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PERFORMANCE OF FLEXIBLE AERODYNAMIC DECELERATORS AT MACH NUMBERS FROM 1.5 TO 6

By

J. S. Deitering
von Kármán Gas Dynamics Facility
ARO, Inc.

TECHNICAL DOCUMENTARY REPORT NO. AEDC-TDR-63-119

July 1963

AFSC Program Area 720F, Project 6065, Task 61525

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PERFORMANCE OF FLEXIBLE AERODYNAMIC DECELERATORS AT MACH NUMBERS FROM 1.5 TO 6

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ARO, Inc.
a subsidiary of Sverdrup and Parcel, Inc.

July 1963
ARO Project No. VA0216

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ABSTRACT

The fourth in a series of tests has been conducted in the 40-Inch Supersonic Tunnel (A) of the von Kármán Gas Dynamics Facility to investigate the drag and stability characteristics of a number of fabric parachute models in the Mach number range from 1.5 to 6 and of a 7.5-in.-diam, 80-deg conical balloon decelerator in the Mach number range from 4 to 5.5. The dynamic pressures at which these models were tested corresponded to altitudes of 64,000 to 140,000 ft at Mach 1.5 to 6, respectively. Two basic parachute families were investigated: a conventional hemisflo-type parachute with varied amounts of reefing and a newly developed series designated as the hyperflo family of high performance parachutes with and without reefing. Tandem parachute models composed of two canopies with common suspension lines were also investigated. Drag and motion data for each configuration were recorded by oscillograph drag traces and high-speed schlieren and regular movies. Selected data are shown.

PUBLICATION REVIEW

This report has been reviewed and publication is approved.

Darreld K Calkins
Darreld K. Calkins
Major, USAF
AF Representative, VKF
DCS/Test

Jean A Jack
Jean A. Jack
Colonel, USAF
DCS/Test

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NOMENCLATURE

A'	Ballute model reference area, 44.18 in.^{2}
C_D	Ballute drag coefficient, drag force/$q_\infty A'$
C_DA	Parachute drag parameter, drag force/q_∞, in.^{2}
d	Forebody base diameter, 3.72 in.
M_∞	Free-stream Mach number
q_∞	Free-stream dynamic pressure, psia
T_o	Tunnel stagnation temperature, °F
x	Distance from Pershing model base to the parachute canopy skirt or ballute apex, in.

1.0 INTRODUCTION

The fourth in a series of investigations (Phase IV) of the drag and stability characteristics of flexible aerodynamic decelerators at supersonic speeds was conducted at the request of the Aeronautical Systems Division (ASD), Air Force Systems Command (AFSC), in the 40-Inch Supersonic Tunnel (A) of the von Kármán Gas Dynamics Facility (VKF), Arnold Engineering Development Center (AEDC), AFSC, during the period of February 18 through 23, 1963. The information obtained in the present investigation is, for the most part, supplementary in nature to that obtained on the performance of flexible parachutes in supersonic flow in Phases II and III of the series. These phases are described in Refs. 1 and 2, respectively. All parachute models tested in this and the two preceding phases were evolved from models which exhibited better overall performances in the exploratory investigation of Phase I (Ref. 3).

With the exception of a single configuration (7.5-in.-diam conical balloon decelerator referred to as a ballute), all configurations tested in this investigation were fabric parachute models with canopies which, aside from varied amounts of reefing, were nearly identical to those of the models in the two preceding phases. A major portion of this investigation was concerned with the performance characteristics of a series of parachute models belonging to the hyperflo family of high performance parachutes. Each of these models was tested with and without reefing in the Mach number range from 1.5 to 3 at dynamic pressures corresponding to altitudes of approximately 64,000 to 105,000 ft, and one model was tested at Mach numbers up to Mach 6 at a simulated pressure altitude of 140,000 ft. In addition to the hyperflo family, hemisflo parachutes with various amounts of reefing and configurations with hyperflo and reefed hemisflo canopies arranged in tandem fashion with common suspension lines were tested in the Mach number range from 1.5 to 3 at the same dynamic pressures. Another configuration investigated was a 7.5-in.-diam Goodyear conical balloon decelerator tested at Mach numbers from 4 to 5.5 at dynamic pressures corresponding to altitudes of 95,000 to 110,000 ft, respectively.

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2.0 APPARATUS

2.1 WIND TUNNEL

The 40-Inch Supersonic Tunnel (A) (Fig. 1) is a continuous, closed circuit, variable density wind tunnel with an automatically driven, flexible-plate-type nozzle. 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 are about one-tenth of the maximum at each Mach number. A complete description of the tunnel and airflow calibration information is given in Ref. 4.

2.2 SUPPORT SYSTEMS AND MODELS

The support system used was identical to that employed in the earlier tests described in Refs. 1 and 2. The parent body used with each decelerator model was a modified 0.111-scale Pershing re-entry vehicle installed in the upstream region of the test section by a strut-mount to the tunnel sidewall with cable supports for added rigidity (Fig. 2). The afterbody of the Pershing model was modified to house a parachute package consisting of the riser line, suspension lines, and deployment bag enclosing the folded canopy. A pull-out line for manual ejection of the parachute package was attached to the rear of the deployment bag and routed through the tunnel angle-of-attack sector (Fig. 3a). The parachute riser line was attached by a swivel and a short control cable inside the Pershing parent body to a tensiometer (rated at 600 lb) to measure dynamic drag loads.

Individual descriptions of the models tested in this investigation are given in section 4.0. Model photographs and construction details are presented in Figs. 3 and 4, respectively.

3.0 TEST PROCEDURE

Table 1 presents the tunnel test conditions at which each configuration was investigated. Before the tunnel start, the parachute models were packaged in the base of the Pershing parent body and were manually ejected after tunnel test conditions had been reached by a pull-out line routed through the tunnel angle-of-attack sector. The deployment bag was allowed to remain on the canopy until the riser and suspension line vibrations had been damped by applying tension to the pull-out line. An abrupt pull on the line then removed the bag from the canopy, and the deployment sequence was completed. A ball bearing swivel was used in the parachute riser line attachment to the drag link control cable to alleviate twisting of the suspension lines. Because of its size, the 7.5-in.-diam Goodyear ballute was not deployed but was suspended in the tunnel before tunnel starting by a suspension line permanently attached to the rear of the ballute and routed through the angle-of-attack sector. When tunnel test conditions were reached, the tension in the trailing suspension line was removed, and the investigation then proceeded with this line in a slack condition. The ball bearing swivel was not used with the ballute model because no unusual model rotations were expected.

Two, high-speed, 16-mm motion picture cameras, two cameras for still photography (one for regular and one for schlieren photography), and an oscillograph for drag readout were used to record parachute performance. One of the movie cameras, operating at approximately 500 frames per second, recorded a sideview of the parachute; the other movie camera, operating at approximately 1,000 fps, was installed in the tunnel schlieren system and recorded the shock wave patterns in the flow field about the parachute canopy and suspension lines. Both motion picture cameras were equipped with a 60-cps timing mark generator for accurately establishing the camera frame speed. The oscillograph recording the drag output of each configuration from the 600-lb tensiometer inside the Pershing Model was similarly equipped with another 60-cps timing mark generator for determining trace speeds. The tunnel test conditions were computed and tabulated during the testing by the VKF ERA 1102 data processing equipment.

4.0 RESULTS AND DISCUSSION

The average drag parameter (C_DA) and observations on the performance of the various model configurations are included in Table 1 with the tunnel test conditions. Each drag parameter is the result of averaging the drag loading as recorded on the individual drag traces. The observations given are the results of evaluations of the film and drag traces.

4.1 8-IN.-DIAM RIBBON-ROOFED HYPERFLO PARACHUTES

Three configurations of the 8-in.-diam nylon ribbon-roofed hyperflo parachutes were investigated with varied amounts of reefing at Mach numbers from 1.5 to 3 at dynamic pressures corresponding to altitudes of 64,000 to 105,000 ft, respectively. The models were identical to the nylon hyperflo models investigated in Ref. 2 except for the amount of reefing applied. The characteristic hyperflo construction of the models included solid, low porosity skirts with inlet angles of 10 deg, high ratios of inlet diameter to maximum canopy diameter (≈ 0.9), and high porosity (approximately 38 percent) flat roofs. Each roof had a nominal one-inch-diameter vent in the center and 12 equal roof gores with eight, 1/4-in. nylon ribbons in each. Model photographs and construction details are presented in Figs. 3b and 4a, respectively. Reefing in each of the three configurations was accomplished before placing the canopy in the deployment bag by means of reefing lines which passed through eyelets or rings sewed on the inside of the canopy inlet to the skirt hem. Inlet diameters of approximately 6.8, 5.65, and 4.4 in. were obtained by reefing.

The parachute with the 6.8-in. reefed canopy inlet diameter was deployed at Mach 3 and tested in half Mach number increments down to Mach 1.5. Except for Mach 1.5, this parachute was very unstable with large amplitude oscillations accompanied by canopy rotations and pulsations. The periods of pulsation were of short enough duration, however, that the overall inflation of this parachute remained satisfactory. At Mach 1.5 the parachute stabilized, and a constant and near maximum canopy inflation (Fig. 5) was achieved even though the suspension lines at times were partially wound up. It should be noted here that the swivel in the riser line, which was intended to prevent wind up of the suspension lines, did not always perform as it should. After repeated oscillations and rotations of the model, the bearings in the swivel would indent the race and effectively cause the swivel to bind or fail.

The parachute with the reefed inlet diameter of 5.65 in. was deployed at Mach 1.5 and was stable and fully inflated for a period of time but rotated rapidly. Shortly after the data were obtained, the swivel failed and allowed the suspension lines to wind up, partially collapsing the canopy. At Mach 2 the suspension line wind-up and canopy collapse were complete, and no further useful data were obtained.

The parachute with the reefed canopy inlet diameter of 4.4 in. was deployed at Mach 2 and performed much like the 6.8-in. reefed inlet diameter parachute. That is, over the Mach number range at which it was tested (Mach 2 to 3), the parachute was very unstable with large amplitude oscillations and some rotation. The parachute exhibited reasonably good inflation characteristics although small and sharp pulsations of the canopy roof were present.

Drag parameters versus Mach number are presented in Fig. 6 for the 6.8- and 4.4-in. reefed inlet diameter parachutes. As in the case of the similar configurations tested in Ref. 2, each of the three configurations in this investigation experienced skirt failures near the roof of the canopy shortly after being subjected to supersonic flow (Fig. 5). These failures may have affected the drag characteristics by reason of increasing the canopy porosity as the testing proceeded, but the effects are not apparent in Fig. 6 because of the lack of data for comparison.

4.2 12.8-IN.-DIAM RIBBON HEMISFLO PARACHUTES

Three reefed configurations of the nylon ribbon hemisflo parachute (Figs. 3c and 4b) were tested over the Mach number range from 1.5 to 3 at dynamic pressures corresponding to altitudes of approximately 65,000 to 105,000 ft, respectively. The hemisflo model was identical except for reefed diameters to a model previously tested and described in Ref. 1. Each canopy had a nominal diameter of 12.8 in., 18 gores, and a porosity of 28 percent. Each gore contained 11, equally spaced, horizontal, 1/4-in. nylon ribbons and five, 1/4-in. butted ribbons in the skirt region. The central roof vent was approximately two inches in diameter. Reefing produced canopy inlet diameters of approximately 6.25, 5, and 3.7 inches.

The parachute with the reefed canopy inlet diameter of 6.25 in. was deployed at Mach 1.5 and was unstable with high-frequency oscillations and rotation and had inflation instability. One of the reefing line eyelets (small, wound metal rings sewed to the hem of the canopy skirt through which the reefing line passed) snagged on one of the butted ribbons in an adjoining gore, causing the symmetry of the canopy to be destroyed. At Mach 2 and 2.5 the parachute was stable but underinflated because of suspension line wind-up. There was little or no oscillation of the parachute at these Mach numbers. The suspension lines unwound at Mach 3, and the canopy achieved better inflation, although some pulsing and rapid rotations were evident. The poor inflation of the parachute at Mach 2 and 2.5 resulted in lower drag parameters (Table 1) in comparison with those obtained at Mach 1.5 and 3. A measure of the stability and inflation of this parachute at Mach 1.5 and 2.5 is illustrated in the photographs of Figs. 7a and b.

