TEXTILES USED IN FREE AIR FACILITY PARACHUTE TEST PROGRAM

D. L. Arenson, Senior Engineer
Cook Research Laboratories Division of Cook Electric Company
Chicago, Illinois

The Cook Research Laboratories Division of Cook Electric Company has been studying parachute performance as part of an Air Force program to develop recovery systems for high speed missiles and target aircraft. A multi-stage recovery system is being considered. In this type of system, the first stage of recovery consists of a small heavy-duty brake parachute. This parachute is deployed at supersonic speeds and decelerates the missile or target aircraft from a high initial velocity to a relatively low speed at which larger parachutes can safely be deployed. These larger parachutes further decelerate the missile to velocities safe for ground impact. Recovery methods associated with large low velocity parachutes, are reasonably well known; therefore, the initial phase of this project has emphasized the development of a small heavy-duty brake parachute which can be deployed at trans and supersonic speeds.

As part of this development, a technique for testing parachutes, under operation conditions, was required. It was desirable that full size parachutes be used in these tests to avoid the use of dimensional model factors. A high speed wind tunnel sufficiently large for full-scale parachute tests was not available for an extended test program. The probability of damage to equipment dropped from aircraft or used with free flight missiles made an extensive test program of that type prohibitively expensive.

The choice of a free air facility finally provided a suitable testing technique. This type of test facility consists of a straight precision aligned track similar to an ordinary railroad. The parachute, or other device to be tested, is mounted on a vehicle powered with a rocket motor. This vehicle runs along the track on stellite lined slippers. This type of facility, in addition to being relatively inexpensive to operate, allows convenient control of test equipment and simplifies obtaining camera records.

The 10,000 foot Free Air Test facility located at Edwards Air Force Base, California was made available for use on this project and two vehicles were designed and built for use on this track. The vehicle shown in Figure 17 was designed and fabricated as a parachute test vehicle and was used in the initial stages of this program. The vehicle is shown in Figure 18 in operation during a test of a FIST Ribbon parachute. The vehicle was powered by 3 to 5 solid propellant rocket motors. Speeds up to 550 miles per hour were attained with this unit. The parachute to be tested initially is packed at the rear of the capsule above the test vehicle. When a predetermined test velocity has been reached, a powder charge initiates a bag deployment of the parachute. The capsule also contains a magnetic tape recorder on which the output of sensing elements measuring parachute drag force, sled velocity, acceleration and impact pressure are recorded. A camera, located at the rear of the vehicle, provides graphic information about parachute stability and performance. Figure 19 shows a test vehicle which has recently been completed for testing parachute operation in the trans and supersonic speed ranges.

This vehicle is shown in operation during a test of a FIST Ribbon parachute. The unit is powered with a liquid oxygen alcohol thrust type rocket motor. The same type of instrumentation, photographic equipment, and magnetic tape recorder used with the subsonic vehicle is also provided in this unit.

At the conception of the program, four basic parachute types were considered to have opening characteristics and performance which might be suitable for use in high speed brake parachute applications. These parachute types, the Guide Surface, the FIST Ribbon, the Ring Slot and Rotafoil parachutes, have been subjected to a series of operational tests on the free air facility. In the course of these tests, such design parameters as fabric type, parachute geometry, and construction details were varied so as to evolve parachutes which would operate satisfactorily at increasingly high deployment velocities. Because of the limitation on the length of this paper, only details of tests with the Guide Surface and FIST Ribbon parachutes will be reported here.

Three variations of the Guide Surface parachute were tested. The Guide Surface parachute is distinguished by the conical guide surface placed below the skirt of the roof portion of the canopy to form a flow separation edge. Stability and drag depend upon the length of this guide surface. The stabilization variation shown in Figure 20, has the longest guide surface and thus gains stability at the expense of drag. The Guide Surface Brake parachute, shown in Figure 21, has a shorter guide surface and thus higher drag with comparatively less stability. The suspension lines on both the Stabilization and Brake variation of the Guide Surface parachute are supported inside the canopy on the fabric ribs which also constrain and define the canopy shape. If the ribs are omitted and the suspension lines carried over the top of the canopy, the Ribless variation of a Guide Surface parachute is obtained. This parachute is shown in Figure 22.

All variations of Guide Surface parachutes used in this test program were designed in accordance with military specification MIL-P-5905A and fabricated from Nylon. The physical dimensions of the Guide Surface parachute used in this program are shown in Figure 23. Parachutes of this type, which were tested in the initial phases of the program, were designed with 12 gores. Canopies were fabricated from materials satisfying U.S. Air Force Specifications No.16208A. The latter specification requires that fabric have the physical properties tabulated in Figures 24 and 25. Both Type I and II fabrics were used. Additional tests were conducted with parachutes fabricated from similar materials which had greater air permeabilities than permitted in the specification. Tests were also conducted with canopies which were sprayed with aircraft dope to reduce the effective air permeability below specification requirements. Suspension lines for all the Guide Surface parachutes were fabricated from 3/4 inch tubular nylon webbing with a tensile strength of 2,250 pounds.

The riser connecting the suspension line to the test vehicle consists of one to four strands of 10,000 pound break strength woven Nylon webbing. For each parachute type tested, performance curves similar to those shown in Figure 26 were obtained. The curves shown are results of tests with Ribless parachutes fabricated from Type I cloth. The upper curve shows the ratio of actual projected diameter to the design diameter as a function of time. The lower curve shows the time dependence of drag force divided by impact pressure (essentially a dynamic drag coefficient). In the range of speeds at which tests were conducted, there is little variation of performance with velocity. For each parachute type, these curves were used to obtain the idealized performance curves, shown in Figure 27.

The Ribless parachute fabricated from the Type I fabric opened properly and performed satisfactorily at speeds in excess of 400 miles per hour. At a deployment velocity of 502 miles per hour, the Ribless parachute fabricated from this material suffered severe damage on opening.

After several construction details had been modified, the Brake parachute also performed satisfactorily at 400 miles per hour.

Ribless and Brake parachute canopies fabricated from non-specifications materials, with an air permeability of 107 cubic feet per square foot per minute at 1/2 inch pressure, never fully inflated in the range of deployment speeds tested. Parachutes with canopies, which were doped to reduce permeability to a nominal 40 cubic feet per square foot per minute at 1/2 inch water pressure differential, were found to open readily in the same range of deployment velocity although they were comparatively unstable in operation.

Stabilization type parachutes, fabricated from Type I fabric, which satisfied the permeability specifications and which were tested in this speed range, showed the same poor inflation characteristics exhibited by the Brake and Ribless parachutes fabricated from the high permeability materials. The solid curves in Figure 27 characterize these inadequate openings. However, parachutes of the same design, fabricated from the Type II fabric, opened satisfactorily. Figure 28 shows a partially inflated or squidded stabilization canopy. This difference in the opening characteristics of parachutes, fabricated from the two different materials, is similar to that which would be expected if the fabrics differed in permeability. Figure 29 compares the permeability of the two fabrics at various pressure differentials up to 20 inches of water. It is seen that the fabrics do not differ appreciably. However, the actual pressure drop across the canopy fabrics in the speed range in which tests were conducted is in the order of two to three times the maximum pressure at which these permeabilities were determined. It is felt that a variation in permeability at higher pressures might explain the different opening characteristics observed. Further experimental information about fabric permeabilities in very high pressure ranges is therefore urgently required.

Stabilization parachutes fabricated from the Type II fabric were deployed with only slight structural damage at speeds in excess of 502 miles per hour.

Parachute tests at high deployment velocity, using the supersonic test vehicle, are now being conducted. Initial tests with this vehicle have been made, using parachutes fabricated from a 13 ounce per square yard nylon with the properties tabulated in Figure 30. A stabilization parachute, fabricated from this material, failed at a deployment velocity of 590 miles per hour. The photograph of that parachute, shown in Figure 31, indicates that the failure occurred along the seams at the junction of rib and canopy. Parachutes with an improved seam design are now being fabricated. However, even with better seam designs, it is apparent that stronger fabrics with more favorable weight and bulk characteristics will be required at transonic speeds.

