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# DRAG AND PERFORMANCE CHARACTERISTICS OF FLEXIBLE AERODYNAMIC DECELERATORS IN THE WAKE OF BASIC AND MODIFIED ARAPAHO "C" TEST VEHICLE CONFIGURATIONS AT MACH NUMBERS FROM 2 TO 5

A. W. Myers and J. S. Hahn

ARO, Inc.

May 1967

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**ARNOLD ENGINEERING DEVELOPMENT CENTER**

**AIR FORCE SYSTEMS COMMAND**

**ARNOLD AIR FORCE STATION, TENNESSEE**

# NOTICES

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## FOREWORD

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

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 AF40(600)-1200. The tests were conducted from June 21 to July 5, 1966, and from August 15 to 25, 1966, under ARO Project No. VT0626, and the manuscript was submitted for publication on March 31, 1967.

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This technical report has been reviewed and is approved.

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## ABSTRACT

Tests were conducted in the 40-in. supersonic tunnel of the von Kármán Gas Dynamics Facility to investigate the drag and stability characteristics of a series of flexible supersonic decelerator models deployed at various positions aft of double-strut mounted forebodies. Data were obtained at Mach numbers from 2 to 5 at dynamic pressures corresponding to pressure altitudes which ranged from 41,000 to 140,000 ft. Selected typical results are presented.

## CONTENTS



## APPENDIXES

I. ILLUSTRATIONS

## NOMENCLATURE

| | |
|---|---|
| a, b, c | Parachute canopy grid dimensions, in. |
| $C_{D_P}$ | Drag coefficient of parachute canopy based on projected canopy area, drag force/$q_\infty S_P$ |
| $D_i$ | Parachute canopy inlet diameter, in. |
| $D_P$ | Parachute canopy projected diameter, in. |
| $D_r$ | Parachute canopy roof cap diameter, in. |
| d | Forebody base diameter, in. |
| f | Parachute canopy reinforcement web thickness, in. |
| $\ell$ | Parachute canopy skirt length, in. |
| $\ell_s$ | Parachute suspension line length, in. |
| $M_\infty$ | Free-stream Mach number |
| m | Canopy surface dimension, in. |
| $q_\infty$ | Free-stream dynamic pressure, psia |
| $S_P$ | Design projected area of inflated parachute canopy, in.$^2$ |
| v, w | Parachute suspension line cross-sectional dimensions, in. |
| x | Distance from the base of the forebody model to the parachute canopy inlet, in. |
| $\lambda_t$ | Total parachute canopy porosity, percent |

# SECTION I
# INTRODUCTION

Tests were conducted in the 40-in. supersonic tunnel (Gas Dynamic Wind Tunnel, Supersonic (A)) of the von Kármán Gas Dynamics Facility (VKF) to determine the wake characteristics of several double-strut mounted forebodies and the drag and stability characteristics of flexible supersonic decelerator models at various positions aft of the forebodies. The forebodies included basic and modified configurations of the Arapaho "C" test vehicle, and the decelerators were "Parasonics," members of the hyperflo family of high performance supersonic parachutes. The tests were conducted in support of the EUREKA (Establishment of an Unsymmetrical Wake Test Capability for Aerodynamic Decelerators) program.

The decelerator models were tested at Mach numbers from 2 to 5 at dynamic pressures corresponding to pressure altitudes which ranged from 60,000 to 140,000 ft.

Selected typical results are presented showing the effects of Mach number, location in the wake, and design parameters on the decelerator drag. The parachute performance and stability (stability as discussed in this report refers only to the conditions of oscillatory motion of the parachute with respect to the forebody model) are summarized for each test condition in Table I.

In the wake survey tests of this program, axial traverses were made with pitot pressure and static pressure rakes at Mach numbers from 2 to 5 at pressure altitudes which ranged from 41,000 to 123,000 ft. These data will be utilized by the Goodyear Aerospace Corporation in the analysis of decelerator performance, and no presentation is made herein.

# SECTION II
# APPARATUS

## 2.1 WIND TUNNEL

Tunnel A is a continuous, closed-circuit, variable density wind tunnel with an automatically driven flexible-plate-type nozzle and a 40- by 40-in. test section. The tunnel operates at Mach numbers from 1.5 to 6 at maximum stagnation pressures from 29 to 200 psia, respectively, and stagnation temperatures up to 300°F ($M_\infty$ = 6). Minimum operating pressures range from about one-tenth to one-twentieth of the maximum pressures. A description of the tunnel and airflow calibration information may be found in the Test Facilities Handbook*.

## 2.2 TEST ARTICLES

### 2.2.1 Forebodies and Support System

A total of three forebodies (Fig. 1) were employed for the decelerator tests. The 0.182-scale model of the basic Arapaho "C" consisted of a cylindrical centerbody with a symmetrical flared afterbody and a probe nose (Configuration 1). Configuration 2 was a variation of the basic configuration obtained by replacing the probe nose with a blunted cone nose. Configuration 3 consisted of a blunted, elliptical cone with a nose shape identical to Configuration 2.

The forebody support system (Fig. 1b) consisted of a strut spanning the width of the tunnel and mounted to the sidewalls. The drag tensiometer and a winch assembly for varying the location of the decelerator aft of the forebody were housed in a vacuum tank, which was also mounted to the tunnel sidewall (Fig. 1b). The decelerator support line passed through the model and strut and into the vacuum tank where it was attached to the tensiometer and winch assembly.

### 2.2.2 Decelerator Models

Design and construction details of the four parasonic parachutes, which are constructed in the shape assumed by an inflated hyperflo parachute (hyperflo parachutes are constructed as truncated cones), with porous roofs and low porosity skirts, are given in Fig. 2. Construction variables investigated were canopy size and roof grid size. Constant total porosity ($\lambda_t$) of 5 percent was maintained for all parachutes by careful application to the roofs of a flexible, thermal coating. Canopy location (x/d) behind the forebodies was varied from 4 to 10.

## 2.3 INSTRUMENTATION

Parachute drag measurements were made with a 200-lb tensiometer located in the winch assembly. A time history of the dynamic drag output from the tensiometer was recorded on an oscillograph, and average

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*Test Facilities Handbook (Sixth Edition). von Kármán Gas Dynamics Facility, Vol. 4." Arnold Engineering Development Center, November 1966.

drag values were determined from the recorded traces. Based on the repeatability of the calibration results, the accuracy of the drag measurement is estimated to be within 8 percent. The uncertainty in the drag measurement includes the combined effects of friction in the pulley systems located in the forebodies and winch mechanism, nonlinearity in the oscillograph output, and the stiffness of the aircraft cable used for the parachute riser lines.

Parachute performance was monitored on two high-speed, 16-mm motion-picture cameras (one for side motion pictures and one for schlieren photography), and additional photographic results were obtained from regular and schlieren still cameras.

## SECTION III
## TEST PROCEDURE

Before each test run, the parachute canopy and suspension lines were packed in a deployment bag, which was then suspended near the base of the forebody model by a pull cord routed from the rear of the bag through the tunnel sector. The pull cord was held taut manually during tunnel start, and when the desired test condition was established, a sharp pull on the cord removed the bag. Parachute location behind the forebody was set by the remotely operated winch assembly using reference marks placed on the tunnel windows.

A summary of the test conditions and decelerator performance results is given in Table I. The observations presented in the table are the results of evaluations of the photographic data.

## SECTION IV
## RESULTS AND DISCUSSION

### 4.1 PARACHUTE DRAG

The combined effects of parachute canopy size and location and forebody model shape on the parachute drag coefficients are presented in Fig. 3 for the lowest dynamic pressure condition. At this test condition, the drag coefficients of the parachutes generally showed large variations when the parachutes were close to the forebody base ($x/d < 5$) because the parachutes would at times cause the wake to open and also because parachute canopy inflation was poor, especially behind Configuration 3. The variations in drag coefficient were smaller at the larger parachute trailing distances (x/d > 6), and the drag coefficient for the larger diameter parachutes was generally higher, although this trend was not consistent. The transition from a stable to an unstable or marginally stable parachute configuration was generally accompanied by a change in drag coefficient; however, no consistent effects of parachute performance on the drag coefficient were observed.

