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NASA CR-502

DEVELOPMENT AND TESTING OF THE DISK-GAP-BAND PARACHUTE USED FOR LOW DYNAMIC PRESSURE APPLICATIONS AT EJECTION ALTITUDES AT OR ABOVE 200,000 FEET

by Clinton V. Eckstrom

Prepared by
G. T. SCHJELDAHL COMPANY
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JUNE 1966

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SUMMARY

The investigation of the Disk-Gap-Band parachute system consisted of a series of wind tunnel tests of models, a design study, vacuum chamber inflation tests, and a series of eleven rocket launched flight tests. The Disk-Gap-Band parachute is utilized for very low dynamic pressure applications and therefore utilizes a water vapor pressurized torus inflation aid to assist in opening the canopy at altitudes at or above 200,000 feet. The parachutes flight tested at altitudes as high as 232,000 feet opened immediately after ejection from the rockets. A problem of suspension line tangling during deployment occurred on the first few flights. This problem of line tangling was solved by modifying the parachute deployment bag to include canopy restraining straps and a shock attenuating lanyard. Movie films from camera payloads indicate that the Disk-Gap-Band parachute is aerodynamically stable at all altitudes of operation and provides constant drag area at all times.

I. INTRODUCTION

Parachutes, of various designs, have been used for several years as wind sensors, or as carriers of meteorlogical instruments at altitudes as high as 200,000 feet. These parachutes and their payloads are carried aloft by small sounding rockets. As experience was gained with these sounding rocket parachute systems certain criteria (Reference 1) were established concerning desired performance characteristics. The Disk-Gap-Band (DGB) parachute design* was originated to meet these requirements, and the performance goals for the DGB parachute system developed and tested on this program were:

1. The parachute should inflate immediately at ejection altitudes of 200,000 feet or higher.
2. The parachute should remain fully open, and provide normal drag area at all times.
3. The parachute should have good drag efficiency based on weight and volume.
4. The parachute should be aerodynamically stable at all altitudes of operation.
5. The parachute canopy should be radar reflective to provide a good track capability.

The program for achieving these performance goals consisted of: 1) a series of wind tunnel tests to determine the DGB canopy configuration for optimum stability and drag performance, 2) a design study to determine the best and simplest way to assist canopy opening by pressure inflation aids, 3) vacuum chamber inflation tests to determine the effectiveness of

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* Patent Pending

the various inflation aid designs, and 4) a series of eleven rocket-launched flight tests to determine deployment and descent capabilities and to qualify the parachute system. The parachutes used for the flight tests were designed for a canopy loading (dynamic pressure) of 0.05 pounds per square foot, which will provide a descent rate of 450 feet per second at an altitude of 200,000 feet.

II. WIND TUNNEL TESTS OF VARIOUS DGB CANOPY CONFIGURATIONS*

A. Models

The Disk-Gap-Band parachute canopy, as suggested by its name, consists of a centrally located disk separated by a gap or space from a band which is perpendicular to the disk. Suspension lines or tapes running from the edge of the disk to the band join the two portions of the canopy. Several variations in area relationships among the three sections of the canopy are possible. Six DGB parachute models, having variations in gap and/or band width as listed in Table 1, were tested. The models were constructed of nonpermeable, reinforced film materials. A typical gore layout is shown in Figure 1.

B. Pendulum Tests

Pendulum type wind tunnel tests were conducted on the six DGB parachute models to determine the effects of the canopy variations on drag and stability. These pendulum tests were conducted in the open section of the University of Minnesota subsonic wind tunnel at a velocity of 45 fps, corresponding to a Reynolds number of approximately 6×10^5. The pendulum device allows the parachute to move freely in the horizontal plane only, thus eliminating the effects of gravity on the model. The pendulum test device, shown in Figures 2 and 3, is used to measure the parachute drag and the angle of attack at which the parachute is stable.

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*The information presented in this section is based on work done by Dr. H. G. Heinrich, E. L. Haak, and R. J. Niccum of the Department of Aeronautics and Engineering Mechanics of the University of Minnesota, sponsored by the G. T. Schjeldahl Company.

TABLE 1

D-G-B MODEL DATA

MODEL	CONSTRUCTED DIAMETER	TOTAL AREA	NOMINAL DIAMETER	DISK DIAMETER D AND AREA RATIO S_D/S_o			GAP WIDTH G		OPEN AREA	BAND WIDTH B AND AREA RATIO S_B/S_o			SUSPENSION LINE LENGTH L	
No.	In.	$In.^2$	In.	In.	D/D_o	S_D/S_o	In.	G/D_o	% S_o	In.	B/D_o	S_B/S_o	In.	L/D_o
1	18	510	25.5	18	0.71	0.50	0.75	0.029	8.32	3.75	0.147	.417	25.5	1.00
2	18	510	25.5	18	0.71	0.50	1.125	0.044	12.50	3.375	0.127	.375	25.5	1.00
3	18	510	25.5	18	0.71	0.50	1.50	0.059	16.65	3.00	0.118	.334	25.5	1.00
4	18	565.5	26.8	18	0.67	0.45	1.50	0.056	15.0	4.00	0.149	.40	26.8	1.00
5	18	482	24.8	18	0.73	0.53	1.00	0.040	12.0	3.00	0.121	.35	24.8	1.00
6	18	499	25.2	18	0.71	0.51	1.32	0.052	15.0	3.00	0.119	.34	25.2	1.00
4a	12	245	17.67	12	0.68	0.46	0.95	0.054	15.0	2.55	0.144	.39	19.4	1.11
6a	12	217.5	16.65	12	0.72	0.52	0.85	0.051	15.0	1.92	0.115	.33	19.5	1.19

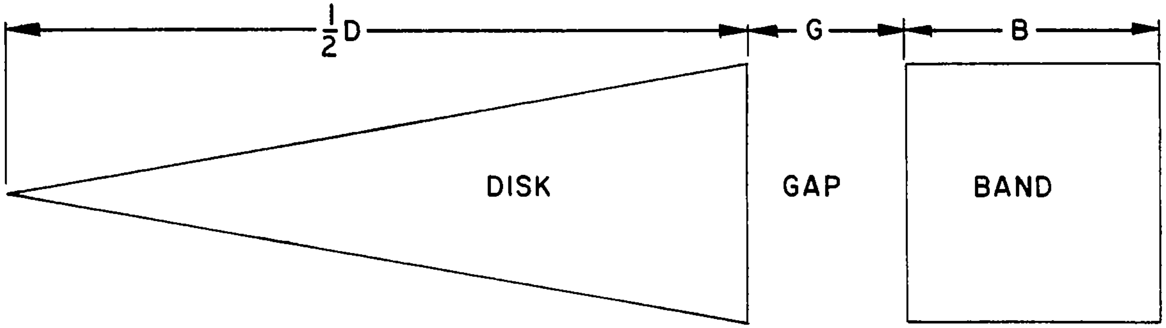

FIG.1 TYPICAL GORE PATTERN

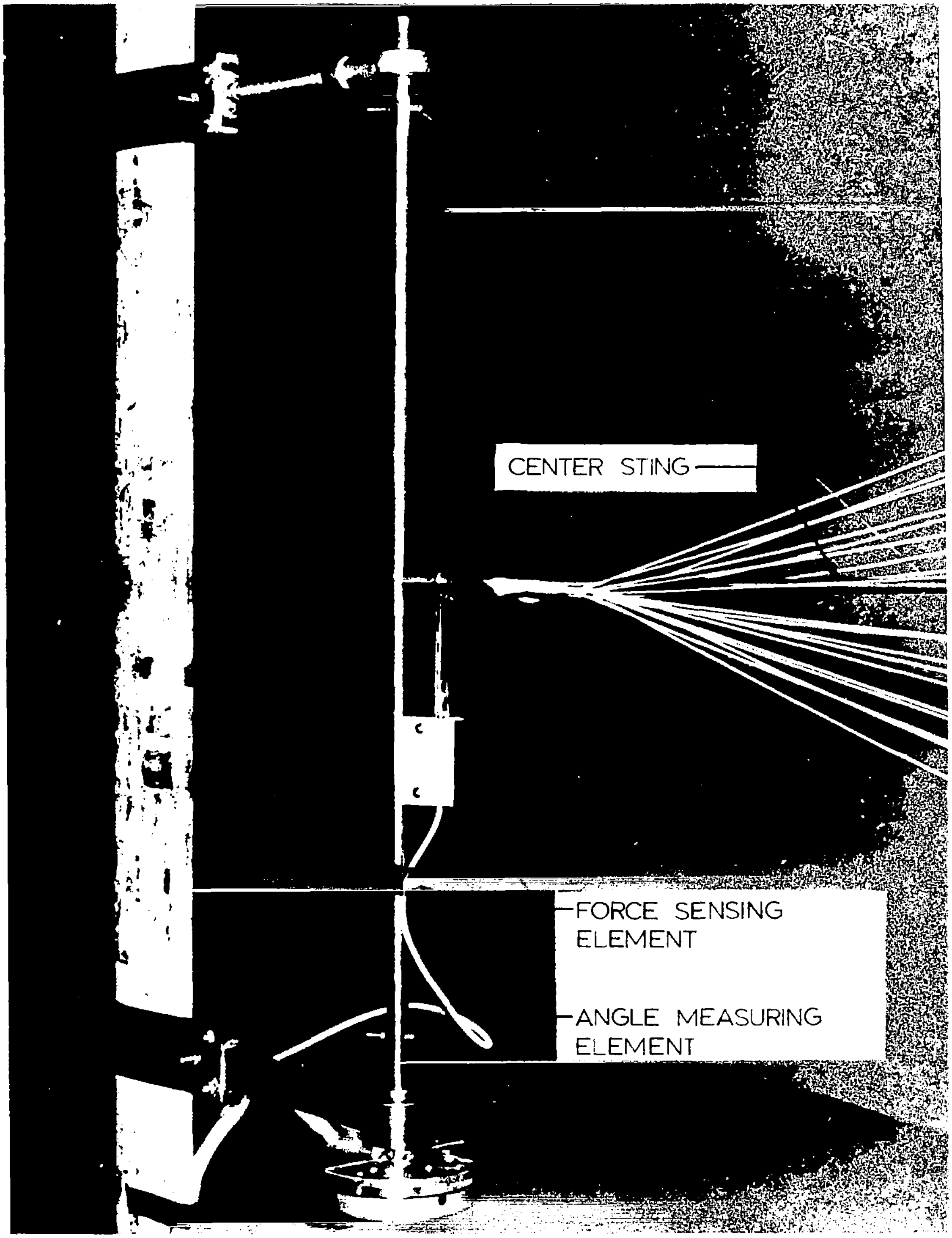

FIG 2. DETAILS OF THE PENDULUM DEVICE WITH FORCE SENSING STRAINGAGE, ANGLE MEASURING ELEMENT, AND CENTER STING

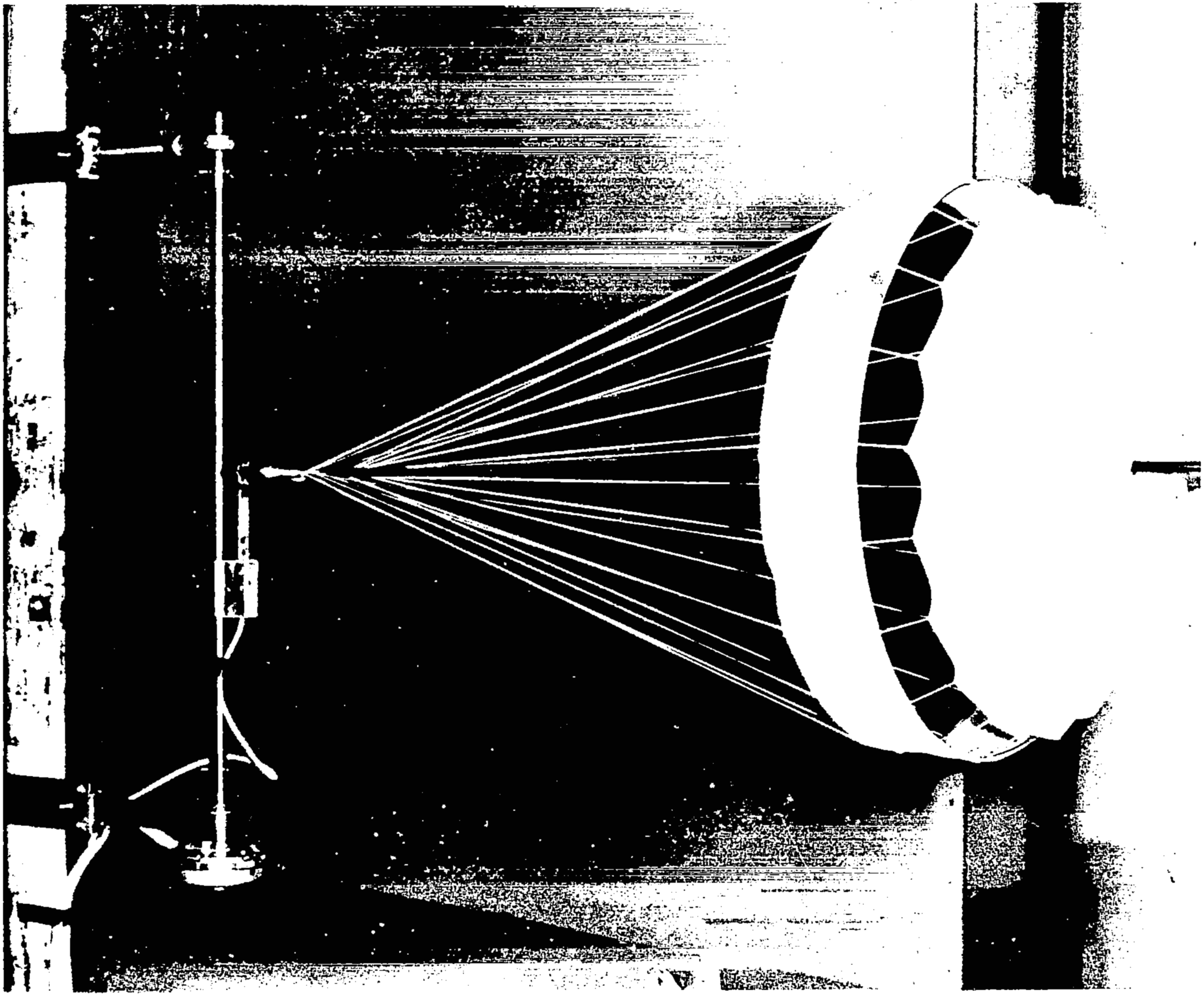

FIG. 3. PENDULUM DEVICE AND PARACHUTE MODEL MOUNTED IN WIND TUNNEL

The results of the pendulum tests, listed in Table 2, indicated that the stable angle of the models ranged from 0 to 4 degrees. The drag coefficients ranged from 0.762 to 0.895, with the more stable configurations generally having the lower drag. Because stability was of prime importance, models 4 and 6 were selected for further testing.

C. Three Component Measurements

New models, designated as 4a and 6a (also listed in Table 1), were fabricated to the same configuration as models 4 and 6, except that they were of smaller constructed diameter.

These new models were placed in the closed test section of the wind tunnel on a three-component strain gage balance, (see Figures 4 and 5), for determination of the tangent force (T) and the normal force (N). The aerodynamic moment (M) is then determined from the normal force measurement. The procedure used in this series of tests is more completely described in Reference 2.

