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MATERIALS AND DESIGN CRITERIA FOR KEVLAR-29 RIBBON PARACHUTES

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Crew Escape and Subsystems Branch
Vehicle Equipment Division
Flight Dynamics Laboratory

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report contains information and design criteria for application of Kevlar-29 (intermediate modulus para-aramid) textile materials to ribbon parachutes. Textile materials for this application are listed, their properties and limitations discussed, and methods for tensile testing presented. Twenty degree conical continuous ribbon parachute test items were designed and fabricated using Kevlar-29 textile materials entirely. The results of air drop and sled track testing at subsonic and transonic conditions are presented and design criteria based on these results are reported. The effects of reefing (two -

stages) on aerodynamic performance of the 15.3 ft nominal diameter parachutes is also reported. The report treats joining techniques for Kevlar-29 parachute components and presents the results of tensile tests of joint samples. Design considerations and fabrication techniques related to application of Kevlar-29 materials are included. A comprehensive list of references useful to the parachute or decelerator system designer is provided.

FOREWORD

Results of several in-house and contracted efforts are reported in this document. In-house efforts were conducted and contracted support efforts sponsored by the Crew Escape and Subsystems Branch of the Vehicle Equipment Division, Flight Dynamics Laboratory, which is a part of the Air Force Wright Aeronautical Laboratories (AFWAL), Wright-Patterson AFB, Ohio.

Early contracted efforts for developing Kevlar-29 textiles were sponsored by the AFWAL Materials Laboratory. Albany International, Inc. (formerly Fabrics Research Laboratory), Dedham, Massachusetts, was responsible under contract to develop woven, twisted, and braided materials.

Woven materials for test item fabrication were produced by the Bally Ribbon Mills, Bally, Pennsylvania, and braided coreless cords were produced principally by FWF Industries, Essex, Connecticut.

Parachute test items were fabricated, under contract, by the M. Steinthal Company, Roxboro, North Carolina, and in-house by the Air Force 4950th Survival Equipment Shop at Wright-Patterson AFB, Ohio.

Parachute drop testing was conducted by the Air Force 6511th Test Squadron at the DOD Joint Parachute Test Facility at El Centro, California and Edwards AFB, California. Rocket powered sled testing was conducted at Holloman AFB by the 6585th Test Group.

The author wishes to acknowledge and thank all of the military and civilian employees, and contractor personnel who participated in the efforts contributing to the reported results.

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LIST OF SYMBOLS

A_p	=	Product of strength degradation factors
BHR	=	Width of horizontal ribbons, in.
BVL	=	Width of vent lines, in.
CDR	=	Drag area ratio
C_D	=	Drag coefficient
C_DS	=	Drag area, sq ft
$(C_DS)_{R1}$	=	First stage drag area, sq ft
$(C_DS)_{R2}$	=	Second stage drag area, sq ft
$(C_DS)_{FO}$	=	Full open drag area, sq ft
D_0	=	Nominal parachute diameter, ft
DF	=	Design Factor
DR1	=	First disreef (an event)
DR2	=	Second disreef (an event)
e_g	=	Length of bottom edge of skirt ribbon, in.
e_v	=	Length of top edge of vent ribbon, in.
F	=	Force in parachute riser, lb
F_0	=	Peak force, lb
F_{OR1}	=	Peak force - stage 1, lb
F_{OR2}	=	Peak force - stage 2, lb
F_{OFO}	=	Peak force - full open, lb
HRBS	=	Actual breaking strength of horizontal ribbon material, lb
HRS	=	Nominal strength of horizontal ribbon material, lb
HRS_{ult}	=	Ultimate strength of horizontal ribbons, lb
l_n	=	Distance along radial tape edges from skirt to intersection of specific vertical tape, in.

