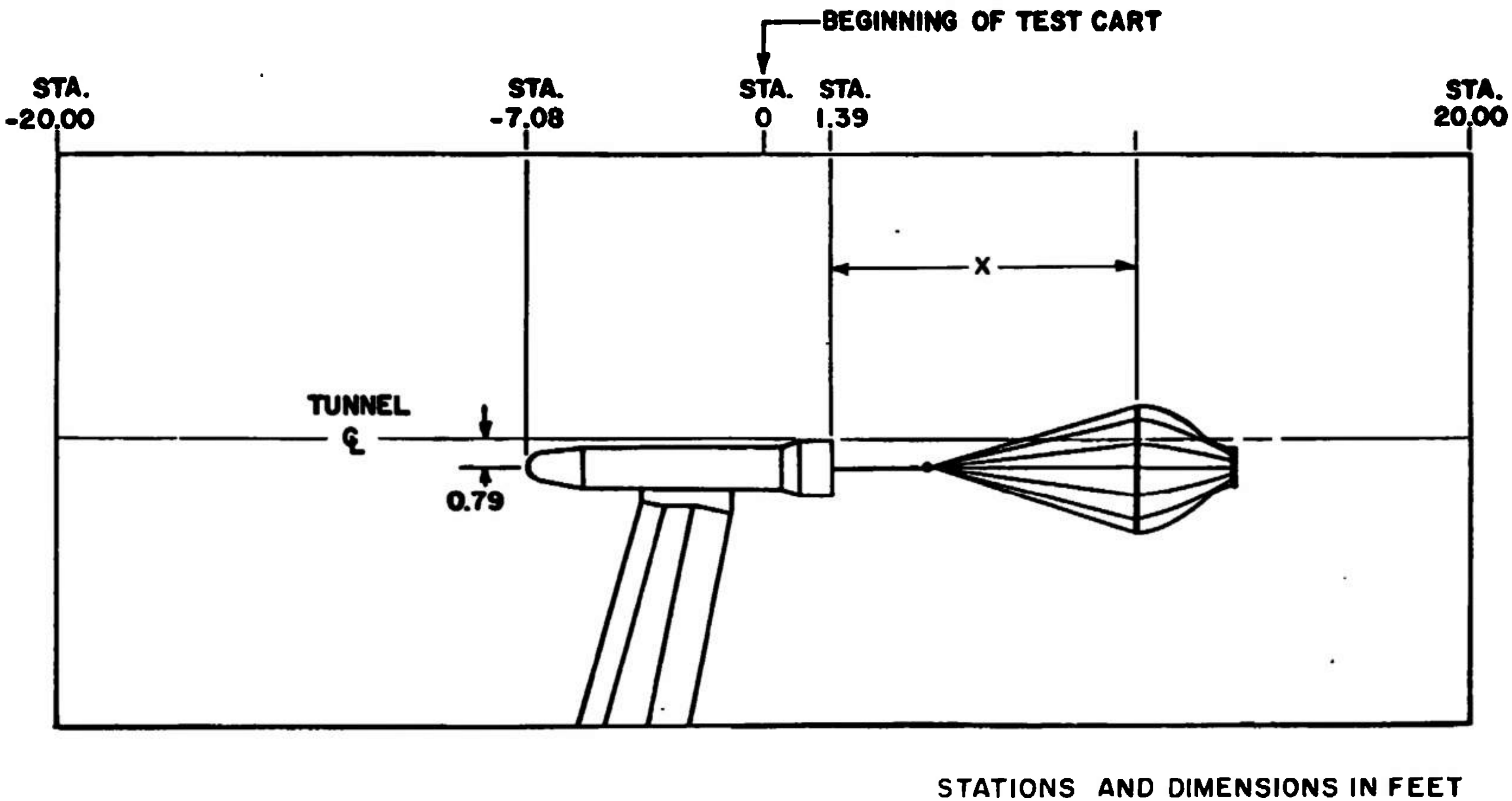


Fig. 1 Model Location in Test Section

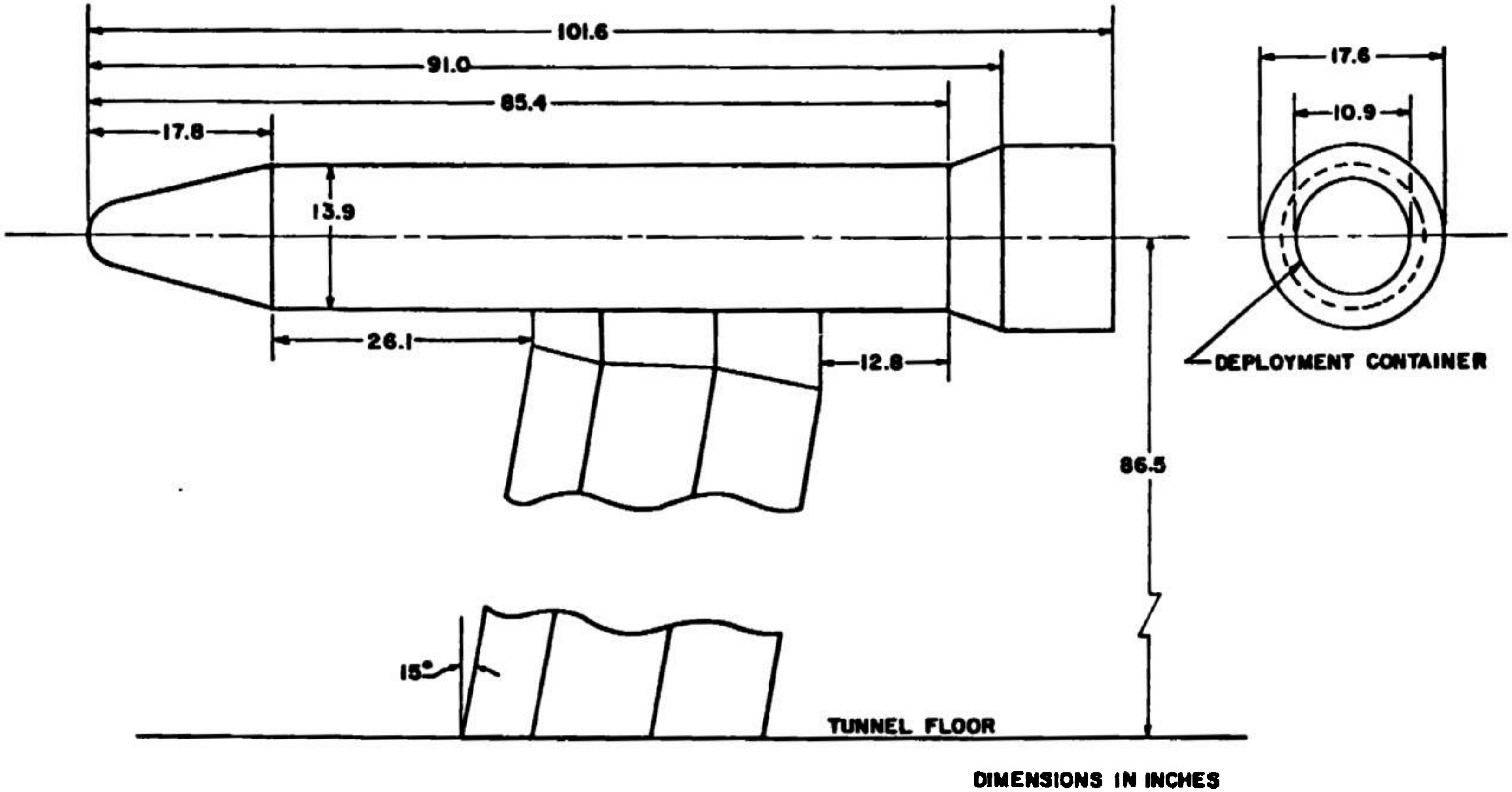


Fig. 2 Dimensioned Sketch of Model Forebody