The effects of increasing dynamic pressure are presented, for parachute Configuration 1, in Fig. 4. For the higher dynamic pressure levels, the forebody wake in the base region was generally less affected by the presence of the decelerators, inflation was better, and the drag was generally higher for x/d < 5. For $M_\infty > 2$ and x/d > 6, the drag coefficients of the parachutes behind forebody Configuration 3 showed only small variations with increasing dynamic pressure, whereas the drag coefficients for parachutes behind Configuration 2 decreased as dynamic pressure was increased. Here again parachute performance at different dynamic pressure levels showed no definite trends that explain the drag differences.

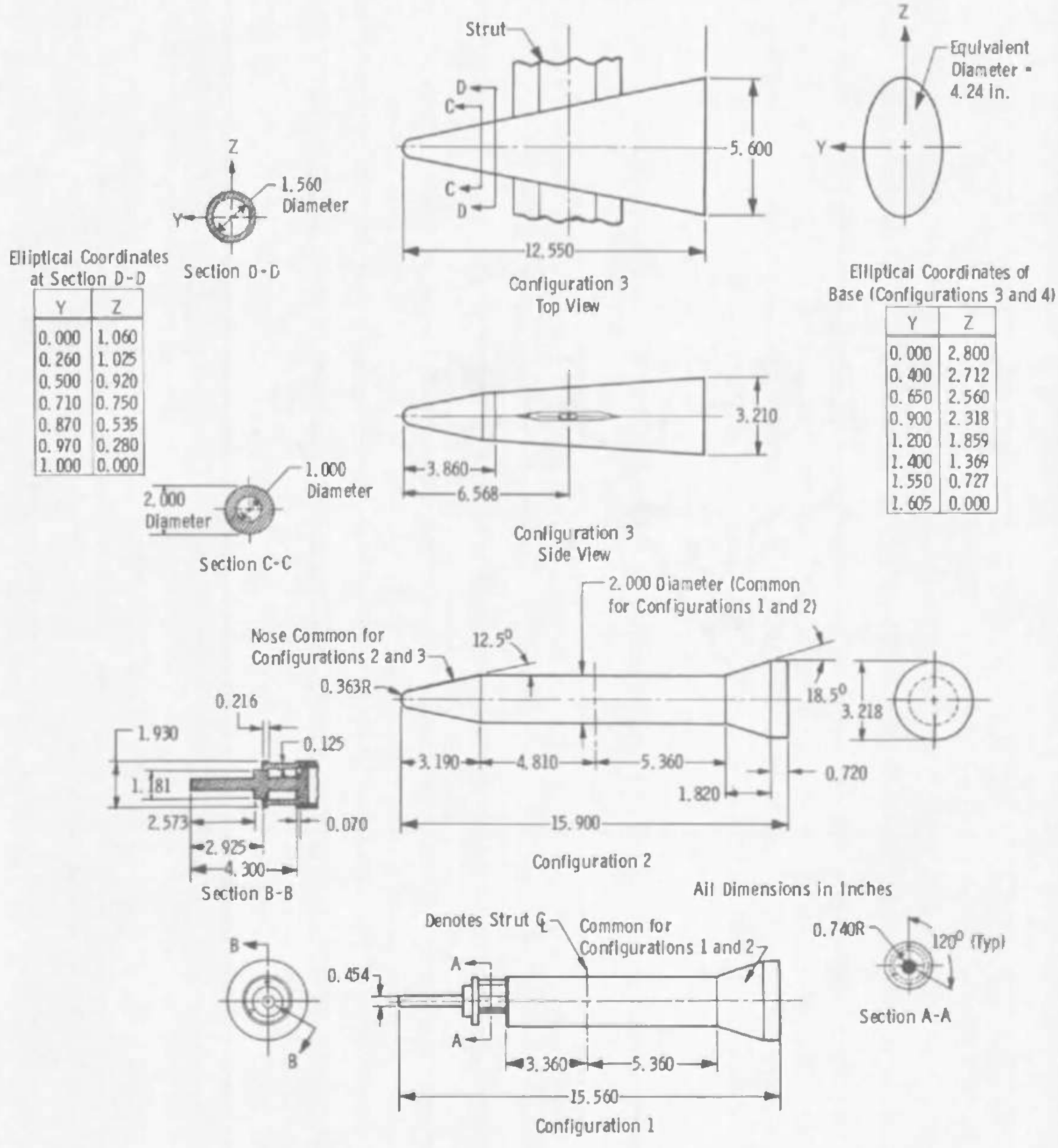
The decrease in the drag coefficients with Mach number is shown in Fig. 5 for x/d locations of 6 and 8. Schlieren photographs are given in Fig. 6, illustrating the open-wake conditions obtained for x/d < 5. Poor canopy inflation is evident in the photograph in Fig. 6b.

### 4.2 PARACHUTE PERFORMANCE

Parachute performance for each test run is presented in Table I. Generally, the canopy roof grid size had little effect on performance. Behind the symmetrical forebody configurations (1 and 2), both the large and small diameter parachutes were generally unstable at small values of x/d and stable at the larger values for $M_\infty < 4$, whereas the converse was true when the parachutes were behind forebody Configuration 3. For Mach numbers of 4 or greater, the parachutes were stable at all values of x/d behind all three forebodies. Increasing the dynamic pressure usually increased the range of x/d values where the parachutes were stable.

## APPENDIXES

I. ILLUSTRATIONS
II. TABLE




Elliptical Coordinates at Section D-D

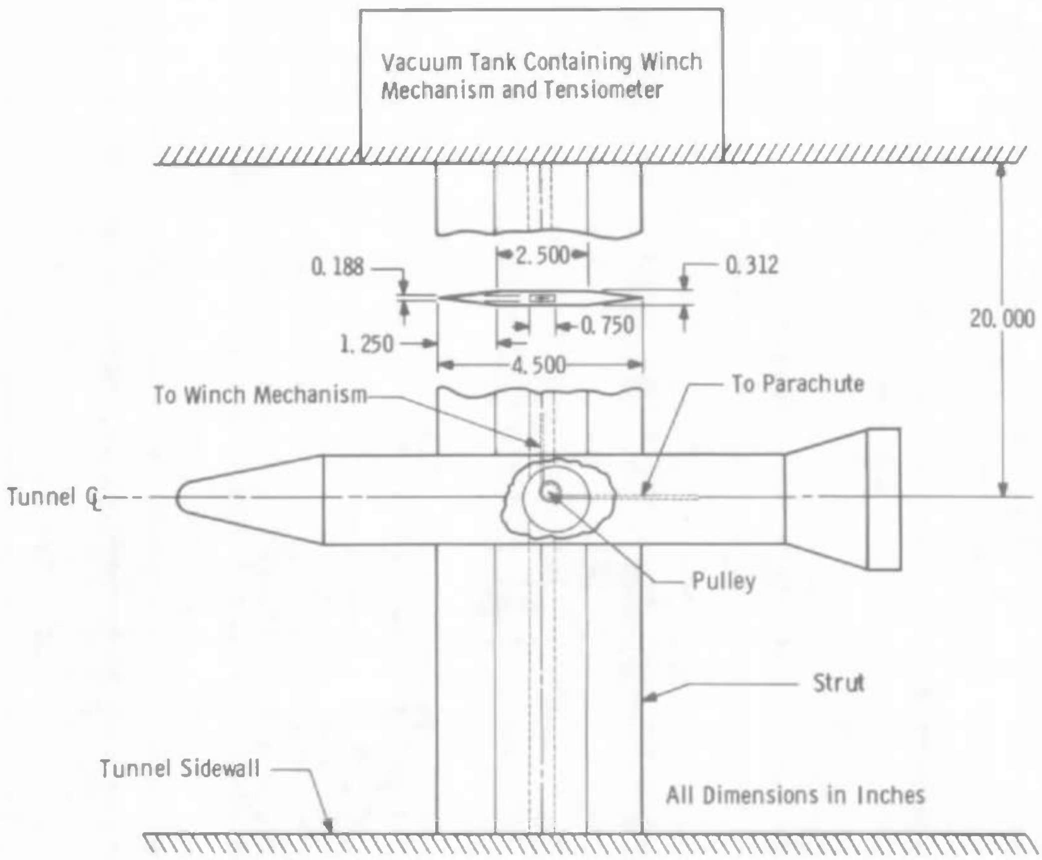
| Y | Z |
|---|---|
| 0.000 | 1.060 |
| 0.260 | 1.025 |
| 0.500 | 0.920 |
| 0.710 | 0.750 |
| 0.870 | 0.535 |
| 0.970 | 0.280 |
| 1.000 | 0.000 |