LIST OF SYMBOLS (Continued)

L_O	=	Slant height of conical surface, in.
L_V	=	Slant height of vent, in.
LS	=	Line stretch (an event)
m	=	Number of specific horizontal ribbon
M	=	Mach number
MSL	=	Mean sea level - a base for measuring altitude
n	=	Number of specific vertical tape
N_g	=	Number of gores in parachute canopy
Q	=	Dynamic pressure, lb/sq ft
Q_{DR1}	=	Dynamic pressure at first disreef, lb/sq ft
Q_{DR2}	=	Dynamic pressure at second disreef, lb/sq ft
Q_{LS}	=	Dynamic pressure at line stretch, lb/sq ft
R_C	=	Radius of closed vent area, in.
RR	=	Reefing ratio
RRS	=	Nominal strength of radial ribbon material, lb
S_O	=	Nominal parachute canopy area, sq ft
SBS	=	Nominal strength of skirt band material, lb
SLS	=	Nominal strength of suspension line material, lb
S_F	=	Safety factor
S_P	=	Inflated parachute projected area, sq ft
TAS	=	True air speed ft/sec
t_{F1}	=	Filling time - first stage, sec
t_{F2}	=	Filling time - second stage, sec
t_{FFO}	=	Filling time - to full open, sec
UF	=	Ultimate Factor
VBS	=	Nominal strength of vent band material, lb

LIST OF SYMBOLS (Concluded)

VLS	=	Nominal strength of vent line material, lb
X	=	Opening shock factor
X_{R1}	=	Opening shock factor - stage 1
X_{R2}	=	Opening shock factor - stage 2
X_{FO}	=	Opening shock factor - full open
α	=	Gore half angle, deg
β	=	Gore angle, deg
Δv	=	Vertical tape spacing, in.
λ_g	=	Geometric porosity, percent
ϵ	=	Width of slots between horizontal ribbons, in.
Φ	=	Included angle in flat lay-out of conical surface, deg or rad
ϕ	=	Angle - vertical tape to horizontal ribbon tangent, deg

SECTION I

INTRODUCTION AND SUMMARY

Yarns of intermediate modulus para-aramid fiber are currently being produced and marketed by E. I. DuPont deNemours and Company under the trade name "Kevlar-29". High strength, low weight, and retention of strength at temperatures which burn or melt current conventional materials are properties which make woven textiles, threads, and cords based on this fiber of interest to aerodynamic decelerator systems designers. Kevlar-29 textile materials developed under Air Force Wright Aeronautical Laboratories (AFWAL) sponsorship are discussed in this report. Development of additional materials has been accomplished by other government agencies and private industry for this and other specialized applications.

Given a set of details describing a parachute application, the designer can utilize existing literature (Reference 1) to determine the appropriate parachute type, size, staging, and geometry. Within the realm of Kevlar-29 materials (largely narrow fabrics and cords) developed during AFWAL programs, and within the scope of Flight Dynamics Laboratory (FDL) Kevlar-29 parachute design, fabrication, and testing experience, this document treats design problems related to ribbon parachutes.

Parachute component strengths can be obtained using the relationships presented in Section VI as a first iteration and the structure subsequently refined as desired through application of more rigorous computerized methods of structural analysis (References 2 and 3) or through a series of drop, wind tunnel, or sled tests. As an example, Appendix D contains the details for a 15.3 ft, 20 degree conical parachute which was the result of FDL efforts to design, fabricate, and demonstrate the feasibility of an all Kevlar-29 drag parachute for a Mid Air Recovery System (MARS) to be used for recovery of remotely piloted vehicles. Previous MARS systems incorporated a nylon drag parachute which was pressure packed at relative high density and which limited the deployment envelope and vehicle weight range by its size and structural capability. Development of the Kevlar-29 MARS drag parachute through several iterations and tests is reported in Reference 4.

Performance of 15.3 ft Kevlar-29, 20 degree conical continuous ribbon parachutes with two stage reefing is presented and discussed. Test data for 19 drops from aircraft and 19 rocket powered sled runs are reported.

An important facet of the technology necessary to apply Kevlar-29 textiles to decelerator systems is tensile testing of materials. Tensile testing techniques and apparatus applicable to other textiles often produce misleading or unacceptable results for Kevlar-29 materials or joint samples. Section III and Appendices B and C treat this area.

Kevlar-29 textile materials can be successfully applied to various decelerator system components including risers, suspension lines, reefing lines, deployment bags, and geometric porosity type parachutes where unit canopy tensile loading is greater than 200 pounds per inch.

While existing Kevlar-29 textile materials developed for decelerator system application are generally applicable, the nonavailability of yarns smaller than 200 denier imposes important limitations when desired material strengths less than 200 pounds per inch of width are required.