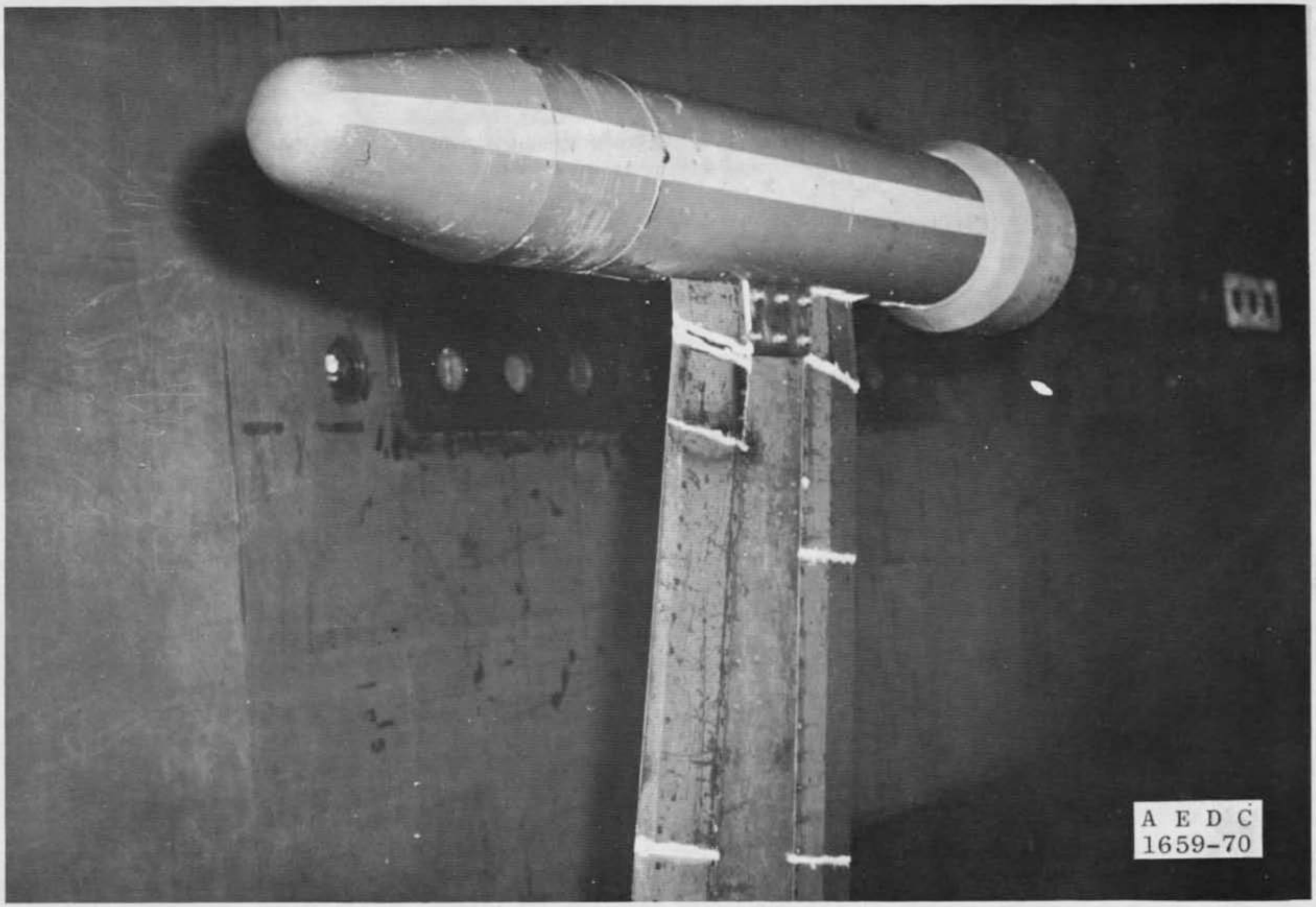


Fig. 3 Installation of Model Forebody in Test Section

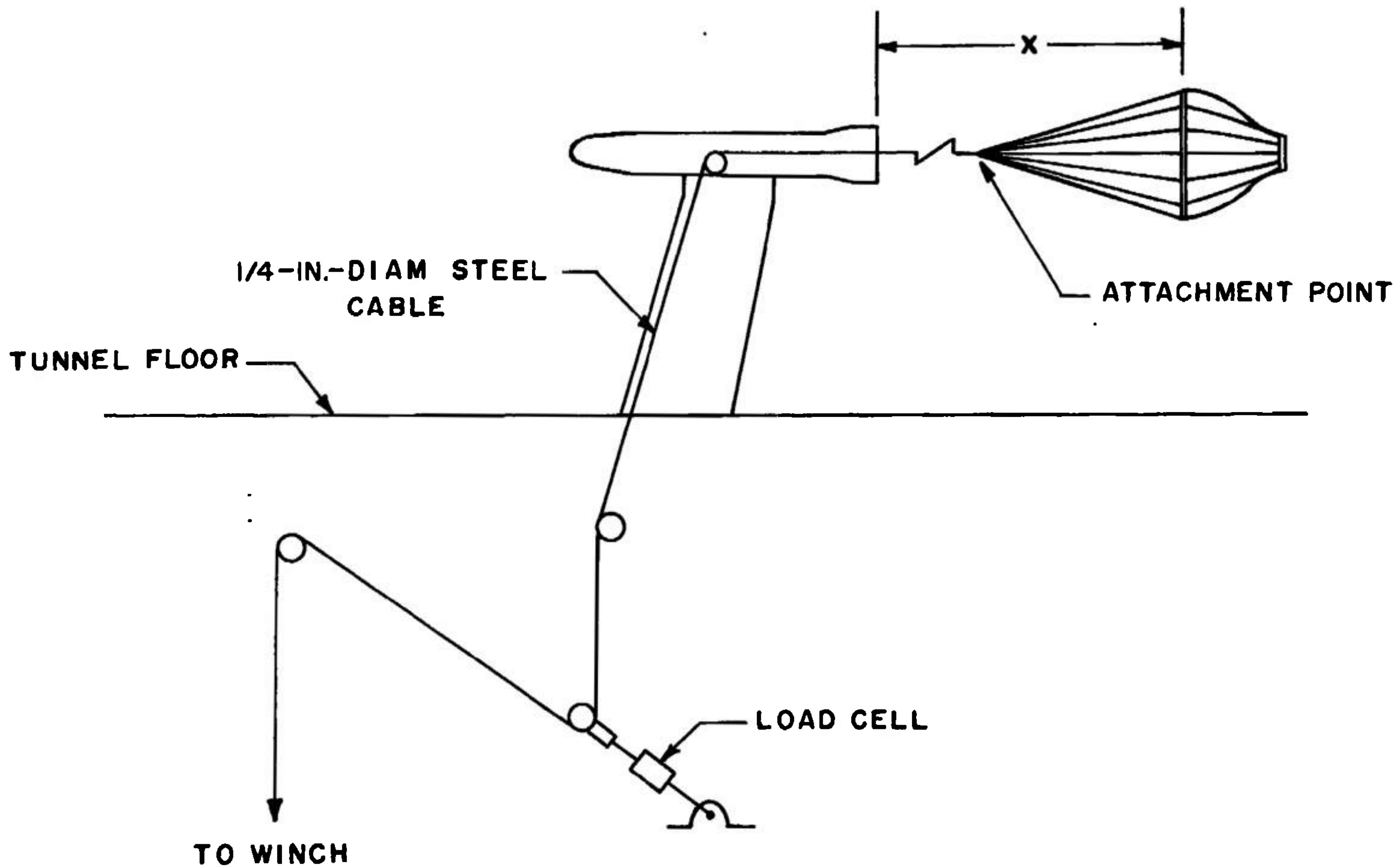


Fig. 4 Sketch of Model Forebody