Elliptical Coordinates of Base (Configurations 3 and 4)

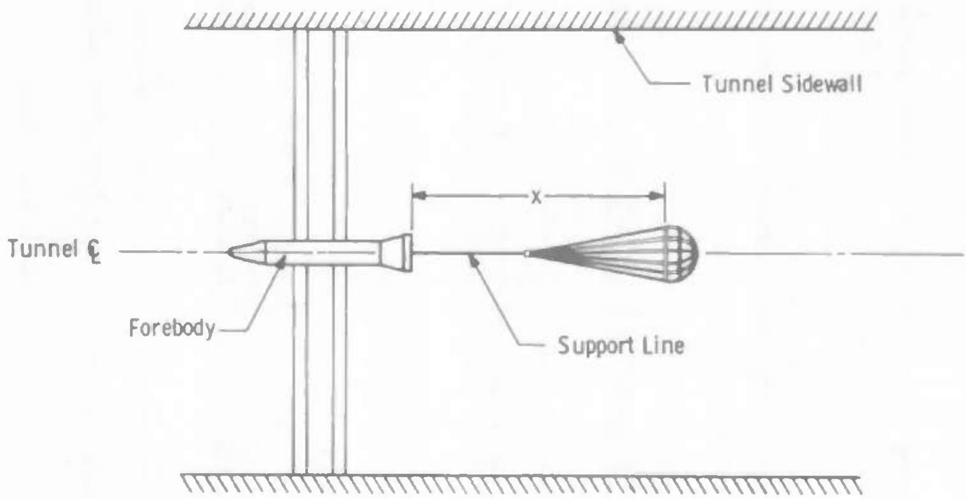
| Y | Z |
|---|---|
| 0.000 | 2.800 |
| 0.400 | 2.712 |
| 0.650 | 2.560 |
| 0.900 | 2.318 |
| 1.200 | 1.859 |
| 1.400 | 1.369 |
| 1.550 | 0.727 |
| 1.605 | 0.000 |

a. Forebody Details

Fig. 1 Forebody and Strut Support Details

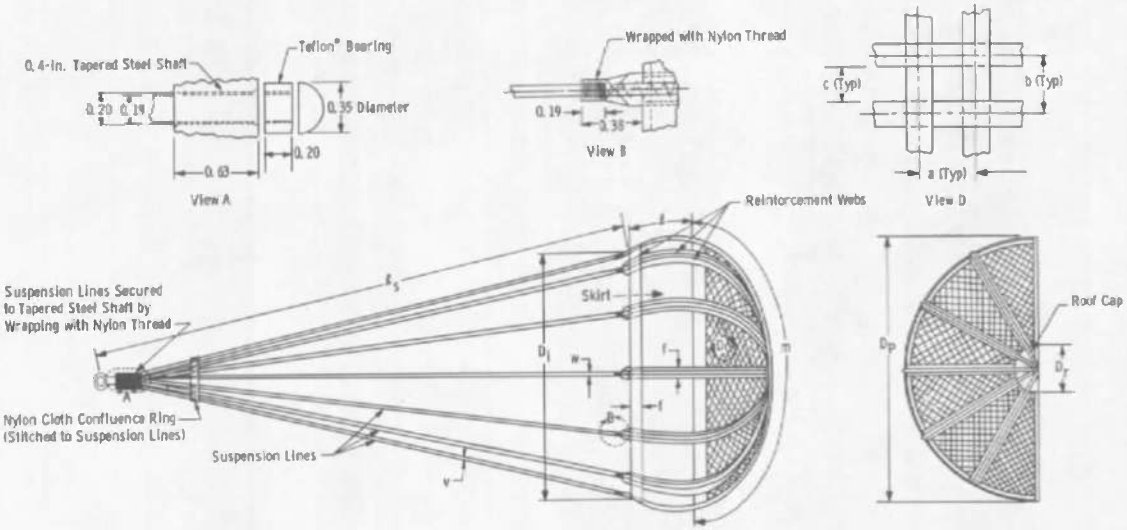



b. Strut Details




c. Tunnel Installation Sketch

Fig. 1 Concluded



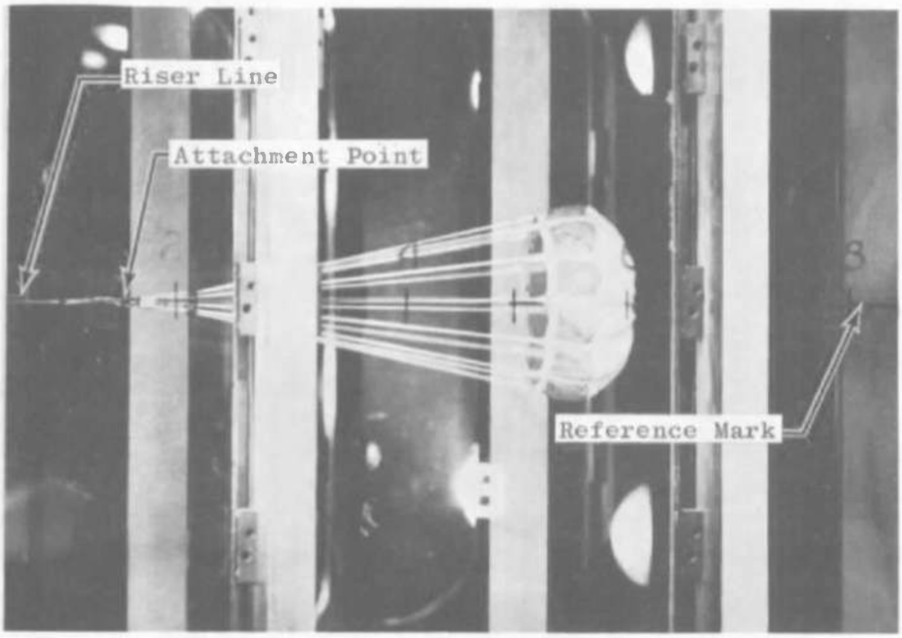

a. Parasonic Parachute Construction

All Dimensions in Inches

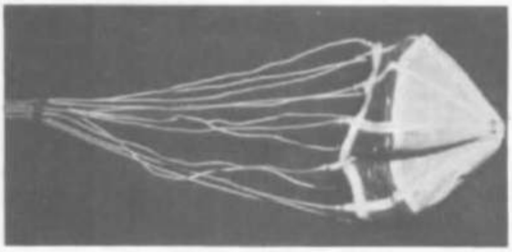
| Parachute Configuration | $\lambda_t$, percent | $D_i$, in. | $D_p$, in. | $D_r$, in. | d, in. | f, in. | w, in. | $\ell_s$, in. | Suspension Line Material | Skirt Material and Roof Cap | Roof Material | a, in. | b, in. | c, in. | Reinforcement Webs | $\ell$, in. | m, in. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 5 | 5.77 | 6.00 | 1.65 | 0.08 | 0.25 | 0.08 | 12.50 | MIL-C-5040 Type I Cord | 4787 Nylon Cloth, 0.84 oz/yd² Coated with D1596-F839 Polyurethane | HT-83-44 Nomex® Mesh Cloth, 3.01 oz/yd², Pre-Coated with D1569-F839 Polyurethane. Porosity Controlled by Coating with D-65 Flexible Thermal Coating | 0.03 | 0.03 | 0.01 | Double-Fold Cotton Bias Tape, 88 by 80 | 1.81 | 6.83 |
| 2 | 5 | 5.75 | 6.00 | 1.71 | 0.08 | 0.25 | 0.13 | 12.50 | | Same as Parachute Configuration 1 | MIL-T-713A, Class II, Type S Nylon Lacing, Pre-Coated on Form with D1569-F839 Polyurethane. Porosity Controlled as Above. | 0.11 | 0.11 | 0.04 | | 1.81 | 6.83 |
| 3 | 5 | 7.57 | 7.86 | 1.96 | 0.06 | 0.25 | 0.08 | 16.70 | MIL-C-5040 Type III Cord with Fibers Removed | Same as Parachute Configuration 1 | Same as Parachute Configuration 1 | 0.03 | 0.03 | 0.01 | | 2.33 | 8.73 |
| 4 | 5 | 7.52 | 7.86 | 2.30 | 0.08 | 0.25 | 0.13 | 17.0 | | Same as Parachute Configuration 1 | Same as Parachute Configuration 2 | 0.11 | 0.11 | 0.04 | | 2.33 | 8.73 |