High joint efficiency (80 to 90 percent of base material strength) can be obtained in Kevlar-29 materials joint construction based on unidirectional tensile testing. Some materials combinations may require several iterations of thread size, stitching patterns, and joint arrangement to obtain efficiencies at these levels.

SECTION II

MATERIALS DEVELOPMENT

Efforts to develop Kevlar-29 textile materials for decelerators were sponsored initially by the Materials Laboratory and later by the Flight Dynamics Laboratory (both currently part of AFWAL). All of the materials developed were based on yarns supplied by the DuPont Company. Initially two para-aramid fibers, Kevalar-29 and Kevlar-49 were considered. Fiber and yarn properties were investigated and results published in Reference 5. Kevlar-49 which has higher tensile strength, lower rupture elongation, and somewhat lower tensile impact performance (critical velocity) has been primarily utilized in composite applications. Textile materials treated in this document will be limited to those based on Kevlar-29 yarns.

1. KEVLAR-29 PROPERTIES

Kevlar-29 is an attractive basic fiber for decelerator textile materials due to its lightweight, high strength, low bulk, and strength retention at elevated temperatures. Relative to nylon, Kevlar-29 fibers offer 3 to 4 times the tenacity (rupture strength per yarn denier), and retains approximately 60 percent of this tenacity (based on tests of single yarns) at the melting temperature of nylon.

Other properties of Kevlar-29 limit the retention of yarn properties when yarns are twisted, braided or woven into textile material configurations suitable for decelerator applications. Low rupture elongation (<5 percent) high tensile modulus (≈ 500 grams per denier) and low yield strain in compression (<1 percent) result in translational efficiencies (i.e., ratio of material strength to total warp yarn strength) in the 70 to 90 percent range for woven fabrics while nearly 100 percent is often possible using nylon yarns. These properties usually dictate material configurational structures which are considerably different from similar strength nylon materials.

2. THE INFLUENCE OF YARN AVAILABILITY

A serious limitation during the time this report was written is the commercial nonavailability of a wide variety of yarn sizes. Currently Kelvar-29 is available only in 200, 400, 1000 and 1500 denier[1] whereas yarns of nylon and other lower modulus fibers are available in many sizes, particularly in the range below 200 denier. In woven materials, non-availability of small denier Kevlar yarn dictates tensile inefficiency when yarn stability is required for good seamability or porosity control. Utilizing the smallest Kevlar-29 yarn (200 denier) in a woven material which must be stitched at joints dictates total strength in excess of 250 pounds per inch of width. When less than this strength is desired, the number of warp yarns required for total strength results in warp yarn spacing which yields "sleazy" fabric in which yarns are free to slip and do not hold stitching effectively (Reference 6). When design strength requirements are less than 250 pounds per inch of woven width, the utilization of overstrength Kevlar-29 materials to obtain seaming efficiency may compromise weight and volume benefits relative to utilizing materials of other fibers (nylon, Dacron, Nomex, etc).

During AFWAL efforts to develop Kevlar-29 decelerator textiles, the sole source for Kevlar yarns (the DuPont Company) made changes in the yarns commercially available. During the materials development effort reported in Reference 6, yarns of all denier were supplied initially by DuPont as rotoset yarns in which the filaments were lightly entangled at periodic intervals to provide cohesion to the assembly. While most of the narrow fabrics developed were accomplished with rotoset yarns, the 200 and 400 denier yarns supplied by DuPont near the end of the program (during 1977), and those currently supplied, are not rotoset. Cohesion in these later yarns is provided by a low-level twist referred to as producer's twist. Yarns of 1000 and 1500 denier continue to be supplied in the rotoset configuration. Elimination of the rotoset configurations did not appreciably change yarn strength. Materials developed with rotoset yarns which were subsequently produced using yarns with producer's twist

[1] A 9000 meter length of one denier yarn has a weight of one gram.

generally exhibit the same properties. However, air permeability in fabrics decreased when non-rotoset yarns were used to weave configurations developed using rotoset yarns, and one weaving firm has indicated that weaving of non-rotoset yarns is made easier if low-level twist is added to producer's twist in filling yarns.