Showing Decelerator Load Cell Installation

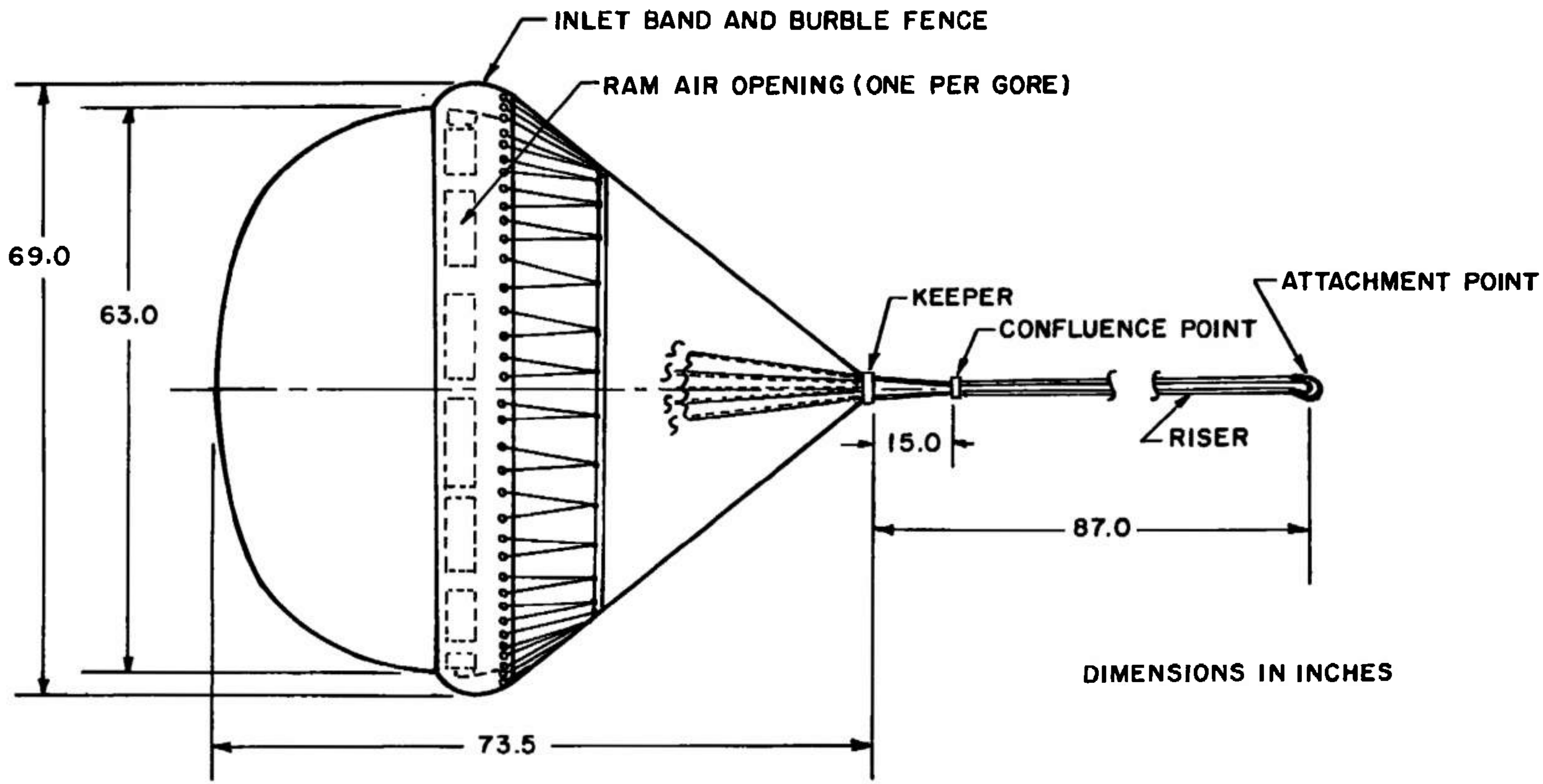
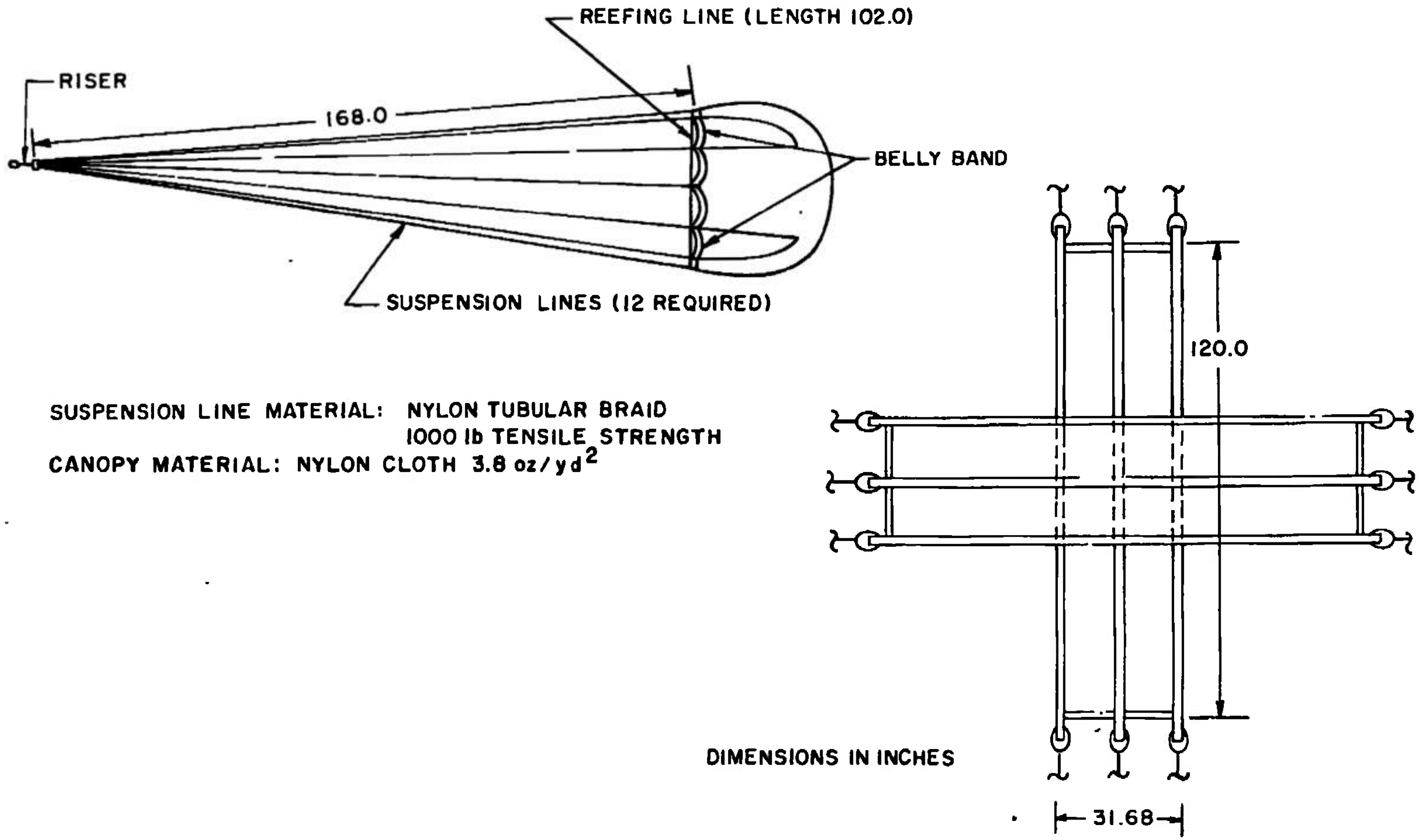
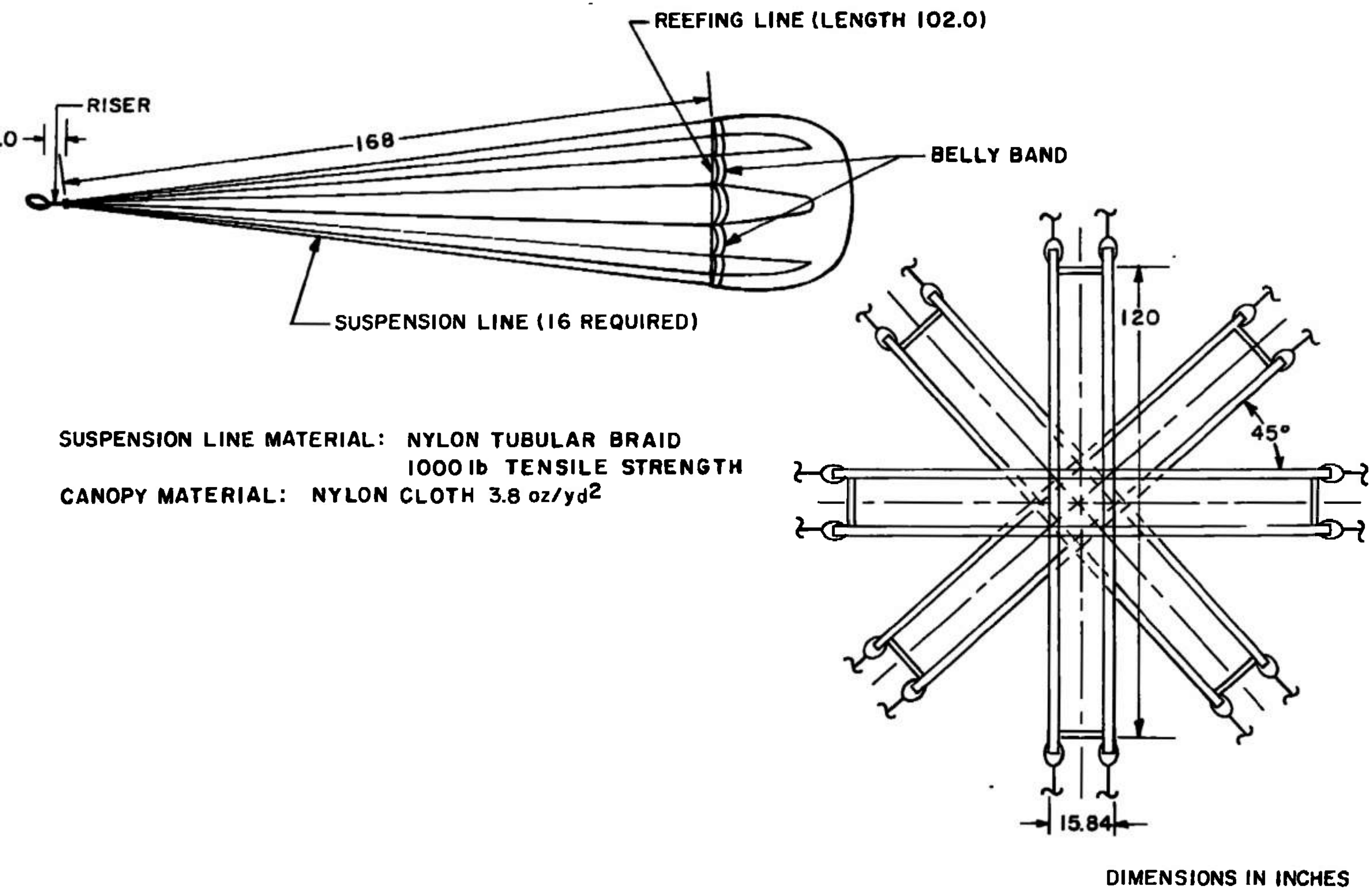