The tangent force is defined as the force which acts along the axis of symmetry of the canopy. The normal force acts perpendicularly to the centerline of the canopy, and produces the aerodynamic moment about a point one nominal diameter below the leading edge of the canopy. The moment is considered to be negative when, for angles of attack greater than the stable angle, it tends to rotate the canopy in the direction toward the stable position. It is considered positive when, for angles of attack less than the stable angle, it tends to rotate the canopy toward the stable position. Thus, a stable position will exist when the moment diminishes to zero and the rate of change of the moment

TABLE 2

RESULTS OF PENDULUM TESTS

MODEL	STABLE ANGLE (deg)	OSCILLATION ANGLE (deg)	$C_{D_{AVE}}$
1	2	± 7	0.864
2	2	± 5	0.822
3	4	± 3	0.774
4	0	± 6	0.762
5	4	± 4	0.895
6	0	± 5	0.814

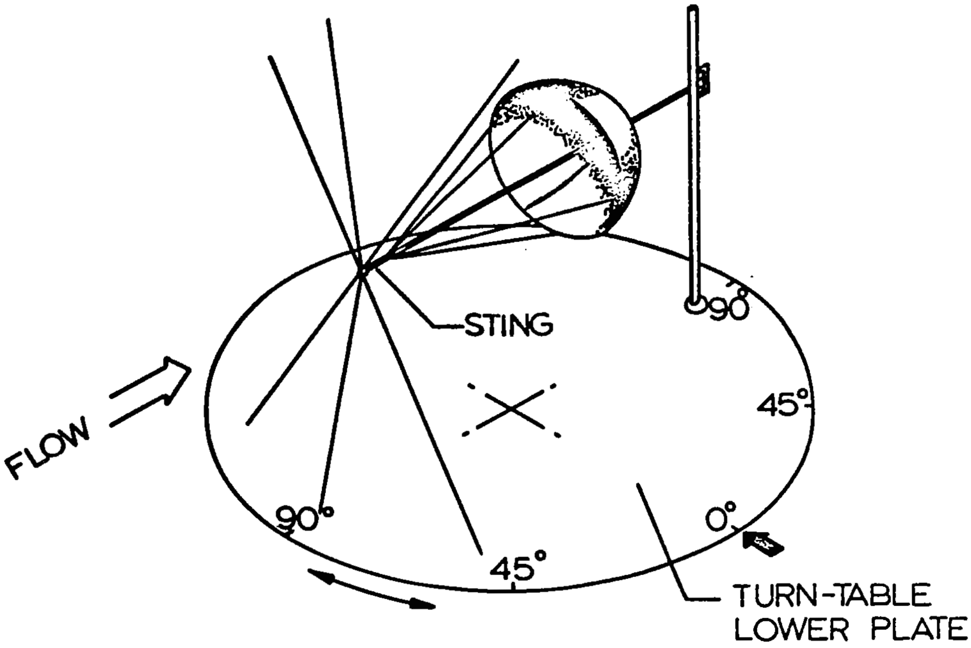

FIG. 4. MODEL SUSPENSION SYSTEM

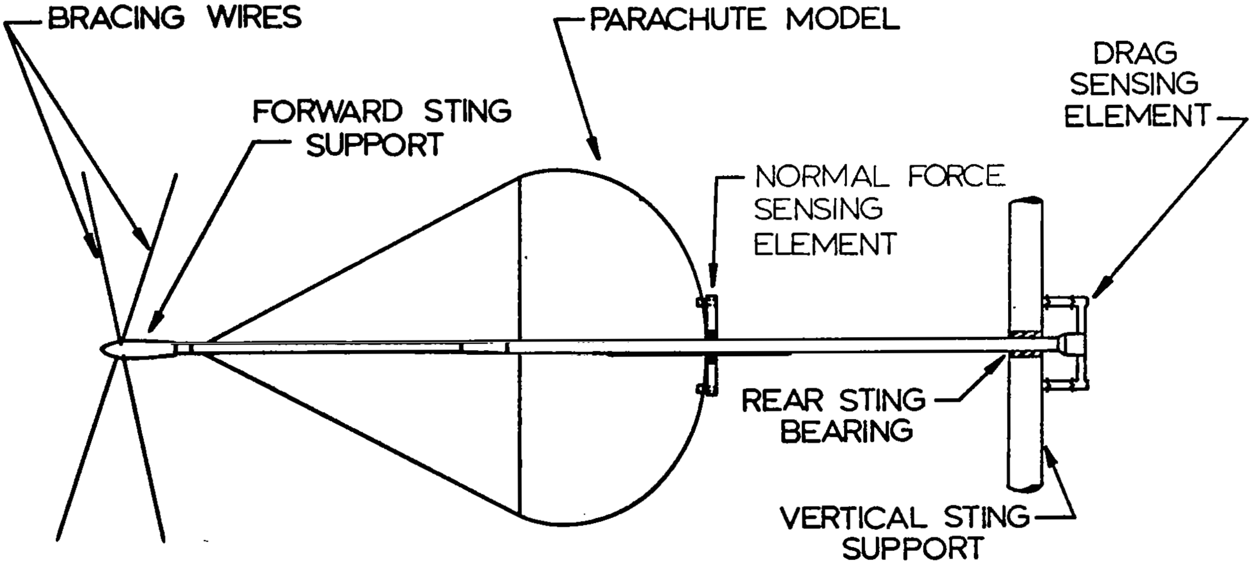

FIG 5. MODEL SUSPENSION AND STRAIN GAGE BALANCE . ARRANGEMENT

coefficient (M) in respect to the angle of attack (α) is less than zero.

The resultant tangent force and aerodynamic moment coefficients, as determined from the three component measurements on models 4a and 6a, are shown in Figures 6 and 7. The tests indicated that model 6a had a smaller region of instability than model 4a. The stable angles of attack, as shown in Figure 7 for these models were 6 and 13 degrees, respectively. In addition it can be seen from Figure 6 that model 6a has a higher tangent force coefficient at its stable angle.

As a result of these tests the DGB canopy configuration, as exemplified by models 6 and 6a, was selected for the flight tests.

D. Models with Simulated Pressurized Tori

One of the first DGB parachutes fabricated during the initial design stages had a pressurized torus located in the leading edge of the band. This torus, when properly pressurized, held the leading edge of the band open to its full constructed diameter. Preliminary wind tunnel tests of this model indicated that it had an extremely high drag coefficient, and yet the canopy was moderately stable. For this reason, it was decided to investigate the effects of tori located at the leading edge of the band, the trailing edge of the band, and the outer edge of the disk. The models fabricated for the pendulum tests and the three component tests were equipped so that wire hoops, simulating pressurized tori, could be installed at any or all of the three locations listed above. To identify each of the configurations possible when using the simulated tori, a sequence of three digits (either zeros or ones) was used after the model number to indicate the number and location of

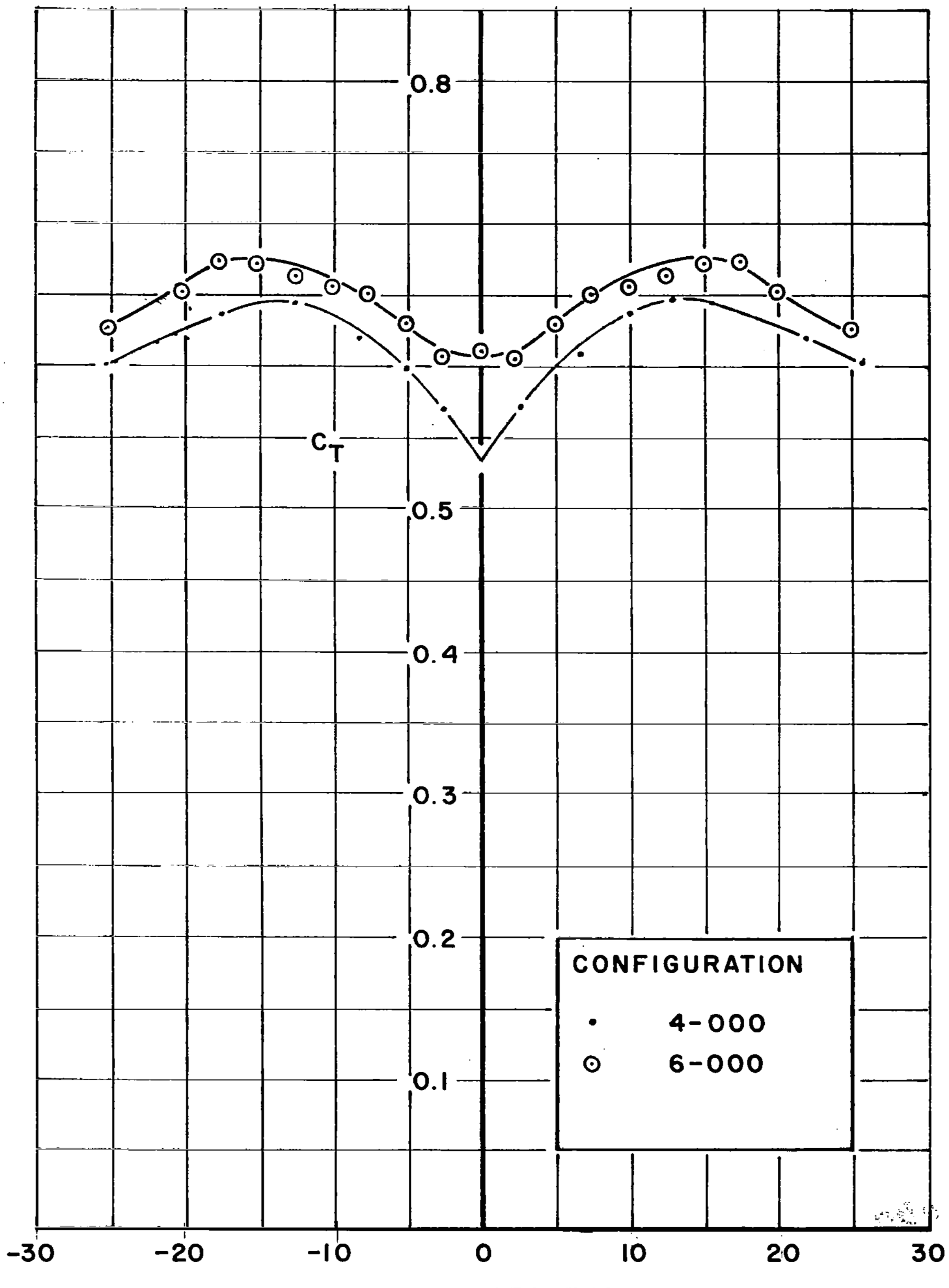

Figure 6. Tangent Force Coefficient vs Angle of Attack for Models 4 and 6

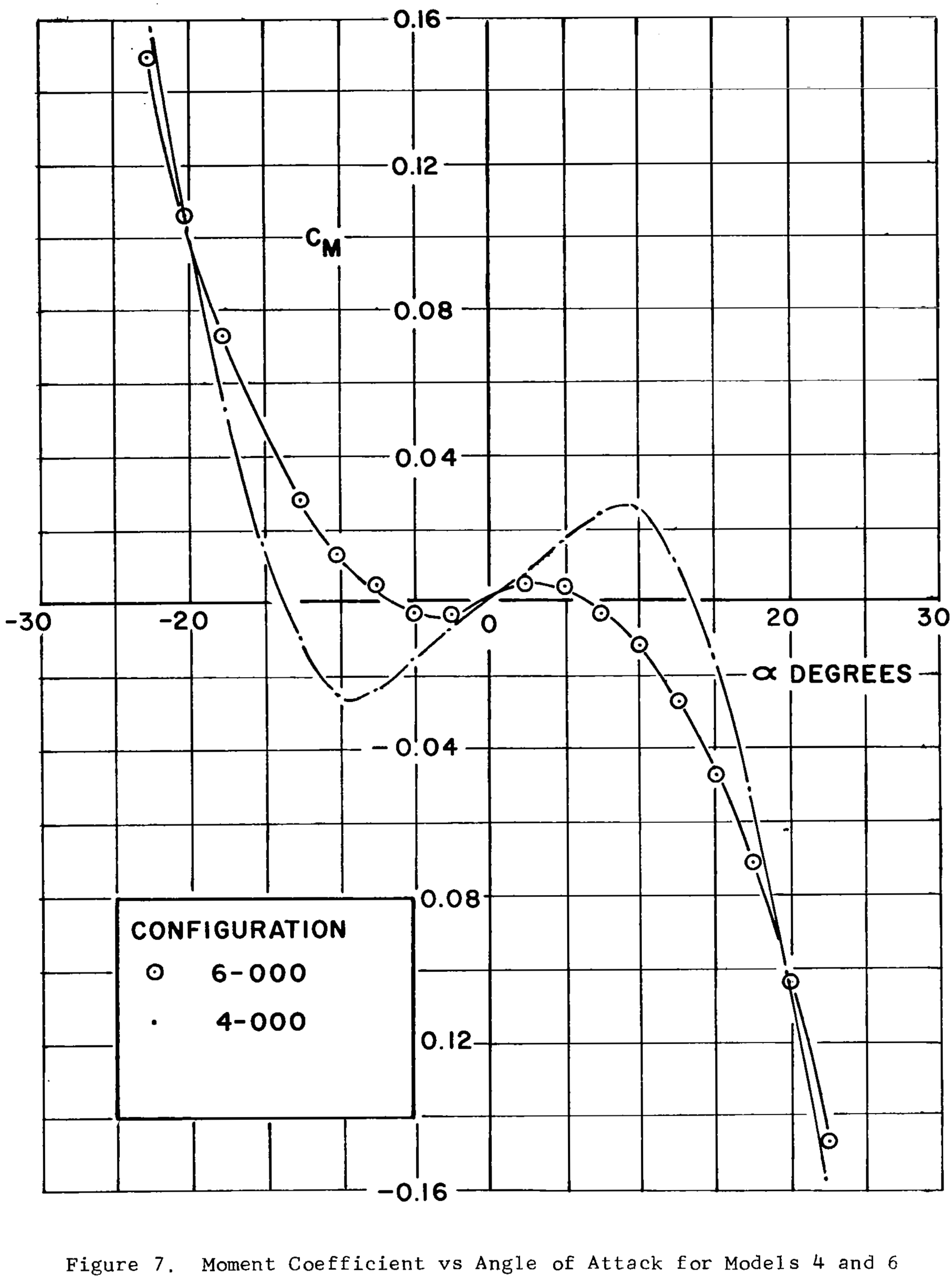

Figure 7. Moment Coefficient vs Angle of Attack for Models 4 and 6

wire hoops on the model. From left to right in the sequence, the number one indicates the presence and zero the absence of a wire hoop at the leading edge of the band, the trailing edge of the band, and the outer edge of the disk, respectively.

For example: 1-010 indicates model number 1 with a hoop at the trailing edge of the band only.

Parachute models 1 to 6 were subjected to pendulum tests with most possible configurations of simulated tori. Results of these tests are presented in Table 3. Figures 8 and 9 show the models and present their stability, drag and stable angle of attack.

Configuration "100" (hoop only on the leading edge of the band) was found to be unstable on models 1 to 4 and was not tested on models 5 and 6. The remaining configurations were quite stable, and it was determined that:

1. The stability of the parachute increased with the number of hoops and was affected very little by their location.
2. The drag increased with the number of hoops, and decreased slightly with an increase in open area provided by the gap between the disk and the band.
3. Models 4 and 6 appeared to have the best overall performance even with the wire hoop configurations.