Extensive tests were also conducted with the Ribbon type parachute. Figure 32 shows a FIST Ribbon type 90 parachute in the process of inflation. The photograph was taken by a camera at the rear of the test vehicle. A single gore of the Ribbon type parachute is shown in Figure 33. Note that it consists of rows of horizontal ribbons spaced by vertical ribbons. The gores are triangular in shape and are joined to one another by radial ribbons which extend from vent to skirt and which transfer the forces developed on the horizontal ribbons to the suspension lines.

All Ribbon parachutes for this test program were designed in accordance with Military Specifications MIL-P-6635 and fabricated from Nylon. Dimensions of parachutes of this type which were tested are tabulated in Figure 34.

The porosity of a Ribbon parachute is the percentage of open area in the canopy divided by its total area and corrected for the air permeability of the ribbons. Porosity influences the opening characteristics and stability of Ribbon parachutes in much the same manner as air permeability affects these characteristics in Guide Surface parachutes. For example, a parachute with excessively high porosity will not inflate properly. Such a partially inflated or squidded Ribbon parachute is shown in Figure 35.

Materials used in the fabrication of ribbon parachutes are summarized in Figure 36. Properties of the ribbons used for the horizontal ribbons are shown in Figure 37.

The 200 pound break strength ribbon was used with parachutes which performed satisfactorily at deployment velocities above 500 miles per hour. The 1000 pound ribbon is being used on parachutes currently being tested on the supersonic test vehicle.

In the subsonic tests, the suspension lines of the test parachutes are attached to one to four strands of 10,000 pounds woven of nylon webbing which acts as a riser and is connected through a tensiometer to a test vehicle.

These risers failed during parachute inflation at approximately 50% of rated static load. See Figure 38. These failures emphasize the need for a design factor of at least 2 to account for dynamic loading in parachute design. This entire test program has and is being conducted with emphasis on development of a workable high speed parachute. There has therefore been little time for the type of studies and controlled tests in which a single parameter is varied over a wide range. However, it has become apparent that such detailed information should be obtained. Typical of questions which should be carefully studied are the following:

How does the strength of parachute fabric vary under dynamic loading conditions?

What is the variation of a fabric permeability with speed in differential pressure ranges from 50 to 1000 inches of water?

How closely should manufacturing tolerances on fabric permeability be held both on various manufacturing runs and over one piece of cloth?

What is the nature of stress distribution in canopies?

What is the actual loss in fabric strength at seams? How can stronger seams be obtained?