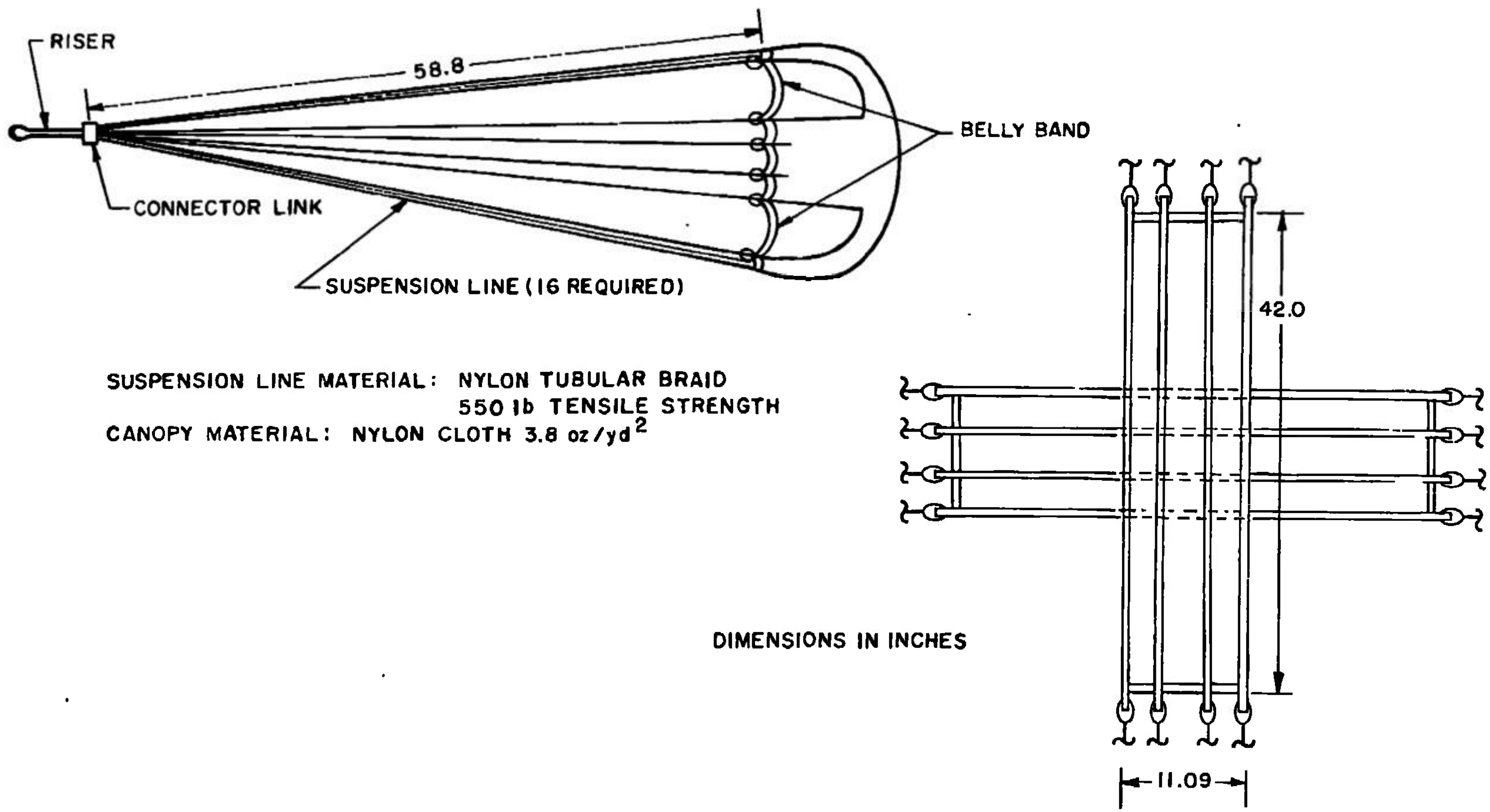
Fig. 5 Dimensioned Sketch of the 80-deg Conical Balloon