The hemisflo parachute with the reefed canopy inlet diameter of 5 in. was deployed at Mach 3 and performed well with the exception of slight inflation instability and some rotation of the canopy. Small oscillations increased with decreasing Mach number down to Mach 2 but were not of sufficient amplitude or frequency to be seriously harmful to the chute's stability. At Mach 1.5 the reefing line parted and allowed the parachute to become fully inflated and very stable. As a result of this reefing loss,

the parachute showed better than a three-fold increase in drag over that of the chute in the reefed condition at Mach 2.

The hemisflo parachute with the reefed canopy inlet diameter of 3.7 in. was deployed at Mach 3. For a short period of time, the canopy had very good inflation and rapid rotation; however, the rotation caused suspension line wind-up to a little less than half their length and partial collapse of the canopy. The parachute was very stable in this condition. With the lines still wound, the parachute was stable at Mach 2.5 and 2, but canopy pulsations had increased with the decrease in Mach number. At Mach 1.5 the lines unwound, but the parachute had low-amplitude, high-frequency oscillations and periods of rapid rotation. Inflation of the canopy was very good only during the periods of rapid rotation.

4.3 9.4-IN.-DIAM NYLON HYPERFLO PARACHUTES

Two configurations of the 9.4-in.-diam flat-roofed hyperflo parachutes (Figs. 3d and 4c) were investigated without reefing at two canopy locations aft of the parent model base of 7 and 9.2 base diameters. One configuration, the all-mesh-roofed parachute, had 12 equal roof gores composed of nylon mesh with a porosity of 35 to 40 percent. It was tested at $x/d = 9.2$ at Mach 3 and at $x/d = 7$ throughout the Mach number range of 1.5 to 6 in half-Mach number increments at dynamic pressures corresponding to altitudes of 68,000 to 140,000 ft for the respective Mach numbers. The second configuration, the ribbon-roofed parachute, had 12 equal roof gores containing eight, equally spaced, 1/4-in. ribbons in each, with a total roof porosity of approximately 32 percent. It was tested from Mach 3 to 4 at $x/d = 9.2$ and from Mach 3 to 1.5 at $x/d = 7$. The range of dynamic pressures to which this parachute was subjected from Mach 1.5 to 4 corresponded to altitudes of 67,000 to 136,000 ft, respectively.

The 9.4-in.-diam all-mesh-roofed parachute was deployed at Mach 3 at $x/d = 9.2$ and was found to be unstable with oscillations and slight rotations. The suspension lines were observed to have considerable high-frequency flutter; sharp, heavy pulsations were present in the canopy roof; and canopy inflation alternated between full inflation and near complete collapse. An attempt was made to increase the dynamic pressure, but a suspension line parted and the parachute sustained extensive damage in the skirt area.

Four deployments of the 9.4-in.-diam all-mesh-roof parachute at $x/d = 7$ were necessary to test it throughout the Mach number range from 1.5 to 6. These deployments were made at Mach 1.5, 3.5, 4, and 6. At Mach 1.5 the parachute was very stable and fully inflated. From past experience with a parachute of this size and degree of stability at $M_\infty = 1.5$, all indications point to subsonic flow conditions existing around the canopy. This could not be positively verified because of the lack of schlieren coverage (most of the chute was upstream of the light path of the schlieren system). The parachute stability decreased at Mach 2 to 3, and oscillation, rotation, and pulsation increased. A slight undulation occurring at the confluence point of the suspension lines at Mach 2 developed into high-frequency vibrations of the suspension lines (Fig. 8a) and vertical oscillation of the canopy at Mach 3. Good inflation of the canopy was exhibited at Mach 2, and although the canopy still maintained good average inflation up to Mach 3, sharp pulsations in the canopy appeared at this Mach number and caused considerable roof distortion. At Mach 3. 5 and 4 the parachute performance was increasingly better than at Mach 3. Canopy inflation was very good at times although sharp pulsations in the canopy appeared now and then, particularly at Mach 3. 5. Vertical oscillations of the canopy were small at Mach 4. The tests at Mach 4. 5, 5, and 5. 5 revealed that the chute was stable and had good canopy inflation. The most notable fault was the suspension line vibration, but this did not seem to seriously affect the overall performance of the parachute. After deployment at Mach 6, the parachute became somewhat unstable, just as was the case at Mach 3. The parachute oscillated at a high frequency and had a large degree of canopy pulsing and suspension line flutter. The pulsing of the canopy was again of a large enough magnitude that considerable roof distortion was observed.

The drag parameters at each Mach number for the 9. 4-in. -diam all-mesh-roofed hyperflo parachute at x/d = 7 are presented in Fig. 9. The decrease in the value of the drag parameter is seen to be quite rapid with increasing Mach number except from Mach 3. 5 to 4. 5 where the reverse is true. The low values for the drag parameter around Mach 3, 3. 5, and 6 coincide with the periods of decreased stability of the parachute.

The 9. 4-in. -diam ribbon-roofed hyperflo parachute located at x/d = 9. 2 was tested in the Mach number range from 3 to 4. The parachute was unstable throughout this range with large oscillations, pulsations, and rotations. The roof began deteriorating (ribbons tearing free) shortly after deployment at Mach 3, and by the time testing began at Mach 4, many of the ribbons in the roof had been destroyed.

A second ribbon-roofed hyperflo parachute was deployed to x/d = 7 at Mach 3 and tested in half-Mach number increments down to Mach 1. 5. This parachute did not perform any better as it was very unstable at all Mach numbers and experienced roof deterioration starting at Mach 3. Figure 8b shows the parachute at Mach 2. 5, and several torn ribbons in the roof are visible. Further deterioration caused complete destruction of the roof at Mach 1. 5.

4.4 PARACHUTES WITH TANDEM HYPERFLO AND HEMISFLO CANOPIES

Six configurations of hyperflo and hemisflo canopies arranged in tandem fashion with common suspension lines (Figs. 3d and 4d) were investigated over the Mach number range from 1.5 to 3 at dynamic pressures corresponding to altitudes of 64,000 to 105,000 ft, respectively. Separation distances between the upstream hyperflo canopy and the downstream hemisflo canopy ranged from 4 to 12 in. The hemisflo canopies were identical in construction to those described in section 4.2, and all had some degree of reefing. The hyperflo canopies, with roof diameters of 4.5, 4.34, and 2.7 in., were constructed with solid piece mesh roofs instead of individual gores because of the small size of these models. The 4.34-in.-diam mesh-roofed-hyperflo canopy located four inches upstream from a reefed 12.8-in.-diam hemisflo canopy (the inlet diameter of which was successively reefed to approximately 6.9, 5.65, 4.4, and 3.7 in.) formed four of these six configurations. The fifth and sixth configurations tested were 12.8-in.-diam hemisflo canopies with reefed inlet diameters of approximately 5 in.; one was located 4 in. aft of a 4.5-in.-diam mesh-roofed hyperflo canopy and the other, 12 in. aft of a 2.7-in.-diam mesh-roofed hyperflo canopy.

The parachute with the 4.34-in.-diam hyperflo and 12.8-in.-diam hemisflo canopy with a reefed inlet diameter of approximately 6.9 in. was deployed at Mach 1.5 and was unstable. There were small oscillations and rotations of the entire chute, and the hemisflo canopy experienced inflation instability. The magnitude of the oscillations increased with Mach number although at Mach 3 periods of lower amplitude oscillations occurred. The hyperflo canopy was fully inflated at all Mach numbers, but the hemisflo chute was not. The hemisflo canopy had a whipping and twisting action behind the hyperflo canopy and experienced inflation instability at all times.

The second configuration containing the hemisflo canopy with a reefed inlet diameter of approximately 5.65 in. was deployed at Mach 1.5 and performed much in the same manner as did the preceding chute. The overall stability was a little better at Mach 1.5 and 2 but about the same at Mach 2.5 and 3 (unstable). Just as before, the hyperflo chute attained full inflation at all Mach numbers while the hemisflo chute experienced inflation instability, twisting, and whipping.

The third configuration tested consisted of the 4.34-in.-diam hyperflo canopy and a hemisflo canopy with a reefed inlet diameter of approximately 4.4 in. The parachute was deployed at Mach 1.5 and was stable, although the hemisflo chute pulsed and whipped to a small degree. Two reefing line eyelets snagged on several of the ribbons, and this may have been a prime reason for the inflation instability of the hemisflo chute. At Mach 2 the parachute was still stable but became unstable at Mach 2.5 and 3 with the hemisflo chute performing in a very erratic manner. Schlieren photographs of the model are presented at Mach numbers 1.5 to 3 in Fig. 10. The orientation of the suspension lines between the two canopies in Fig. 10b gives an indication of the twisting that the hemisflo canopy experienced much of the time.

The fourth and last configuration to be tested with the 4.34-in.-diam hyperflo canopy contained a hemisflo canopy with a reefed inlet diameter of 3.7 in. This parachute was deployed at Mach 3 and was unstable at all Mach numbers except Mach 1.5. The period of worst instability occurred at Mach 2.5 where the typical instability was a severe whipping and pulsing of the hemisflo canopy. At Mach 1.5 the chute was very stable, and for one of the few times in the entire test of this type of parachute, the hemisflo canopy maintained good inflation and stability (see Fig. 11a).

Drag parameters for the four parachutes just described are presented versus Mach number in Fig. 12. The underinflation of the hemisflo chute caused by the reefing line eyelets snagging on the canopy ribbons is evident in the comparatively lower drag parameter values.

The fifth and sixth configurations of the tandem parachutes consisted of 12.8-in.-diam hemisflo canopies with reefed inlet diameters of approximately 5 in. and hyperflo canopies with diameters of 4.5 and 2.7 in. at locations of 4 and 12 in. upstream of the hemisflo canopies, respectively. Both parachutes were deployed at Mach 3. The parachute with the 4.5-in.-diam hyperflo canopy was unstable at Mach 3 and 2.5; however the chute stabilized suddenly during the Mach 2 run and good inflation of the hemisflo canopy was achieved. The hyperflo canopy invariably had good inflation characteristics in all the six configurations tested. When changing from Mach 2 to Mach 1.5, the reefing line tore loose in several places on one side of the hemisflo canopy, causing the entire parachute to rotate slowly at Mach 1.5. The sixth and last configuration of the tandem parachutes had the 2.7-in.-diam hyperflo canopy 12 in. upstream of the hemisflo canopy. The order of stability in reference to Mach number was just reversed to that of the fifth configuration; that is, the parachute was stable with reasonably good inflation at Mach 3 (Fig. 11b), and oscillation and hemisflo canopy inflation instability increased with decreasing Mach number. At Mach 1.5 the parachute had high-frequency, low amplitude oscillation, and the hemisflo chute had very poor inflation characteristics (pulsing and whipping) and was almost collapsed at times.

Certain characteristics were common to each of the six tandem parachute configurations tested. Each exhibited good hyperflo canopy inflation, very poor overall hemisflo canopy performance, and high-speed flutter of the suspension lines. Since previous examinations of the hemisflo parachute indicated better performance at the lower Mach numbers, the hyperflo canopy was installed in the hemisflo parachute suspension lines to slow the flow reaching the hemisflo canopy. Although this was accomplished, the flow reaching the hemisflo canopy appears to have been of such an unsteady nature that proper stability and inflation of the hemisflo canopy was a rare occurrence.