3. SPECIFICATION MATERIALS

The materials listed in Tables 1 through 4 are those which have been developed for and in many cases used by the Materials Laboratory or the Flight Dynamics Laboratory. Military Specifications (Reference 7, 8, 9, and 10) have been written for these materials, most of which are included in a previously published decelerator design guide (Reference 1). Materials in the tables evolved through a process of trial constructions leading to the desired tensile strengths. Most of the constructions tried produced efficient materials which resulted in tensile strengths higher or lower than the desired specification target strength. Many of these materials are included in Reference 6, and should be referred to when materials between the strengths or efficiencies represented in the tables of specification materials are desired.

a. Kevlar-29 Threads

Table 1 lists Military Specification (Reference 8) sewing threads which were developed in diameters or sizes representative of common threads based on other fibers. Resulting breaking strengths are of course much higher in the Kevlar-29 threads. Sewing trials indicated that the threads can be stitched with standard sewing machines with only minor machine adjustments, but that maladjustments may impose high stresses on machine parts due to the strength of Kevlar-29 threads.

Previously published (References 1 and 8) tables of specification Kevlar-29 thread included size A. Although size A thread was developed, the 100 denier yarn required was available only in small quantities. This thread should not be considered as an available specification material at this time.

TABLE 1

SPECIFICATION KEVLAR-29 SEWING THREADS
(REFERENCE MIL-T-87128)

SIZE (1)	YARN DENIER	PLY	TWIST (2) (TURNS PER IN.) SINGLE YARNS	PLIED YARNS	LENGTH PER LB (MIN YARSS)	BREAKING STRENGTH (LB.)
B	200	2	12S	6Z	10,000	16
E	200	3	12S	6Z	6,700	25
F	200	4	10S	5Z	5,000	35
FF	400	3	8S	4Z	3,350	60
3	400	5	10S	5Z	2,100	80
4	1000	3	7S	3.5Z	1,400	115
5	1000	4	7S	3.5Z	1,050	150
6	1500	3	6S	3Z	900	175
8	1500	5	5S	2.5Z	550	225

NOTES:

(1) Thread Sizes are Dimensionally Similar to Threads of Conventional Fibers

(2) S and Z Indicate Twist in Opposite Directions

TABLE 2

SPECIFICATION KEVLAR-29 TAPE AND
WEBBING (REFERENCE MIL-T-87130)

Type	Class	Width (in)	Breaking Strength (Min) (lb)	Weight (max) (oz/yd)	Warp Yarns			Fill Yarns			Weave
					Denier	Ply	Total Ends Min.	Denier	Ply	Picks Per Inch	
I	1	1/2	250	.06*	200	1	42	200	1	39*	Plain
	2	1/2	550	.09	400	1	39	400	1	22	Plain
	3	1/2	800	.12	200	1	122	200	1	35	1/3 Twill-Center Reversal
	4*	1/2	3500	.56	1500	1	79	400	1	24	Double Plain
II	1	9/16	500	.08*	400	1	39*	400	1	22*	Plain
	2*	9/16	700	.13	400	1	58	400	1	32	Plain
IV	1	3/4	500	.11*	200	1	90	200	1	38	Plain
	4	3/4	3000	.50	1500	2	31	1500	1	12	Plain
	5	3/4	4100*	.60	1500	2	41	1500	1	11	Plain

* Indicates additions or changes to previously published quantities based on experience in obtaining production quantities, using materials, and demonstrated variances among weavers.

TABLE 2 (Cont'd)

SPECIFICATION KEVLAR-29 TAPE AND WEBBING (REFERENCE MIL-T-87130)

Type	Class	Width (in)	Breaking Strength (Min) (lb)	Weight (Max) (oz/yd)	Warp Yarns Denier	Warp Yarns Ply	Warp Yarns Total Ends Min.	Fill Yarns Denier	Fill Yarns Ply	Fill Yarns Picks Per Inch	Weave
VI	1*	1	370	.08	200	1	50	200	1	45	Plain
	2	1	525	.12	200	1	90	200	1	50	Plain
	3	1	750	.12*	200	1	108	200	1	35	Plain
	5	1	1500	.23*	400	1	108	400	1	26	Plain
	6a*	1	2400	.36	1000	2	40	1000	1	15	Plain
	6	1	2500	.36	1500	2	24	1500	1	14	Plain
	7	1	3000	.52*	1000	2	48	1000	1	15	Plain
	8	1	4000	.55	1500	2	39*	1000	1	12	Plain
	9	1	6000	1.00	1500	3	49*	1500	1	12*	2/2 HB Twill* Center Reversal
	9a*	1	7000	1.04	1500	2	76	1500	2	18	5/1 Twill Center Reversal
	10	1	9500	1.50	1500	3	76	1500	1	8	2/2 HB Twill Center Reversal
	11	1	12,500	1.65	1500	3	89	1500	1	9	Plain

* Indicates additions or changes to previously published quantities based on experience in obtaining production quantities, using materials, and demonstrated variances among weavers.