The tangent and moment coefficients for models 4a-001, 4a-111, 6a-001, and 6a-111 were also determined by three component measurements. The results of these tests, presented in Figures 10, 11, and 12, indicated that the stability and tangent force of the parachute increases as the number of hoops is increased.

TABLE 3. RESULTS OF PENDULUM TESTS

MODEL	CONF.	α°_{STABLE}	$\Delta\alpha^\circ$	C_{DAV}
1 P(1) = 8.32%	000	2°	±7°	0.864
G(2) = 0.75"	101	4°	±6°	0.911
B(3) = 3.75"	001	6°	±5°	0.834
2 P = 12.5%	000	2°	±5°	0.822
G = 1.125"	101	3°	±4°	0.894
B = 3.375"	001	1°	±4°	0.870
3 P = 16.65%	000	4°	±3°	0.774
G = 1.5"	101	4°	±3°	0.907
B = 3.0"	001	2°	±3°	0.882
4 P = 15%	000	0°	±6°	0.762
G = 1.5"	101	2°	±5°	0.860
B = 4.0"	001	2°	±4°	0.849
5 P = 12%	000	4°	±4°	0.895
G = 1.0"	100	5°	±4°	0.971
B = 3.0"	101	2°	±2°	0.984
	001	2°	±4°	0.946
	110	4°	±7°	0.907
	111	2°	±2°	0.997
	011	2°	±3°	0.971
	010	3°	±4°	0.907
6 P = 15%	000	0°	±5°	0.814
G = 1.32"	100	2°	±6°	0.906
B = 3.0"	101	2°	±4°	0.937
	001	0°	±4°	0.926
	110	0°	±6°	0.888
	111	2°	±2°	1.012
	011	0°	±4°	0.913
	010	0°	±6°	0.839

(1) Porosity (2) Gap (3) Band Width

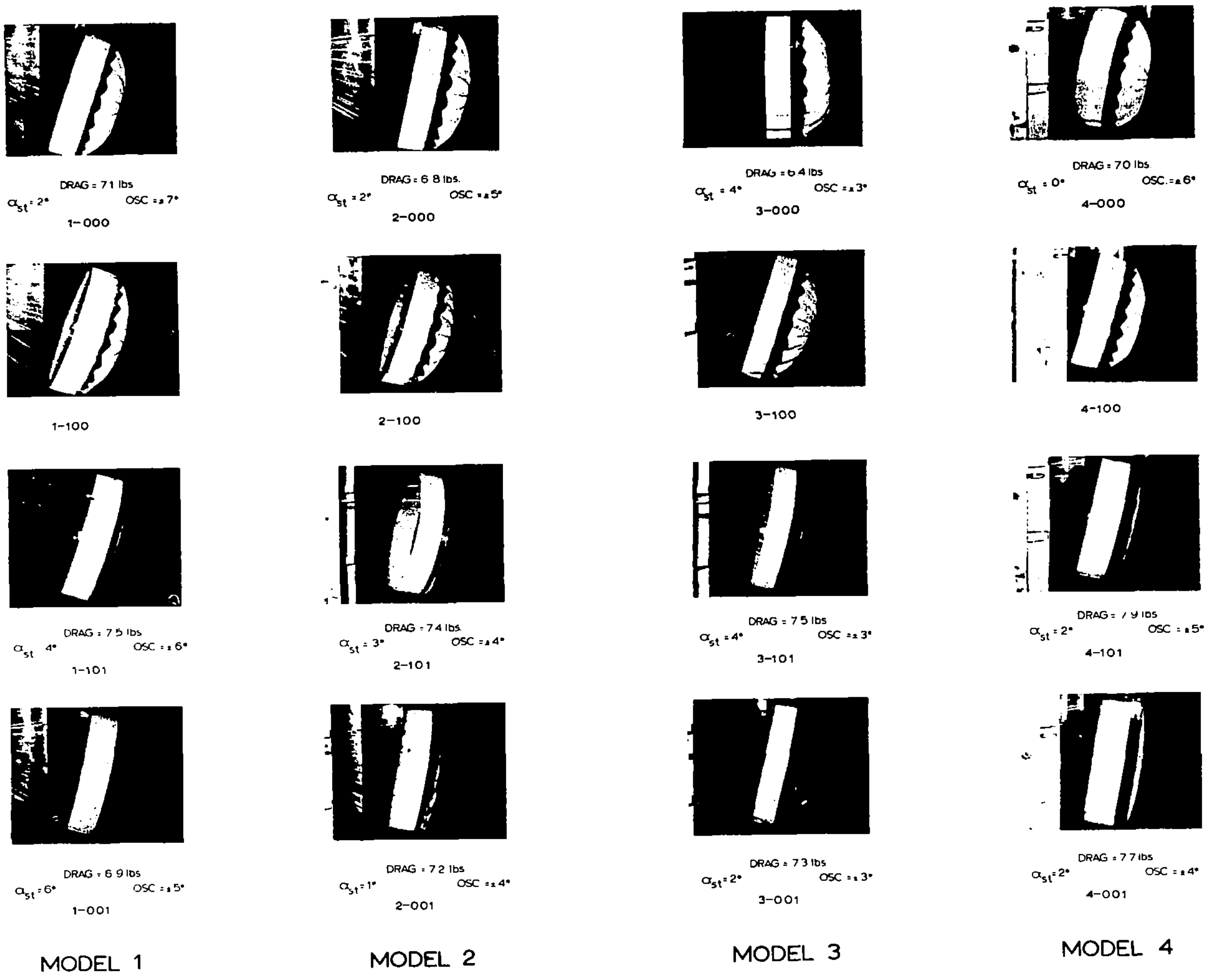

FIG. 8. MODELS 1, 2, 3, 4 IN VARIOUS TEST CONFIGURATIONS *(OSCILLATION ABOUT THE STABLE ANGLE OF ATTACK)

DRAG = 7.0 lbs.
α_{st} = 4° OSC. = ± 4°
5-000

DRAG = 7.6 lbs.
α_{st} = 5° OSC. = ± 4°
5-100

DRAG = 6.6 lbs.
α_{st} = 0° OSC. = ± 5°
6-000

DRAG = 7.3 lbs.
α_{st} = 2° OSC. = ± 6°
6-100

DRAG = 7.7 lbs.
α_{st} = 2° OSC. = ± 2°
5-101

DRAG = 7.4 lbs.
α_{st} = 2° OSC. = ± 2°
5-001

DRAG = 7.6 lbs.
α_{st} = 2° OSC. = ± 4°
6-101

DRAG = 7.5 lbs.
α_{st} = 0° OSC. = ± 4°
6-001

DRAG = 7.1 lbs
α_{st} = 4° OSC = ± 7°
5-110

DRAG = 7.8 lbs.
α_{st} = 2° OSC. = ± 2°
5-111

DRAG = 7.2 lbs.
α_{st} = 0° OSC. = ± 6°
6-110

DRAG = 8.2 lbs
α_{st} = 2° OSC. = ± 2°
6-111

DRAG = 7.6 lbs
α_{st} = 2° OSC = ± 3°
5-011

DRAG = 7.1 lbs
α_{st} = 3° OSC = ± 4°
5-010

DRAG = 7.4 lbs
α_{st} = 0° OSC = ± 4°
6-011

DRAG = 6.8 lbs
α_{st} = 0° OSC = ± 6°
6-010

MODEL 5 **MODEL 6**

FIG 9 MODELS 5 AND 6 IN VARIOUS TEST CONFIGURATIONS *(OSCILLATION ABOUT THE STABLE ANGLE OF ATTACK)

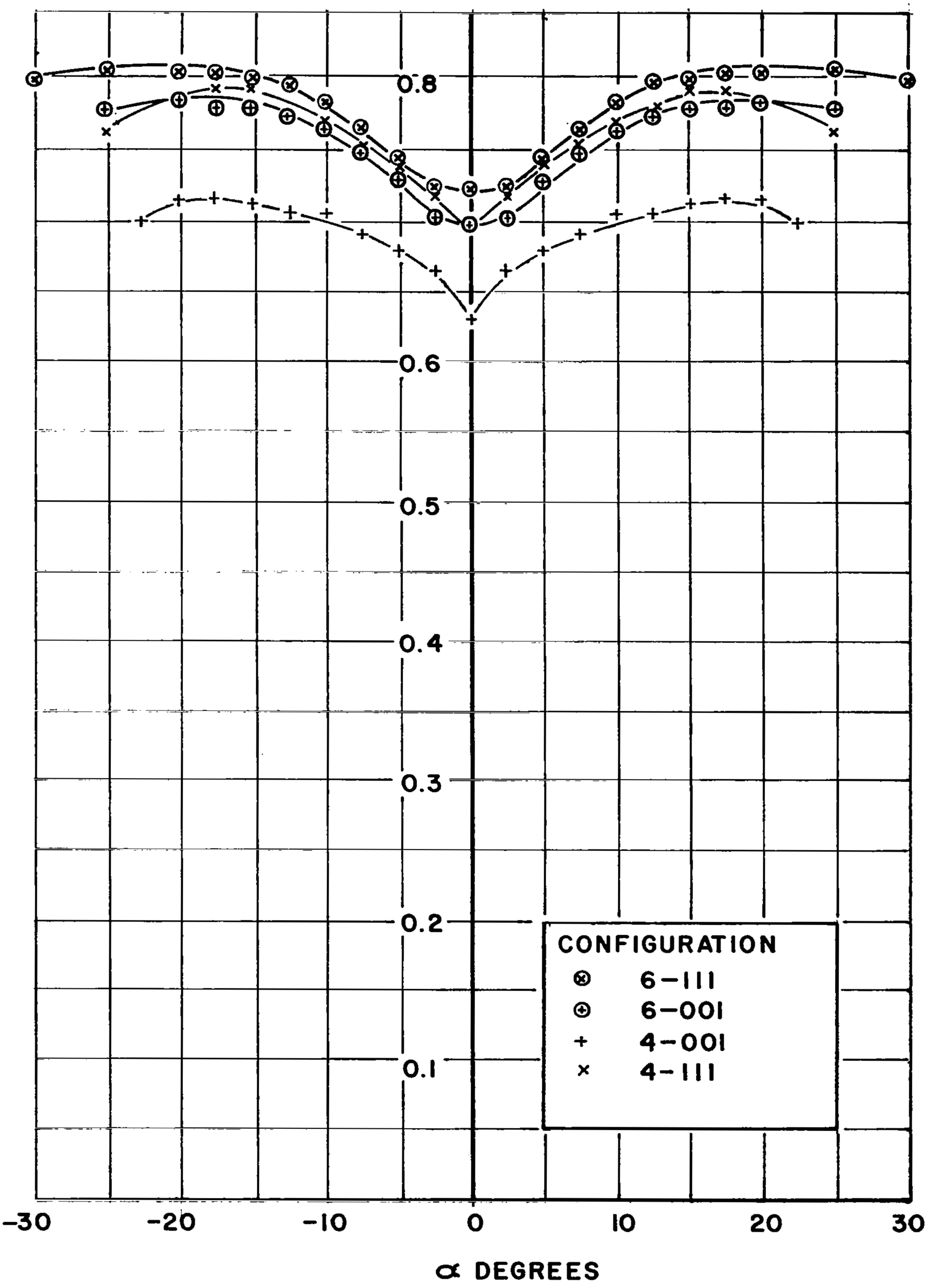

Figure 10. Tangent Force Coefficient vs Angle of Attack for Models 4 and 6 with Simulated Tori