Figure 17. Subsonic Test Vehicle

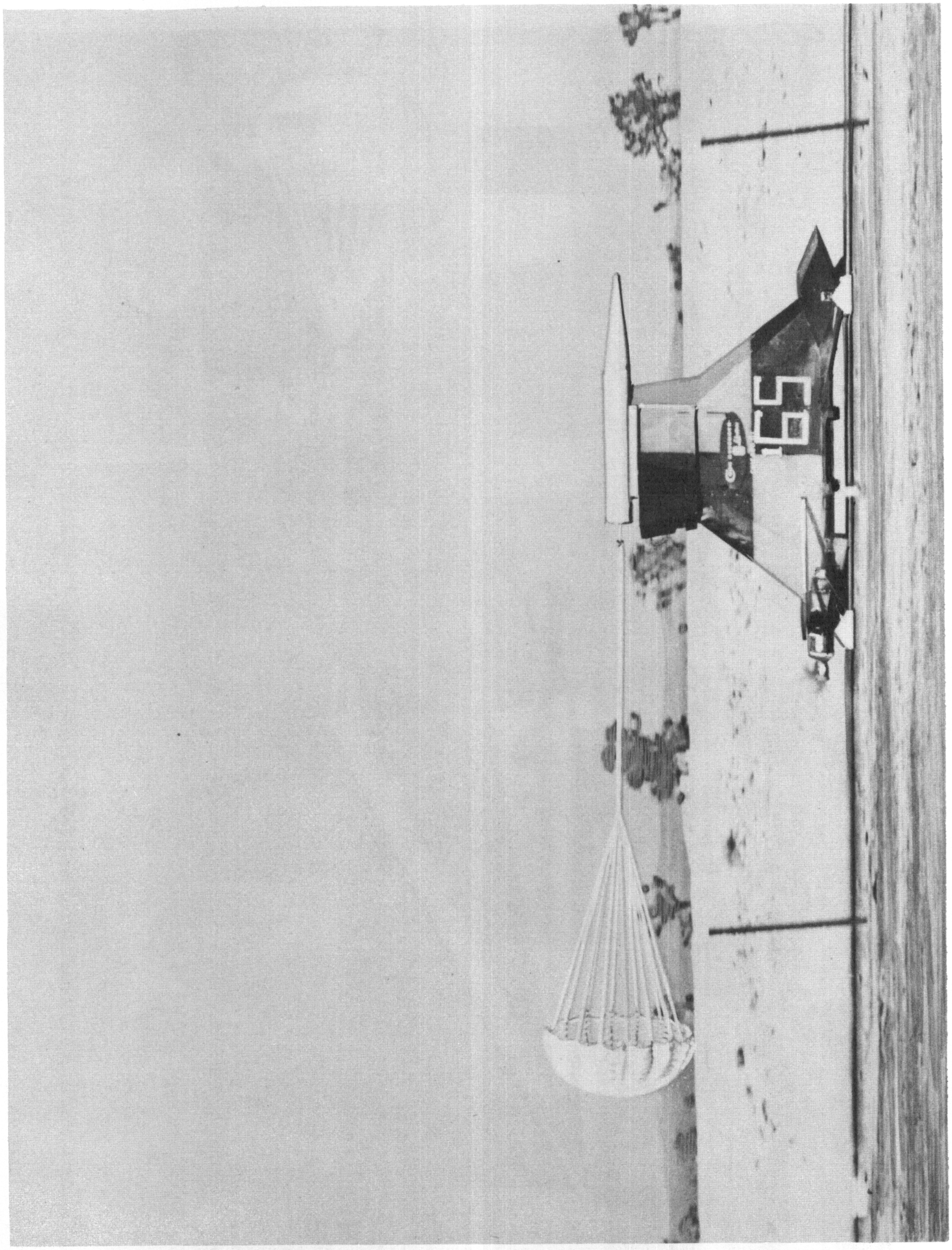


Figure 18. Subsonic Test Vehicle in Operation

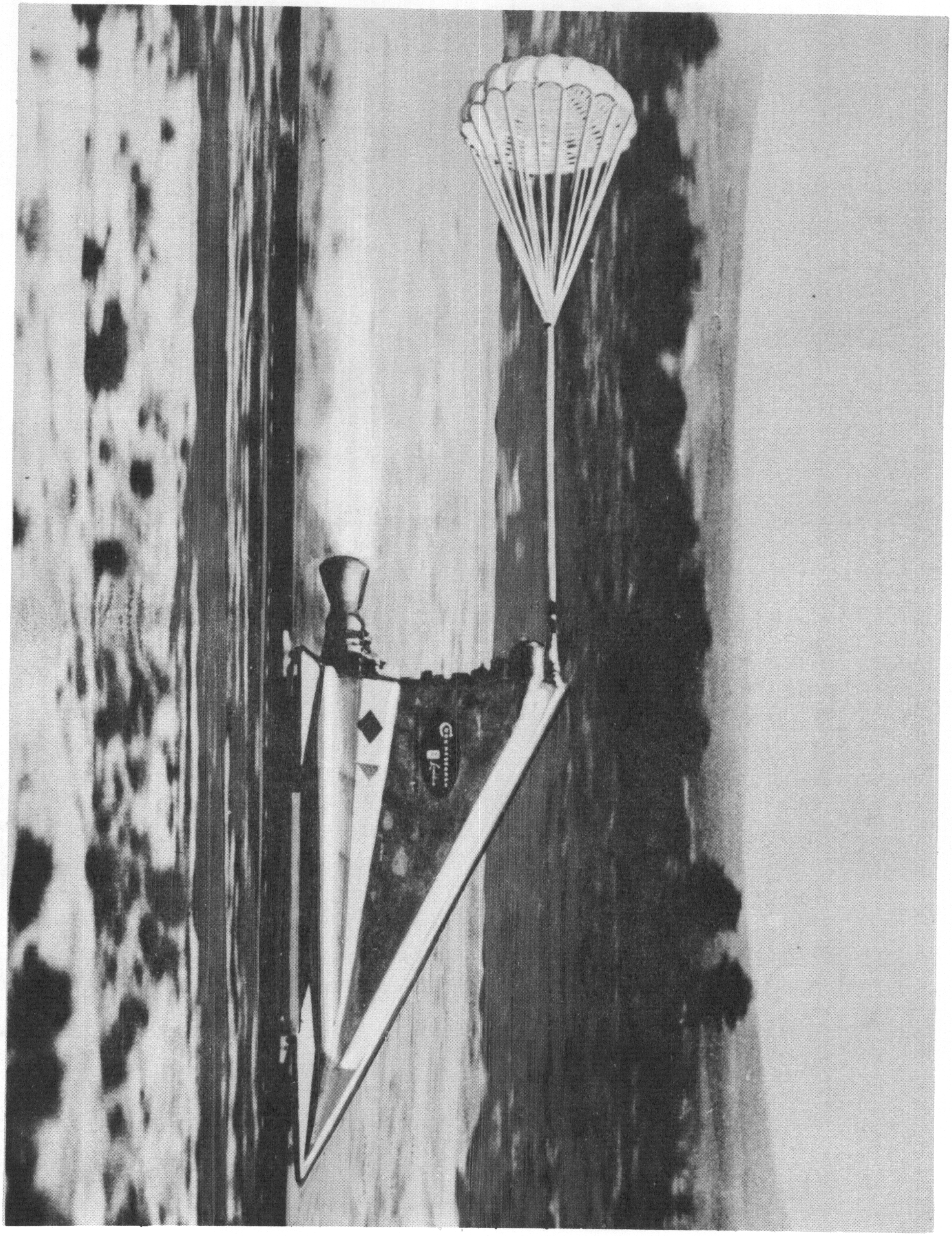


Figure 19. Supersonic Test Vehicle

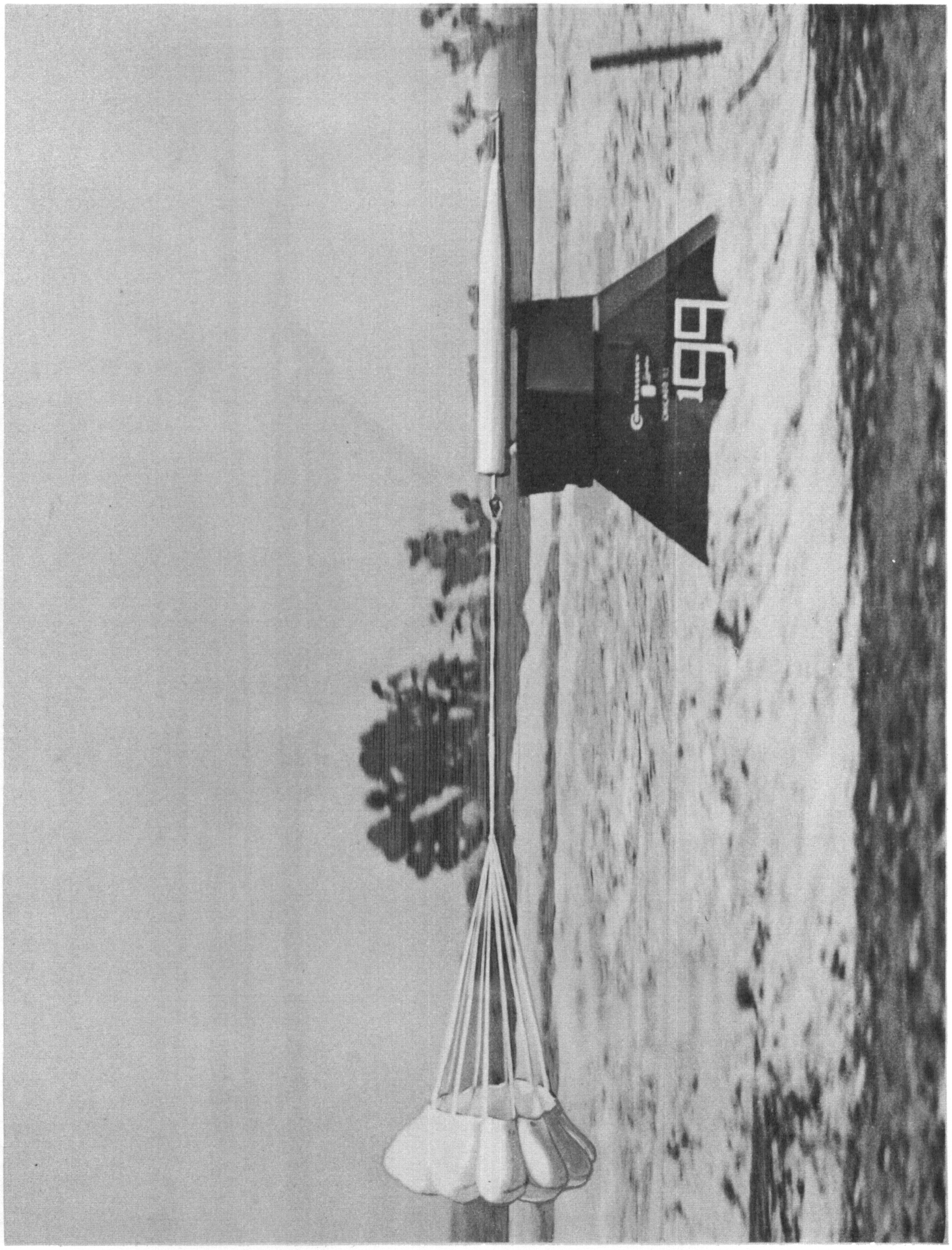


Figure 20. Guide Surface Stabilization Parachute

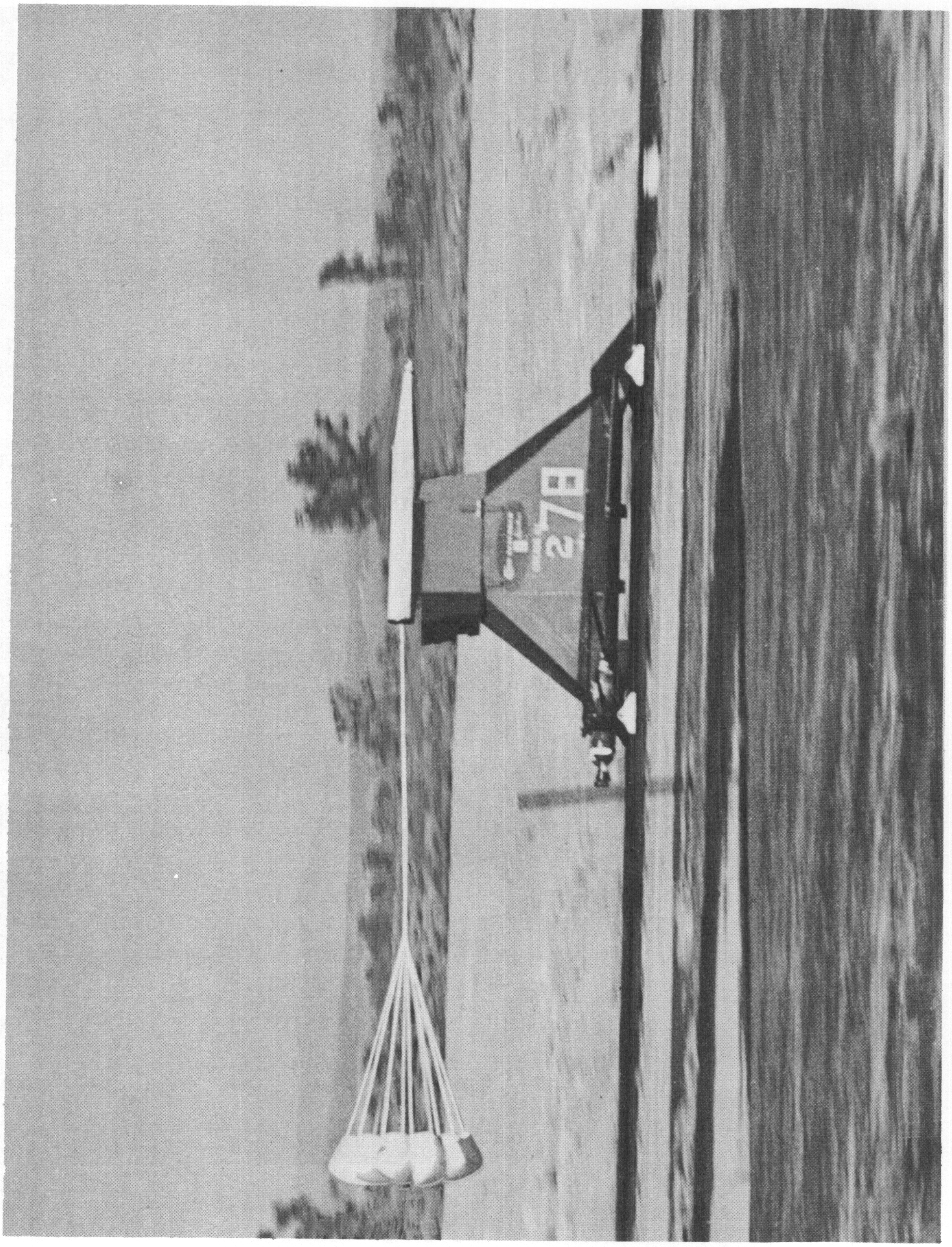


Figure 21. Guide Surface Brake Parachute

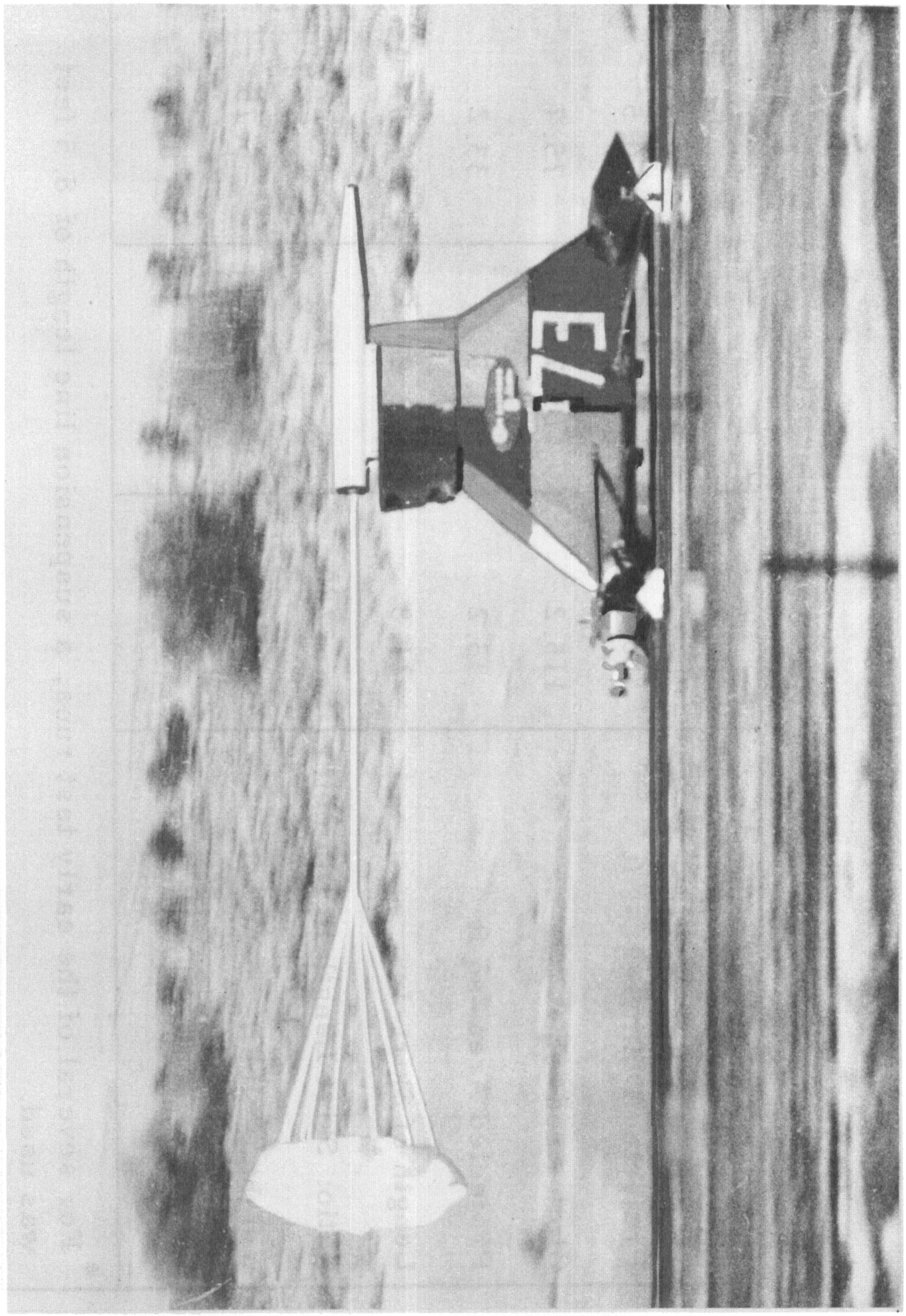


Figure 22. Guide Surface Ribless Parachute

Guide Surface Parachute Dimensions

Parachute Type	Stabilization	Brake	Ribless
Projected Diameter - ft	6.5	6.0	6.5
Cloth Area-sq ft	115.2	65.7	75.7
Projected Area-sq ft	33.2	28.3	33.2
Length of Skirt-in.	21.8	12.8	17.9
Ratio: Skirt Length to Diameter	.280	.178	.229
Weight - lbs	7.3	5.37	5.75
Suspension Line Length - ft	8.1*	7.5*	8.1*

*For several of the early test runs, a suspension line length of 8.5 feet was used.