b. Design Details

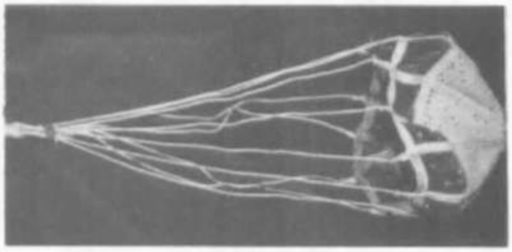
Fig. 2 Decelerator Design and Construction Parameters



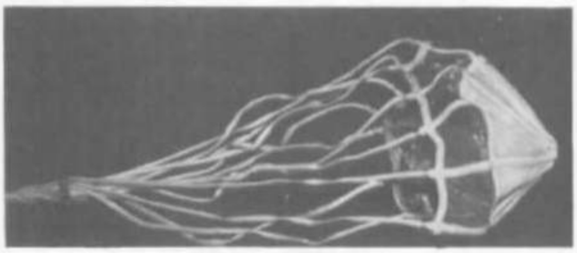

c. Configuration 1 in Tunnel A, $M_\infty = 2$, $q_\infty = 0.5$ psia



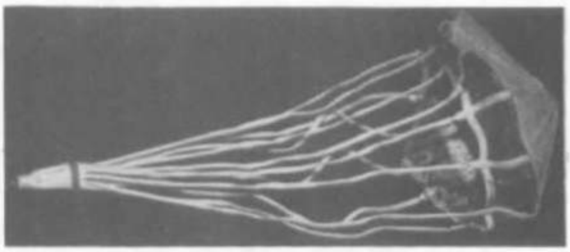
Configuration 1



Configuration 2



Configuration 3



Configuration 4

d. Configuration Photographs

Fig. 2 Concluded

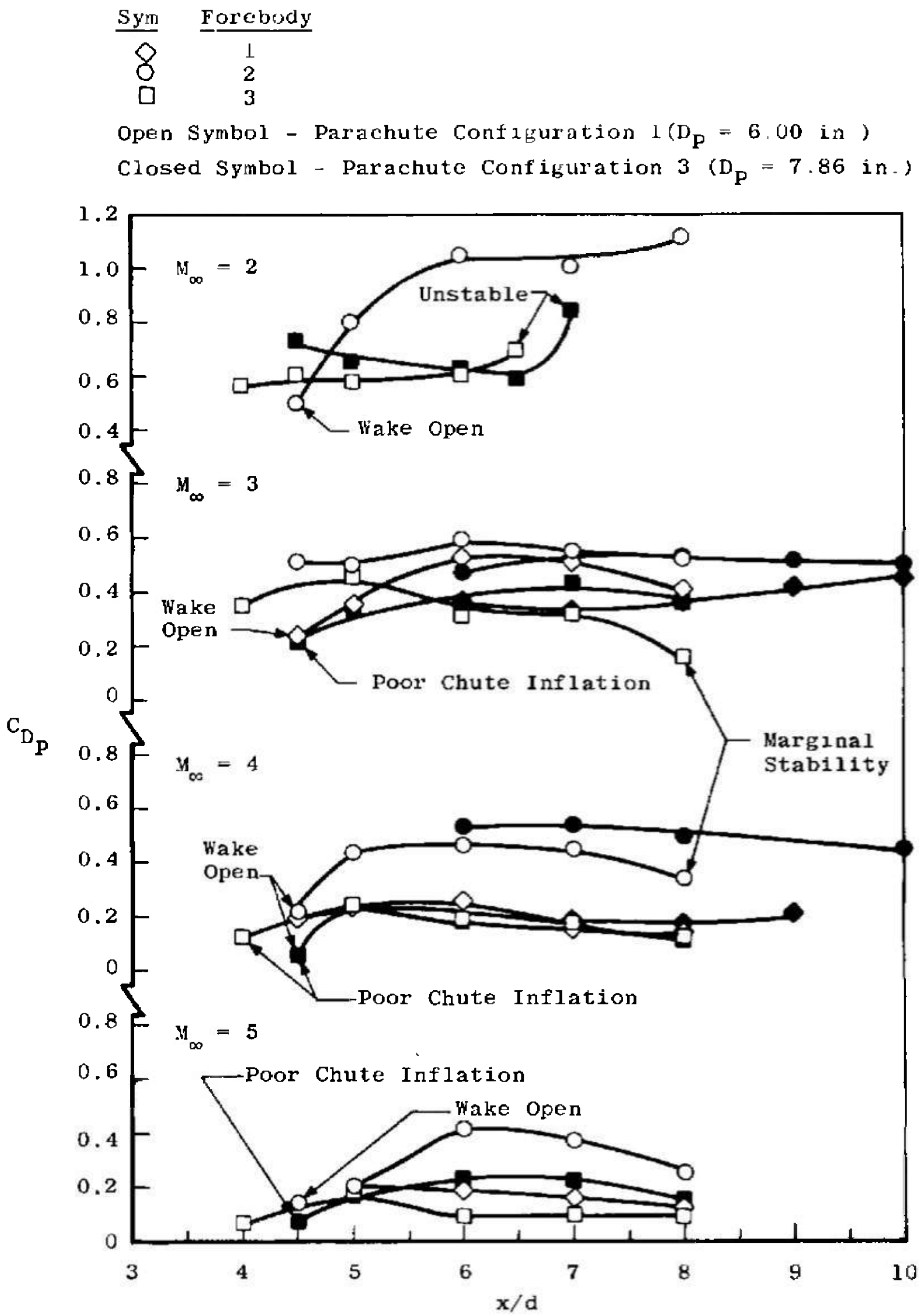



Fig. 3 Effects of Forebody Shape, Canopy Size, and Canopy Location in the Wake on Parachute Drag Characteristics, $q_\infty = 0.5$ psia