a. Standard Cross Parachute, Ten-Foot Diameter (Reefed)
Fig. 6 Dimensioned Sketch of the Cross Parachutes



b. Modular Cross Parachute, Ten-Foot Diameter (Reefed)
Fig. 6 Continued



c. Standard Cross Parachute, 3.5-Foot Diameter
Fig. 6 Concluded

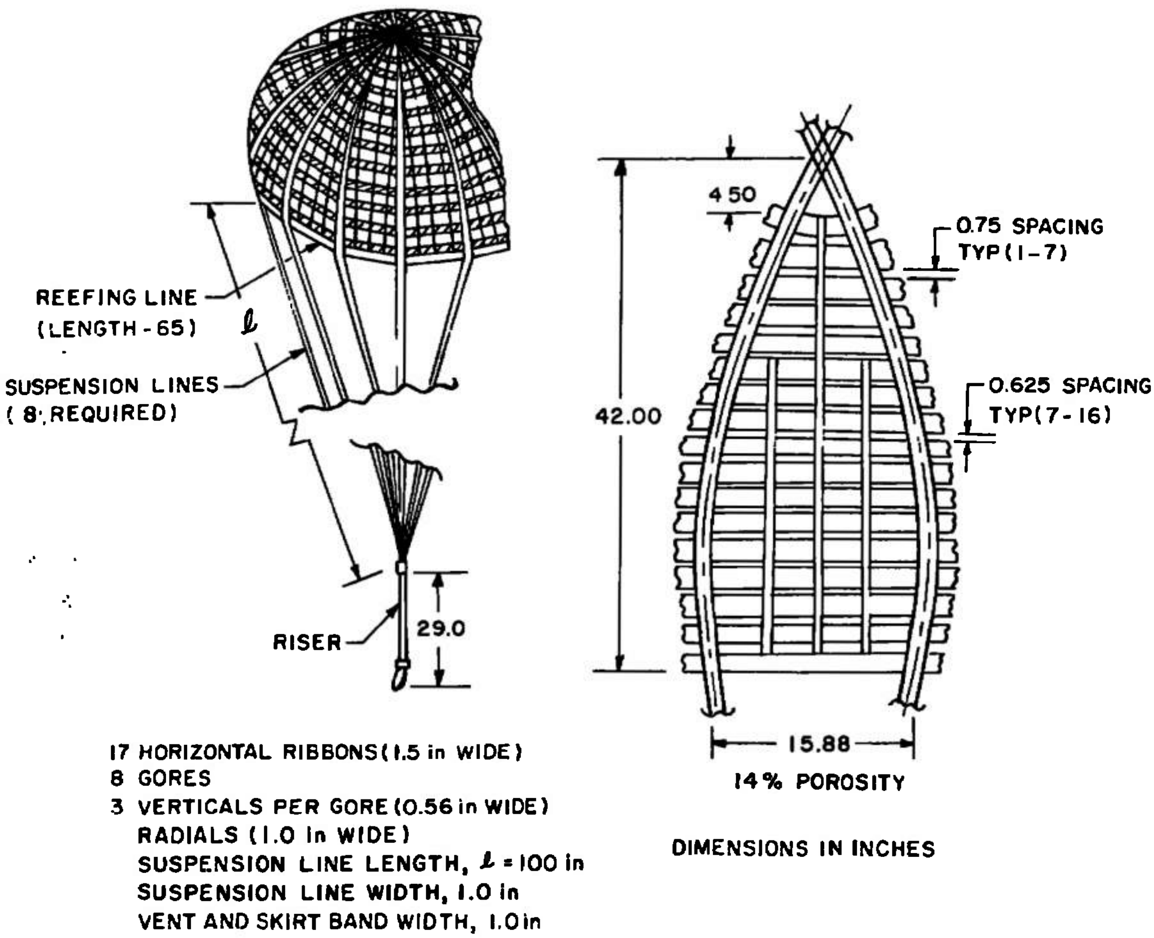


Fig. 7 Dimensioned Sketch of the Six-Foot Nominal-Diameter Hemisflo Parachute (Reefed)