Figure 23. Dimensions of Guide Surface Parachutes

Properties of Nylon Canopy Fabrics Used for Guide Surface Parachutes

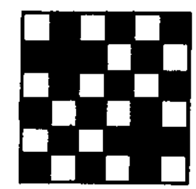
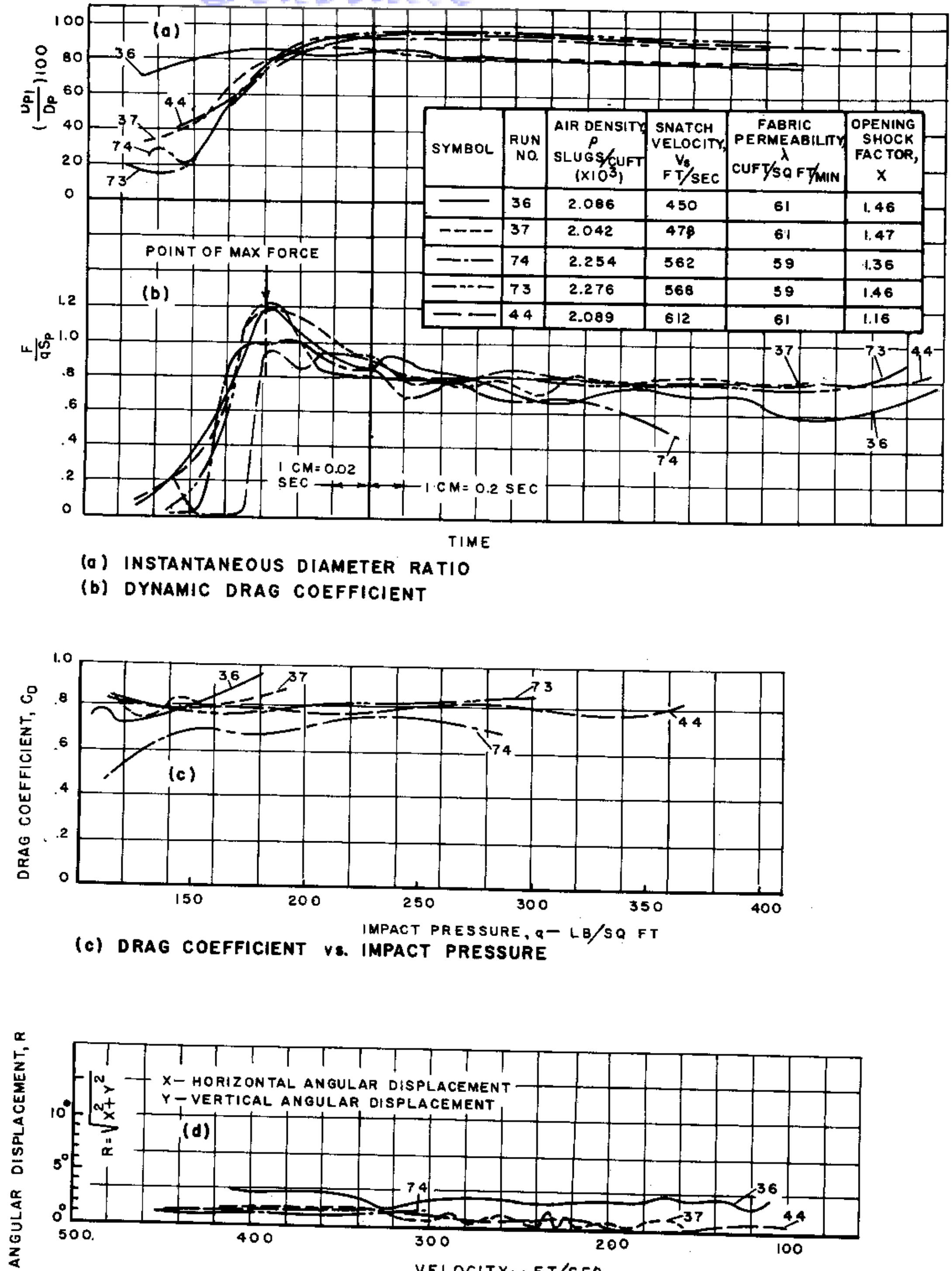
Applicable Specification	U.S. Air Force Spec.No.16208A Type I	U.S. Air Force Spec.No.16208A Type II
Weave	2/2 Twill	
Thread Count (Minimum)		
Warp	70	53
Filling	70	48
Yarn Ply (Minimum)		
Warp	Single	2
Filling	Single	2
Weight (Ounces per Sq.Yd.)(Maximum)	4.75	7.00

Figure 24. Fabric Properties as Specified in USAF Spec. 16208A

Properties of Nylon Canopy Fabrics Used for Guide Surface Parachutes(cont.)

Applicable Specification	U.S. Air Force Spec.No.16208A Type I	U.S. Air Force Spec.No.16208A Type II
Breaking Strength(Raveled-Strip) (Pounds Per Inch, Minimum)		
Warp	200	300
Filling	200	300
Ultimate Elongation(Percent,Minimum)		
Warp	30	30
Filling	30	30
Tear Strength(Strip Tear) (Pounds, Minimum)		
Warp	15	20
Filling	15	20
Thread	210 denier/34 filament (Single Ply)	210 denier/34 filament (Double Ply)
Air Permeability(Cu.Ft./Sq.Ft./Min. at 1/2 in. water Press.Diff.	(Spec: 50 to 90) 59	Spec. (50 to 90) 62

Figure 25. Fabric Properties as Specified in USAF Spec. 16208A (cont.)



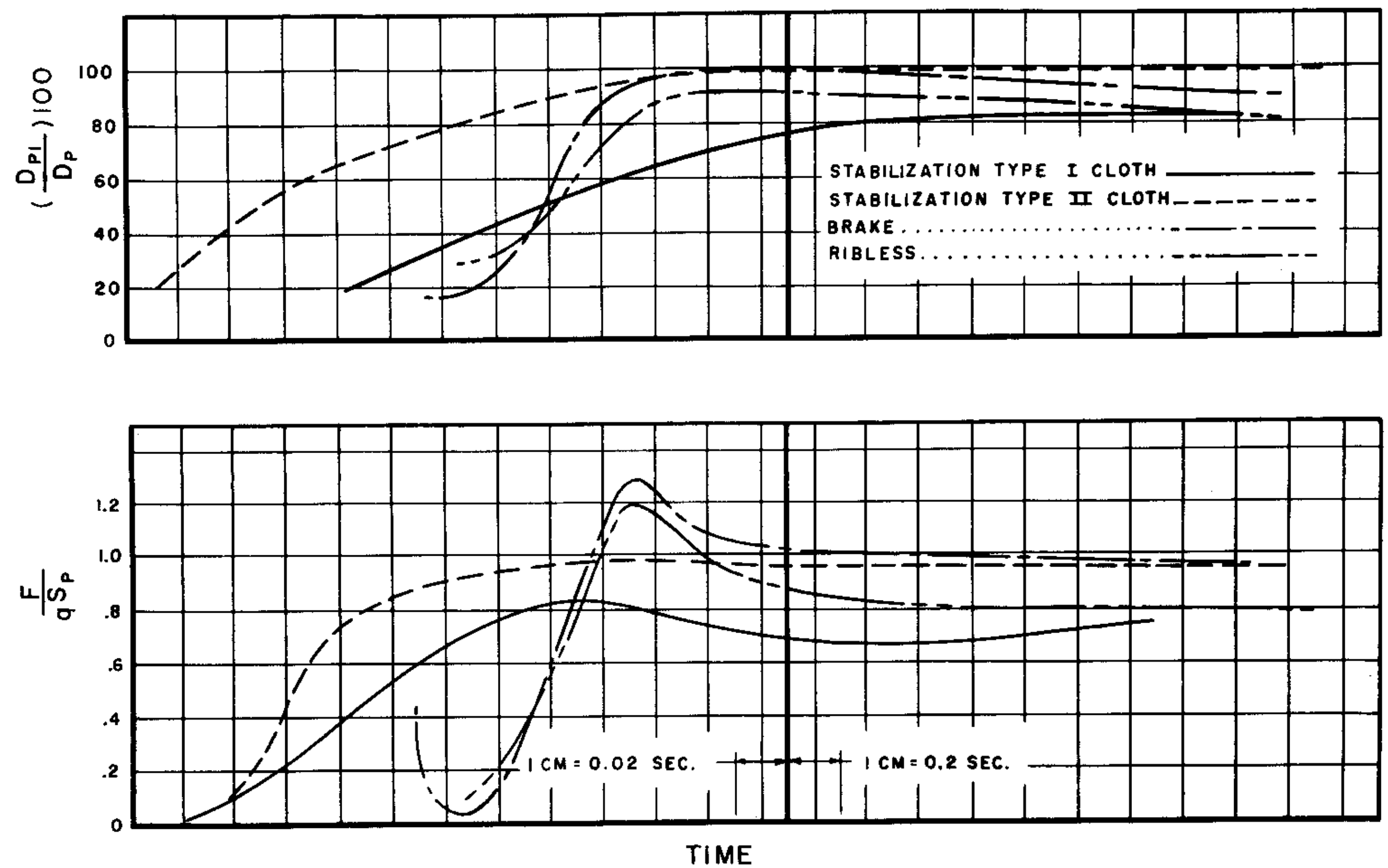
SYMBOL	RUN NO.	AIR DENSITY ρ SLUGS/CUFT $(X10^3)$	SNATCH VELOCITY, V_s FT/SEC	FABRIC PERMEABILITY λ CUFT/SQ FT/MIN	OPENING SHOCK FACTOR, X
————	36	2.086	450	61	1.46
– – – –	37	2.042	478	61	1.47
—·—	74	2.254	562	59	1.36
—··—	73	2.276	568	59	1.46
— —	44	2.089	612	61	1.16