4.5 7.5-IN.-DIAM CONICAL BALLUTE

A single configuration of the 7.5-in.-diam, 80-deg conical ballute (Figs. 3e and 4e) was tested at x/d = 0 and 8 in the Mach number range from 4 to 5.5 at dynamic pressures corresponding to altitudes of 96,000 to 110,000 ft, respectively. The ballute was constructed of nonporous rubber-coated fabric in eight equal gores and was encompassed by a "fence" near the base of the model. The fence projected from the side of the model an additional 10 percent of the model's maximum projected diameter of 7.5 in. The ballute was inflated by ram air pressure through four diametrically opposed, forward facing, screened inlets. It was suspended in the tunnel prior to the tunnel start instead of being deployed at test conditions as in the case of the parachute models, and the trailing suspension line used for this purpose can be seen in Fig. 13. The model was first tested at x/d = 8, and it proved to be very stable with complete and constant inflation throughout the Mach number range from 4 to 5.5. Midway through the Mach number range two adjacent inlet screens were lost, but this did not have any effect whatsoever on the performance. The ballute was finally tested at x/d = 0 with all four inlet screens removed. At this position it was also stable throughout the Mach number range from 4 to 5.5 with a very slow oscillating motion. This model oscillation may have been due either to its close proximity to the Pershing model base or to the long trailing suspension line which was vibrating freely or to a combination of both. Drag coefficients based on projected area (excluding the fence) are plotted versus Mach number in Fig. 13. Model drag loads at x/d = 0 and 8 decreased slightly with increasing Mach number, and the lowest drag occurred at x/d = 0. These loads were three to five times as large as most of the loads generated by parachutes of comparable diameters in previous tests.

5.0 CONCLUDING REMARKS

Tests were conducted to investigate the performance characteristics of four series of parachute configurations in the Mach number range of

1. 5 to 3, and one series was also tested in the Mach 3 to 6 range. A conical balloon decelerator was also investigated at Mach numbers from 4 to 5. 5. The following observations are a result of these tests:

1. The 8-in. -diam nylon ribbon-roofed hyperflo parachutes with various reefed inlet diameters were found to be stable only at Mach 1. 5 and unstable at Mach numbers 2 to 3.
2. The 9. 4-in. -diam all-mesh-roofed hyperflo parachute located seven model base diameters downstream was tested from Mach 1. 5 to 6 and showed the best overall performance of any parachute investigated in this test. The 9. 4-in. -diam ribbon-roofed hyperflo parachute was unstable at Mach numbers 1. 5 to 4 at canopy locations of 7 and 9. 2 base diameters aft of the Pershing parent model.
3. The tandem parachutes composed of reefed hemisflo canopies aft of hyperflo canopies had only fair performance characteristics. The hyperflo chute in each configuration always achieved good inflation, but the hemisflo chute was almost always unstable with poor inflation characteristics.
4. The 7. 5-in. -diam, 80-deg conical ballute with a fence was a very stable configuration that achieved good inflation throughout the Mach number range from 4 to 5. 5.

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TABLE 1
TEST CONDITIONS AND RESULTS

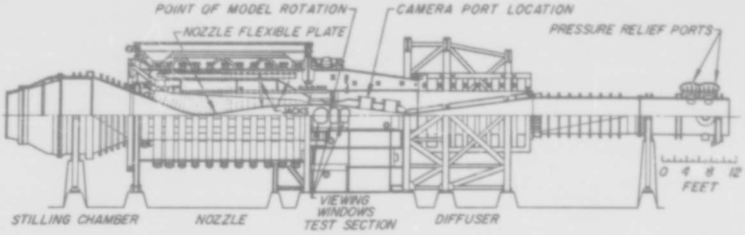
Parachute Model	M_∞	q_∞, psia	T_0, °F	C_DA, in.^{2}	Remarks
8-in.-diam Ribbon-Roofed Hyperflo (Reefed Inlet Diam = 6.8 in.)	2.98	0.78	76	31.0	Very unstable
	2.48	1.08	85	31.7	Very unstable
	2.00	1.25	87	37.0	Very unstable
	1.50	1.32	89	40.1	Very stable; good inflation
8-in.-diam Ribbon-Roofed Hyperflo (Reefed Inlet Diam = 5.65 in.)	1.50	1.11	73	19.0	Stable: fully inflated with rapid rotation before partially collapsing.
	2.00	1.06	88	-	Parachute collapsed with suspension lines wound tightly.
8-in.-diam Ribbon-Roofed Hyperflo (Reefed Inlet Diam = 4.4 in.)	2.00	1.04	69	27.5	Very unstable; good inflation
	2.48	1.04	79	27.5	Very unstable; good inflation
	2.98	0.82	89	25.0	Very unstable; fair inflation
12.8-in.-diam Hemisflo (Reefed Inlet Diam = 6.25 in.)	1.50	1.30	75	29.9	Unstable: A reefing line eyelet snagged on a skirt ribbon causing rotation.
	2.00	1.27	89	9.8	Stable: Suspension lines wound half their length and parachute partially collapsed.
	2.48	1.04	94	10.9	Same characteristics as at $M_\infty = 2.00$
	2.98	0.78	97	17.4	Better inflation but canopy had rapid rotations
12.8-in.-diam Hemisflo (Reefed Inlet Diam = 5 in.)	2.98	0.78	78	11.2	Inflation instability
	2.48	1.05	86	12.4	Increase in oscillation
	2.00	1.22	92	13.1	Same characteristics at $M_\infty = 2.48$
	1.50	1.29	94	45.3	Very stable: full inflation: Reefing line parted before reaching $M_\infty = 1.50$.
12.8-in.-diam Hemisflo (Reefed Inlet Diam = 3.7 in.)	2.98	0.79	80	25.3	Very stable: Suspension lines wound about half their length and canopy partially collapsed.
	2.48	1.03	88	21.4	Stable: under-inflation: Lines wound halfway.
	2.00	1.26	94	19.0	Same characteristics as at $M_\infty = 2.48$
	1.50	1.30	97	22.8	Suspension lines unwound; unstable
9.4-in. All-Mesh-Roofed Hyperflo (x/d = 9.2)	2.98	1.00	76	38.7	Unstable-oscillatory and inflation instability
9.4-in. All-Mesh-Roofed Hyperflo (x/d = 7)	1.50	1.10	47	63.6	Very stable; full inflation
	2.00	1.04	56	59.0	Stable; good inflation
	2.48	1.06	64	44.7	Inflation instability
	2.98	0.82	69	38.7	High frequency oscillation with small rotations; inflation instability
	3.47	0.60	52	38.5	Fair stability: vibrations in suspension lines; fair inflation stability
	3.98	0.40	58	40.5	Stable; good inflation
	2.98	0.83	72	44.5	High frequency oscillation and pulsation of canopy
	3.98	0.39	54	42.1	Fair stability; good inflation
	4.49	0.35	79	44.0	Stable: good inflation
	4.98	0.35	83	37.4	Same characteristics as at $M_\infty = 4.49$
	5.50	0.41	92	30.5	Good stability and inflation
	6.00	0.72	138	26.0	Increased oscillation: inflation instability.
	6.00	1.17	134	-	Several suspension lines parted: no useful data
9.4-in.-diam Ribbon-Roofed Hyperflo (x/d = 9.2)	2.98	1.01	79	40.0	Very unstable
	3.48	0.56	96	44.6	Very unstable: ribbons in roof and skirt panels torn
	3.98	0.37	99	55.7	Violent instability

{ Indicates continuous tunnel run

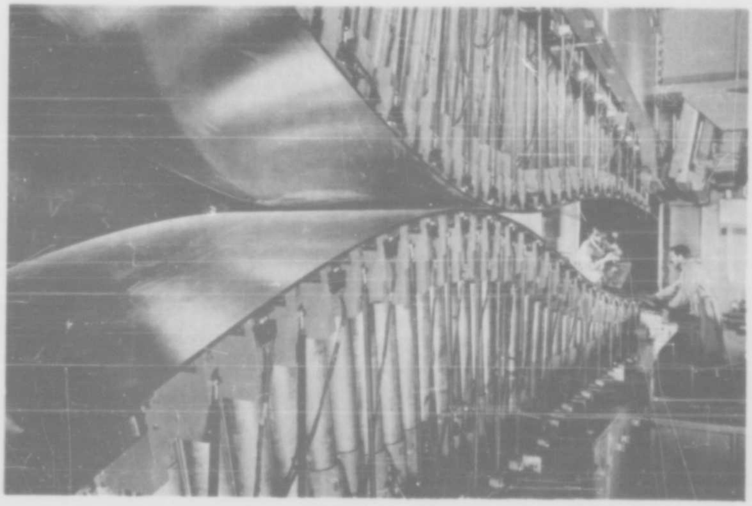
TABLE 1 (Concluded)

Parachute Model	M_∞	q_∞, psia	T_0, °F	C_DA, in.^{2}	Remarks
9.4-in.-diam Ribbon-Roofed Hyperflo (x/d = 7)	2.98	0.81	60	40.2	Unstable: Several ribbons in roof parted.
	2.48	1.05	65	39.9	Unstable: inflation instability
	2.00	1.00	85	28.7	Very unstable: Roof deteriorated rapidly.
	1.50	1.19	91	-	Roof destroyed
Hemisflo (Reefed Inlet Diam = 6.9 in.) with 4.34-in.-diam Hyperflo	1.50	1.27	74	16.4	Hemisflo inflation instability: high frequency oscillation: canopy rotations
	2.00	1.28	82	15.0	Oscillations increased
	2.48	1.07	86	15.2	Very unstable
	2.98	0.80	90	12.5	Unstable: hemisflo whipping
Hemisflo (Reefed Inlet Diam = 5.65 in.) with 4.34-in.-diam Hyperflo	1.50	1.27	74	17.0	Low amplitude oscillation: roof portion of hemisflo under-inflated: chute rotation
	2.00	1.28	83	14.5	Same characteristics as at M_∞ = 1.50
	2.48	1.01	89	16.6	Chute unstable.
	2.98	0.80	95	14.3	Chute unstable: increased hemisflo pulsations
Hemisflo (Reefed Inlet Diam = 4.4 in.) with 4.34-in.-diam Hyperflo	1.50	1.28	74	14.1	Stable, but hemisflo under-inflated with pulsations: Two reefing line eyelets snagged on skirt ribbons.
	2.00	1.22	89	13.2	Small oscillations: hemisflo inflation instability
	2.48	1.03	92	14.7	Unstable
	2.98	0.76	94	13.7	Unstable
Hemisflo (Reefed Inlet Diam = 3.7 in.) with 4.34-in.-diam Hyperflo	2.98	0.76	71	13.9	Chute unstable; hemisflo fully inflated at times
	2.48	1.00	80	16.4	Unstable; hemisflo more erratic
	2.00	1.20	88	15.4	Chute oscillations decreased; hemisflo still erratic
	1.50	1.24	93	17.3	Very stable; Hemisflo had good inflation.
Hemisflo (Reefed Inlet Diam = 5 in.) with 4.5-in.-diam Hyperflo	2.98	0.78	77	17.7	Unstable: hemisflo inflation instability
	2.48	1.03	94	18.4	Unstable
	2.00	1.24	102	17.3	Unstable
	2.00	1.24	102	15.8	Stable; good inflation
	1.50	1.38	103	15.1	Stable: hemisflo under-inflated: Reefing line eyelets snagged on skirt ribbons at this Mach number.
Hemisflo (Reefed Inlet Diam = 5 in.) with 2.7-in.-diam Hyperflo	2.98	0.79	79	11.0	Very stable: Hemisflo was under-inflated but did not pulse.
	2.48	1.07	85	14.8	Stable: Hemisflo had inflation instability.
	2.00	1.21	89	10.8	High-frequency oscillation: hemisflo under-inflated and pulsing
	1.50	1.32	91	11.5	Unstable: hemisflo partially collapsed
7.5-in.-diam Ballute with 10% Fence (x/d = 8)	4.00	2.08	74	43.6	Very stable and fully inflated
	4.52	2.02	91	40.1	Very stable and fully inflated
	5.02	1.98	96	40.5	Very stable and fully inflated
	5.50	1.56	89	38.2	Very stable and fully inflated
	5.50	2.06	81	38.1	Very stable and fully inflated
7.5-in.-diam Ballute with 10% Fence (x/d = 0)	4.00	2.02	86	40.6	Stable with very slight rocking motion
	4.52	2.02	85	38.3	Stable with very slight rocking motion
	5.02	1.99	86	36.5	Stable
	5.50	2.06	81	35.0	Stable