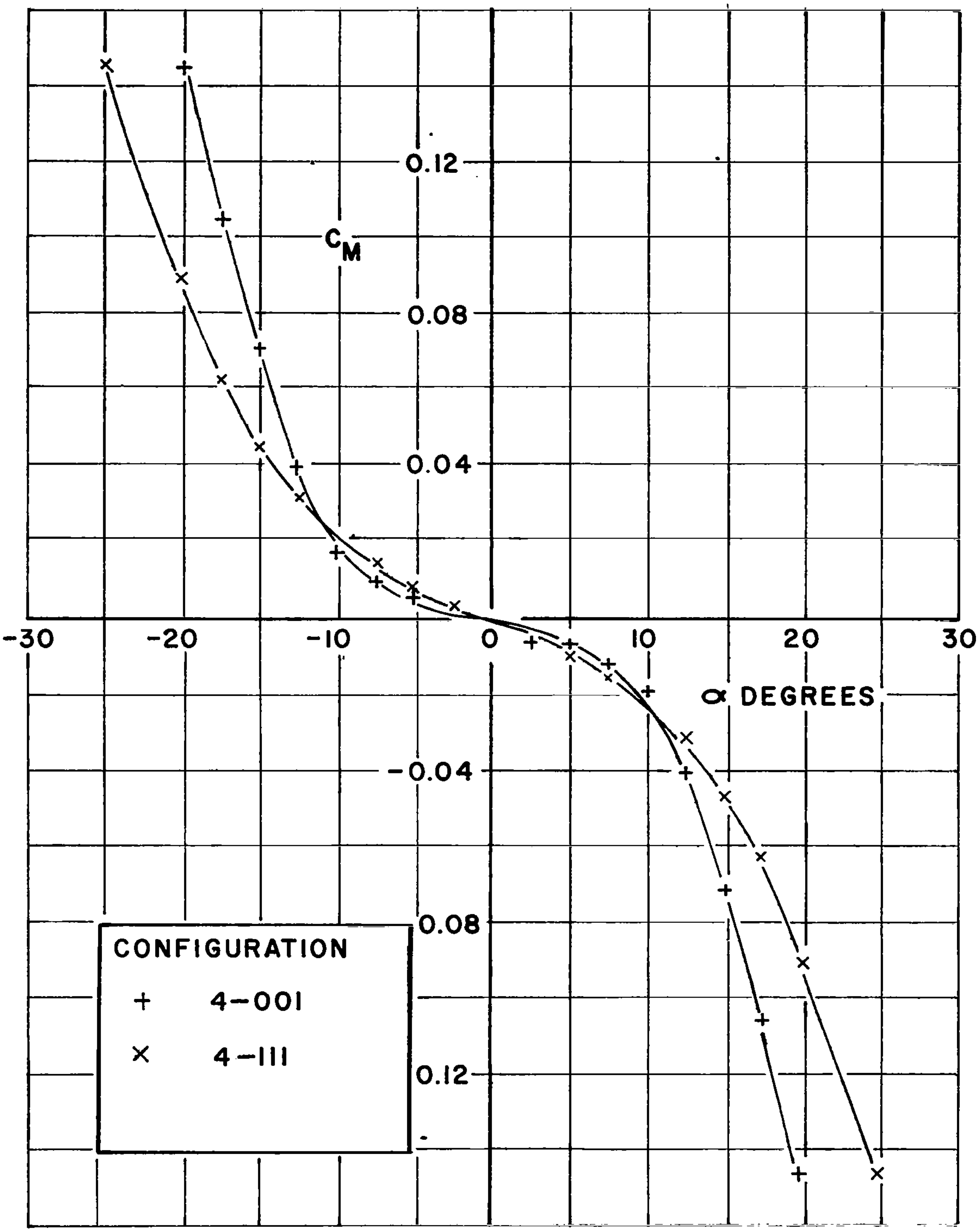

Figure 11. Moment Coefficient vs Angle of Attack for Model 4 with Simulated Tori

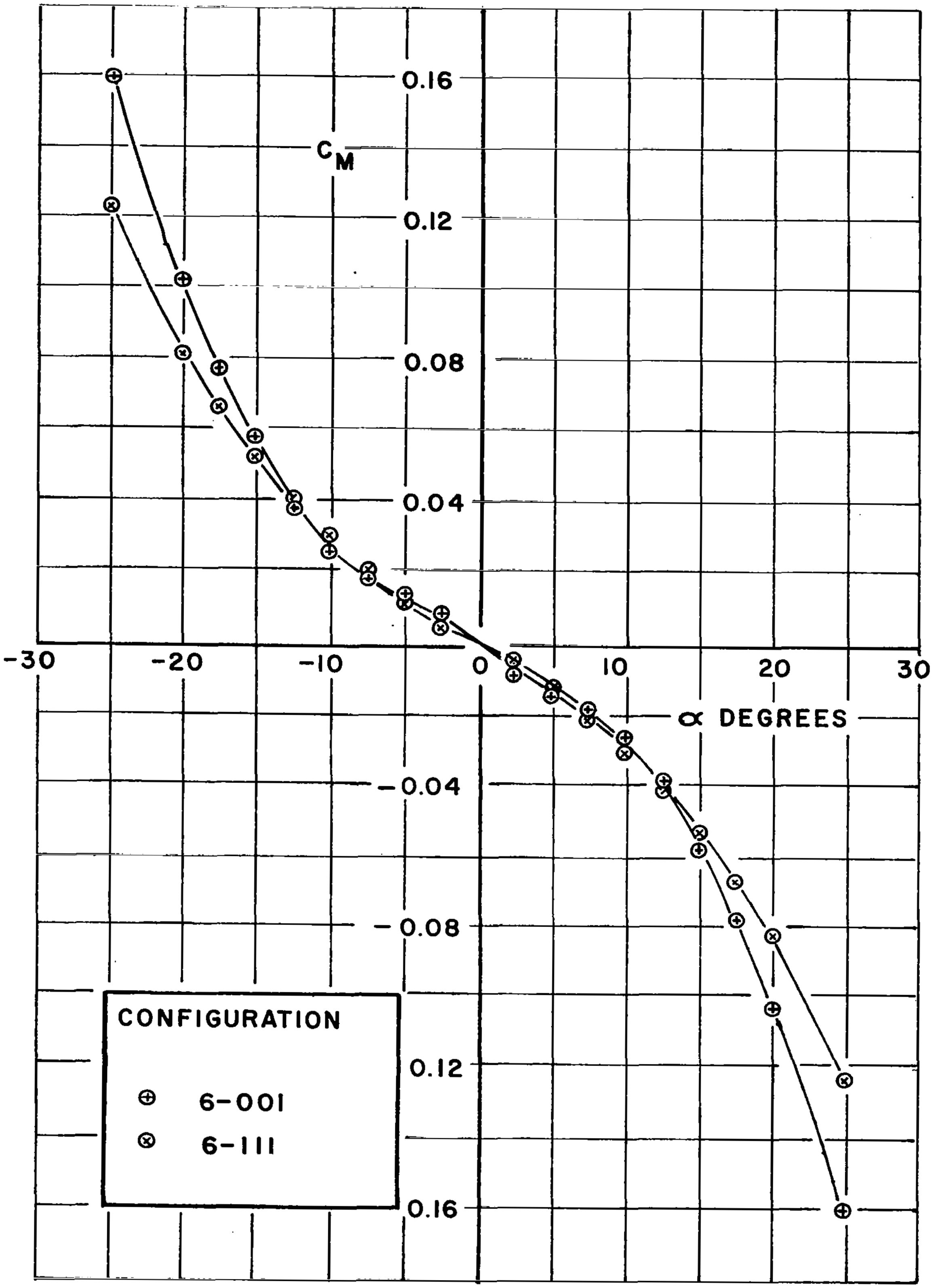

Figure 12. Moment Coefficient vs Angle of Attack for Model 6 with Simulated Tori

III. CANOPY INFLATION AID DESIGN

A. Background

The primary purpose of canopy inflation aids is to assist and assure initial opening of the parachute canopy immediately after ejection from the deployment bag. The secondary purpose is to maintain canopy shape after inflation. As indicated in Section III-C one of the original goals of this program was to design a parachute canopy which was pressure inflated and rigidized to the "constructed shape", thus attaining maximum drag efficiency during the initial period of flight. The initial period of flight for these parachutes is intended to occur at or above 200,000 feet altitude where the atmospheric pressure is 0.149 mm Hg or less. Therefore only a minimum amount of inflation gas would be needed for pressurization of rigidizing tori.

If inflation pressure necessary to maintain constructed canopy shapes was not possible, the alternate design goal was to use a pressurized torus to maintain the canopy in its inflated "natural shape". This meant that the inflation aid would not exert any force on the canopy as long as the canopy remained fully open. However, if the canopy had any tendency to partially collapse, squid, or pump, the inflation aid would prevent these changes in shape.

B. Inflation Aids for "Constructed Shape" Canopy Rigidization

In order to pressure inflate the Disk-Gap-Band canopy to its constructed shape, the inflation aid would probably be located at the outer edge of the disk portion of the canopy as shown in Figure 13-A.

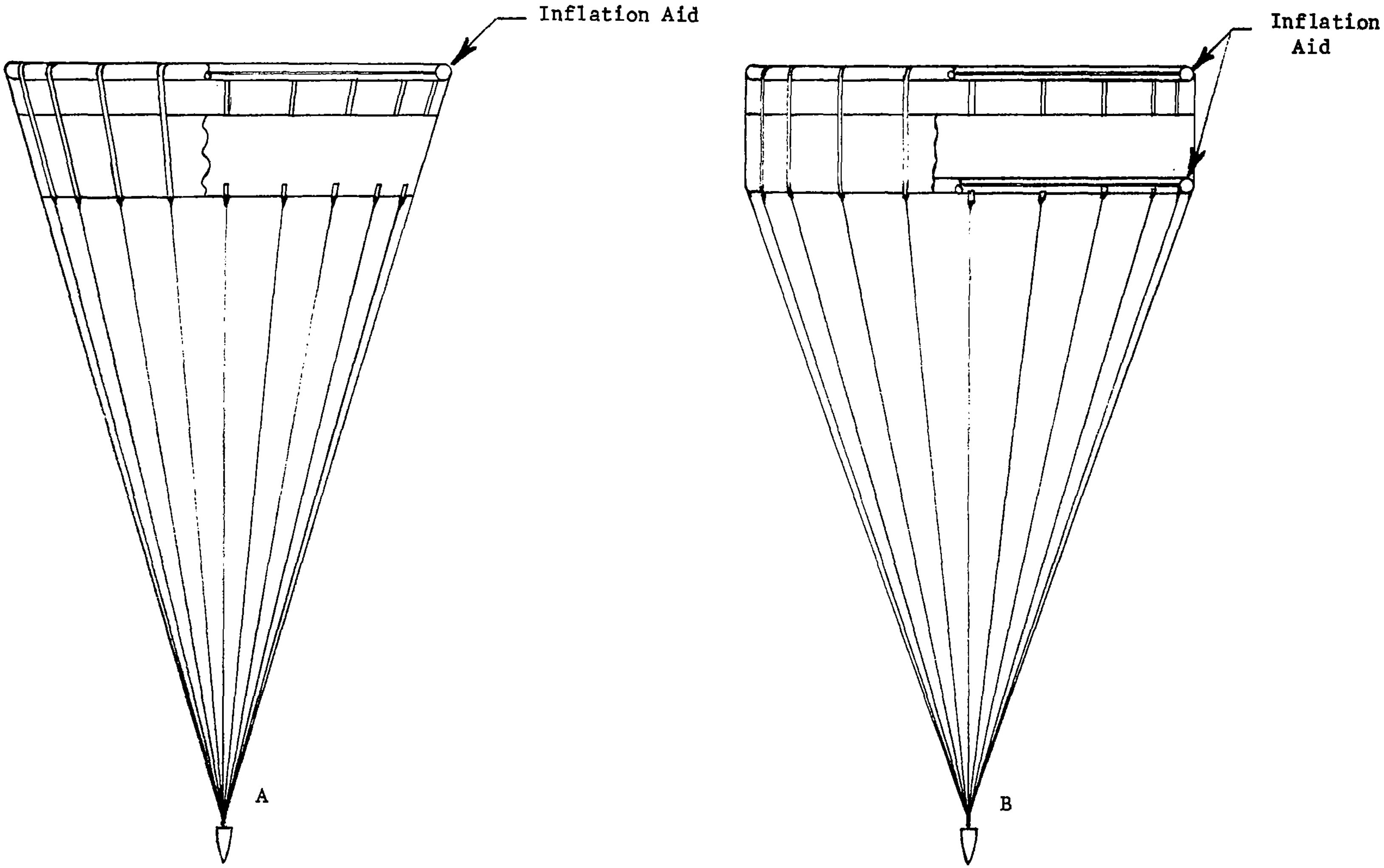

Figure 13

Disk-Gap-Band Parachute Canopy Pressure Inflated to the Constructed Shape

An additional inflation aid might be required at the lower edge of the band as shown in Figure 13-B.

The simplest inflation aid to provide a smooth circular cross-section is a torus. It was therefore desirable to place a torus around the outer edge of the disk. Fabrication of a separate torus and disk, and joining the two items at all points in a strong joint would require much material. To keep the material required to a minimum, an integral disk-torus was designed with the torus portion formed by a continuation of the disk material. A typical gore pattern for this type design is shown in Figure 14.

Because the sealing tapes have considerably greater strength in shear than in peel, the longitudinal sealing tape was placed inside the torus, where it was subject to shear forces. The longitudinal sealing tape was continuous around the disk to prevent leaks at the corners of the torus. Torus corners (joints) were fabricated in the regular manner before the longitudinal seal was made. Details of the torus corner and the longitudinal sealing tape are shown in Figure 15. The integral disk-torus was fabricated from the scrim material without difficulty as the scrim thread remained on the exterior of the torus and the sealing tapes were on the interior. Full strength of the laminate was maintained by using a scrim tape with the adhesive on the smooth Mylar side, or by using Mylar tape of greater thickness than the Mylar part of the basic laminate material.

Three 12-foot diameter integral disk-tori were fabricated with cross-section diameters of 2, 3, and 4 inches.

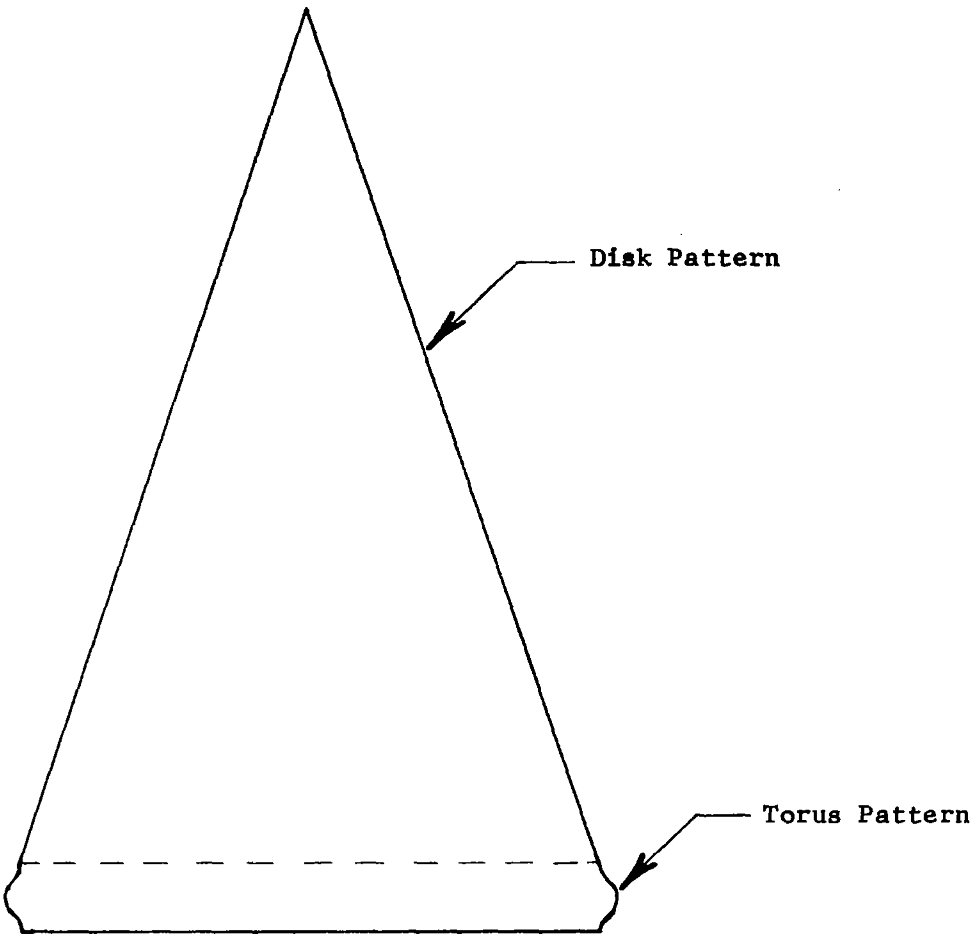

Figure 14

Integral Disk-Torus Gore
Pattern

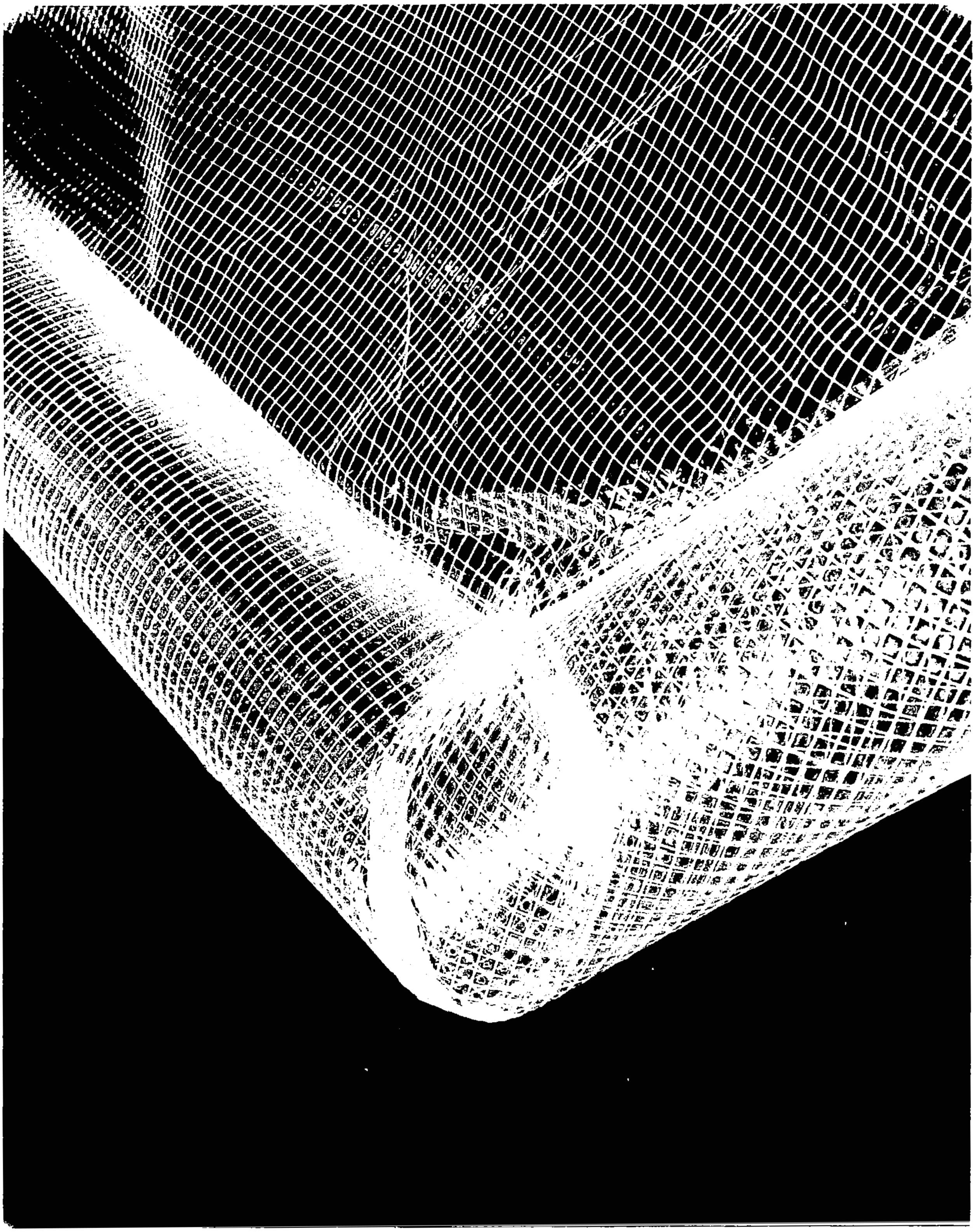

Figure 15. Details of Integral Disk-Torus Construction

Canopy rigidity was then tested to determine the torus inflation pressures necessary to withstand various canopy loadings. Aerodynamic loading was simulated by placing flexible sheets of polyethylene on the canopy disk.