(a) INSTANTANEOUS DIAMETER RATIO
(b) DYNAMIC DRAG COEFFICIENT

(c) DRAG COEFFICIENT vs. IMPACT PRESSURE

(d) STABILITY— ANGULAR DISPLACEMENT vs. VELOCITY

Figure 26. Performance of Ribless Parachutes



PERFORMANCE CURVES
OF
GUIDE SURFACE PARACHUTES

Figure 27. Idealized Performance of Guide Surface Parachutes

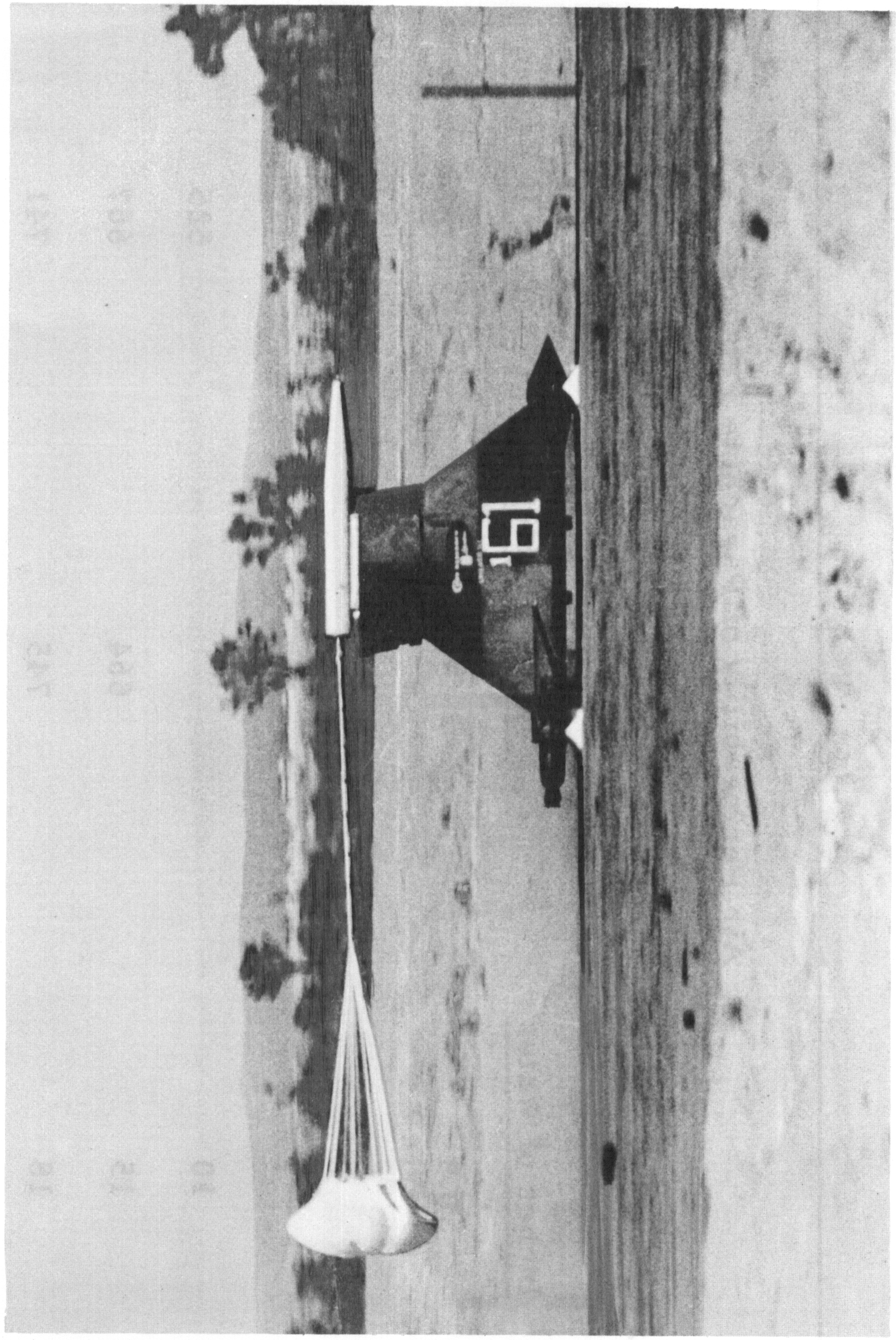


Figure 28. Partially Inflated Stabilization Parachute

Air Permeability of Parachute Fabrics

Pressure Differential	Air Permeability Cu. Ft./Sq. Ft./Min.	
Inches of Water	Type I Fabric	Type II Fabric
0.5	59	62
5	322	335
7	407	419
10		525
15	664	667
18	745	741
20	790	787

Figure 29. Comparison of Permeabilities of Types I and II Fabrics

NYLON CANOPY FABRIC USED IN TRANSONIC TESTS

Weave:	2 x 2 Basket
Thread Count:	43 (Warp and Fill)
Yarn:	Five ply of 210 denier high tenacity bright nylon both warp and fill
Thread:	1050 Denier - 34 Filament
Weight:	13 to 13-1/4 ounces per square yard
Break Strength: (Ravel Test)	775 Pounds per inch (Varies from 770 to 840)
Tear Strength:	80 Pounds (Warp and Fill)
Ultimate Elongation:	30 Per Cent
Air Permeability:	15 to 20 Cu. Ft./Sq. Ft./Min. at 1/2" Water Pres. Diff.
Thickness:	0.027 Inches