{ Indicates continuous tunnel run

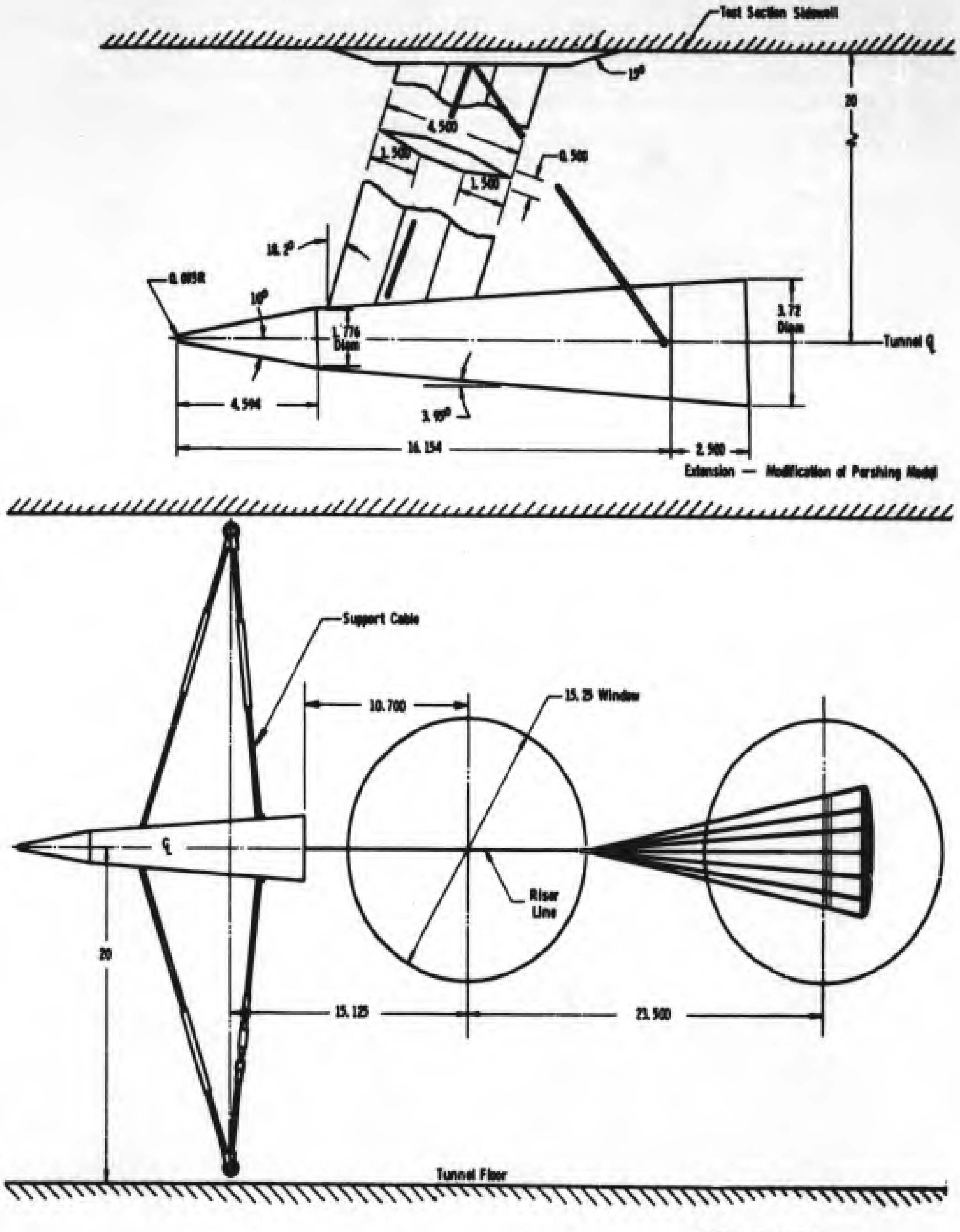


Assembly



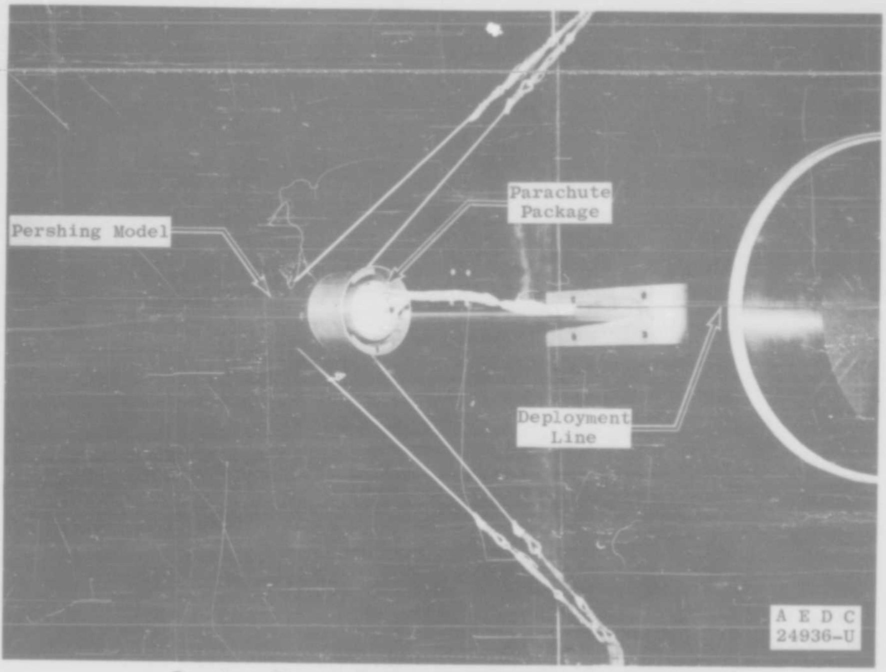
Nozzle and Test Section

Fig. 1 The 40-Inch Supersonic Tunnel (A)

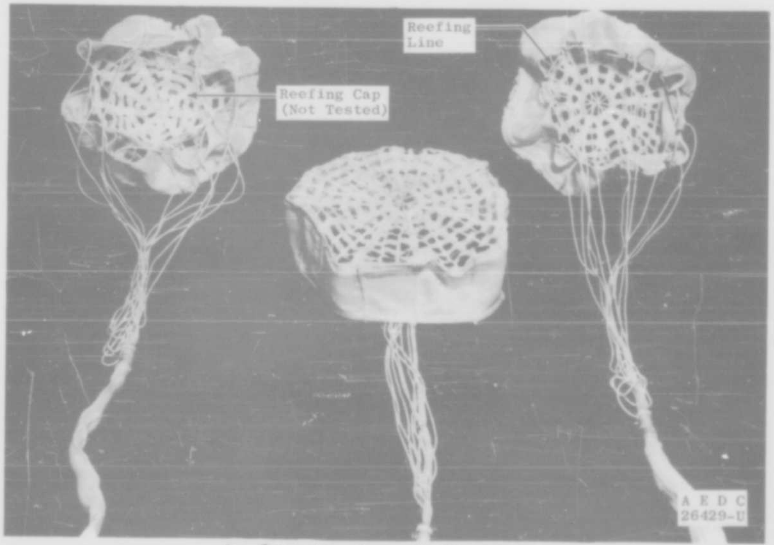


All Dimensions in Inches.

Fig. 2 Sketch of Model Installation

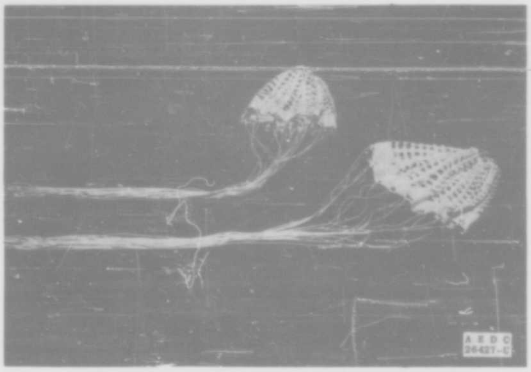


a. Parachute Package Readied for Deployment from Parent Model

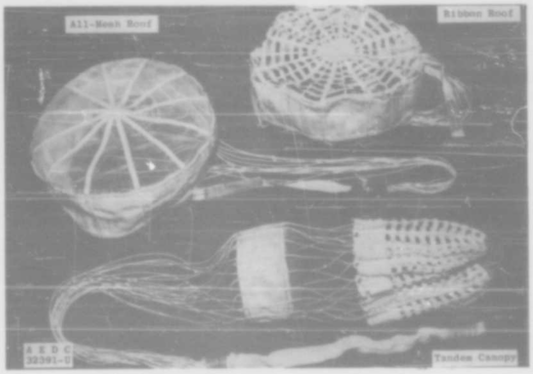


b. 8-in.-diam Hyperflo Parachutes

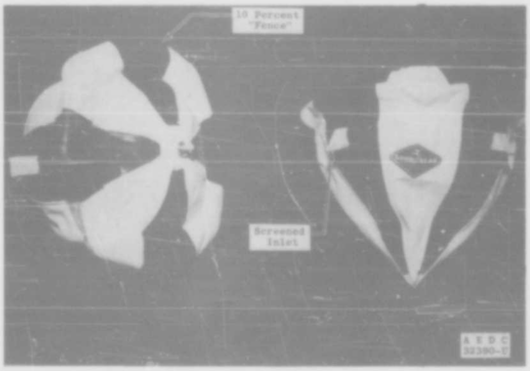
Fig. 3 Installation and Model Photographs