The inflation pressure at which the torus buckled or collapsed was determined by overpressurizing and then reducing the pressure in the torus until a buckle appeared. The pressure at which the buckled torus straightened was determined by reversing the above procedure. Decreasing torus pressure most nearly simulates the flight conditions. However, the test applied only static loads and higher dynamic loads are to be expected during actual flight. Therefore, the pressures necessary to straighten a buckled torus were of interest.

A disk loading of 5 to 6 pounds was anticipated in the descent of the parachute carrying a temperature-sensing, telemetry package. This would require pressures of 0.75 to 1.5 psi in the 4-inch diameter torus to assure proper rigidization of the canopy disk. Torus diameters of less than 4 inches were not satisfactory in holding the disk rigid, as the inflation pressures necessary were considerably greater than those needed on the 4-inch torus.

Since residual air or water vapor would not provide the inflation pressures required, isopentane capsules or pressure bottles were necessary. However, because such pressure sources were not compatible with the packing volumes or packing methods used, studies of the "constructed shape" canopies was discontinued. If a good high pressure inflation system becomes available in the future the aerodynamic properties of the constructed shape canopy have been established as have the design and fabrication technology.

C. Inflation Aids for A "Natural Shape" Canopy

After program emphasis changed to "natural shape" canopies two new inflation aids were designed. One of these designs utilized a separate torus located inside the band portion of the canopy as shown in Figure 16. The torus was attached to the inside of the band at each gore suspension tape by a strap arrangement. This allowed some flexibility of movement between the torus and the band of the canopy.

The second design was designated as a "pillow band inflation aid". In it, each section of the band between suspension lines formed an inflatable pillow as shown in Figure 17. The pillows were nearly square as the distance between suspension tapes was nearly equal to the band width. To form the pillows the band was made of two thicknesses of material. The edges of each individual section were sealed using a folded tape on the inside of the pillow. This put the sealing tapes in shear when the pillow was stressed by inflation.

The main design feature of the pillow band was that each pillow was a separate inflatable. This meant that failure to inflate one or more of the pillows would not degrade the performance of the band as an inflation aid, either during initial inflation or after complete deployment of the canopy. The inflated pillows form a small angle at their junction point, so that the series of connected pillows approximate a torus.

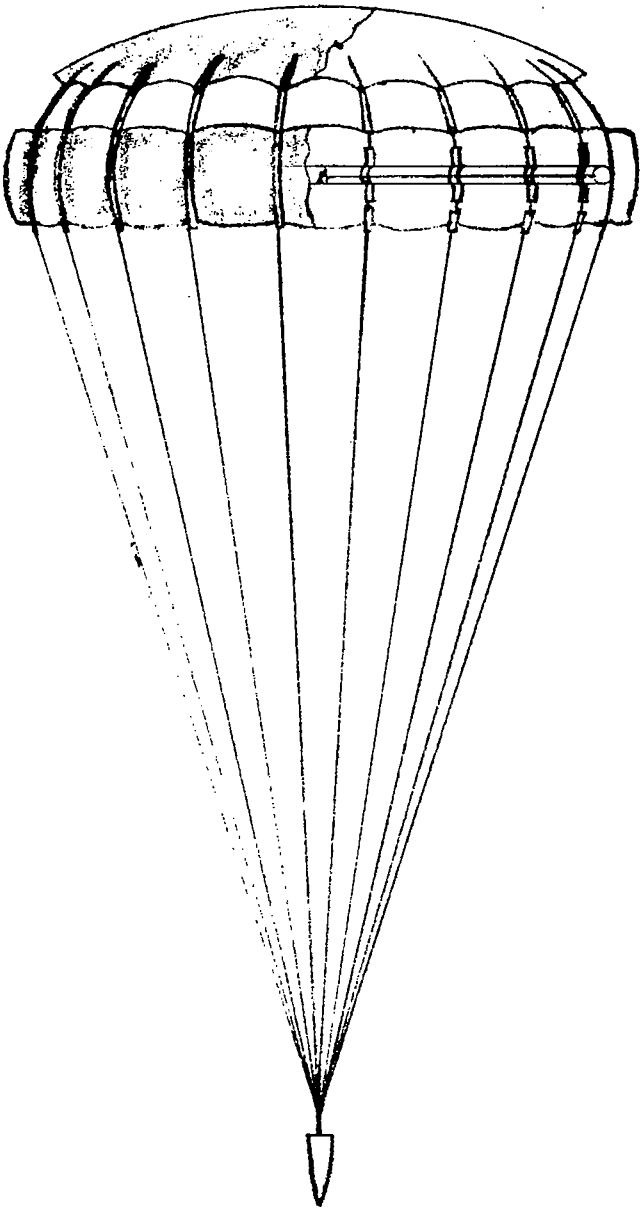

Figure 16

Natural Shape Disk-Gap-Band Parachute With
Separate Torus Inflation Aid

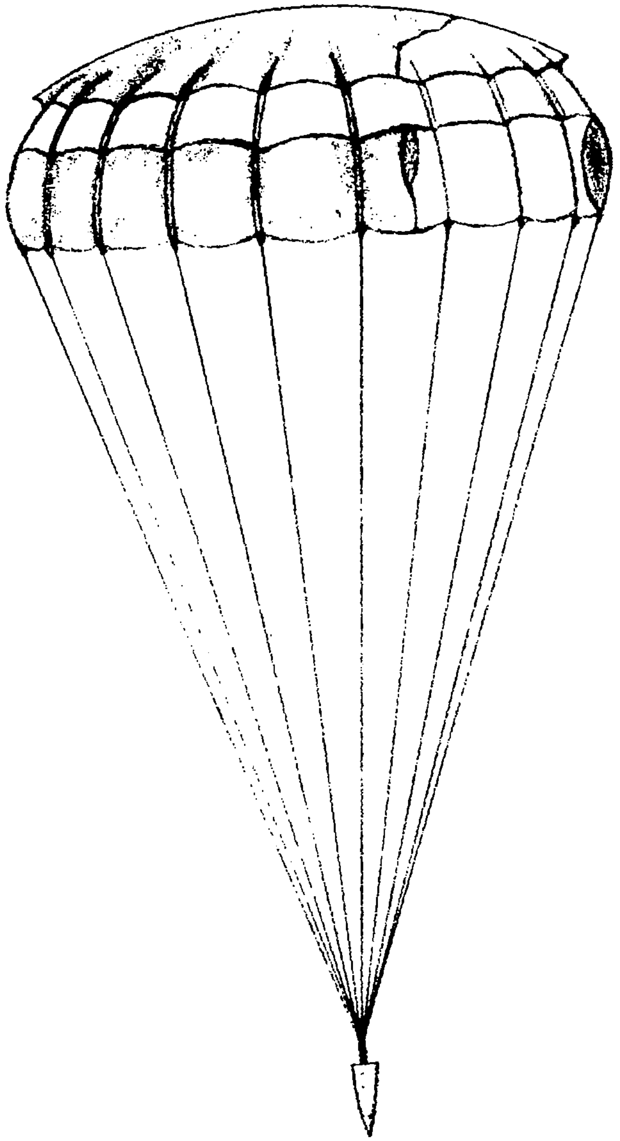

Figure 17

Natural Shape Disk-Gap-Band Parachute With Pillow Band Inflation Aid

IV. VACUUM CHAMBER TESTS OF INFLATION AIDS

A. Test Procedure

The inflation tests were conducted in the Langley Research Center 60-foot diameter vacuum sphere. Simulated altitudes of 200 to 215 thousand feet were obtained for the tests. The pump down time required to achieve these pressure altitudes was about eight hours.

The standard parachute canister with the packed parachute was put inside a test fixture in the vacuum sphere. The test fixture was sealed, except for one vent line which was valved to open either to the vacuum chamber or the atmosphere. During the pump down period, the vent was open to the atmosphere so that the packed parachute was not subjected to a vacuum during this time. Two minutes prior to the start of the test, the vent on the test fixture was closed to the atmosphere and opened to the vacuum chamber. This change of pressure in the test fixture partly simulated the pressure changes encountered during the two-minute flight of the sounding rocket from ground level to maximum altitude.

At the end of the two-minute pressure equalization time, the cover of the test fixture was released by squib-actuated bolts. When it was certain that the squibs had fired and the cover released, the drop weight on the opposite end of the cable was released; this removed the test fixture cover.

A lanyard, attached to the lower surface of the test fixture cover, pulled on the forward bulkhead of the parachute canister, sheared the holding pins, and opened the parachute canister. The parachute suspension lines were fastened to the forward bulkhead and deployed as the cable pulled the test fixture cover and the canister bulkhead upward. After the suspension lines were deployed full length, the canopy was pulled from the deployment bag fold by fold. The deployment bag usually remained in the canister during the deployment.

B. Inflation Tests

A series of seven parachute inflation tests were conducted to determine the capabilities of various inflation methods to open the parachute immediately after it ejects from the canister. Information concerning these tests is presented in Table 4.

The first inflation test was with a DGB parachute having an integral 3-inch diameter torus located on the edge of the canopy disk. Residual air was the inflation medium. On this test, the upper portion of the deployment bag did not eject from the canister at the proper time. As a result, the attachment lanyard and parachute suspension lines passed through the center of the upper part of the deployment bag. When the canopy ejected from the canister, it forced the upper portion of the deployment bag out of the canister. The deployment bag remained around the suspension lines next to the edge of the canopy, and completely prevented the canopy from inflating.

On the subsequent tests, only the main portion of the parachute deployment bag was used, thus allowing the parachute to deploy freely from within the canister.

During examination of the parachute used on the first test, it was noted that there was some blocking (self-adhesion) of material which would be detrimental to canopy deployment. This problem was alleviated by dusting

TABLE 4

VACUUM CHAMBER INFLATION TESTS

TEST NO.	TYPE AND LOCATION OF INFLATION AID	INFLATION MEDIUM	TEST RESULTS
1	Integral 3-inch diameter torus on edge of canopy disk	Residual air	Canopy opening restricted because of reefing by the upper half of the deployment bag which slid back on suspension lines.
2	Pillow Band	Residual air	Only partial inflation of pillows - incomplete opening.
3	Separate 3-inch diameter torus located on inside of band	Residual air	Successful test on initial opening - not enough pressure to rigidize torus.
4	Pillow Band	Various amounts of water in blotters	Very successful opening - stayed rigid even though 4 pillows were punctured by falling glass from ceiling light fixtures.
5	Separate 4-inch diameter torus located on inside of band	6 cc of water in blotters	Instantaneous full inflation and rigidization of torus.
6	No inflation aids	--	Parachute partially opened without inflation aid.
7	Separate 3-inch diameter torus located on inside of band	1.5 cc of water in blotters	Only partial inflation

the surface of the material with silicone powder. No further problems of material blocking were noted.

The second inflation test was with a DGB parachute having a pillow band inflation aid as shown in Figure 17. The pillow band was constructed of two thicknesses of material, sealed at the upper and lower edges, and also where the suspension lines crossed the band. Residual air was the inflation medium. When tested, the pillows only partially inflated, and the parachute canopy did not completely open.

The third inflation test was with a DGB parachute having a 3-inch diameter torus located on the inside surface of the band as shown in Figure 16. When tested, the initial opening of the canopy was quite good, however, there was not enough pressure in the torus to hold the canopy completely open after initial inflation.

At this time in the testing sequence, it was decided that not enough residual air could be retained in an inflation aid to provide the inflation pressures desired. Therefore, it was decided to use small amounts of water as an inflation medium. The water was placed in blotters. For the fourth inflation test, the DGB parachute with the pillow band inflation aid was used. Different amounts of water were placed in each of the 20 pillows which form the band. Figures 18 and 19 indicate the rapid opening provided by water as an inflation medium. Examination of Figures 18a, 19a, and 19b reveals that the canopy had opened quite far, even before it was completely out of the canister. Figures 18b and 19c show the extent of opening after the canopy has traveled approximately 25 feet.