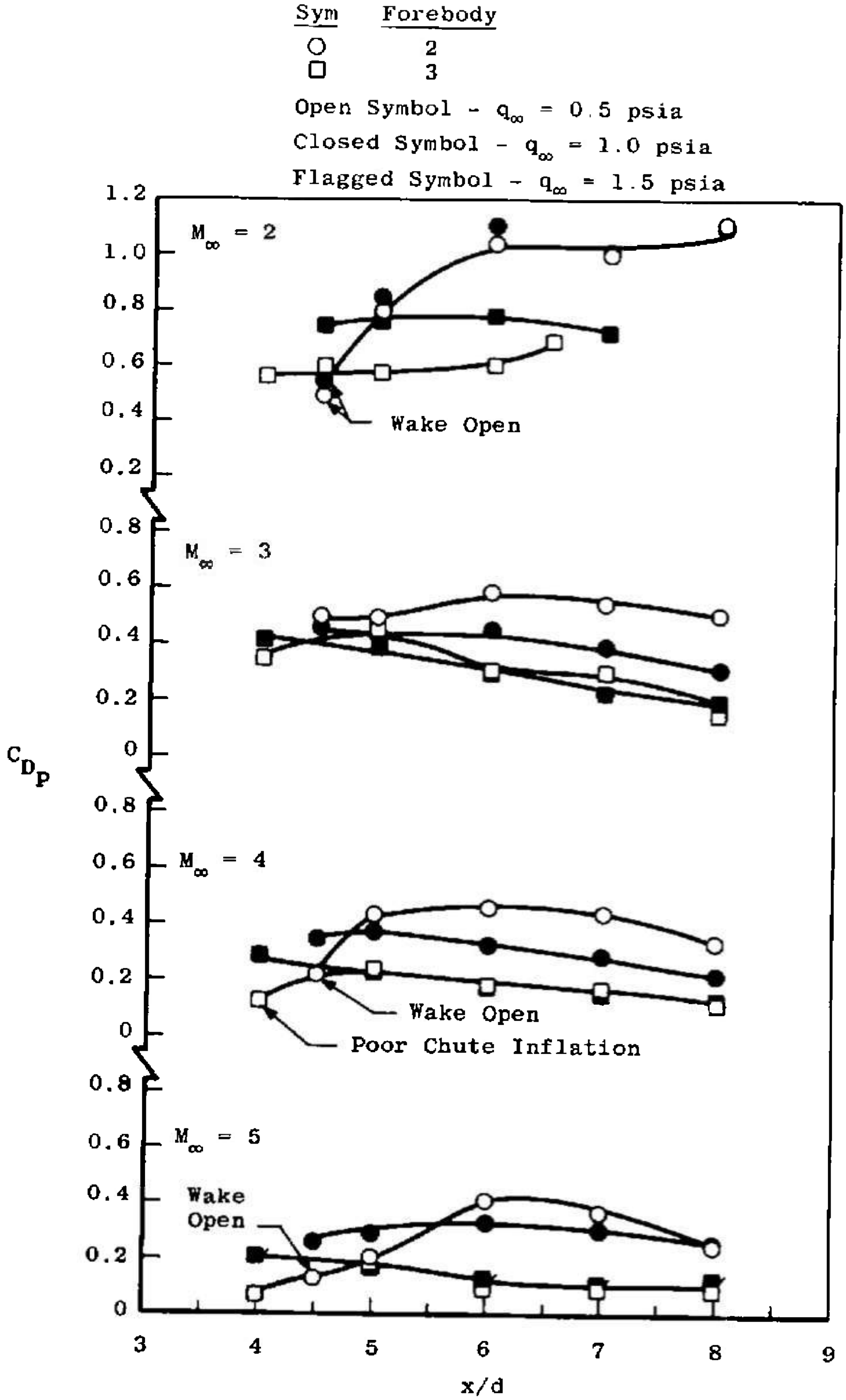



Fig. 4 Effects of Dynamic Pressure on Parachute Drag Characteristics, Parachute Configuration 1

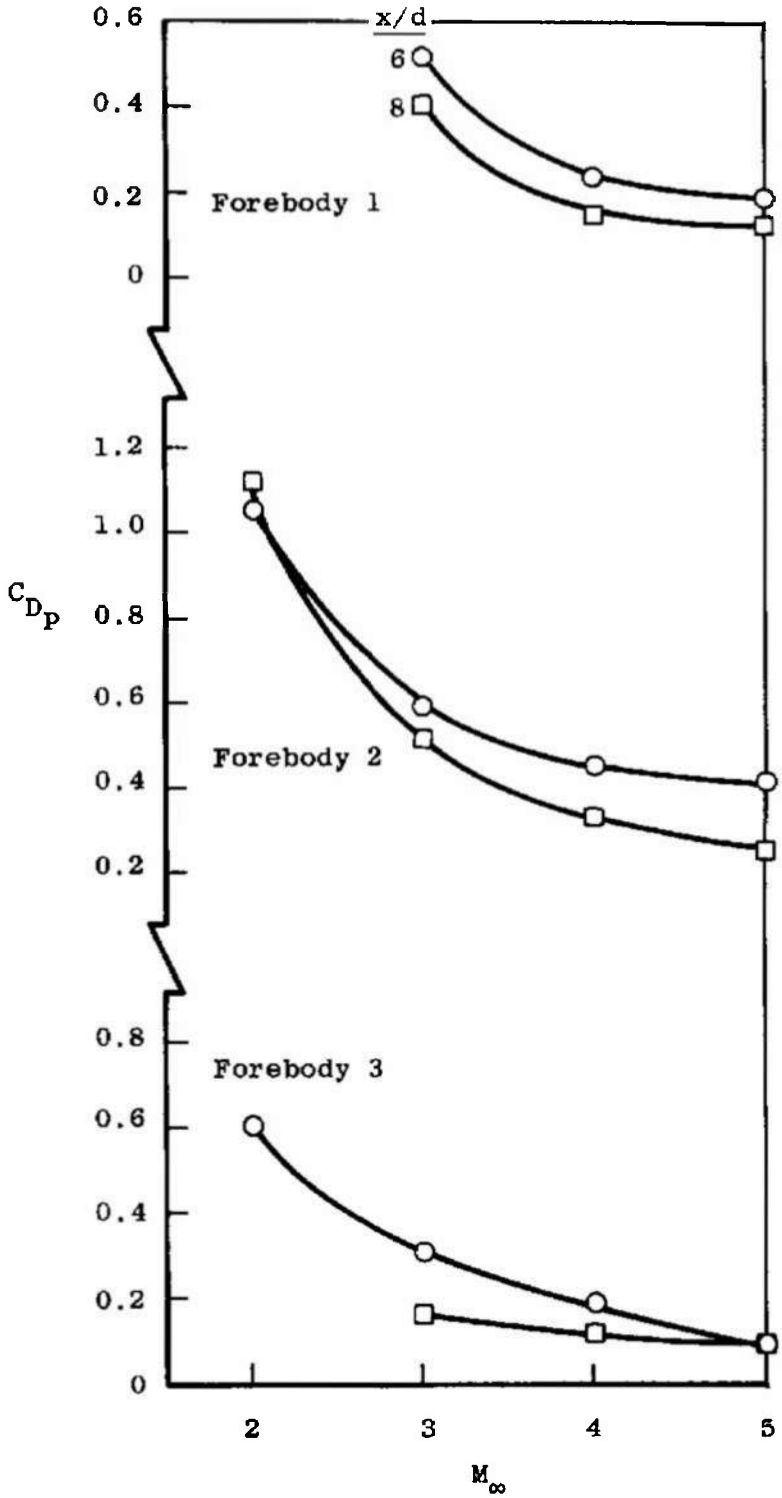
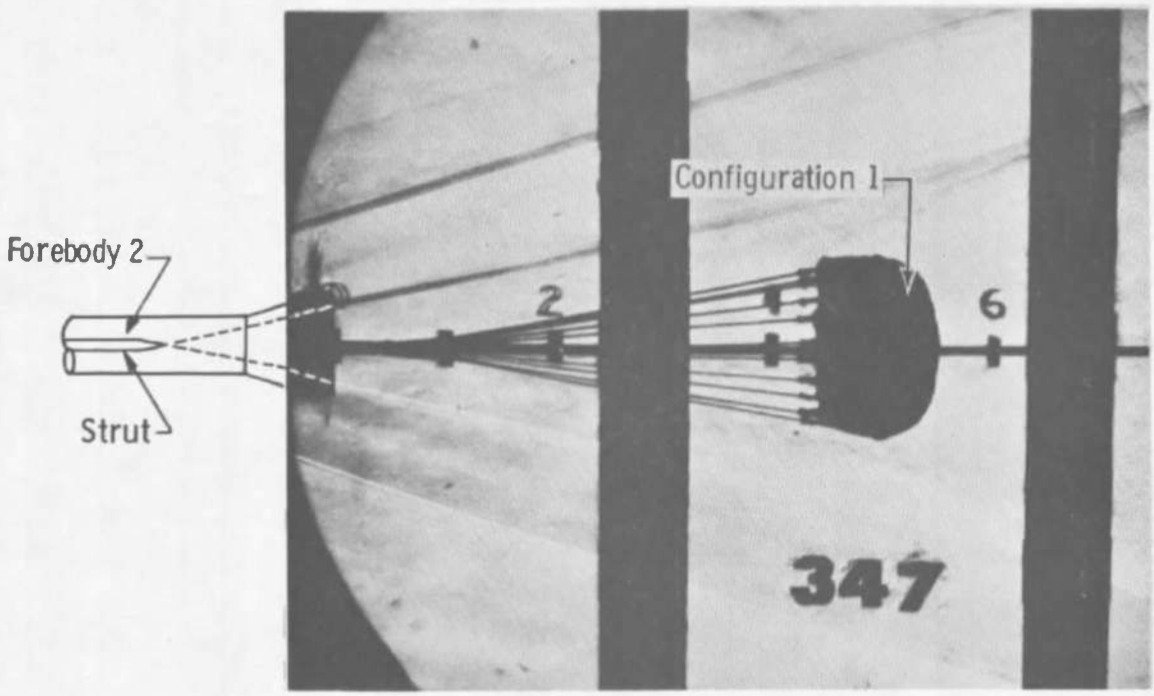
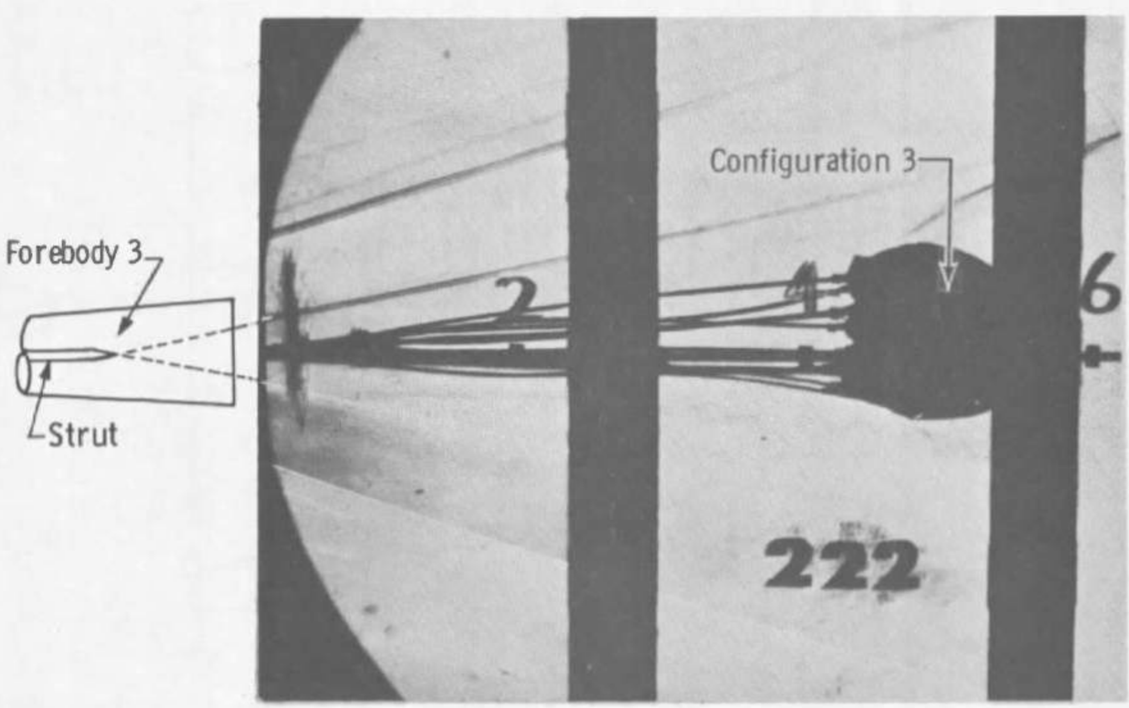