Figure 30. Properties of Thirteen Ounce Nylon

Figure 31. Damage to Stabilization Parachute

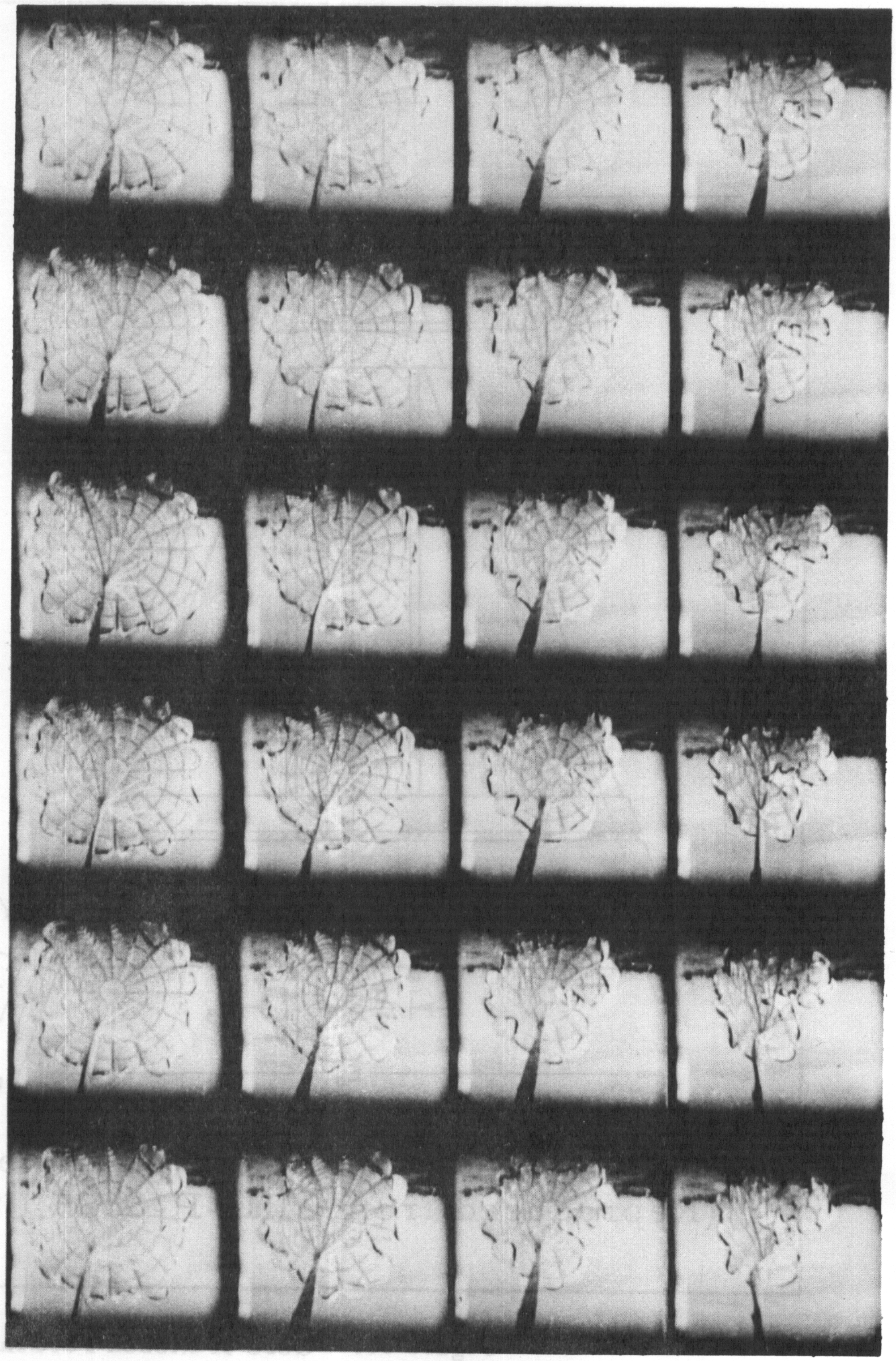


Figure 32. Inflation of Ribbon Parachute

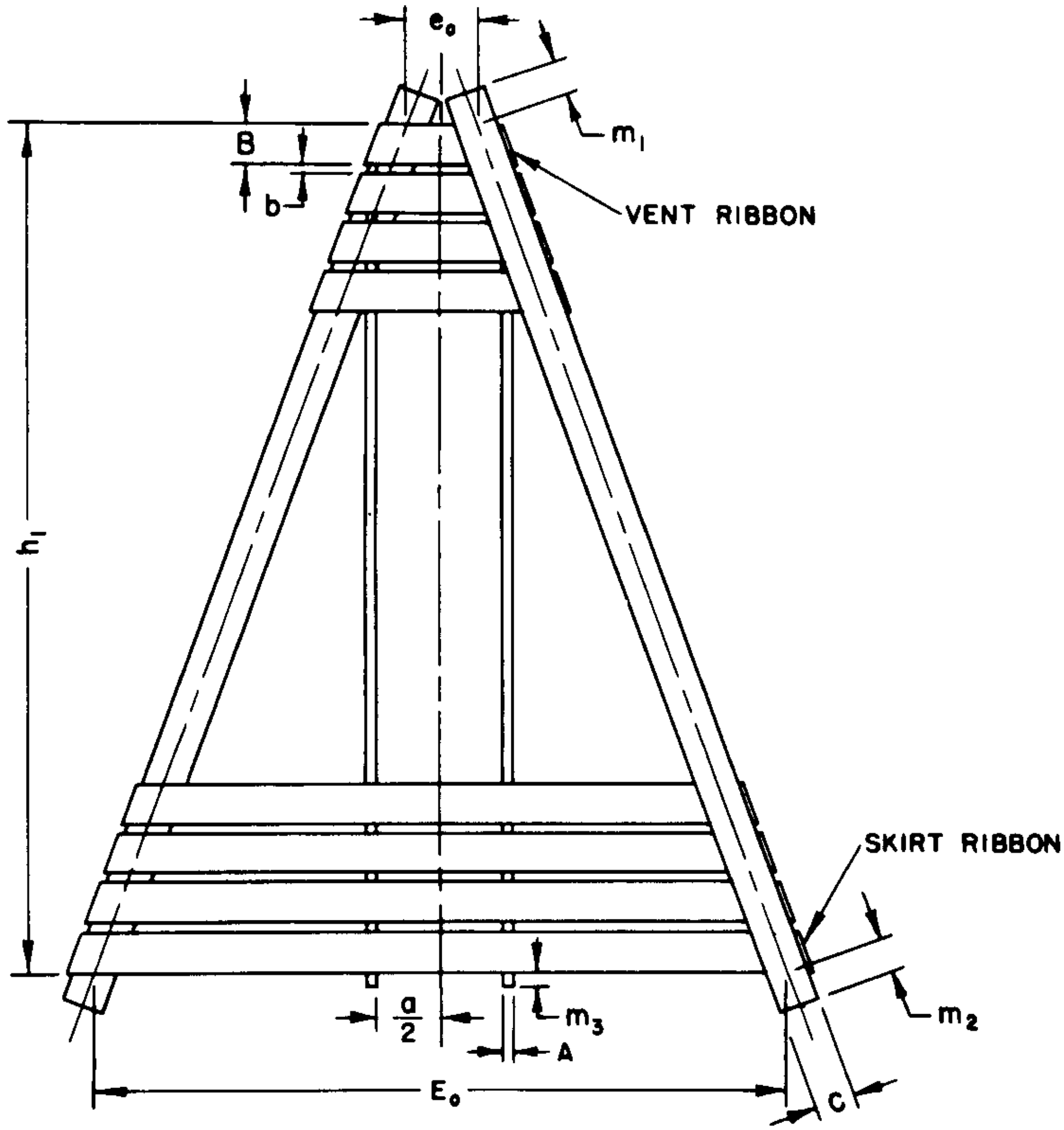


Figure 24. Gore Assembly
(Reproduced from MIL-P-6635 USAF, Ref. 7)