c. 12.8-in.-diam Hemisflo Parachutes

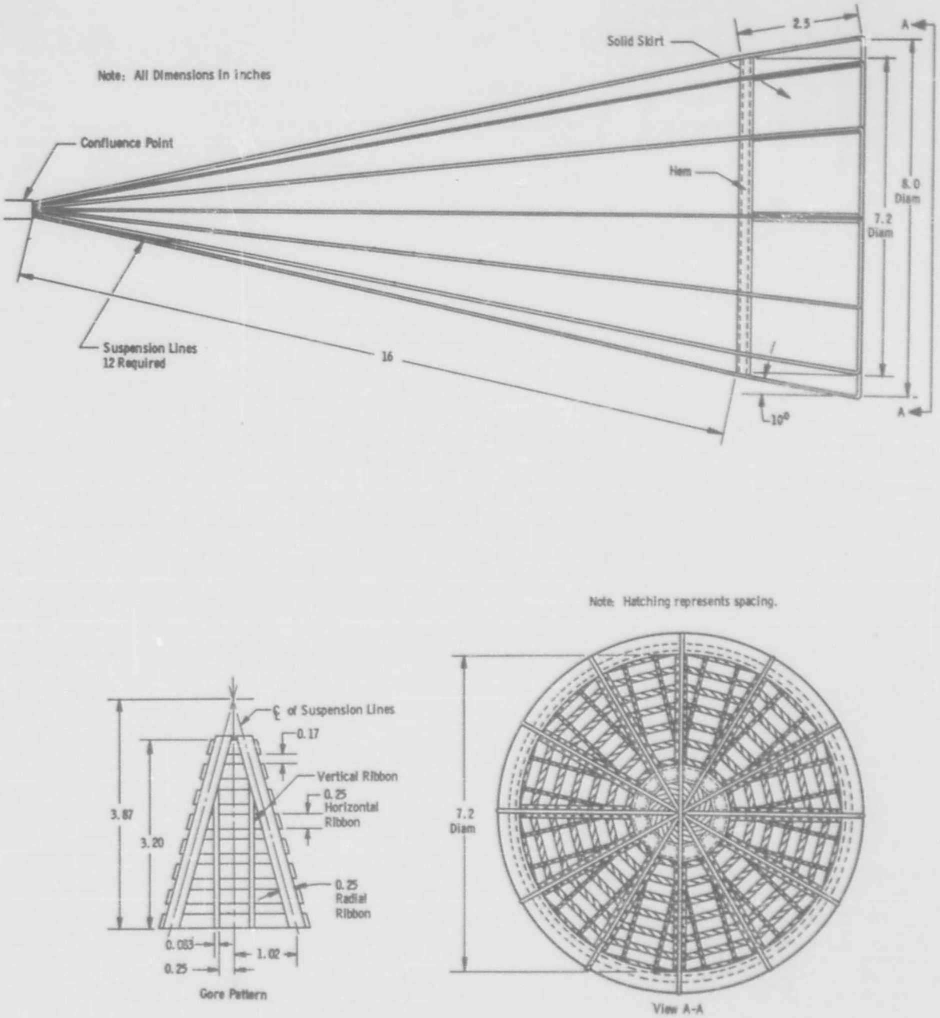


d. 9.4-in.-diam Hyperflo and Tandem Canopy Parachutes



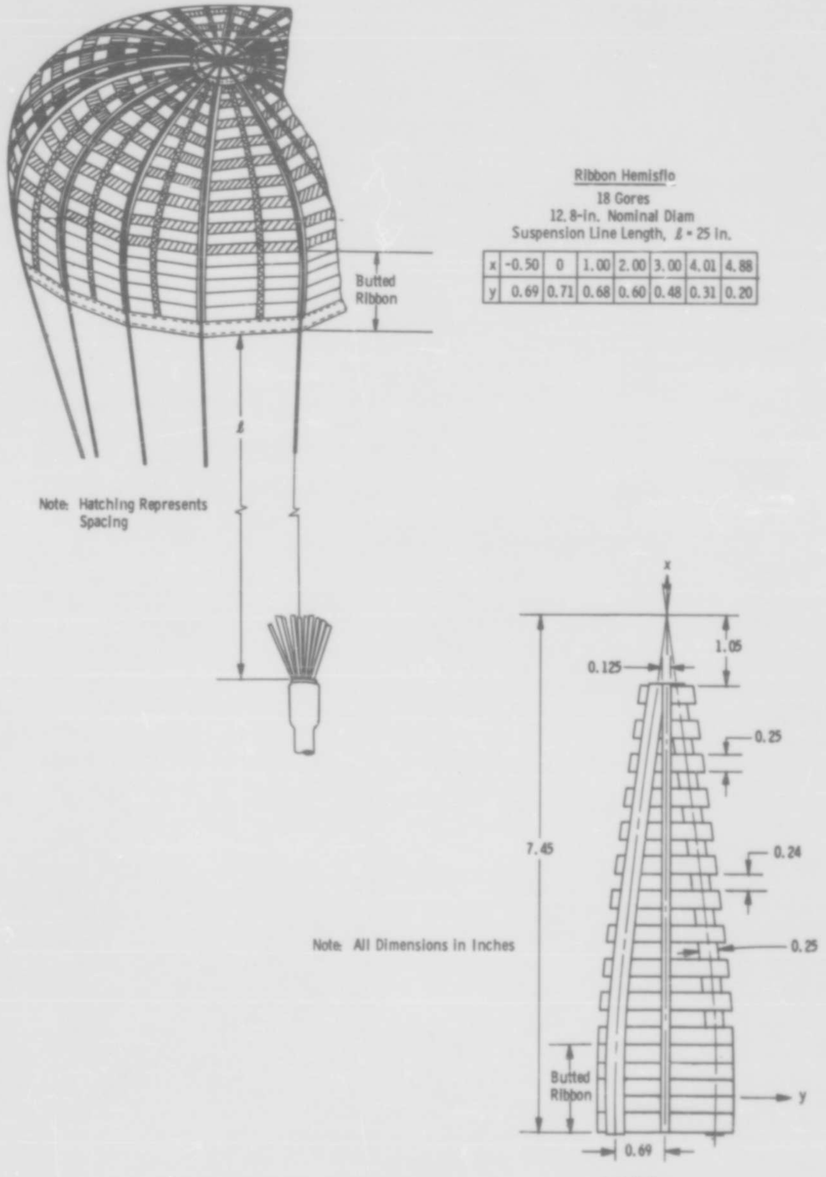
e. 7.5-in.-diam Conical Ballute

Fig. 3 Concluded



a. 8-in.-diam Ribbon-Roofed Hyperflo

Fig. 4 Parachute Model Construction Details



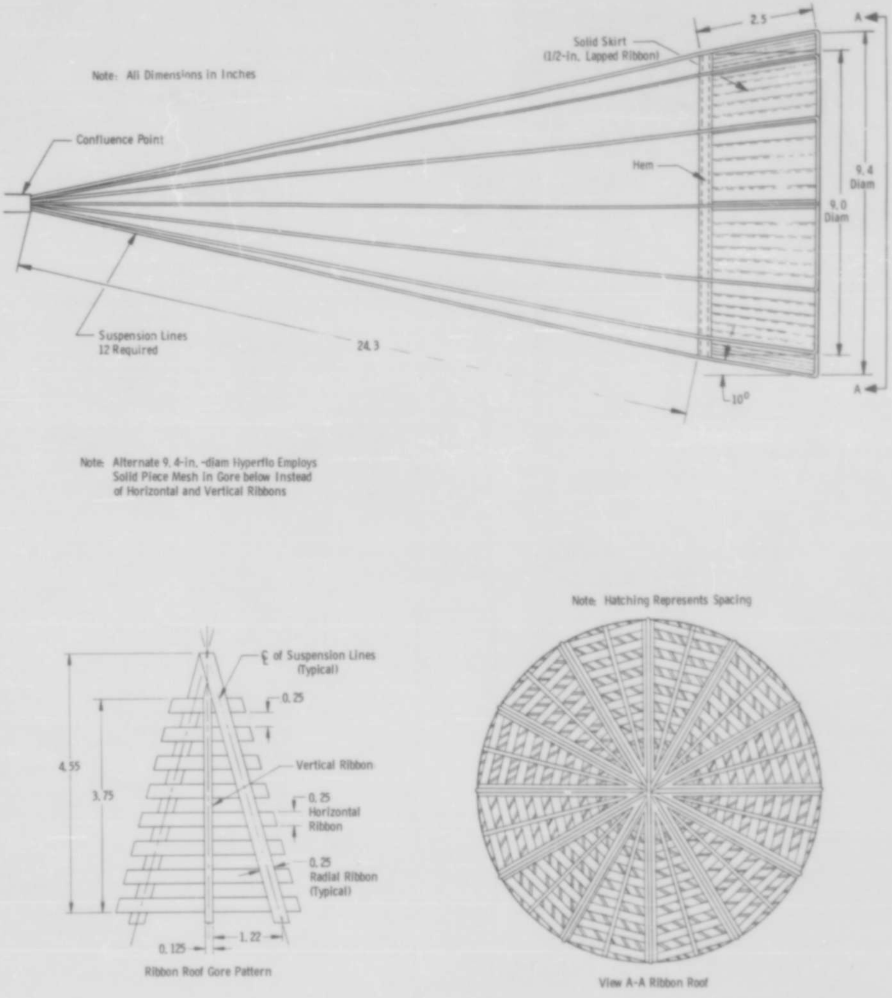
Ribbon Hemisflo
18 Gores
12.8-in. Nominal Diam
Suspension Line Length, ℓ = 25 in.