Fig. 5 Variation of Parachute Drag Coefficient with Mach Number, Configuration 1, $q_\infty$ = 0.5 psia




a. Forebody 2, Parachute Configuration 2




b. Forebody 3, Parachute Configuration 3

Fig. 6 Schlieren Photographs of Deployed Parachutes at $M_\infty = 4$, $q_\infty = 0.5$ psia, and $x/d = 4.5$

## TABLE I
## DECELERATOR TEST CONDITIONS AND PERFORMANCE RESULTS

| Parachute Configuration | $M_\infty$ | Forebody Configuration | x/d Min | x/d Max | $q_\infty$, psia | $C_{D_p}$ Min | $C_{D_p}$ Max | Remarks |
|---|---|---|---|---|---|---|---|---|
| 1 | 2.0 | 1 | 4.5 | 9.0 | 0.6, 1.5 | 0.54 | 1.54 | Stable at x/d ≤ 6, unstable at x/d > 6, oscillations of ±8 deg at x/d ≥ 8, violent pulsing of canopy at x/d = 4.5 to medium pulsing at x/d = 5 and 6. |
| | 3.0 | | 4.5 | 8.0 | 0.6 | 0.23 | 0.53 | Stable, slowly spinning, and fair inflation at x/d ≤ 5, unstable at x/d ≥ 6. |
| | | | 4.5 | 8.0 | 1.0 | 0.31 | 0.38 | Fair inflation, very stable at x/d ≤ 5, stable at x/d ≥ 6. |
| | | | 4.5 | 8.0 | 1.5 | 0.31 | 0.37 | Stable but violently pulsing at x/d = 4.5, stable with fair inflation at x/d ≥ 5. |
| | 4.0 | | 4.5 | 8.0 | 0.5 | 0.14 | 0.30 | Very stable, violently pulsing and spinning at x/d = 4.5, medium pulsing and fair inflation at x/d ≥ 5. |
| | | | 4.5 | 8.0 | 1.0, 1.5 | 0.12 | 0.20 | Very stable, violently pulsing at x/d = 4.5, medium pulsing (fair inflation) at x/d ≥ 5, spinning at x/d ≥ 5, $q_\infty$ = 1.0. |
| | 5.0 | | 4.5 | 8.0 | 0.5, 1.5 | 0.13 | 0.43 | Very stable and good inflation at x/d ≤ 5, stable, slowly spinning, and medium pulsing (fair inflation) at x/d ≥ 6. |
| | 2.0 | 2 | 4.5 | 8.0 | 0.6 | 0.47 | 1.14 | Very stable (x/d = 4.5) to stable and good inflation at x/d ≤ 5, very unstable (±10 to ±14 deg) at x/d ≥ 6. |
| | | | 4.5 | 8.0 | 1.0 | 0.51 | 1.17 | Very stable but violent pulsing at x/d = 4.5; very unstable (±10 deg) and coning at x/d ≥ 5. |
| | 3.0 | | 4.5 | 8.0 | 0.6 | 0.53 | 0.61 | Very stable and fair inflation at x/d ≤ 6. Unstable at x/d ≥ 7. |
| | | | 4.5 | 8.0 | 0.8, 1.0 | 0.32 | 0.58 | Very stable (x/d = 4.5) to stable, and fair to poor inflation, oscillations of ±4 deg at x/d > 6, $q_\infty$ = 0.8. |
| | 4.0 | | 4.5 | 8.0 | 0.5 | 0.21 | 0.50 | Very stable (x/d ≤ 5) to stable, and good x/d ≤ 6) to fair or poor inflation, oscillations of ±4 deg at x/d ≥ 7. |
| | | | 4.5 | 8.0 | 0.8 | 0.23 | 0.52 | Very stable (x/d ≤ 5) to stable, and good (x/d ≤ 5) to poor inflation, violent pulsing at x/d = 8. |
| | | | 4.5 | 8.0 | 1.0 | 0.22 | 0.40 | Very stable, violent pulsing at x/d = 4.5, generally good inflation at x/d ≥ 5. |