TABLE 2 (Cont'd)

SPECIFICATION KEVLAR-29 TAPE AND WEBBING (REFERENCE MIL-T-87130)

Type	Class	Width (in)	Breaking Strength (Min) (lb)	Weight (Max) (oz/yd)	Warp Yarns			Fill Yarns			Weave
					Denier	Ply	Total Ends Min.	Denier	Ply	Picks Per Inch	
VII	1	1 1/8	1100	.23	400	1	96	400	1	34	Plain*
	2	1 1/[illegible]	2750	.45	1000	1*	45	1000	1*	13	Plain
	6	1 [illegible]	3500	2.00	1500	2	140	1500	2	14	5/1 HB Twill Center Reversal
VIII	1	1 1/4	800	.23	400	1	60	1000	1	26	Plain
IX	1	1 1/2	500	.13*	200	1	82	200	1	48	Plain
	2	1 1/2	1100	.19*	200	1	172	200	1	36	Plain
	5	1 1/2	2000	.52*	1000	1	96	1000	1	18	Plain
X	1	1 3/4	1000	.19*	200	1	156	200	1	34	Plain
	2	1 3/4	1200	.35	400	1	103	1000	1	23	Plain
	3	1 3/4	2500	.45	1000	1	84	1000	1	16	Plain

*Indicates additions or changes to previously published quantities based on experience in obtaining production quantities, using materials, and demonstrated variances among weavers.

TABLE 2 (Cont'd)

SPECIFICATION KEVLAR-29 TAPE AND WEBBING (REFERENCE MIL-T-87130)

Type	Class	Width (In)	Breaking Strength (Min) (lb)	Weight (Max) (oz/yd)	Warp Yarns Denier	Warp Yarns Ply	Warp Yarns Total Ends Min.	Fill Yarns Denier	Fill Yarns Ply	Fill Yarns Picks Per Inch	Weave
X	4*	1 3/4	3000	.54	1000	1	96	1000	1	17	Plain
	5	1 3/4	4000	.60	1000	2	55	1000	1	15	Plain
	6	1 3/4	4500	.80	1500	2	50	1500	1	17	Plain
	7	1 3/4	6500	1.00	1500	1	140	1500	1	11	Plain
	8	1 3/4	8000	1.20	1500	2	88	1000	1	10	Plain
	9	1 3/4	10000	1.75	1500	2	127	1500	1	12	2/2 HB Twill Center Reversal
	11	1 3/4	15000	2.40	1500	3	121	1500	1	13	Double Plain
	13	1 3/4	20000	2.50	1500	3	137	1500	1	9	Double Plain
XI	3	2	400	.13*	200	1	60	200	1	50	Plain
	5	2	600	.15	200	1	92*	200	1	46*	Plain
	7	2	800	.17*	200	1	124	200	1	42	Plain
	9b	2	1000	.18	200	1	150	200	1	40*	Plain

*Indicates additions or changes to previously published quantities based on experience in obtaining production quantities, using materials, and demonstrated variances among weavers.

TABLE 2 (Concluded)

SPECIFICATION KEVLAR-29 TAPE AND WEBBING (REFERENCE MIL-T-87130)

Type	Class	Width (In)	Breaking Strength (Min) (Lb)	Weight (Max) (oz/yd)	Warp Yarns			Fill Yarns			Weave
					Denier	Ply	Total Ends Min.	Denier	Ply	Picks Per Inch	
XI	9a	2	1000	.23	200	1	164	200	1	46	Plain
	11	2	1500	.28*	400	1	108	400	1	31	Plain
	13	2	2000	.32	400	1	142	400	1	30	Plain
	14	2	2500	.40*	1000	1	77	400	1	26	Plain
	15	2	3000	.48*	1000	1	96	400	1	24	Plain
	16	2	4000	.65*	1000	2	58	1000	1	20	Plain
	17	2	5000	.88*	1500	1	110	1500	1	13	Plain
	18*	2	6000	1.10	1500	1	140	1500	1	13	Plain
	19	2	8000	1.15*	1500	1	160	1500	1	12	Plain

*Indicates additions or changes to previously published quantities based on experience in obtaining production quantities, using materials, and demonstrated variances among weavers.