x	-0.50	0	1.00	2.00	3.00	4.01	4.88
y	0.69	0.71	0.68	0.60	0.48	0.31	0.20

Note: Hatching Represents Spacing

Note: All Dimensions in Inches

b. Hemisflo
Fig. 4 Continued

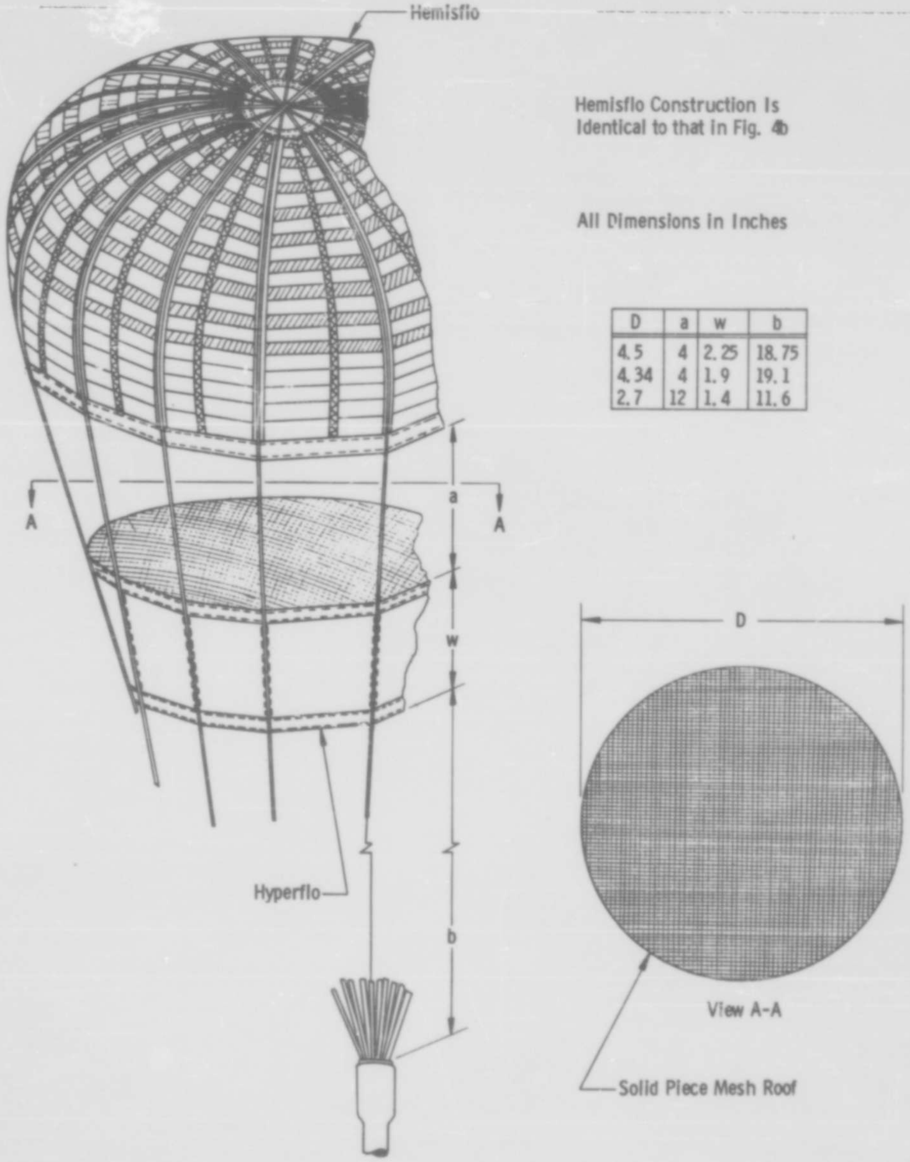


Ribbon Roof Gore Pattern

View A-A Ribbon Roof

c. 9.4-in.-diam Hyperflo

Fig. 4 Continued



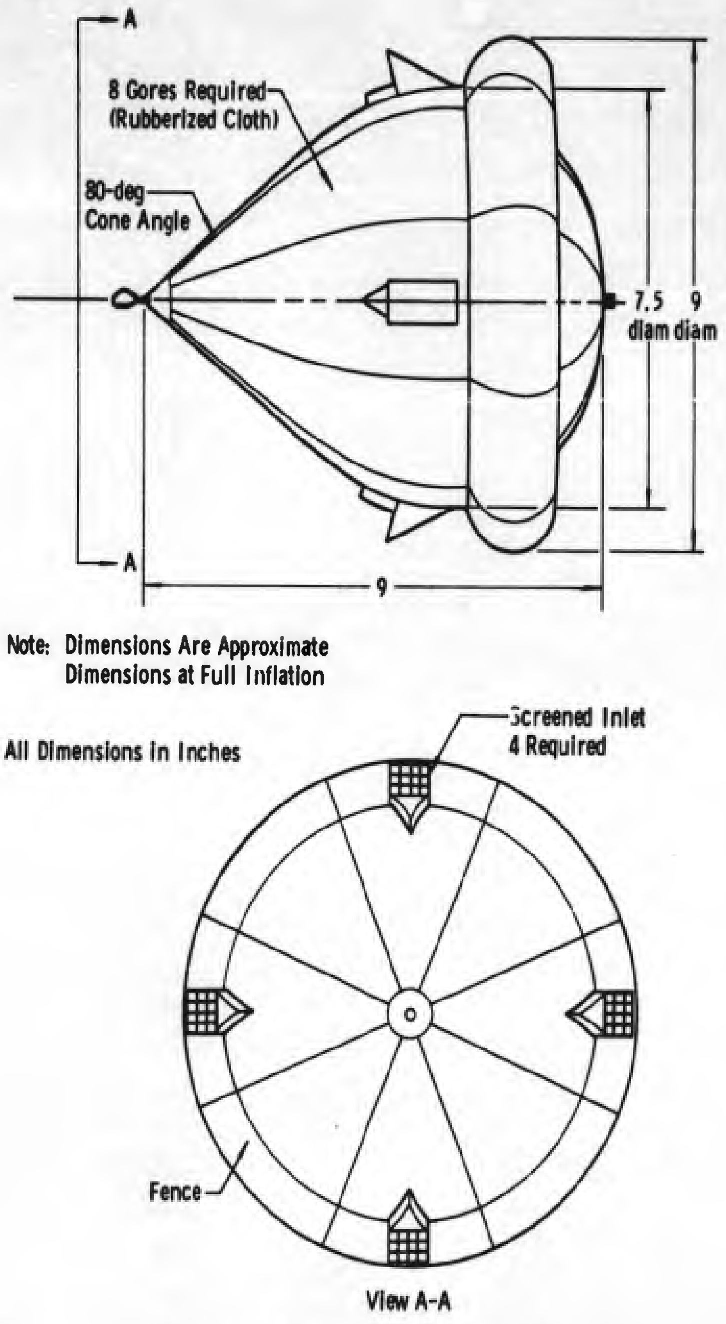
Hemisflo Construction Is Identical to that in Fig. 4b

All Dimensions in Inches

D	a	w	b
4.5	4	2.25	18.75
4.34	4	1.9	19.1
2.7	12	1.4	11.6

d. Tandem Canopy

Fig. 4 Continued



e. Sketch of 7.5-in.-diam Conical Ballute

Fig. 4 Concluded

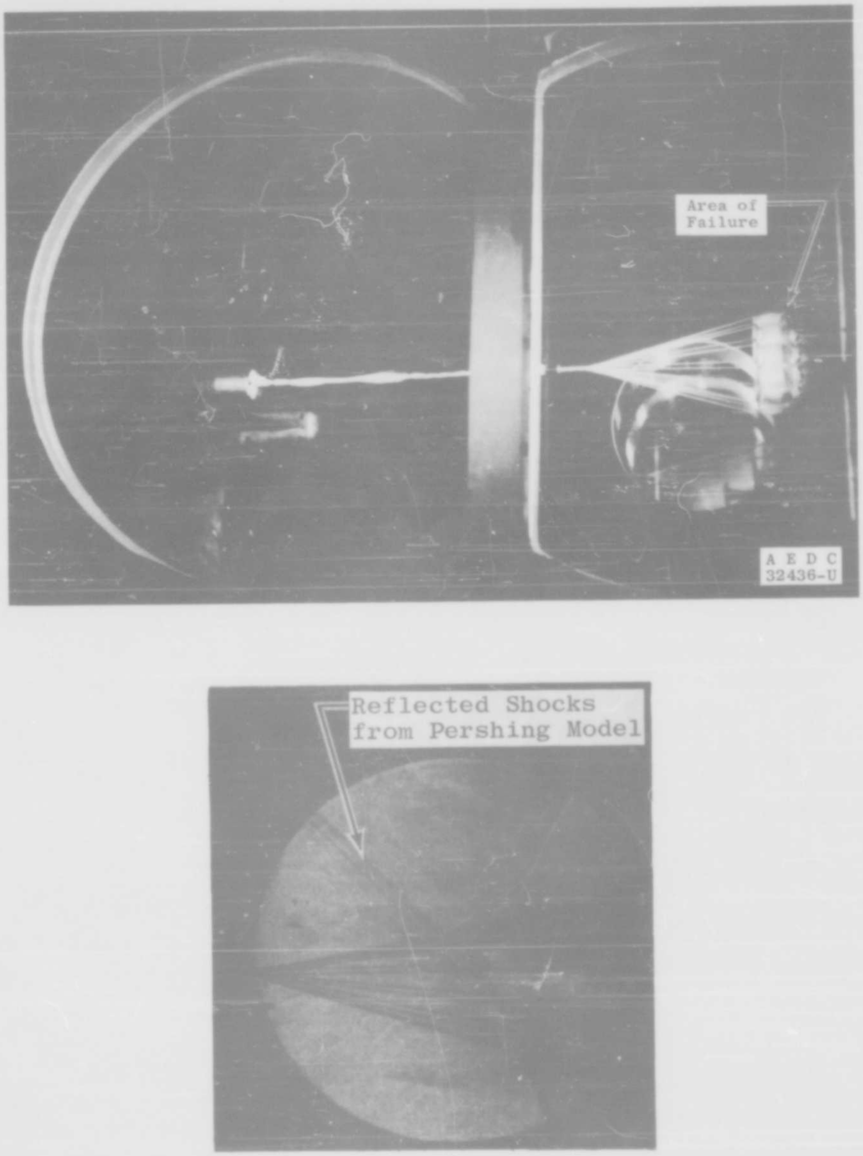


Fig. 5 Side View and Schlieren Photographs of 8-in.-diam Ribbon-Roofed Hyperflo Parachute (Reefed Inlet Diam ≈ 6.8 in.) at $M_\infty = 1.5$

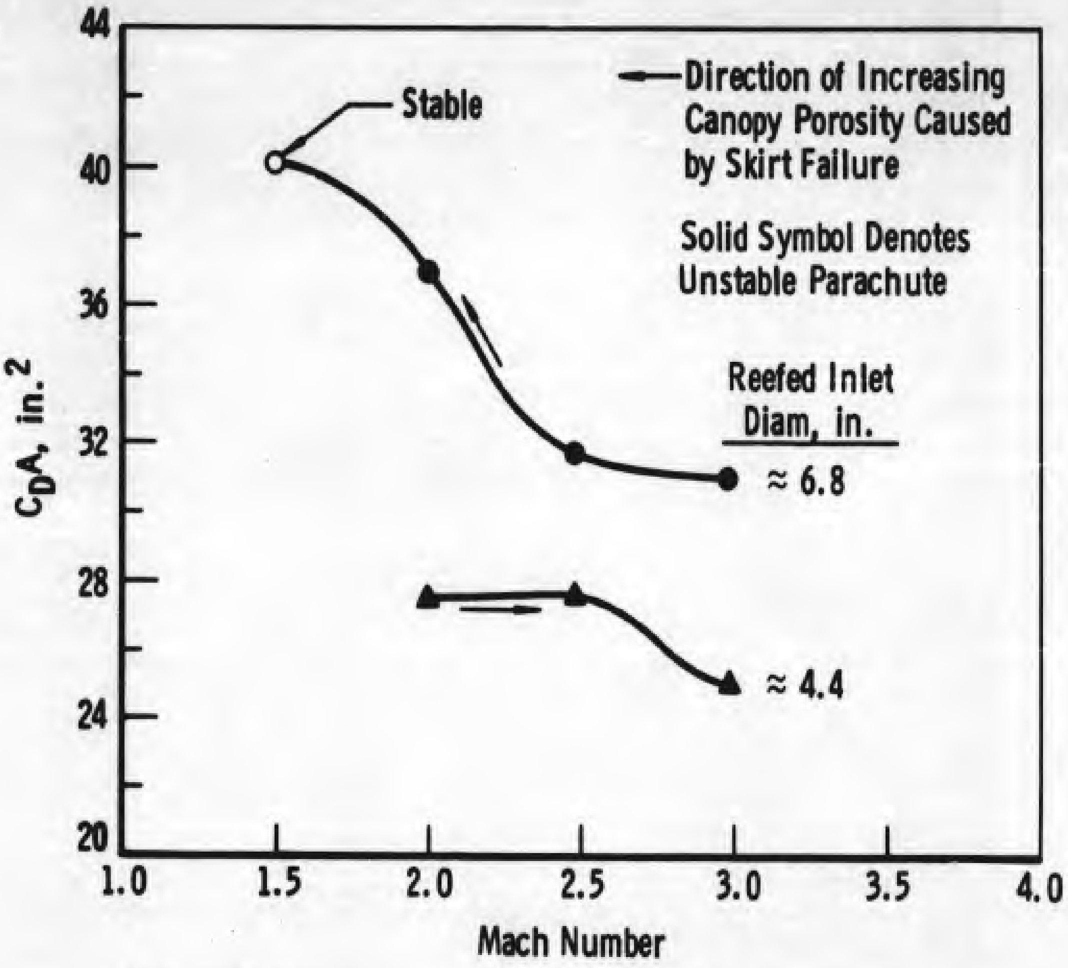
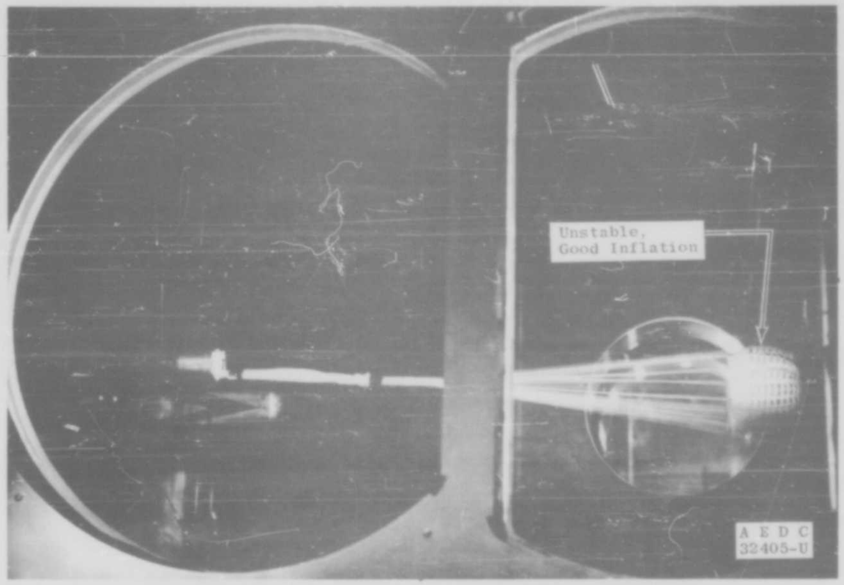
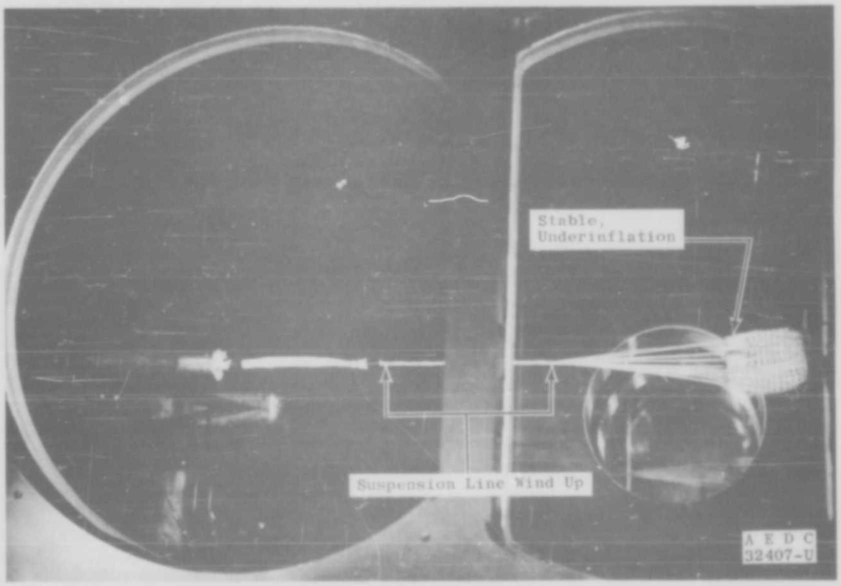