Figure 33. Gore of Ribbon Parachute

a. Summary of Dimensions of FIST Ribbon Parachutes

PARACHUTE TYPE	FIST 90	FIST 91	FIST 92	FIST 104	FIST 107	FIST 109	FIST 110
Nominal Diameter - Feet	8.7	8.7	8.7	8.7	8.6	8.4	8.4
Projected Diameter - Feet (Constructed)	5.8	5.8	5.8	5.8	5.7	5.6	5.6
Area of Canopy (S_o) - Square Feet	58.0	58.0	58.0	58.0	56.6	54.0	54.0
Total Porosity - Percent	23.3	23.7	20.7	21.1	17.6	8.6	13.2
Weight - Pounds	4.59	4.59	4.59	4.59	4.59	4.59	4.59
Width of Gore at Skirt Ribbon (E_o) - Inches	20.6	20.6	20.5	20.5	20.1	19.8	19.6
Width of Gore at Vent Ribbon (e_o) - Inches	2.25	2.25	2.25	2.25	2.25	2.25	2.25
Length of Gore - Skirt to Vent (h_1) - Inches	46.1	46.1	46.0	46.0	45.6	44.8	44.2
Width of Vertical Ribbon (A) - Inches	0.625	0.625	0.625	0.625	0.625	0.625	0.625
Spacing between Vertical Ribbons (a) -Inches	6.0	8.0	6.0	8.0	6.0	6.0	6.0
Number of Vertical Ribbons	2	2	2	2	2	2	2
Width of Horizontal Ribbons (B) - Inches	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Number of Horizontal Ribbons	16	16	17	17	18	21	19
Average Spacing between Horizontal Ribbons (b) Inches	0.938	0.938	0.750	0.750	0.563	0.140	0.344
Width of Radial Ribbon (C) - Inches	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Number of Gores & Suspension Lines	16	16	16	16	16	16	16
Suspension Line Length (L_s) - Feet	8.7	8.7	8.7	8.7	8.6	8.4	8.4

NOTE: All letter identifications above refer to Figure 2 of Military Specification MIL-P-6635 (USAF) (Ref. 7) reproduced as Figure 24 in this report.

Figure 34. Dimensions of Ribbon Parachutes

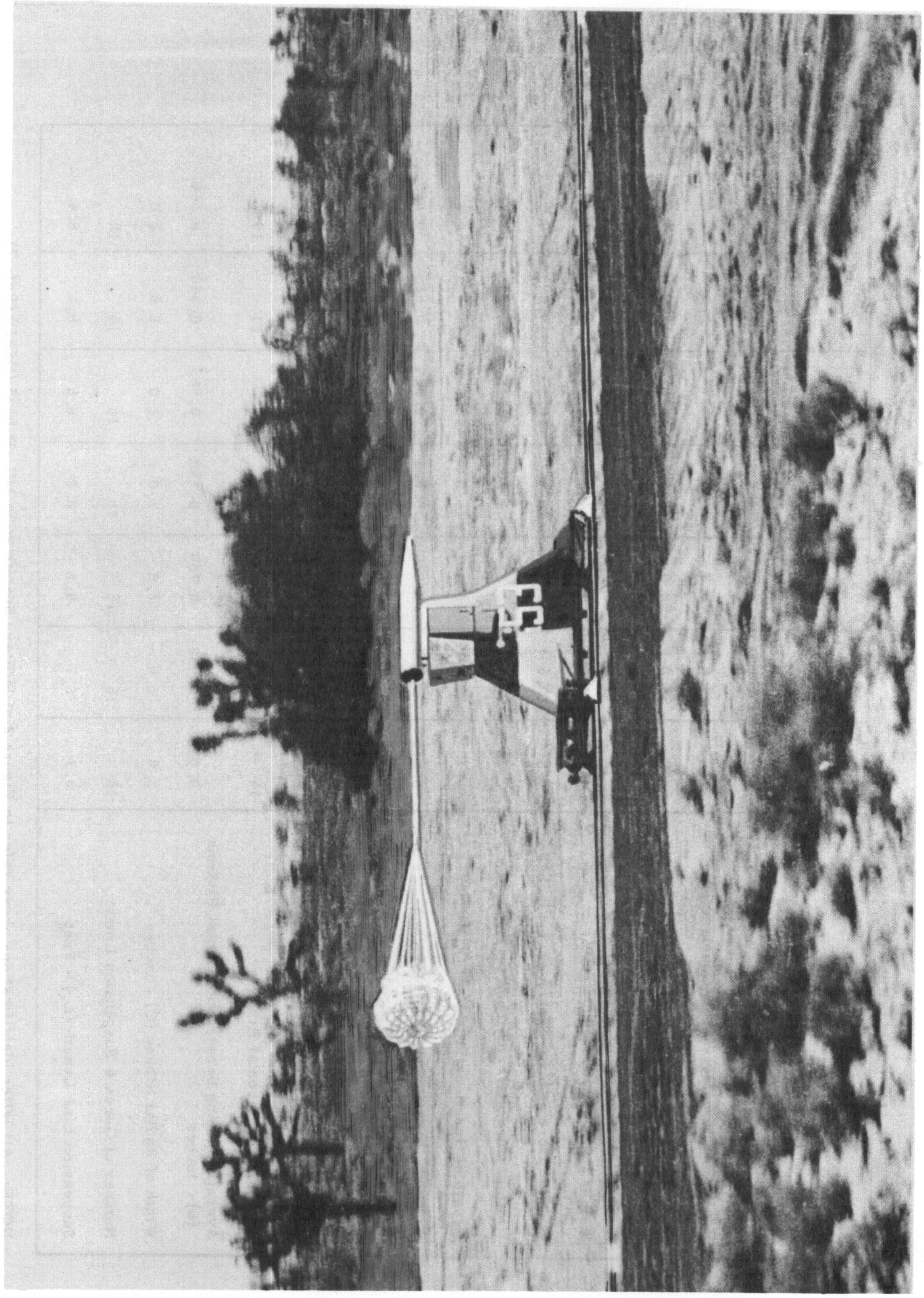


Figure 35. Partially Inflated Ribbon Parachute

b. Materials Used in FIST Ribbon Parachutes for Phase I Tests

PART	MATERIAL	SPECIFICATION	SIZE	MINIMUM TENSILE STRENGTH
Horizontal Ribbons	Ribbon; Nylon Parachute	MIL-R-5608A	Width = 2 inches	200 pounds
Radial Ribbons	Ribbon; Nylon Parachute	MIL-R-5608A	Width = 2 inches	200 pounds
Vertical Ribbons	Ribbon; Nylon Parachute	MIL-R-5608A	Width = 0. 625 inch	70 pounds
Reinforcing Webbing	Type; Nylon Reinforcing	MIL-T-5038	Width = 1 inch	1000 pounds
Vent Reinforcing	Webbing; Nylon Tubular	MIL-W-5625	Width = 1 inch	3000 pounds
Suspension Lines	Webbing; Nylon Tubular	MIL-W-5625	Width = 9/16 inch	1500 pounds
Pocket Bands	Webbing; Nylon Tubular	MIL-W-5625	Width = 1/2 inch	1000 pounds
Thread	Thread; Nylon	AN-T-9A	Size E 3 cord	8. 5 pounds 24. 0 pounds

NOTE: All parachutes manufactured in accordance with Military Specification MIL-P-6635 (USAF) (Ref. 7)

Figure 36. Ribbon Parachute Materials

PHYSICAL PROPERTIES - RIBBON PARACHUTE MATERIAL
(Specifications comply with MIL-R-5608A)

Class	Width	Weight	Break Strength	Warp Ends		Picks Per Inch	Elongation	Perme-ability	Yarn	Denier
	In.	Yd./Lb.	Lbs.	Total	Selvedge		Percent	Cu. Ft./Sq. Ft./Min/@ 0.5 In. Pres. Diff.	Warp	Filling
Lightweight	2	120	200	657	32		18	150	30	40
Extra Heavy-weight	2	30	1000	378	0	36	18		210	210

Figure 37. Properties of Ribbons

Failure of Risers Under Dynamic Load Conditions

Run No.	Parachute Type	Deployment Velocity	Number of Strands	Total Rated Strength	Load At Failure Under Dynamic Conditions
		MPH		Pounds	Pounds
13	Guide Surfaces Stabilization	294	1	10,000	4346
38	Ribbon 92	442	2	20,000	10,500
39	Ribbon 92	422	2	20,000	11,100
94	Ribbon 107	486	3	30,000	14,045

Figure 38. Failure of Parachute Risers