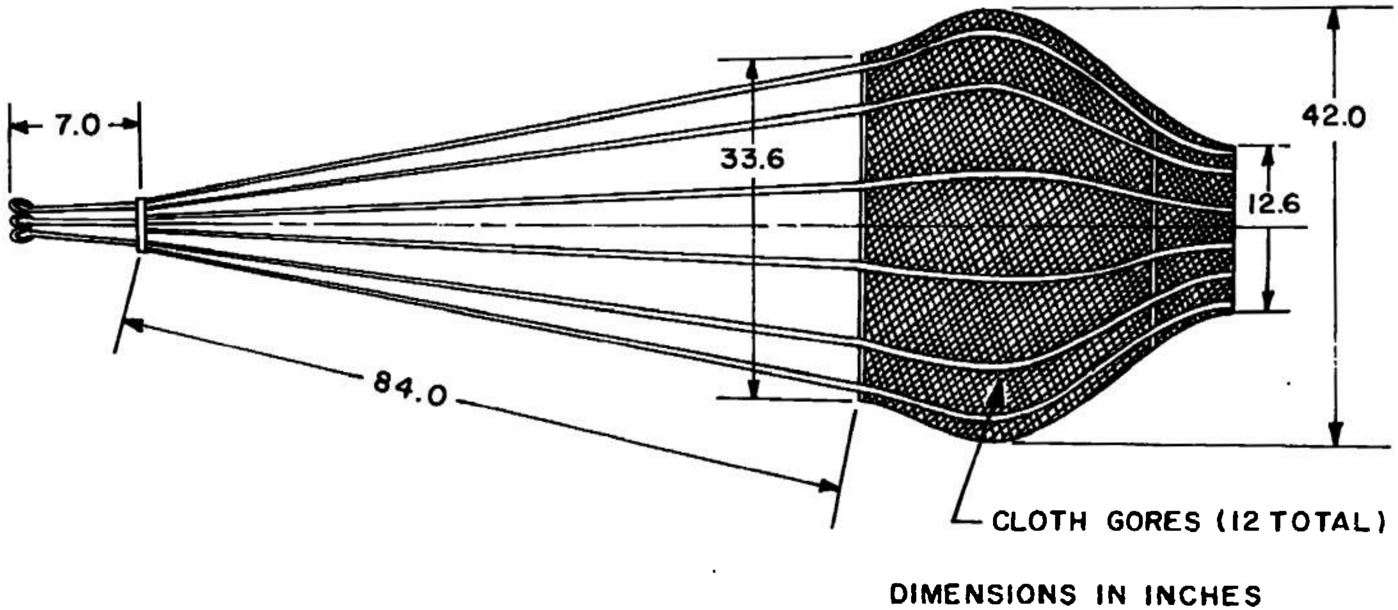
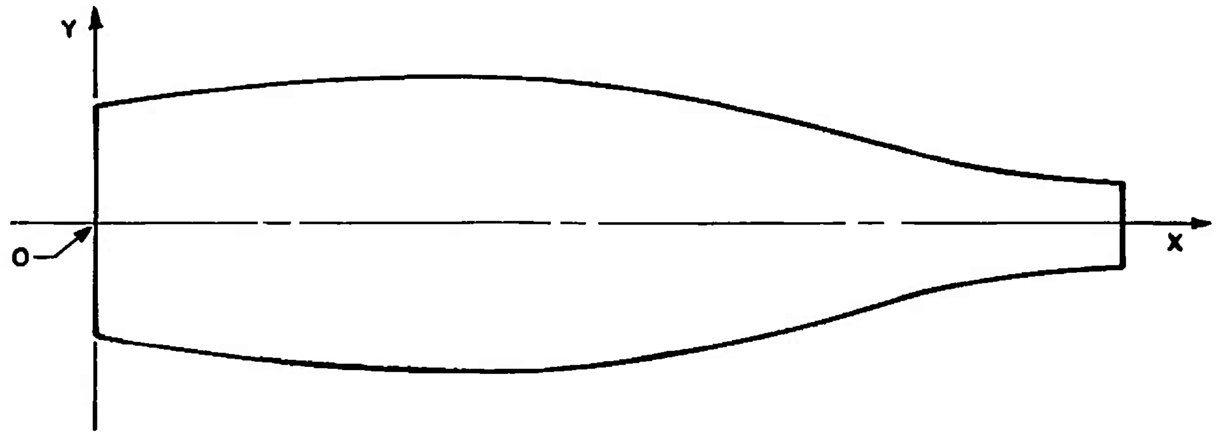


Fig. 8 Dimensioned Sketch of the Supersonic X Parachute

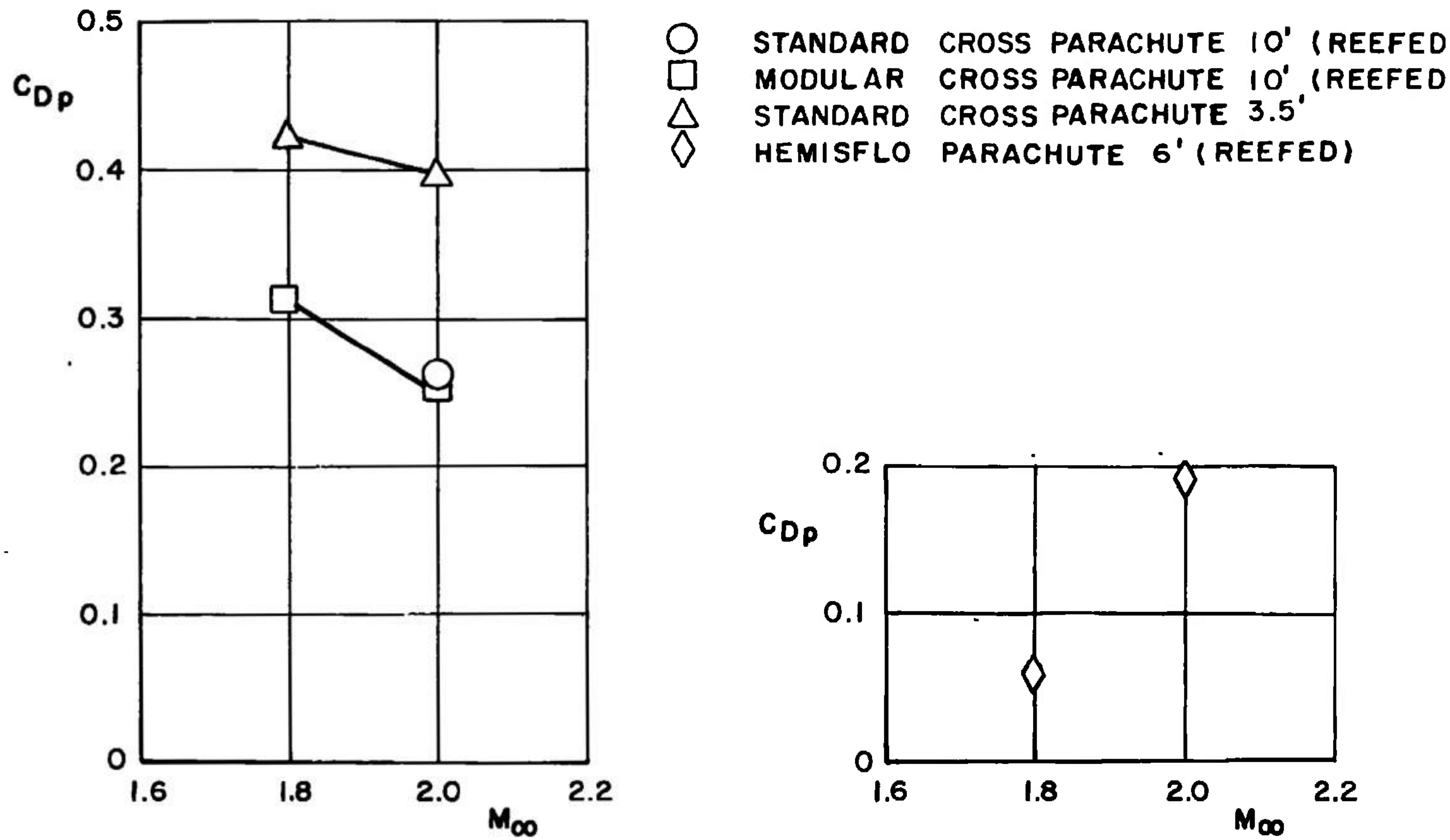


GORE COORDINATES

X	SUPERSONIC X-2 Y	X	SUPERSONIC X-2 Y
0.0	4.389	23.10	4.704
2.10	4.599	25.20	4.347
4.20	4.809	27.30	3.864
6.30	5.019	29.40	3.360
8.40	5.208	30.02	———
10.50	5.355	31.50	2.898
12.60	5.481	33.60	2.457
14.35	5.498	35.70	2.016
14.70	5.481	37.06	———
16.80	5.418	37.80	1.743
18.90	5.250	39.90	1.659
21.00	5.019	40.06	1.649