TABLE I (Continued)

| Parachute Configuration | $M_\infty$ | Forebody Configuration | x/d Min | x/d Max | $q_\infty$, psia | $C_{D_P}$ Min | $C_{D_P}$ Max | Remarks |
|---|---|---|---|---|---|---|---|---|
| 1 | 5.0 | 2 | 4.5 | 8.0 | 0.5 | 0.13 | 0.42 | Very stable (x/d ≤ 5) to stable, and good (x/d ≤ 5) to fair inflation |
| | | | | | 1.0 | 0.24 | 0.35 | Very stable, medium pulsing at x/d = 4.5 and 8.0, good (x/d = 5) to fair inflation for other x/d's |
| | 2.0 | 3 | 4.0 | 6.5 | 0.6 | 0.56 | 0.69 | Very stable to stable (x/d = 5) and good inflation at x/d ≤ 5, unstable at x/d ≥ 6. |
| | | | 4.0 | 6.5 | 1.0 | 0.38 | 0.79 | Stable and good to fair (x/d = 5) inflation at x/d ≤ 5, unstable at x/d = 6, marginal stability at x/d = 6.5. |
| | | | 4.0 | 6.5 | 1.5 | 0.81 | 0.93 | Very stable (x/d ≤ 4.5) to stable and good (x/d ≤ 4.5) to fair inflation, stable at x/d ≥ 5 |
| | 3.0 | | 4.0 | 8.0 | 0.6 | 0.16 | 0.46 | Very stable and good inflation at x/d = 4, unstable at x/d = 5, marginal stability at x/d = 6, stable but large oscillations at x/d ≥ 7. |
| | | | 4.0 | 8.0 | 1.0, 1.5 | 0.20 | 0.45 | Very stable (x/d = 4, $q_\infty$ = 1) to stable and good (x/d = 4) to fair inflation. |
| | 4.0 | | 4.0 | 8.0 | 0.5 | 0.12 | 0.24 | Unstable at x/d = 4, stable and poor (x/d = 5) to fair inflation at x/d ≥ 5. |
| | | | 4.0 | 8.0 | 1.0 | 0.14 | 0.29 | Very stable and good to fair inflation. |
| | | | 4.0 | 8.0 | 1.5 | 0.14 | 0.34 | Stable and fair (x/d = 4) to good inflation. |
| | 5.0 | | 4.0 | 8.0 | 0.5, 1.5 | 0.07 | 0.20 | Unstable at x/d = 4, very stable and good ($q_\infty$ = 1.5) to fair ($q_\infty$ = 0.5) inflation at x/d ≥ 5 |
| 2 | 2.0 | 1 | 4.5 | 8.0 | 0.6 | 0.44 | 0.69 | Canopy motionless at x/d = 5 and 6, stable and good inflation at x/d = 8, unstable (±7 deg) at x/d = 4.5 and 7 |
| | | | 4.5 | 8.0 | 1.26 | 0.57 | 0.98 | Very stable (x/d = 5 and 6) to stable and generally good inflation at all x/d's. |
| | | | 4.5 | 6.0 | 2.0 | 0.54 | 0.79 | Very stable (x/d = 5) to stable (x/d = 4.5) and good inflation at x/d ≤ 5; unstable (±8 deg) at x/d = 6 |
| | 3.0 | | 4.5 | 8.0 | 0.5 | 0.31 | 0.62 | Virtually motionless with good inflation at x/d = 5 and 6, unstable (±8 deg) at x/d = 4.5 and 8, very unstable (±12 deg) at x/d = 7. |
| | | | 4.5 | 8.0 | 1.0 | 0.32 | 0.51 | Stable (±4 deg) and fair inflation at x/d = 4.5, virtually motionless with good inflation at x/d = 5 and 6, marginal stability (±5 deg) at x/d ≥ 7. |
| | | | 4.5 | 8.0 | 1.5 | 0.30 | 0.36 | Virtually motionless with good inflation at x/d ≤ 5, fair inflation and stable (±4 deg) at x/d = 6 and 8 to unstable (±6 deg) at x/d = 7. |

## TABLE I (Continued)

| Parachute Configuration | $M_\infty$ | Forebody Configuration | x/d Min | x/d Max | $q_\infty$, psia | $C_{D_P}$ Min | $C_{D_P}$ Max | Remarks |
|---|---|---|---|---|---|---|---|---|
| 2 | 4.0 | 1 | 4.5 | 8.0 | 0.5 | 0.24 | 0.32 | Virtually motionless with good inflation at x/d ≤ 6, stable (±3 deg) and fair inflation at x/d = 7, marginal stability at x/d = 8. |
| | | | 4.5 | 8.0 | 1.0, 1.5 | 0.14 | 0.23 | Stable (±4 deg) and fair inflation at x/d = 8, $q_\infty$ = 1.0, very stable and good inflation elsewhere, motionless at x/d < 6. |
| | 5.0 | | 4.5 | 8.0 | 0.5 | 0.17 | 0.23 | Very stable, good inflation at all x/d's (some packing creases still in canopy). |
| | | | 4.5 | 8.0 | 1.0, 1.5 | 0.15 | 0.21 | Very stable, slight pulsing (x/d = 4.5) increasing with x/d to medium pulsing (x/d = 8). |
| | 2.0 | 2 | 4.5 | 8.0 | 0.6 | 0.39 | 0.73 | Very stable and good inflation at x/d = 5 and 6, unstable (±6 to ±8 deg) at x/d = 4.5, 7, and 8, coning at x/d = 8 |
| | | | 4.5 | 8.0 | 1.0 | 0.39 | 0.73 | Stable (±3 to ±4.5 deg) and good to fair inflation at x/d ≤ 6, unstable (±7.5 deg) and coning at x/d ≥ 7. |
| | 3.0 | | 4.5 | 8.0 | 0.5 | 0.32 | 0.47 | Very stable and good inflation at x/d ≤ 6, unstable (±7 deg) at x/d ≥ 7. |
| | | | 4.5 | 8.0 | 0.76 | 0.34 | 0.50 | Motionless and good inflation at x/d ≤ 5, unstable (±6 deg) at x/d = 6 and 7; marginal stability at x/d = 8. |
| | | | 4.5 | 8.0 | 1.0 | 0.33 | 0.49 | Motionless and good inflation at x/d ≤ 5, oscillations of ±4 deg (x/d = 7) to ±3 deg (x/d = 8) at x/d ≥ 7, unstable (±7 deg) at x/d = 6. |
| | 4.0 | | 4.5 | 8.0 | 0.5 | 0.31 | 0.49 | Very stable (motionless at x/d ≤ 5) and good inflation at x/d ≤ 6, stable and good (x/d = 7) to fair (x/d = 8) inflation at x/d ≥ 7. |
| | | | 4.5 | 8.0 | 0.76 | 0.23 | 0.37 | Motionless with good inflation at x/d ≤ 5, fair inflation with oscillations of ±4 deg (x/d = 6) to ±2.5 deg (x/d = 8) at x/d ≥ 6. |
| | | | 4.5 | 8.0 | 1.0 | 0.21 | 0.36 | Medium pulsing, very stable (x/d = 4.5 and 8) to stable (x/d = 5, 6, and 7). |
| | 5.0 | | 4.5 | 8.0 | 0.5 | 0.11 | 0.30 | Medium to violent pulsing, some packing creases in canopy, very stable at x/d ≤ 5, marginal stability at x/d = 6, unstable (±10 deg) at x/d ≥ 7. |
| | | | 4.5 | 8.0 | 1.0 | 0.21 | 0.28 | Medium pulsing, very stable (x/d ≤ 5) to stable (x/d ≥ 6), packing creases in canopy. |