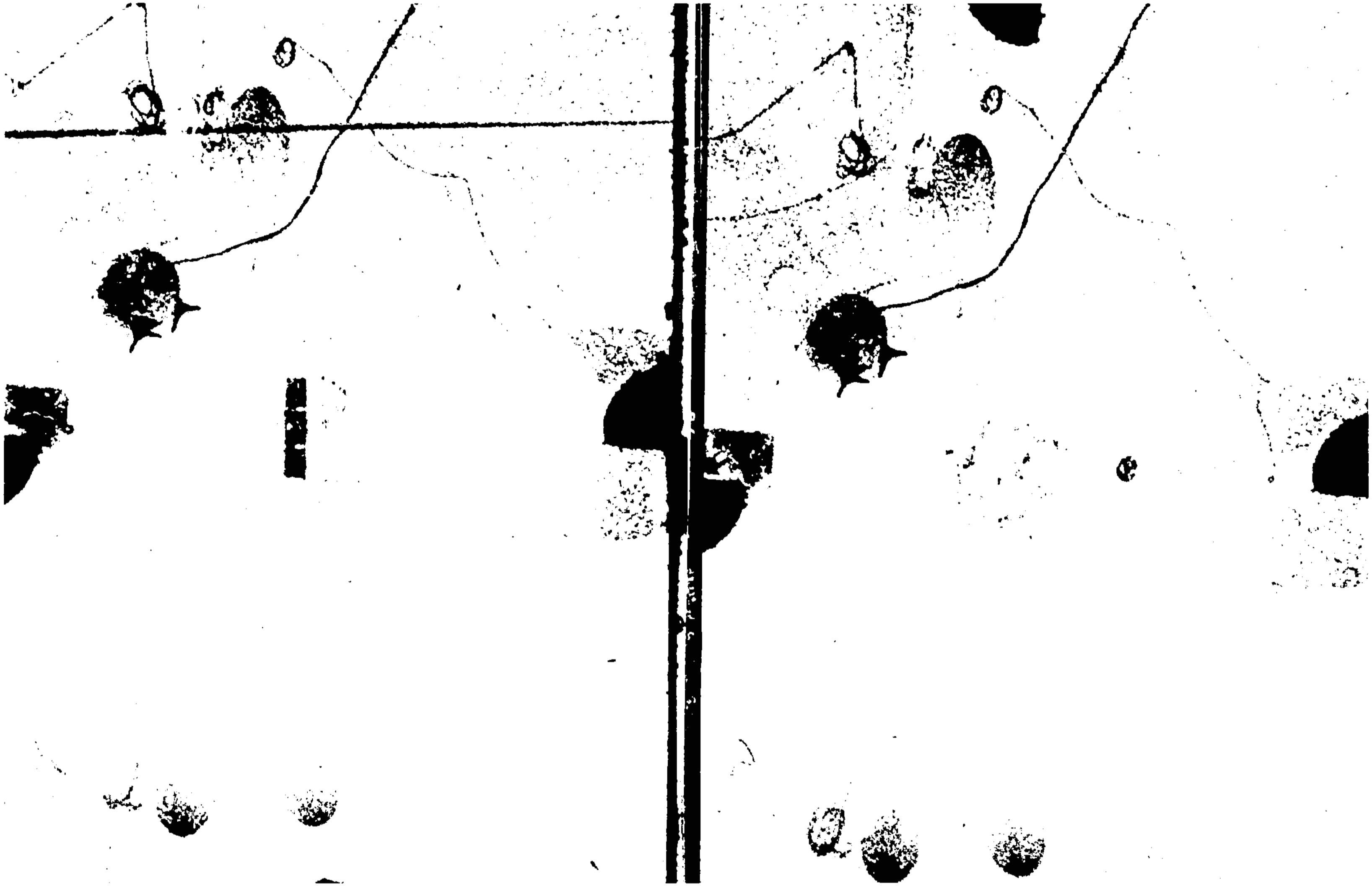

Figure 18, Top View of Vacuum Chamber Showing Inflation Test of the Disk-Gap-Band Parachute

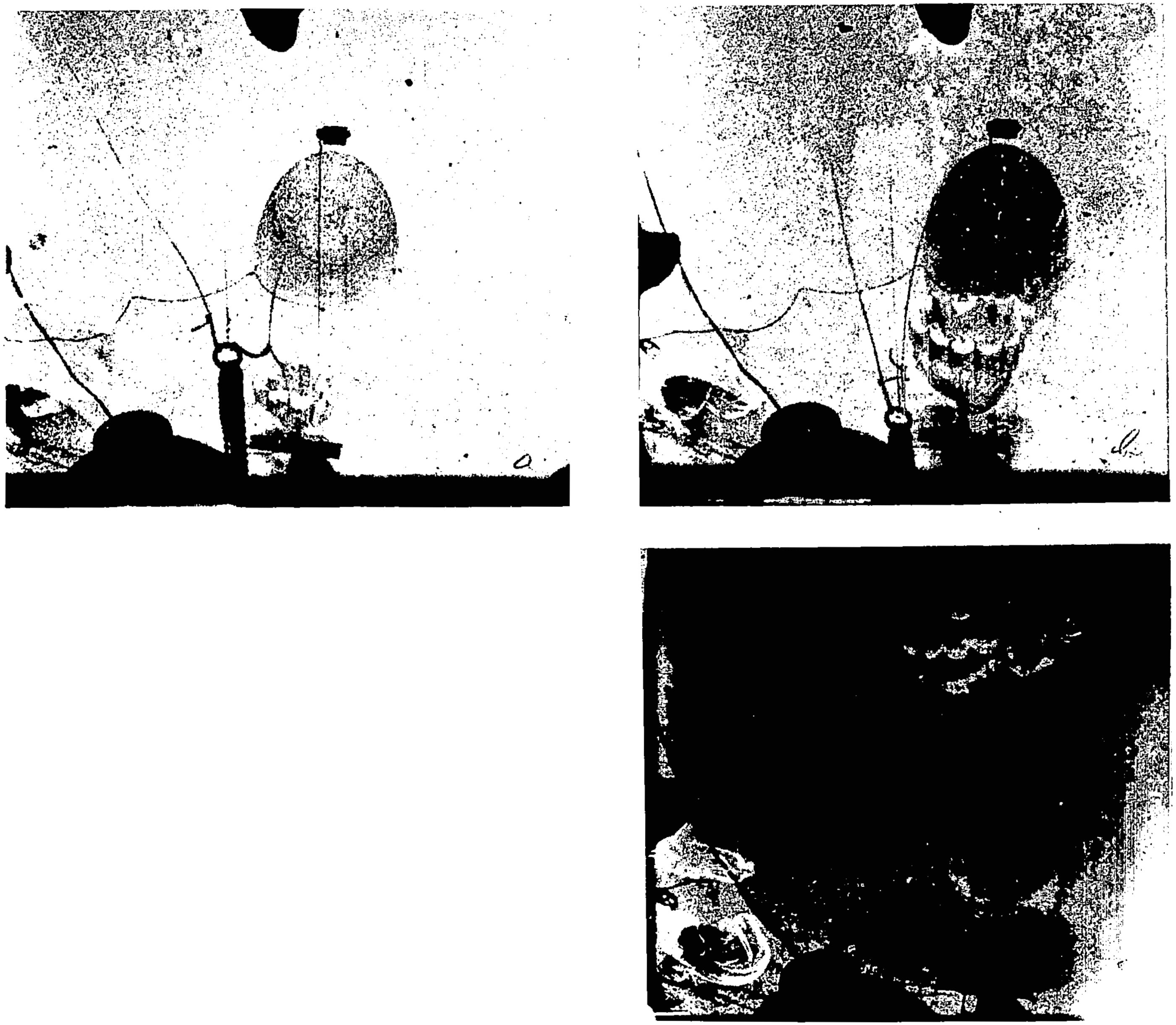

Figure 19. Side View of Vacuum Chamber Showing Inflation Test of the Disk-Gap-Band Parachute

The fifth inflation test was with a DGB parachute having a separate 4-inch diameter torus inflation aid located on the inside surface of the band. The inflation medium was 6 cc of water soaked in blotters. As can be seen from Figure 20, inflation was instantaneous and the torus completely rigidized. This was the most successful test of the series.

For comparison purposes, a DGB parachute with no inflation aid of any kind was ejected in the sixth test. The opening characteristics were not as bad as expected since the canopy opened partially in the short distance it traveled.

Calculations indicated that 1.5 cc of water in a 3-inch diameter torus inflation aid should provide complete pressurization, if all the water evaporated, and the temperature of the water vapor did not drop below that of the test chamber. Test No. 7 was with such an inflation aid. The 1.5 cc of water did not provide complete inflation. This was explained by further vacuum chamber tests which revealed that the temperature of the water decreased considerably as it vaporized because of the energy required for vaporization. Sample tests indicated that the temperature of the water decreased so much that the unvaporized water froze. It was also demonstrated that excess water could be used as a heat sink. This may explain why 6 cc of water worked quite well in Test No. 5 whereas 1.5 cc of water was only partially successful in Test No. 7.

C. Results

The first inflation tests, conducted in the vacuum chamber, indicated that residual air did not provide sufficient pressure in the torus or

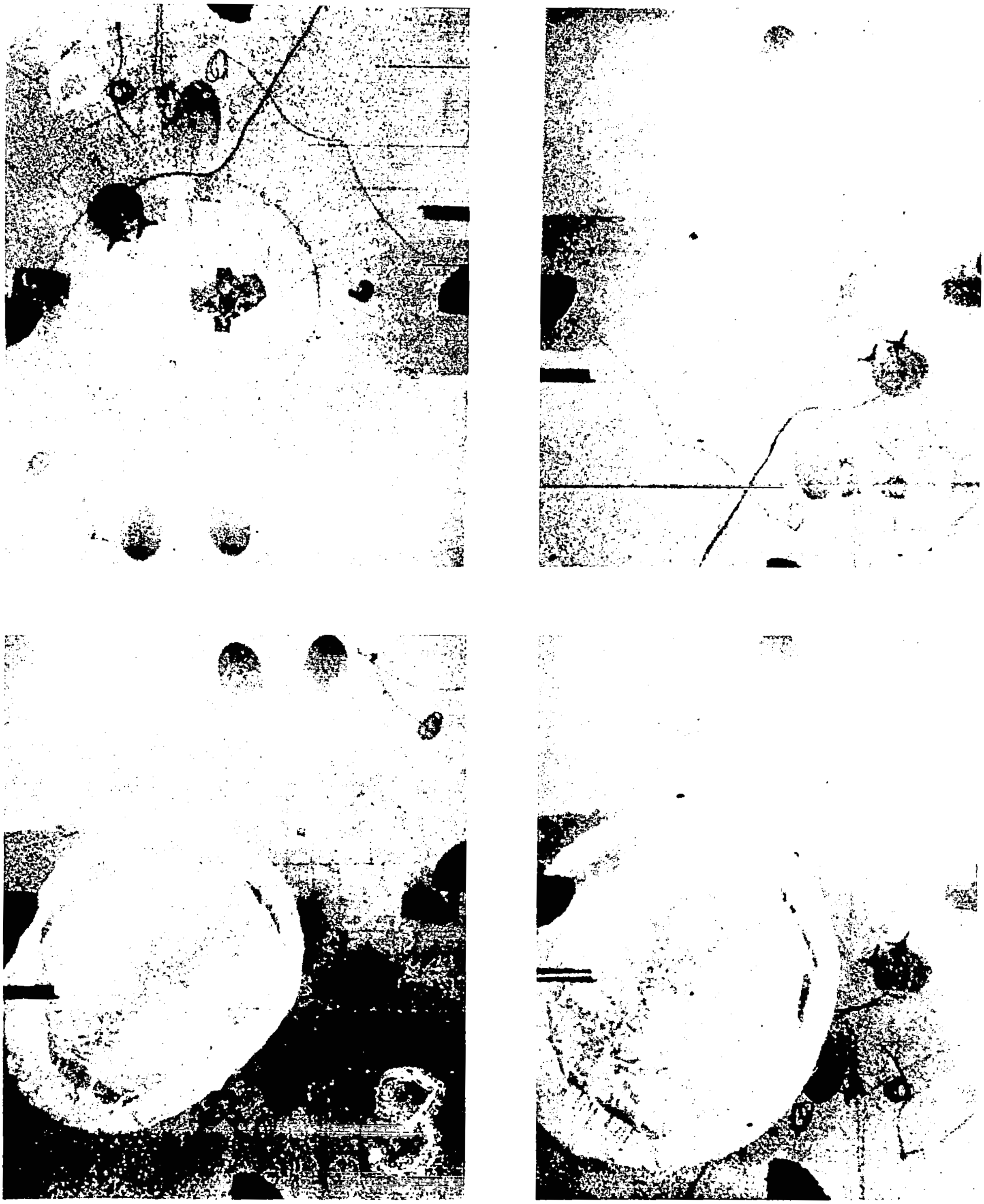

Figure 20. Top View of Vacuum Chamber Showing Inflation Test of the Disk-Gap-Band Parachute with a Torus Inflation Aid

the pillow band to effectively aid canopy deployment at simulated altitudes of 200,000 feet or more. Further tests using water vapor as the pressurizing medium for the torus and pillow bands were very successful in providing rapid and complete opening of the parachute canopy immediately after ejection from the canister. In addition water vapor provided some canopy rigidization after canopy deployment was completed.

The water is stored in the torus or pillows by placing it in blotters and wrapping it in Saran wrap. This is necessary to prevent evaporation of the water under atmospheric conditions. Care is taken to assure that the water vapor can escape when the blotter packet is subjected to low pressures.

A 4-inch diameter torus with 6 cc of water was selected as the inflation aid system for the high altitude flight tests, as it required much less packing volume than the pillow band inflation aid system.

V. PARACHUTE DROP TEST FROM A HELICOPTER

To better observe the deployment, inflation, and descent characteristics of the Disk-Gap-Band parachute it was dropped from a helicopter at low level.

The canopy and its inflation aid, the folding and packing procedure, the suspension line holder, and the deployment bag were all similar to those to be used on the rocket flight tests.

As shown in Figures 21 and 22 a through d, the inflation occurred almost instantaneously after release from the helicopter.

At 600 feet altitude there was a 12 to 15 knot wind. The helicopter was headed into the wind to give zero ground speed at the time of the drop. The lower level wind direction changed about the time of the drop and this change carried the parachute away from the ground camera and toward the runway seen in the photos. Observations of the DGB parachute descent, confirmed by the photos, indicated that the canopy did not oscillate during the descent. The parachute did drift with the wind, but no exact information on angle of drift or of wind velocities was available for analysis.

The test is considered completely successful, and there was no visible damage to the DGB parachute other than the loosening of some scrim threads on the material as it was dragged across the concrete runway after ground impact.