DIMENSIONS IN INCHES

Fig. 9 Gore Dimensions of the Supersonic X Parachute



a. Cross Parachute

b. Hemisflo Parachute

Fig. 10 Variation of Parachute Drag Coefficient with Mach Number

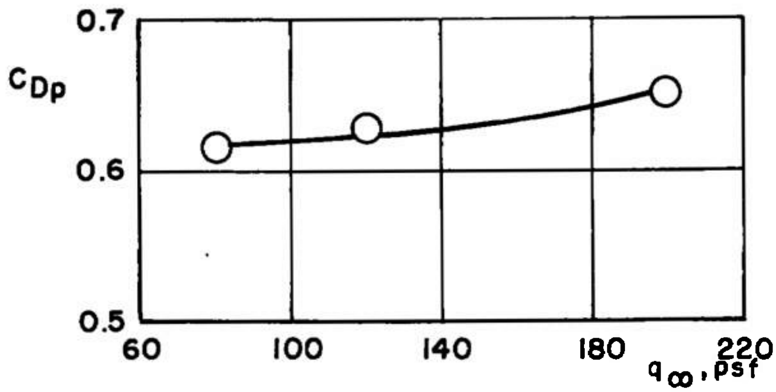


Fig. 11 Variation of the Supersonic X Parachute Drag Coefficient with Free-Stream Dynamic Pressure, $M_\infty = 2.5$, X/D = 7

C_{D_p}	σ	SKEWNESS	KURTOSIS	$(N_i)_{MAX}$	N
0.261	0.101	0.304	3.076	197	4092

$$C_{D_p} = 0.261 \begin{array}{l} +0.209 \\ -0.181 \end{array} \quad \text{(95\% CONFIDENCE LEVEL)}$$

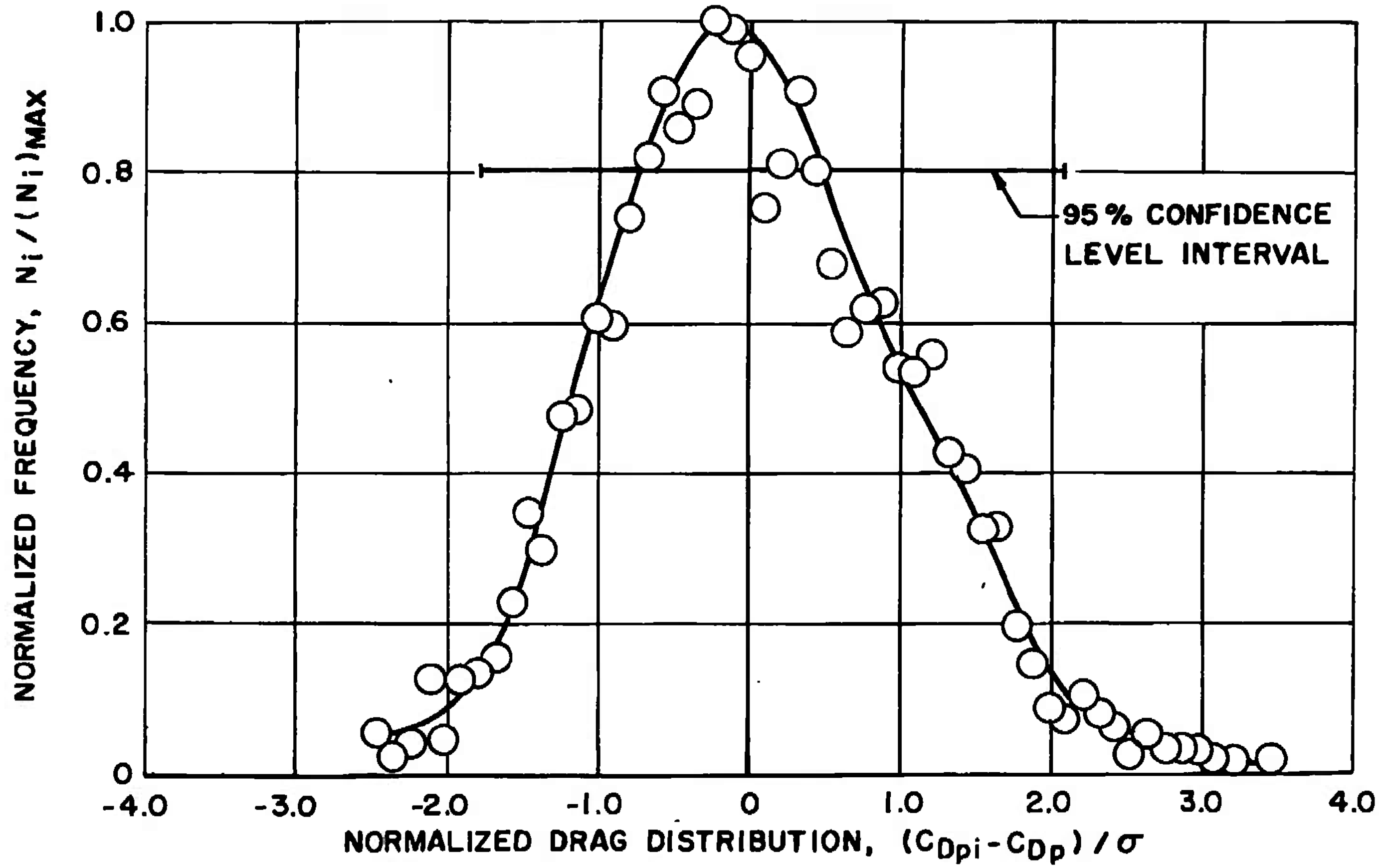
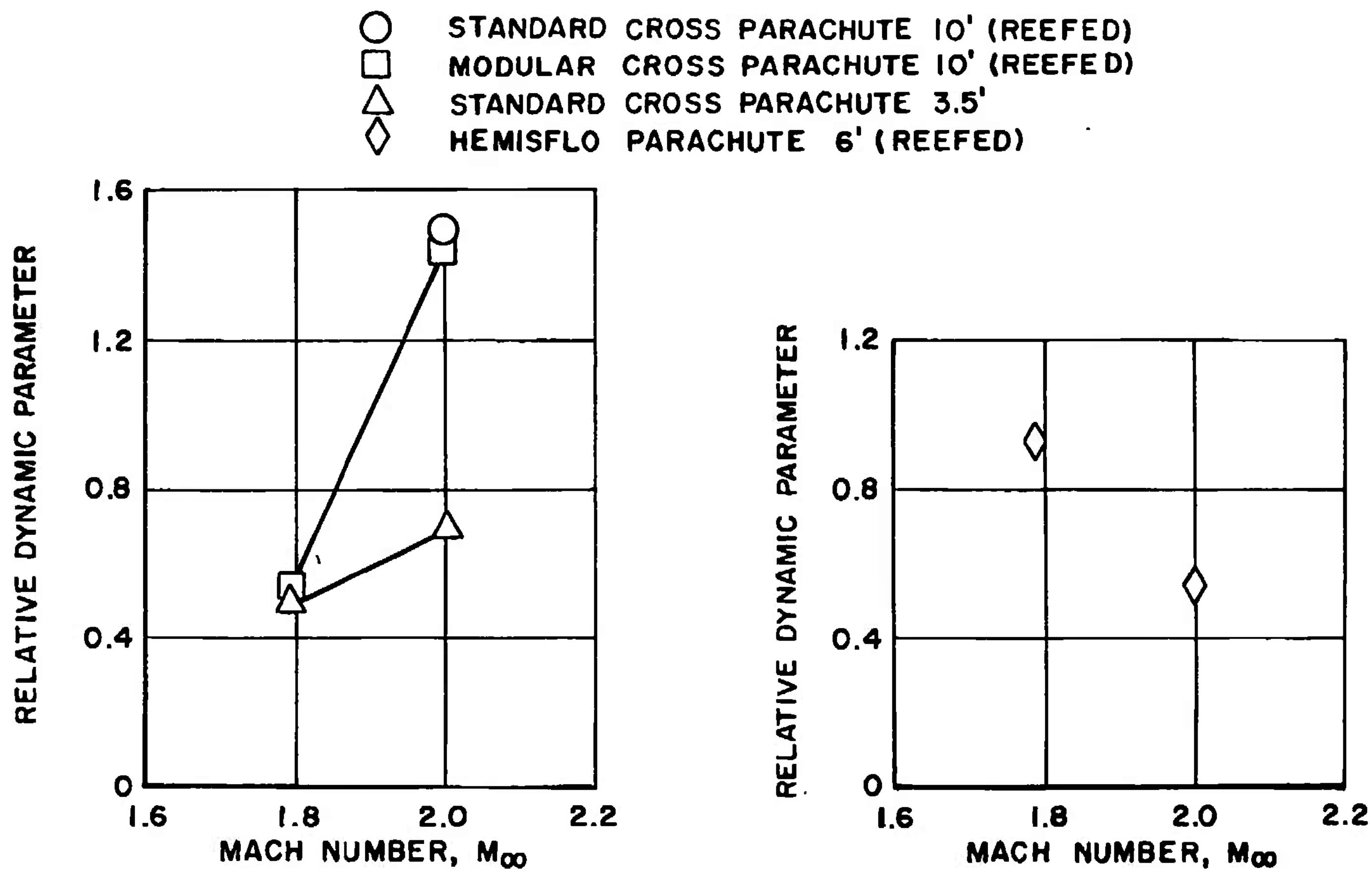