Fig. 6 Drag Parameter versus Mach Number for Two Reefed 8-in.-diam Ribbon-Roofed Hyperflo Parachutes

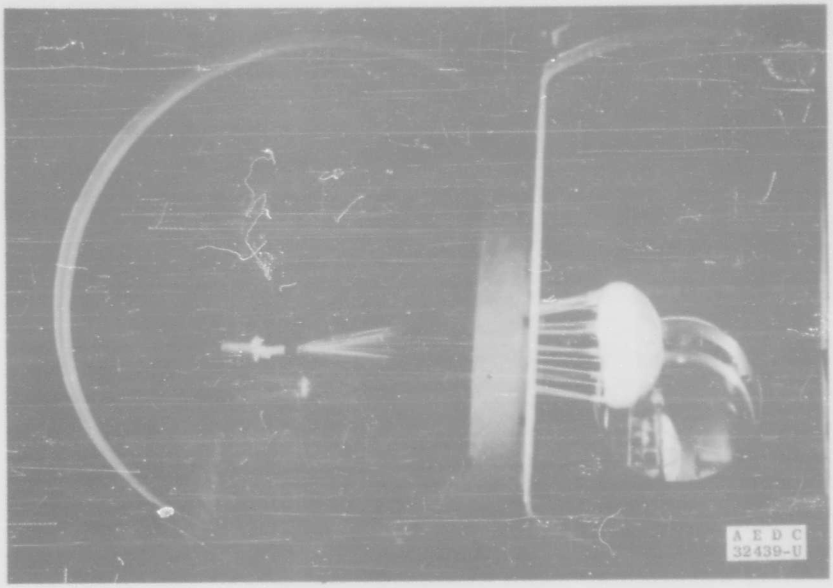


a. $M_\infty = 1.5$

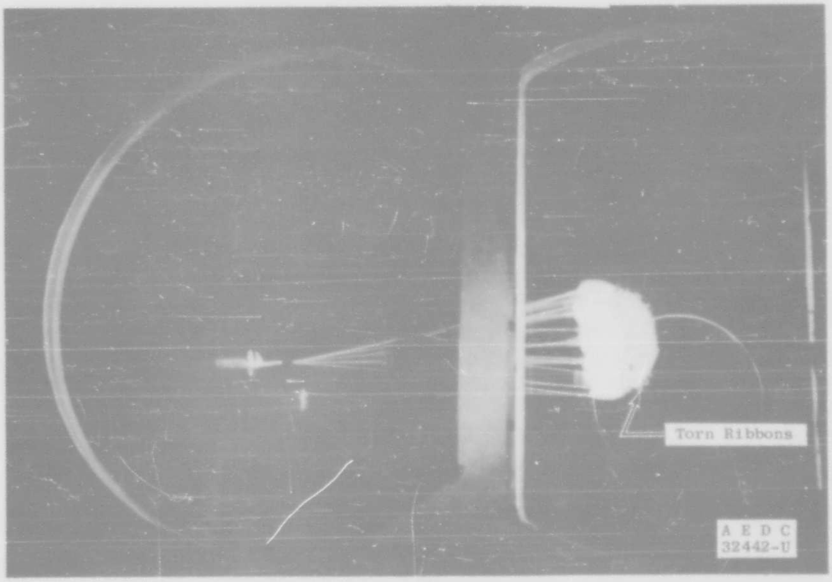


b. $M_\infty = 2.48$

Fig. 7 Photographs of the 12.8-in.-diam Hemisflo Parachute Inflation Characteristics, Reefed Inlet Diam = 6.25 in.



a. All-Mesh-Roofed Hyperflo



b. Ribbon-Roofed Hyperflo

Fig. 8 Photographs of the 9.4-in.-diam Hyperflo Parachutes Subjected to Supersonic Flow, $x/d = 7$, $M_\infty = 2.48$

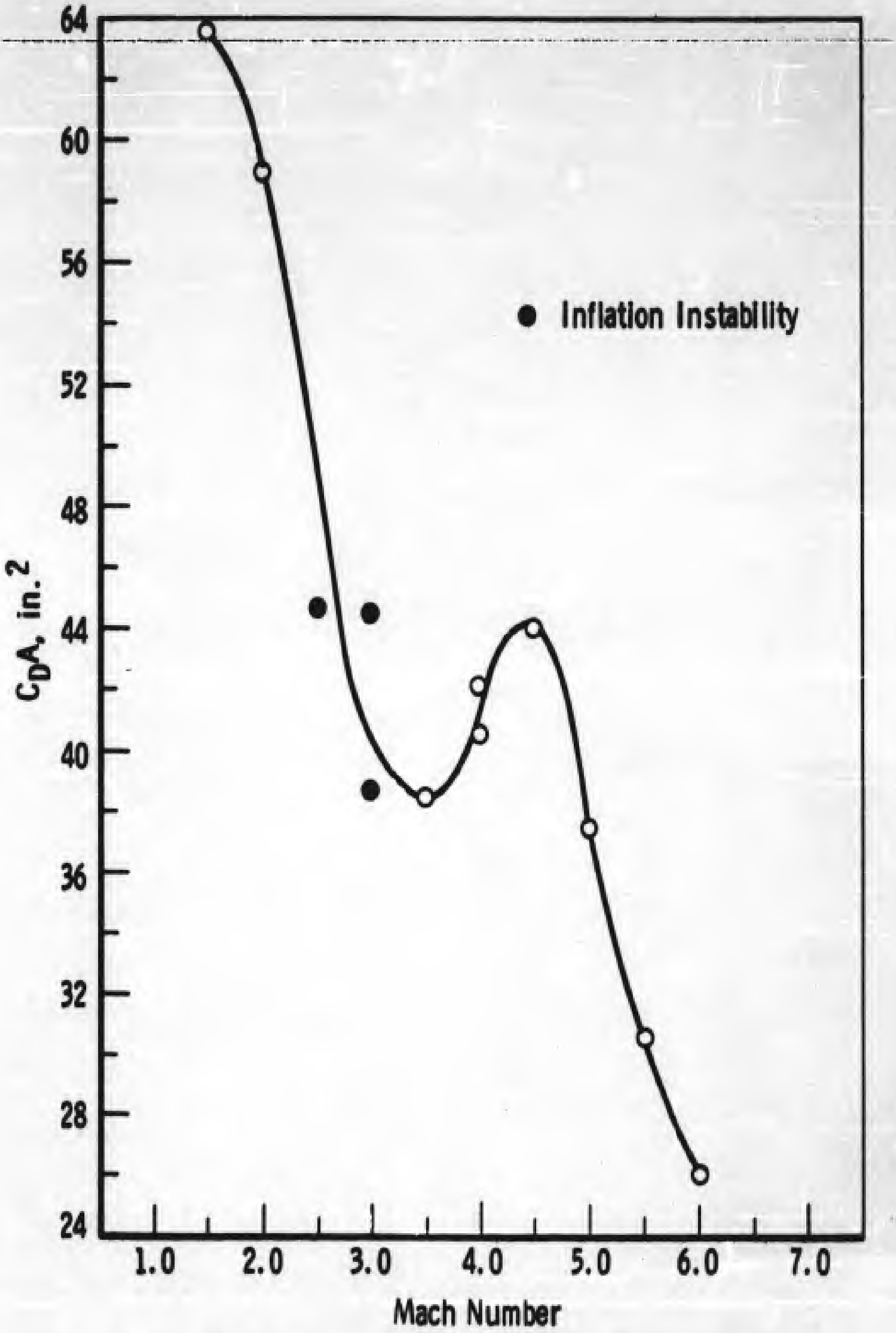
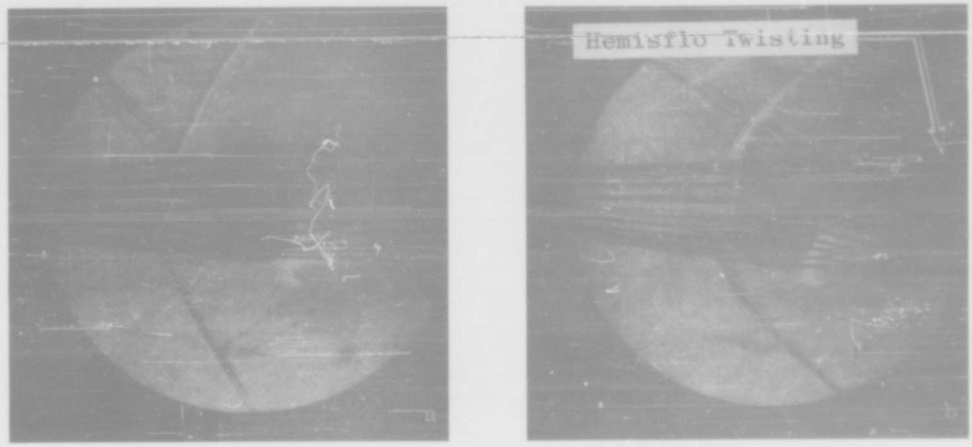
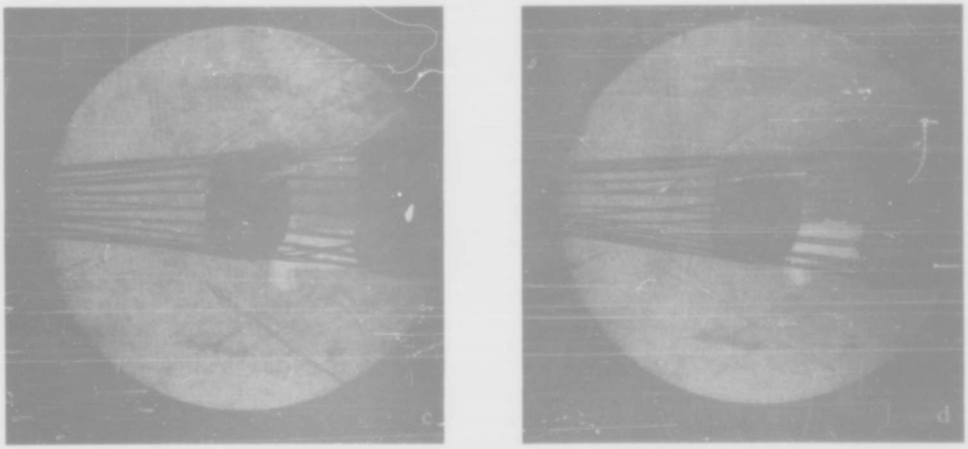