## TABLE I (Continued)

| Parachute Configuration | $M_\infty$ | Forebody Configuration | x/d Min | x/d Max | $q_\infty$, psia | CDp Min | CDp Max | Remarks |
|---|---|---|---|---|---|---|---|---|
| 2 | 3.0 | 3 | 4.0 | 8.0 | 0.6, 1.5 | 0.36 | 0.64 | Very unstable at x/d = 8, $q_\infty$ = 1.5, very stable with no pulsing ($q_\infty$ = 1.5) to medium pulsing ($q_\infty$ = 0.6) at x/d = 4, stable with good ($q_\infty$ = 0.6) to fair ($q_\infty$ = 1.5) inflation at other x/d's. |
| | 4.0 | 3 | 4.0 | 8.0 | 0.5 | 0.05 | 0.18 | Stable but violent pulsing at x/d = 4, very stable and good inflation at x/d = 5, stable and fair inflation at x/d = 7, but unstable at x/d = 6 and 8. |
| | | | 4.0 | 8.0 | 1.0, 1.5 | 0.11 | 0.23 | Very stable and good inflation at x/d = 4, stable (±4 deg) and medium to violent pulsing at x/d ≥ 5. |
| 3 | 3.0 | 1 | 6.0 | 10.0 | 0.6 | 0.32 | 0.53 | Very stable (x/d = 6) to stable (x/d = 7) and no pulsing (x/d = 6) to violent pulsing (x/d = 7) at x/d ≤ 7, unstable (x/d = 8 and 9) to very unstable x/d = 10). |
| | | | 6.0 | 10.0 | 1.0 | 0.30 | 0.45 | Very stable (x/d = 6) to stable (x/d = 7 and 8) and medium (x/d = 6) to violent (x/d = 7 and 8) pulsing at x/d ≤ 8, very unstable at x/d ≥ 9. |
| | | | 6.0 | 8.0 | 1.5 | 0.33 | 0.60 | Stable with medium pulsing at x/d ≤ 7, unstable at x/d = 8, skirt ruptured in several places. |
| | 4.0 | 1 | 6.0 | 9.0 | 0.5 | 0.18 | 0.41 | Very stable, medium pulsing (x/d = 6) decreasing to slight pulsing (x/d = 9), spinning. |
| | | | 6.0 | 8.0 | 1.5 | 0.10 | 0.18 | Very stable, medium pulsing (x/d = 6) to violent pulsing (x/d = 7 and 8), spinning. |
| | 3.0 | 2 | 6.0 | 10.0 | 0.5, 1.0 | 0.47 | 0.61 | Very stable, violent pulsing at $q_\infty$ = 1.0, medium pulsing at $q_\infty$ = 0.5. |
| | 4.0 | 2 | 6.0 | 10.0 | 0.5, 1.0 | 0.41 | 0.57 | Very stable; slight pulsing at $q_\infty$ = 0.5, medium (x/d = 7) to violent pulsing at $q_\infty$ = 1.0. |
| | 2.0 | 3 | 4.5 | 7.0 | 0.6 | 0.59 | 0.85 | Very stable and good inflation at x/d ≤ 6.5, unstable at x/d = 7, yawing at x/d ≥ 6. |
| | | | 4.5 | 7.0 | 0.8, 1.0 | 0.70 | 1.06 | Very stable and good inflation at x/d ≤ 6, unstable at x/d ≥ 6, yawing at x/d = 7. |
| | 3.0 | 3 | 4.5 | 3.0 | 0.6 | 0.21 | 0.43 | Very stable with violent pulsing (x/d = 4.5) decreasing to slight pulsing (x/d = 6) at x/d ≥ 6, unstable at x/d = 7 and 8. |
| | | | 4.5 | 8.0 | 1.5 | 0.44 | 0.52 | Violent to medium pulsing at all x/d's, very stable at x/d = 4.5 and 6, stable at x/d = 5, 7, and 8. |

## TABLE I (Concluded)

| Parachute Configuration | $M_\infty$ | Forebody Configuration | x/d Min | x/d Max | $q_\infty$, psia | $C_{D_P}$ Min | $C_{D_P}$ Max | Remarks |
|---|---|---|---|---|---|---|---|---|
| 3 | 4.0 | 3 | 4.5 | 8.0 | 0.5 | 0.05 | 0.23 | Stable (x/d = 4.5) to very stable, violent pulsing (x/d = 4.5) decreasing to medium pulsing at larger x/d's |
| | | | 4.5 | 8.0 | 1.5 | 0.20 | 0.42 | Mostly stable, but periods of instability at x/d = 6, violent pulsing (x/d = 4.5) decreasing to medium pulsing at larger x/d |
| | 5.0 | | 4.5 | 8.0 | 0.5, 0.8, 1.0 | 0.10 | 0.32 | Stable, violent pulsing at x/d ≤ 5, medium pulsing ($q_\infty$ = 0.5) or medium to violent ($q_\infty$ = 0.8 and 1.0) at x/d ≥ 6. |
| 4 | 3.0 | 1 | 6.0 | 8.0 | 0.6, 1.5 | 0.38 | 0.60 | Unstable at x/d = 8, $q_\infty$ = 0.6, otherwise very stable, slight pulsing ($q_\infty$ = 0.6) to medium pulsing ($q_\infty$ = 1.5). |
| | 4.0 | | 6.0 | 8.0 | 0.5 | 0.32 | 0.43 | Very stable and good inflation at x/d = 6, marginal stability at x/d = 8; unstable at x/d = 7, packing creases in canopy. |
| | | | 6.0 | 8.0 | 1.5 | 0.26 | 0.41 | Very stable with slight pulsing at x/d = 6, stable with medium pulsing at x/d = 7 and 8. |
| | 3.0 | 2 | 6.0 | 10.0 | 0.6 | 0.52 | 0.80 | Virtually motionless with good inflation at x/d ≤ 8, marginal stability (x/d = 9) to instability (x/d = 10) with violent pulsing at x/d ≥ 9. |
| | | | 6.0 | 10.0 | 1.0 | 0.50 | 0.63 | Motionless with medium pulsing at x/d ≤ 7, stable (±3.5 deg) with medium to violent pulsing at x/d ≥ 8. |
| | 4.0 | | 6.0 | 10.0 | 0.5, 1.0 | 0.43 | 0.60 | Very stable with slight pulsing at x/d ≤ 8, stable (±3 to ±4 deg) with violent pulsing at x/d = 9 and 10. |
| | 2.0 | 3 | 4.5 | 7.0 | 0.6 | 0.71 | 0.79 | Very stable (x/d ≤ 5) to stable with no pulsing to medium (x/d = 7) pulsing. |
| | | | 4.5 | 7.0 | 1.0 | 0.62 | 0.88 | Stable, violent (x/d = 4.5) to slight pulsing. |
| | 3.0 | | 4.5 | 8.0 | 1.0 | 0.53 | 0.64 | Unstable at x/d = 4.5 and 8, very stable to stable (x/d = 7) with slight to medium (x/d = 7) pulsing at other x/d's. |
| | 4.0 | | 4.5 | 8.0 | 0.5 | 0.07 | 0.27 | Stable with violent pulsing at x/d = 4.5, very stable with medium to slight pulsing at x/d = 5 and 6, unstable at x/d ≥ 7. |
| | | | 4.5 | 8.0 | 1.5 | 0.14 | 0.46 | Unstable at x/d = 4.5, 7, and 8, stable with medium to violent pulsing at x/d = 5 and 6, chute ruptured in several places. |
| | 5.0 | | 4.5 | 8.0 | 0.5 | 0.20 | 0.30 | Spinning slightly, stable with generally violent pulsing. |

Note: The following nomenclature applies regarding parachute stability.

Very Stable - Oscillations between 0 and ±2 deg.
Stable - Oscillations between ±2 and ±5 deg.
Unstable - Oscillations between ±5 and ±10 deg.
Very Unstable - Oscillations greater than 10 deg.

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13 ABSTRACT

Tests were conducted in the 40-in. supersonic tunnel of the von Kármán Gas Dynamics Facility to investigate the drag and stability characteristics of a series of flexible supersonic decelerator models deployed at various positions aft of double-strut mounted forebodies. Data were obtained at Mach numbers from 2 to 5 at dynamic pressures corresponding to pressure altitudes which ranged from 41,000 to 140,000 ft. Selected typical results are presented.

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| Arapaho "C" | | | | | | |
| aerodynamic decelerators (2) | | | | | | |
| flexible decelerators | | | | | | |
| models | | | | | | |
| aerodynamic configurations | | | | | | |
| double-strut mounted forebodies | | | | | | |
| supersonic flow | | | | | | |
| 1—15 | | | | | | |
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