Fig. 12 Typical Distribution Plot of the Standard Cross Parachute, Ten-Foot Diameter (Reefed), Dynamic Drag Characteristics, M_∞ = 1.998, X/D = 9.887



a. Cross Parachutes

b. Hemisflo Parachute

Fig. 13 Variation of Relative Dynamic Parameter with Mach Number

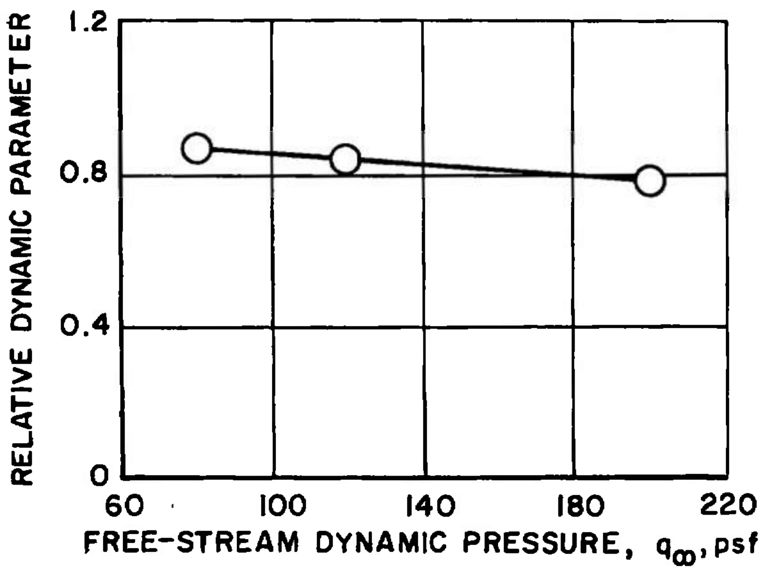


Fig. 14 Variation of the Supersonic X Parachutes Relative Dynamic Parameter with Free-Stream Dynamic Pressure, $M_\infty = 2.5$, $X/D = 7$

TABLE I
SUMMARY OF PARACHUTE STATISTICAL ANALYSIS RESULTS

DECELERATOR	MACH NUMBER M_∞	DYNAMIC PRESSURE q_∞, psf	X/D	C_{D_p}	σ	SKEWNESS	KURTOSIS	N	RELATIVE DYNAMIC PARAMETER
CROSS 10' std.	1.998	120.2	9.887	0.261	0.101	0.304	3.076	4092	1.492
CROSS 10' mod.	2.000	122.3	9.887	0.247	0.092	-0.103	2.798	4091	1.434
	1.790	119.8	9.895	0.309	0.042	-0.309	3.361	4082	0.525
CROSS 3.5' std.	1.999	122.0	4.719	0.379	0.068	-0.001	2.904	4071	0.696
	1.790	120.1	4.719	0.431	0.055	-0.099	2.618	4075	0.485
SUPERSONIC X	2.498	80.1	7.007	0.614	0.140	0.235	2.734	4049	0.873
	2.498	119.4	7.007	0.629	0.137	0.039	2.805	4066	0.840
	2.498	199.0	7.007	0.645	0.131	-0.016	2.751	4072	0.784
HEMISFLO	1.998	121.4	6.879	0.190	0.027	-0.138	2.574	4079	0.544
	1.789	120.5	6.887	0.058	0.014	0.560	3.847	4072	0.924

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Final Report - October 27 and 28, 1970

5. AUTHOR(S) (First name, middle initial, last name)

M. L. Homan, ARO, Inc.

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13. ABSTRACT

A test was conducted in the Propulsion Wind Tunnel (16S) to determine the aerodynamic performance of four types of decelerators. Data were obtained at Mach numbers from 1.8 to 2.5 at free-stream dynamic pressures from 80 to 200 psf. Increasing the Mach number resulted in a decrease in the steady-state drag coefficient and an increase in the dynamics of the cross parachutes. At Mach number 2.5, increasing the free-stream dynamic pressure resulted in a decrease in the dynamics and an increase in the steady-state drag coefficient of the Supersonic X parachute.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
1 parachutes						
aerodynamic characteristics						
supersonic flow						
performance						
deceleration						
pressure						
drag						
stability						
3 balloons						

2. Decelerators -- Aerodynamic Characteristics

Arnold AFS Tenn