TABLE 3

SPECIFICATION KEVLAR-29 TUBULAR WEBBING (REFERENCE MIL-W-87127)

Type	Width (In) (1)	Weight Per Lin. Yard (Oz) (2)	Breaking Strength (Lb Min) (3)	Warp Yarns (4)	Fill Yarns Per Inch (4)	Yarn Denier (5) Warp	Yarn Denier (5) Fill
I	1/2	.28*	1250	39	40	1000	1000
II	9/16	.25*	1500	45	34	1000	1000
III	9/16	.32*	2000	41	27	1500	1000
IV	3/4	.48*	2800	59	27	1500	1500
V	1	.68*	3500	81	27	1500	1500

NOTES:

(1) Width tolerance ±1/16 inch

(2) Table weights approximately 10 percent greater than measured samples

(3) Table strengths approximately 10 percent less than measured samples

(4) All yarns single ply - half of ends on each side of flattened tube

(5) Twist - Warp yarns 1,000 denier - 4 turns per inch, 1500 denier - 3 turns per inch

Fill yarns zero or producer's twist

*Indicates additions or changes to previously published quantities based on experience in obtaining production quantities, using materials, and demonstrated variances among weavers.

TABLE 4

SPECIFICATION KEVLAR-29 CORELESS
CORD (REFERENCE MIL-C-87129)

Type	Breaking Strength (Lb Min)	Carriers (1 End Per Carrier)	Yarn Denier	Yarn Plies Per End	Yarn Twist (Turns Per Inch) (1)	Picks Per Inch (2)	Minimum Length Per Lb (Ft.) (3)
I	35	4	200	1	5	9	13500
II	70	8	200	1	5	18	6500
III	125	8	400	1	5	12	3200
(4)	250	16	400	1	5	14	1800
IV	400	16	200	3	2.5	15	1100
V	600	16	1000	1	4	12.5	720
VI	750	16	1500	1	3	10.5	430
VII	1000	16	1000	2	2.1	10	338
VIII	1500	16	1500	2	1.8	8	203
IX	2000	16	1500	3	1	6.5	135
(4)	2600	16	1500	4	1	9	110
X	3500	16	1500	6	1	5.5	70
XI	5000	24	1500	5	1	5.5	60
XII	6500	24	1500	6	1	4	50

NOTES

(1) Half of carriers S twist, half Z twist. When plied yarns are used value shown is for ply twist with single yarns at zero or producer's twist.

(2) Picks per inch determined by the ratio of the rate at which braid is drawn off the braiding machine to the revolution speed of yarn carriers.

(3) Minimum length per pound numbers represent approximately 10 percent less than minimum lengths indicated by actual sample measurements.

(4) Cords developed subsequent to printing of MIL-C -87129.

Finishes of polyvinyl butyral (Reference 8) and finishes which were proprietary to thread manufacturers were tried with good stitching success. Thread without finish was also demonstrated as sewable in a limited range of sizes and conditions.

b. Kevlar-29 Tape and Webbing

Table 2 lists tape and webbings developed as specification materials. This compilation includes the information current at the time of this writing. Asterisks in the table indicate additions or changes (to previously published values) which are based on experience in obtaining production quantities, using materials, and demonstrated variances among weavers. The Type XI, Class 3 (and to some extent Class 5), two-inch wide ribbons exhibit yarn migration and general sleaziness and should not be generally used in applications where ribbon free lengths flutter or where stitched intersections are heavily loaded. A suitable coating for stabilizing the structure of these materials has not been developed (Reference 6). Further discussion of the utilization of Type XI Class 3 and 5 materials is contained in Section V.

c. Kevlar-29 Tubular Webbing

Table 3 contains five tabular webbings which are woven as flat tubes with half of warp and fill yarns located on each side.

d. Kevlar-29 Coreless Cord

A 2,600 lb cord (marked in Table 4 by an asterisk) has been added. To the previously published list of specification coreless cords Reference 6 and 9. Also changed have been the length per pound values which are approximately 10 percent under those indicated in the development experience. Picks per inch as represented in the table, reflect the ratio of braiding machine carrier and take-off speeds as opposed to actual count per linear dimension along the cord axis.