Fig. 9 Drag Parameter versus Mach Number for the 9.4-in.-diam All-Mesh-Reefed Hyperflo Parachute, x/d = 7



a. $M_\infty = 1.50$, $q_\infty = 1.28$ psia

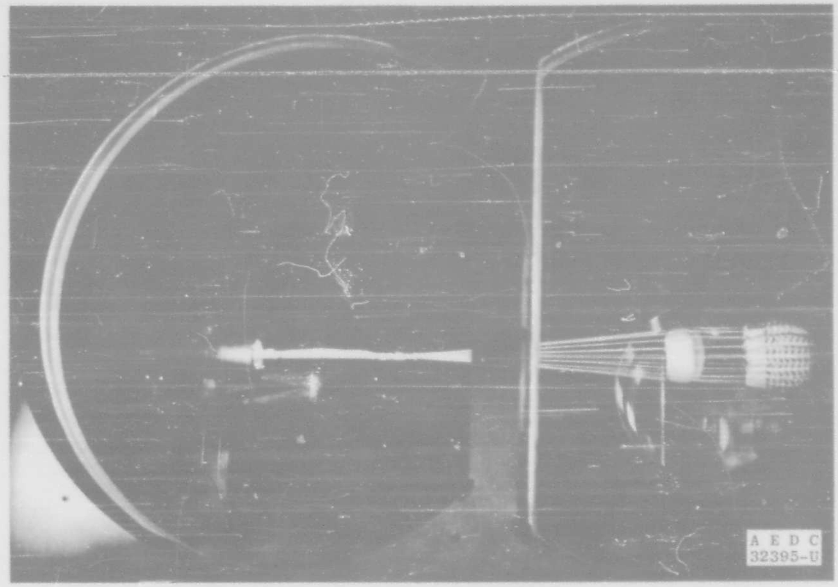
b. $M_\infty = 2.00$, $q_\infty = 1.22$ psia



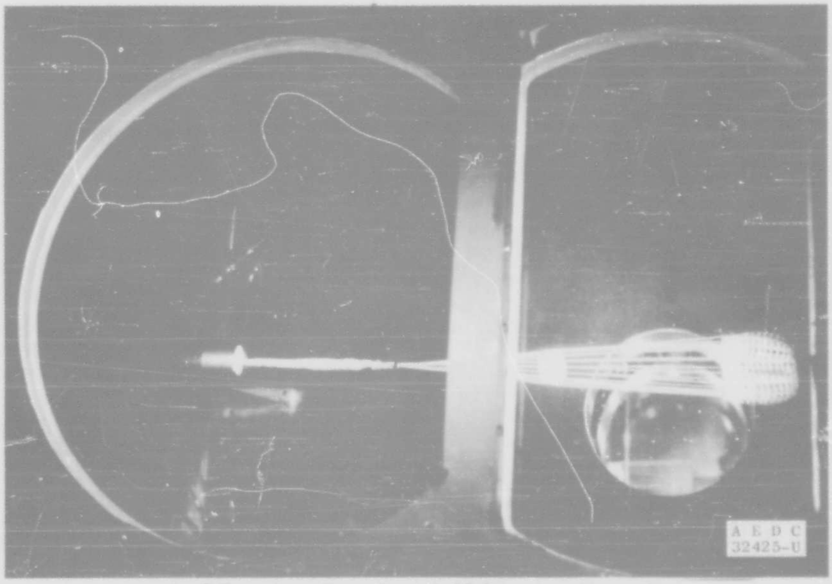
c. $M_\infty = 2.48$, $q_\infty = 1.03$ psia

d. $M_\infty = 2.98$, $q_\infty = 0.76$ psia

Fig. 10 Flow Field Shock Wave Patterns about a Tandem Parachute Consisting of a 4.34-in.-diam Hyperflo Canopy with a 12.8-in.-diam Hemisflo Canopy (Reefed Inlet Diam = 4.4 in.)



a. 4.34-in.-diam Hyperflo with 12.8-in.-diam Hemisflo (Reefed Inlet Diam = 3.7 in.), M_∞ = 1.5



b. 2.7-in.-diam Hyperflo with 12.8-in.-diam Hemisflo (Reefed Inlet Diam = 5 in.), M_∞ = 2.98

Fig. 11 Photographs of Tandem Canopy Parachutes Subjected to Supersonic Flow

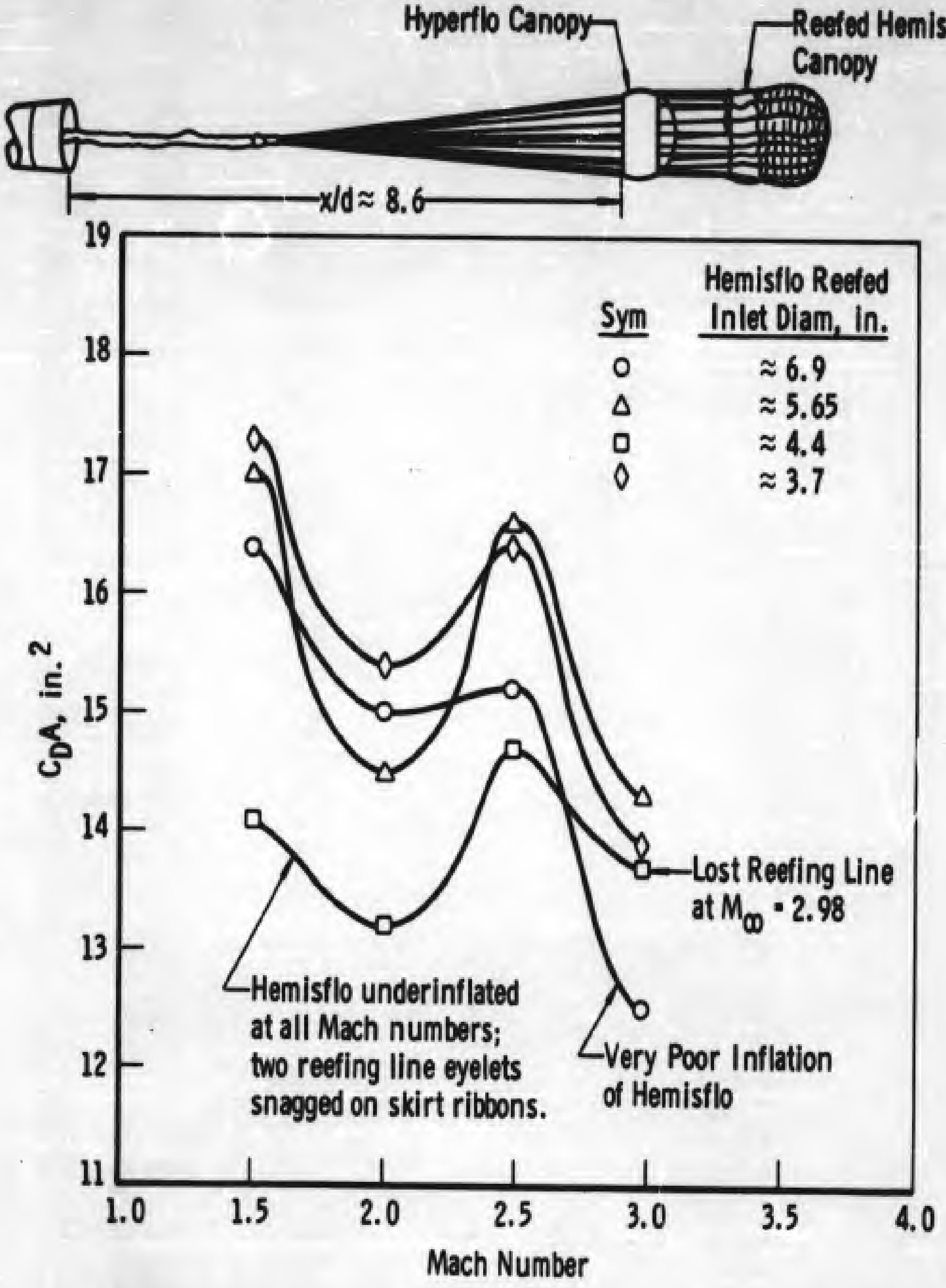


Fig. 12 Drag Parameter versus Mach Number for 4.34-in.-diam Hyperflo-Reefed Hemisflo Parachutes

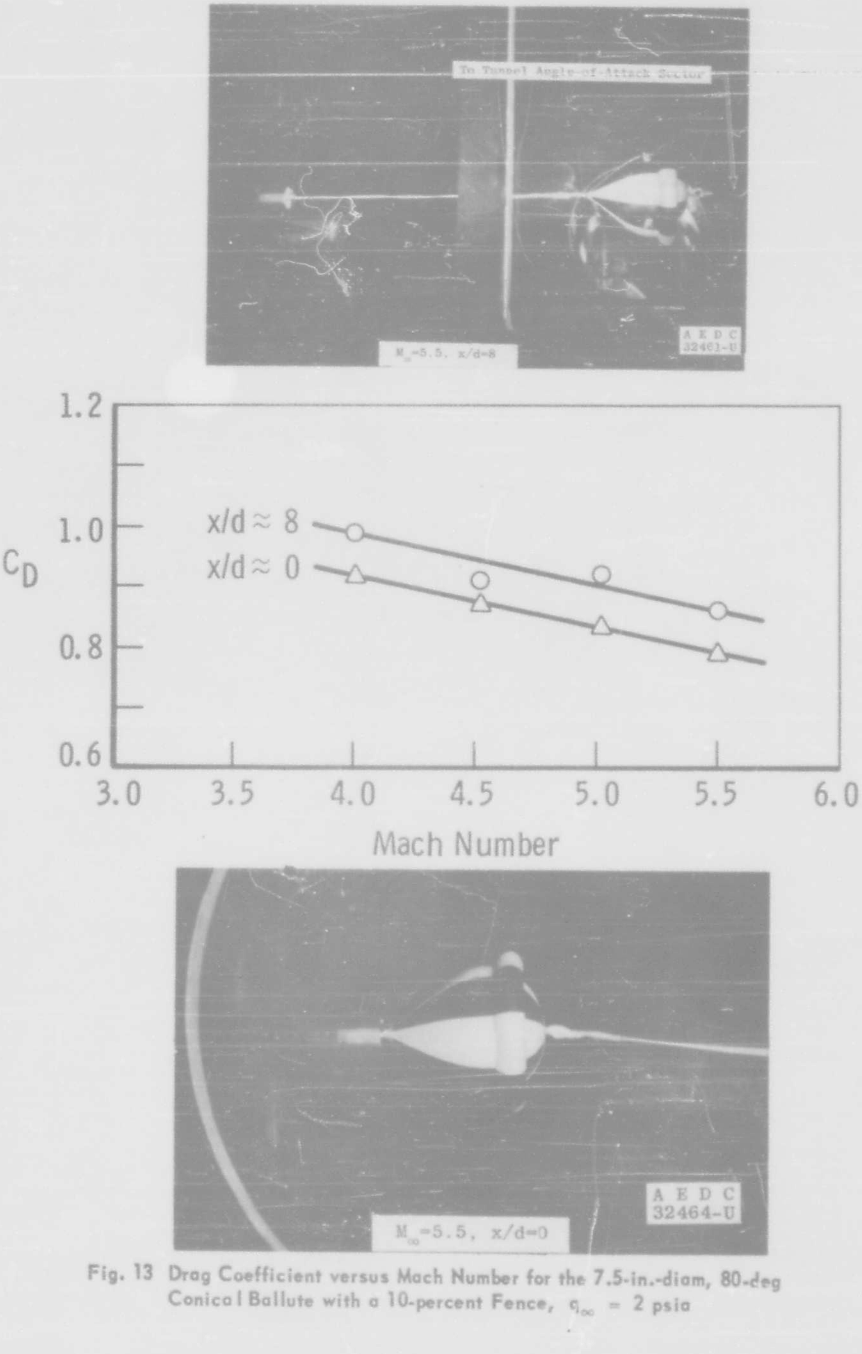


Fig. 13 Drag Coefficient versus Mach Number for the 7.5-in.-diam, 80-deg Conical Ballute with a 10-percent Fence, q_∞ = 2 psia

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Unclassified Abstract

1. Deceleration
2. Parachutes
3. Drag
4. Stability
5. Tests
6. Supersonic characteristics

I. AFSC Program Area 720F, Project 6065, Task 61525
II. Contract AF 40(600)-1000
III. ARO, Inc., Arnold AF Sta, Tenn.
IV. J. S. Deitering
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3. Drag
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