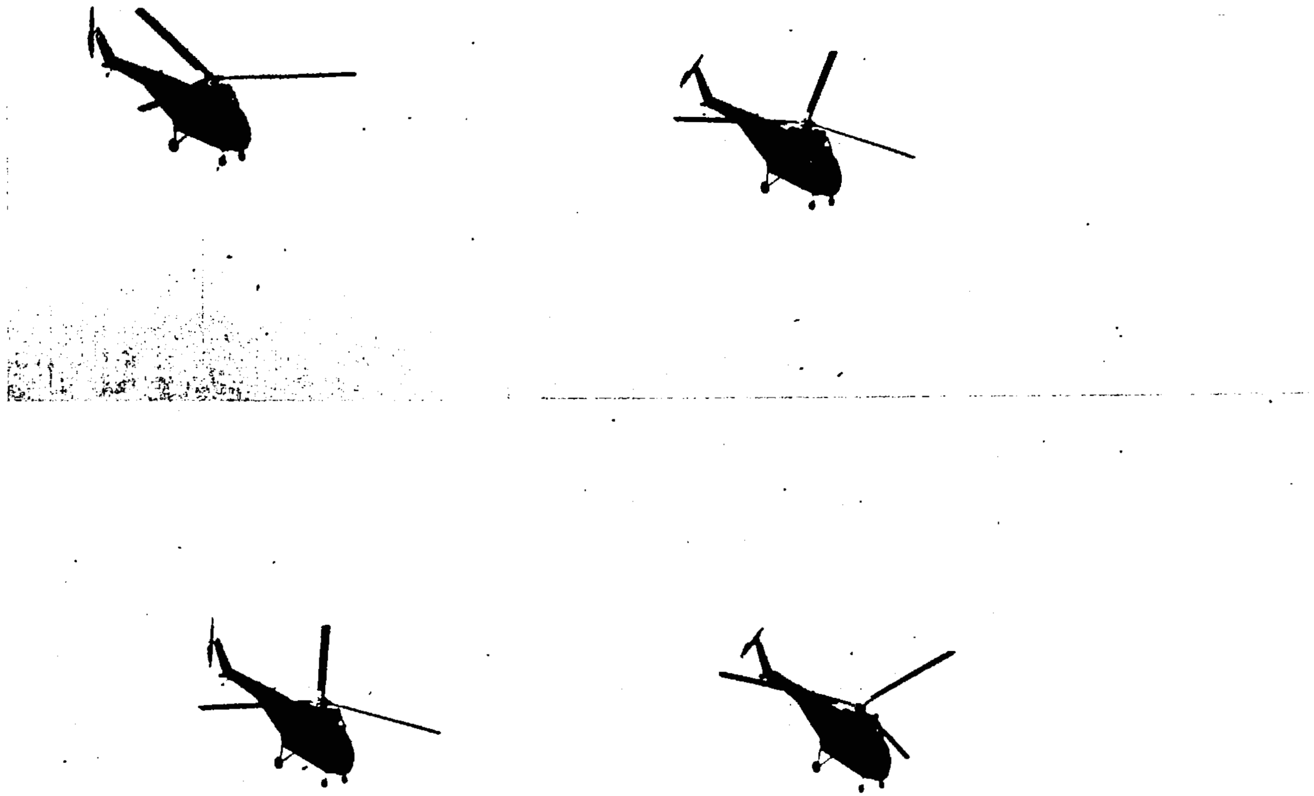

Figure 21. Deployment of the DGB Parachute from a Helicopter

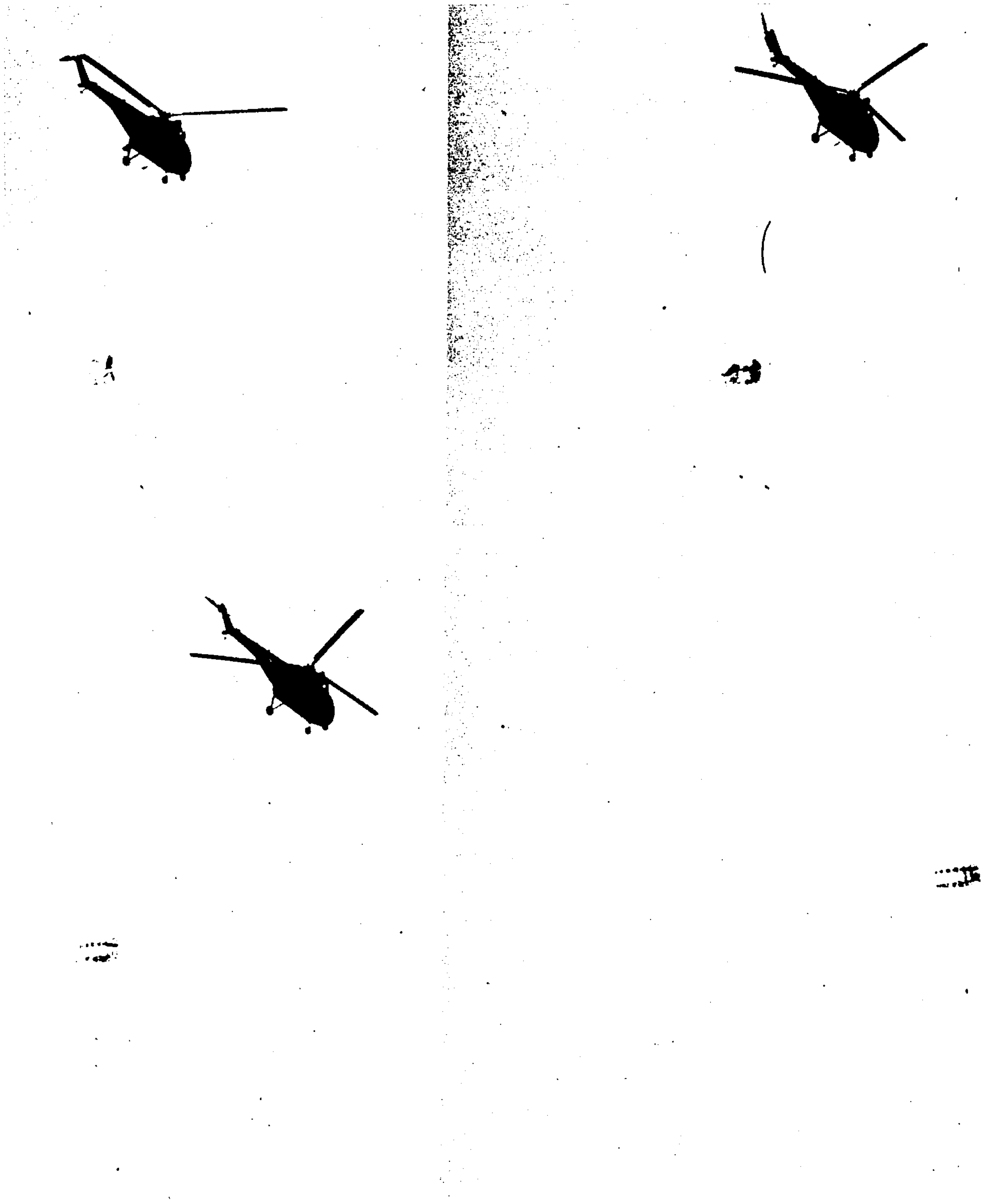

Figure 22. Deployment of the DGB Parachute from a Helicopter

VI. HIGH ALTITUDE FLIGHT TESTS

A. General

Four series of flight tests were conducted (for a total of 11 flights) to determine the performance of the Disk-Gap-Band parachute system under actual operational conditions. Series 1, 2, and 4 flight tests were conducted at White Sands Missile Range in New Mexico. Series 3 tests were at NASA Wallop Station in Virginia. NASA Langley Research Center was in charge of the flight test program, and supplied all equipment including payloads. Solid propellant, spin-stabilized, sounding rockets were used to boost the parachute and payloads to altitudes of 194,000 to 232,000 feet under normal conditions. An N-9 type 16mm camera, as described in Reference 3, was used to record parachute performance on four flight tests; and a High-G camera payload system, also supplied by NASA Langley Research Center, was used on two flights. Radar track of the descending parachute system provided information on the descent rates.

B. Flight Test Parachutes

The DGB parachutes used for the flight tests were constructed of an extremely thin (0.00025 inches thick) metalized polyester film reinforced by scrim. The metalized film gave radar reflectivity and resistance to air flow, while the scrim provided tear resistance and the tensile strength needed to absorb shock loads and other aerodynamic forces. Because the DGB parachute is constructed of nonpermeable reinforced film, its stability probably does not change with altitude as do parachutes constructed of woven materials whose permeability varies with atmospheric density. (References 2 and 4).

Details of the construction of the DGB parachutes used in the flight tests is presented in Table 5.

All the DGB parachutes flight tested were equipped with torus inflation aids. The inflation aids were pressurized with water vapor. The 4-inch cross-section diameter tori were designed to assist in the canopy opening only, and did not influence the inflated canopy other than to assure that it retained its natural "in flight" shape. The water which vaporized to pressurize the torus was stored in blotters wrapped in Saran, and located in the torus. All the DGB parachutes (except no. 9) were equipped with miniature ball bearing swivels, located between the parachute and the payload. The swivels were utilized to allow differential rotation between the parachute and the payload while the rocket imparted 1800 RPM rotation rate was dissipating.

It should be noted that the DGB parachutes numbers 6, 8, 9, and 10 had 12.5 per cent open area rather than the 15 per cent open area used at the start of the flight test program. The open area was reduced to determine if a corresponding increase in drag efficiency would result.

At the beginning of the flight test program, the standard method of deploying or ejecting the nose cone payload and the parachute was used. This is as follows: (Reference 3)

1. At or near the maximum altitude of the rocket flight an explosive charge is fired which forces the nose cone (containing the payload) and the parachute deployment bag from the forward end of the rocket.
2. The parachute deployment bag is restrained by a lanyard

TABLE 5

DGB PARACHUTE CONSTRUCTION DATA

SERIAL NO.	NOMINAL DIAMETER (feet)	TOTAL AREA S_o (sq ft)	DISK DIA. (ft)	GAP WIDTH (inches)	OPEN AREA (%S_o)	BAND WIDTH (inches)	SUSPENSION LINE LENGTH (feet)	PARACHUTE WEIGHT
1	16.8	222	12	10-1/2	15	24	18	2.6
2	16.8	222	12	10-1/2	15	24	18	2.6
3	16.8	222	12	10-1/2	15	24	18	2.6
4	18	255	12.86	11-3/8	15	25-7/8	20	2.8
5	18	255	12.86	11-3/8	15	25-7/8	20	2.8
6	16.6	216	12	8-1/2	12.4	24	18	2.49
7	16.8	222	12	10-1/2	15	24	18	2.49
8	16.6	216	12	8-1/2	12.4	24	18	2.50
9	17.75	247.5	12.86	9	12.4	25-7/8	20	2.19
10	16.6	216	12	8-1/2	12.4	24	18	2.50

and a cable from traveling more than about 5 feet ahead of the rocket.

3. The payload continues forward, deploying the suspension lines and the canopy.
4. The parachute canopy remains attached to the deployment bag by means of a break cord attached to the canopy apex, until the suspension lines and the canopy are deployed full length, and the break cord snaps.

This method of deployment was later found to be unsatisfactory and was modified as indicated in Part D of this section.

C. Series One Flight Tests

The first series of tests, conducted from White Sands Missile Range (WSMR) in July of 1964, consisted of three flights. The parachutes for these flights were 16.8 feet nominal diameter DGB parachutes, serial numbers 1, 2, and 3 as listed in Table 5. The first DGB parachute flight tested had a Delta temperature sensing instrument as the payload. The purpose of this first flight test was to prove the parachute system worked before the more expensive camera payloads were used. Examination of the radar track of the parachute descent indicated everything operated normally. The second DGB parachute was then flight tested with an N-9 camera as the payload. Again the radar track indicated normal operation. A third flight test was therefore conducted, again with an N-9 camera payload. Examination of the radar track of this third flight indicated descent rates slightly higher than anticipated. The parachutes and camera payloads of both flights 2 and 3 were recovered, and examination of the film from flight 2 indicated near perfect operation after deployment. Four frames of the movie film from flight 2 showing ejection, line stretch, inflation and steady descent are shown in Figure 23.

Wind tunnel tests of a DGB model indicated that this particular configuration was aerodynamically stable at an angle of attack of plus or minus six degrees. The film from the flight test indicated even better stability once the initial opening and deployment disturbances had damped out. Examination of the film from flight 3 indicated that the suspension lines became entangled during ejection, resulting in a constricted canopy size, as shown in Figure 24, during the steady descent portion of the flight. Data concerning these flights are presented in Table 6. Examination of these flight data reveals that the average C_D value for the first flight is very low. This may indicate restriction of the canopy size by suspension line entanglement. The C_D given for flight 2 is correct for a DGB parachute with 15 per cent open area.

D. Series Two Flight Tests

A second series of flight tests was conducted from WSMR in September of 1964 to determine if suspension line keepers, located at the confluence point of the suspension lines, would assist in preventing line tangling problems. The size of the parachutes used for these tests was increased to a nominal diameter of 18 feet as indicated in Table 5, to provide the maximum possible drag area for the available packing volume.

The suspension lines of DGB parachutes numbers 4 and 5 also tangled

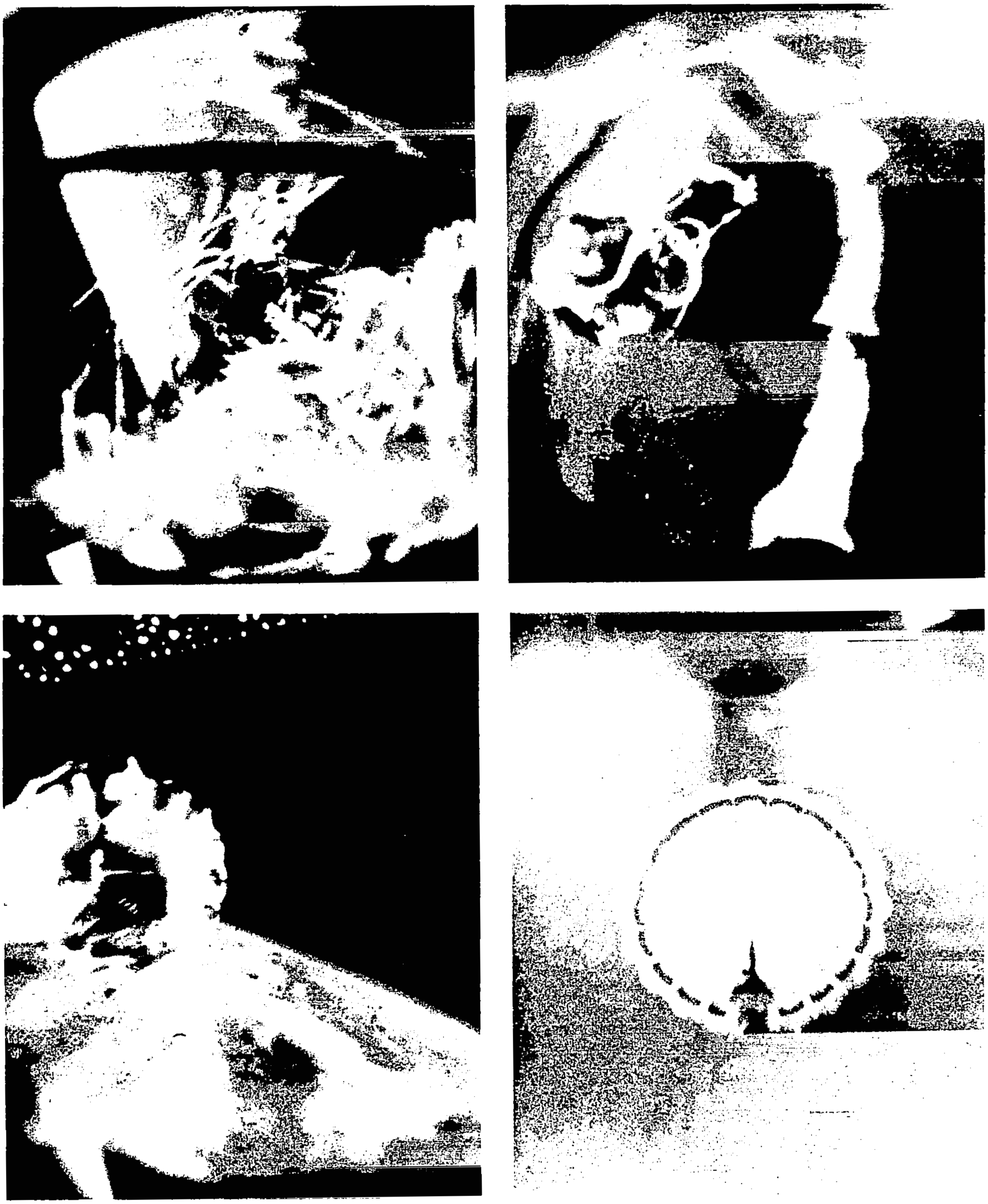

Figure 23. Deployment Sequence of DGB Patachute Ejected from a Sounding Rocket at 209,000 feet Altitude

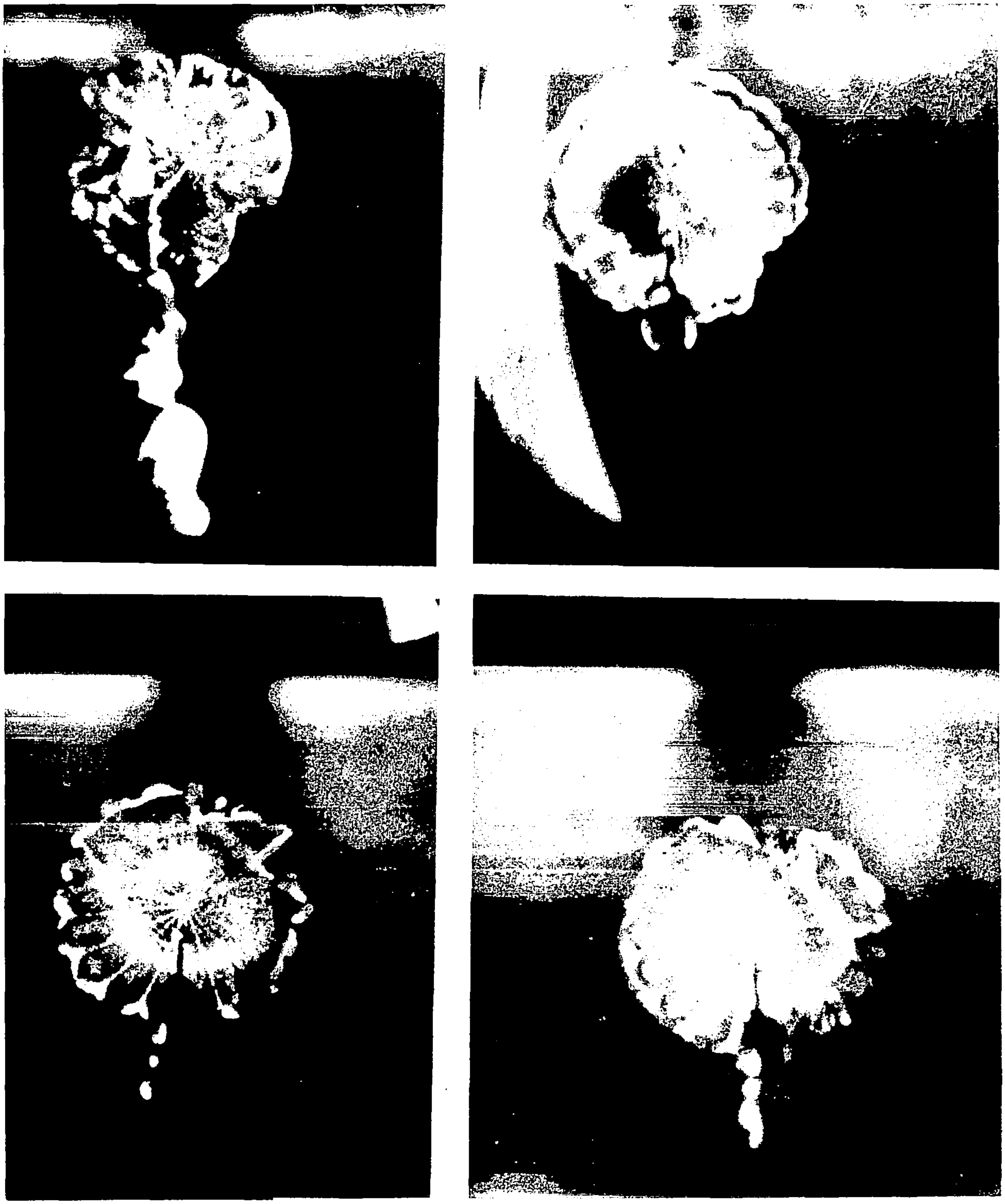

Figure 24. Restricted Canopy Shape Resulting from Tangled Suspension Lines

TABLE 6

DGB PARACHUTE FLIGHT TEST DATA

TEST SERIES	FLT. NO.	DGB SERIAL NO.	LOCATION	DATE	TIME	PAYLOAD TYPE	PAYLOAD WEIGHT, (lb)	MAXIMUM ALTITUDE, (ft)	AVE C_D	REMARKS	TOTAL WT.
1	1	1	WSMR*	7-8-64	0430 MST	Delta Inst.	3.30	229K	0.300	Not Recovered	5.90
1	2	2	WSMR	7-9-64	0630 MST	N-9-2 Camera	7.94	209K	.475	Good Flight	10.54
1	3	3	WSMR	7-14-64	0745 MST	N-9-3 Camera	7.94	224K	.350	Lines Tangled	10.54
2	4	4	WSMR	9-17-64	0645 MST	Hi-G Camera	7.87	205K	.450	Lines Tangled	10.67
2	5	5	WSMR	9-24-64	1300 MST	N-9-1 Camera	7.94	213K	.325	Lines Tangled	10.74
3	6	6	Wallops Island	3-4-65	1110 EST	Ballast	----	129K	No Test	-------------	-----
3	7	7	Wallops Island	5-4-65	1345 EST	Ballast	8.34	194K	.575	Good Flight	10.83
4	8	8	WSMR	5-20-65	0545 MST	N-9-1 Camera	8.35	219K	.500	Good Flight	10.85
4	9	9	WSMR	5-21-65	1100 MST	Dart Inst.	1.67	285K		Unsatisfactory Deployment	3.86
4	10	10	WSMR	6-3-65	0730 MST	Hi-G Camera	7.04	232K	.520	Good Flight	9.54
4	11	8	WSMR	6-2-65	1300 MST	Delta Inst.	3.30	232K	.500	Good Flight	5.80

*WSMR - White Sands Missile Range, New Mexico.

during the deployment sequence of the flight tests. Examination of the recovered parachutes revealed that the tangling of lines on both flights was partly due to improper use of the suspension line keepers. However of more importance was the determination that the parachute ejection and deployment sequence did not occur as anticipated. It was found from an examination of the motion pictures of these tests, and those of series one, that the parachute canopy was ejecting immediately from the deployment bag and following closely behind the payload. During this time the suspension lines deployed from the line holder but were not under tension and were flying loose. As the parachute canopy opened and attained aerodynamic drag it moved aft from the payload. However, in three of the four flights having movie coverage, the lines tangled during the period they were not under tension, thus preventing full deployment of the parachute canopy. The analysis of the flight test movies showed that the standard deployment method was not providing proper control of the parachute deployment sequence, and that a new or modified deployment method was required.

E. Redesign of the Deployment System

The most important item to be considered on any parachute deployment method is the assurance that suspension lines are kept in tension at all times during line and canopy deployment. To accomplish this, the deployment bag was redesigned by placing one and three-quarter inch wide canopy restraining straps inside the bag, and by attaching the suspension line holding strip to the deployment bag. This accomplished three things: 1) attaching the suspension line holding strip to the deployment bag assured that the lines deployed from the payload attachment end only; 2) use of the deployment of the last loop of the suspension lines as the activating mechanism for release of the canopy assured against premature release; and 3) restraint of the canopy until the suspension lines were fully deployed assured that the canopy did not eject from the deployment bag until the suspension lines were stretched full length and under tension.

A prototype modified deployment bag containing a packed parachute was sent to NASA Langley Research Center (LRC) for ejection tests in the 60-foot diameter vacuum sphere test facility. The ejection tests conducted by LRC indicated the need for a shock attenuating system to absorb the momentum forces of the ejecting deployment bag containing a restrained canopy. A modified deployment bag with a shock attenuating lanyard is shown in Figure 25.

This same test series also confirmed that the previously used deployment method did not operate as expected and that the canopy ejected from the bag before lines were fully extended. The break cord did not restrain the canopy or aid in deployment of the canopy or suspension lines.

F. Series Three Flight Tests

After the deployment sequence had been satisfactorily modified, a third series of flight tests was conducted at NASA Wallops Station, Wallops Island, Virginia, for the purpose of confirming the operation of the new deployment bag under actual flight conditions. Two flights were planned with parachutes numbers 6 and 7 using dummy payloads

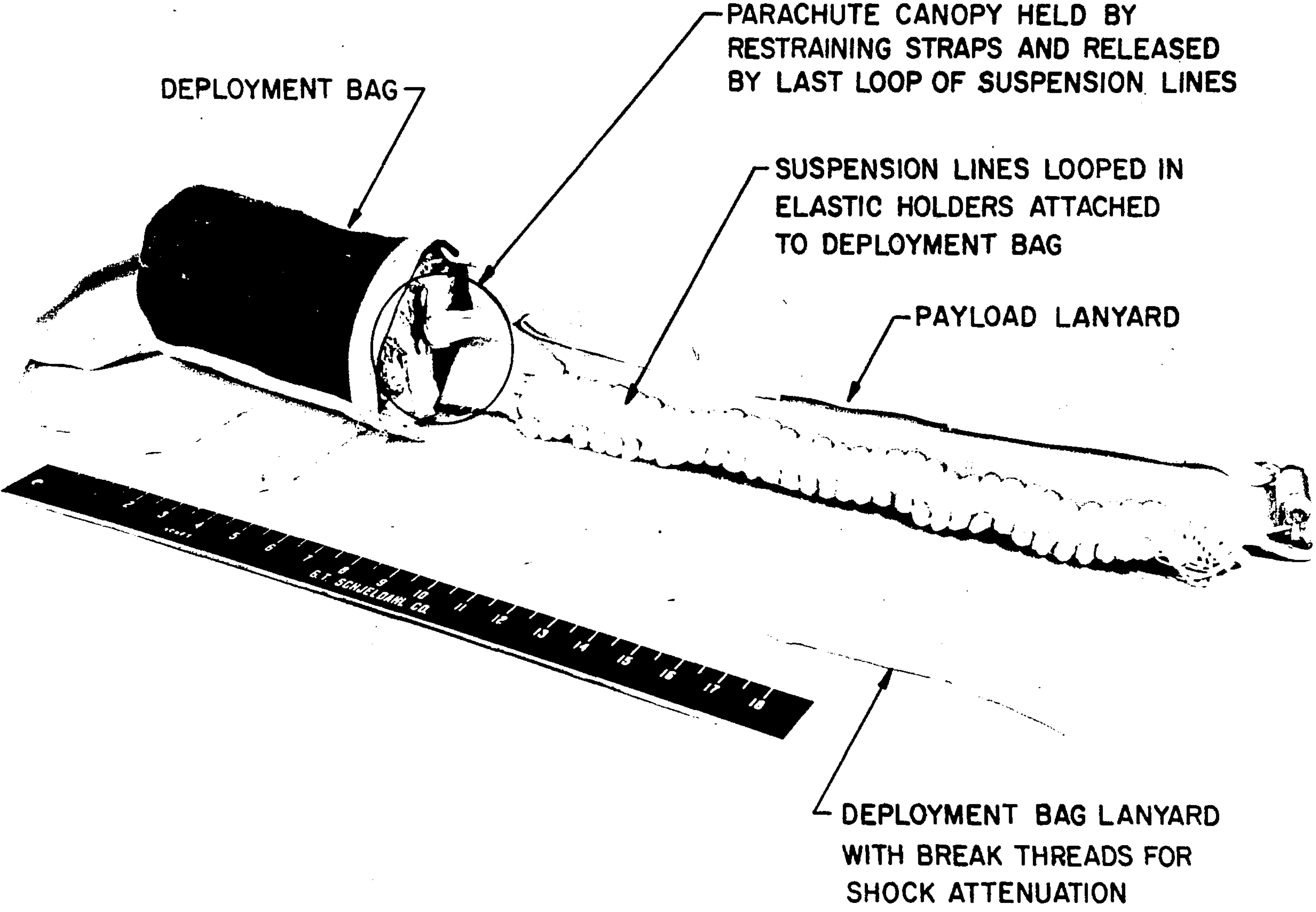

Figure 25. Modified Deployment Bag With Packed Parachute

which were buoyant. As can be seen from Table 6, flight 6 was considered "no test" as the rocket vehicle did not attain the required flight altitude for proper test conditions. However, the parachute did eject from the rocket and the deployment bag, after the prescribed time interval. The parachute ejection took place at an altitude of 129,000 feet. The parachute was recovered and was found to have the following damage:

1. The payload lanyard (1000-pound strength nylon line) had broken and the dummy payload (weight approximately 8.35 pounds) was not found.
2. Several suspension lines had broken, some at the confluence point, some midway, and others near the edge of the canopy.
3. The canopy had split down the center and a portion of the disk had separated and was not found.

Flight number 7 was also conducted at Wallops Station, but at a later time when wind conditions were more favorable for the rocket launch. This flight attained a maximum altitude of 194,000 feet and ejection, deployment, and descent of the parachute were completely successful. Figure 26 is a photograph of the descending parachute taken from a chase airplane. The parachute and the dummy payload were recovered by ship., and later examination revealed that there had been no significant damage. This third series of flight tests and the vacuum chamber ejection tests conducted at Langley Research Center indicated that the modified deployment system was working well.

G. Series Four Flight Tests

The fourth and final series of flight tests was then conducted at

Figure 26. DGB Parachute in Descent on Flight No. 7

WSMR, New Mexico in May and June of 1965. Two flights used camera payloads, a third flight was with a special lightweight DGB parachute and a Dart instrument package. A fourth flight was conducted when the parachute from flight number 8 was recovered and repacked, and used with a Delta instrument payload on flight number 11. The radar track of the first flight of this series, number 8, indicated excellent operation. The unit was recovered immediately, and the camera film processed. The camera film indicated that the ejection process took place in an orderly manner, and was extremely rapid. The entire ejection, deployment and inflation sequence took place on the first thirty-two frames of the movie film taken at 64 frames per second. The second flight of this series (9) was with the lightweight DGB parachute and a small Dart instrument package. For this particular flight the payload weight was less than the weight of the parachute. Therefore, the total rocket payload was very small and the rocket attained a much higher flight altitude than usual. Ejection of the parachute and payload took place at approximately 135 seconds after launch whereas the maximum altitude or 285,000 feet was not reached until 15 seconds later. The parachute ejection was observed on the radar but no separate targets were identified. A signal was received from the Dart instrument during the flight. The time of loss of the signal from the instrument coincided with the time of impact of the radar target. However, no exact reason can be given for the failure of the parachute to deploy properly. Because it is the usual procedure to eject the parachute and payload from the rocket at, or very near, the point of maximum altitude of the rocket flight, this particular experiment is being repeated by NASA Langley Research Center under more favorable ejection conditions. Additional information will be available at a later time.

The third flight of this series (no. 10) was with a standard DGB parachute system and a camera payload. The radar track indicated excellent operation and the unit was recovered. Examination of the camera indicated that it had not operated; this was later traced to failure of the batteries. Therefore no film of this flight is available. The average drag coefficient for this flight was 0.52, the highest experienced in the flight test program.

An extra flight test was conducted by reusing the first parachute recovered from this flight (no. 8). A standard Delta meteorological instrument was used as a payload. The radar track again indicated a good flight. In addition, there was little or no variation in the strength of the transmitted signal from the Delta instrument which indicates a very stable flight.

The modified deployment system used on the last two series of flight tests proved quite successful in preventing tangling suspension lines, by keeping the parachute under tension during the deployment sequence.

VII. CONCLUSIONS AND RECOMMENDATIONS

Correct deployment of the DGB parachute from a sounding rocket can be achieved at altitudes of 200,000 feet or higher by using a deployment bag which retains the canopy portion of the parachute until the suspension lines have been deployed full length and are under tension.

DGB parachutes equipped with torus inflation aids (pressurized with water vapor) inflate immediately at ejection altitudes of 200,000 feet or higher.

Movie films of the DGB parachute operating at or near 200,000 feet altitude indicate that the DGB parachute is very stable in flight, and remains fully open providing normal drag area at all times.

It has been determined from flight tests that the DGB parachute has an effective drag coefficient of approximately 0.5 based on total canopy area.

The DGB parachute system has been successfully tested at canopy loadings (dynamic pressures) as low as 0.052 pounds per square foot.

It is recommended that further studies be conducted with lighter weight parachute, and payload systems having lower canopy loadings to determine what maximum flight altitudes and minimum descent rates are possible.

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