e. Kevlar-29 Broad Fabric

Although the major emphasis of the AFWAL material development efforts addressed narrow fabrics, two broad fabrics were developed to the Military Specification stage for application as decelerator system materials but a final specification has not been written. Appendix A contains a draft specification for the two fabrics developed. Both fabrics are woven from 200 denier rotoset Kevlar-29 yarns. The air permeability of both fabrics is in the range from 50 to 90 cubic feet per minute per square foot at .5 inches of water differential pressure. Type I fabric has a tensile strength of 350 pounds per inch in both the warp and fill directions while Type II has a warp strength of 230 pounds per inch and a fill strength of 220 pounds per inch. Weaving arrangements and configurational trials leading to these two fabrics are contained in Reference 6.

Broad fabric for fabricating deployment bags and other accessories is commercially available in tight seamable weaves and were not addressed by the scope of the AFWAL materials development efforts.

SECTION III

TENSILE TESTING OF KEVLAR-29 MATERIALS

Determination of the tensile rupture or breaking strength of Kevlar-29 textile materials often dictates apparatus and testing technique which differs substantially from conventional testing practice as applied to materials based on lower modulus, higher elongation fibers, like nylon and polyester. Early tensile testing efforts revealed problems related to incomplete rupture of all load bearing yarns, nonsimultaneous failure of load bearing yarns and high incidence of failures which occur at the terminating test apparatus or jaws.

1. NARROW FABRIC

Tensile testing of woven narrow fabrics was the subject of a FDL sponsored effort (Reference 12) which resulted in a tensile test specimen terminating apparatus or jaw suitable for Kevlar-29 materials testing. Appendix B contains details of this apparatus and the technique for performing tensile testing. Jaws described in sketches of Appendix B should be limited to loads under 20,000 pounds. Redesign involving more strength in side plates could be accomplished to extend the tensile limit. Low elongation of Kevlar-29 yarns dictate particular care in loading tensile specimens in jaws. Tensile testing crosshead speeds (speed at which jaws separate) in the range from .5 to 12 inches per minute have minimal effect on rupture strength of most Kevlar-29 materials. Uneven tensions in the warp yarns, damage to yarns in the weaving process, and other weaving defects can have drastic effects on breaking strengths. Variation in test results for woven narrow fabrics when testing is properly conducted and when test materi l is free of gross defects has been small. Reference 12 results indicate a coefficient of variation (100 times the standard deviation divided by the average breaking strength) less than 5.0 percent for 7 different Kevlar-29 constructions in a nominal strength range from 250 to 15,000 pounds.

2. CORELESS CORD

Meaningful tensile testing of coreless Kevlar-29 cords demands special attention. Special wrapping techniques must be utilized with split capstan or pin jaws (Reference 12 and Appendix C) to yield meaningful results. An in-house FDL program to demonstrate apparatus and technique for tensile testing Kevlar-29 cord is described in Appendix C. The program results indicate that a simple pin through formed eye splices at the ends of tensile specimens is also an acceptable apparatus for testing coreless cords.

3. BROAD FABRIC

The tensile strength of broad fabrics can be established by testing ravel strips of the fabric in the pin jaw configuration developed in Reference 12 and described in Appendix B.

SECTION IV

KEVLAR-29 PARACHUTE TESTING EXPERIENCE AND RESULTS

1. PREVIOUSLY REPORTED TESTING

The Flight Dynamics Laboratory has been involved in the application of Kevlar-29 textile materials to deceleration and recovery systems over the past eight years (1972-1980). This involvement has included wind tunnel, sled and free flight testing over extremely wide ranges of Mach number, dynamic pressure, loading and velocity. The earliest FDL Kevlar testing included transonic wind tunnel testing to establish feasibility of the basic material and is reported in References 13 and 14. After further development of Kevlar-29 decelerator textiles, more transonic wind tunnel testing was conducted generating data necessary to make comparisons between Kevlar-29 and nylon conical ribbon parachutes. Results of this testing is documented in Reference 15. Small-scale (5 to 8 inch D_o) Kevlar-29 Supersonic X type parachute wind tunnel testing at free stream Mach numbers to M = 8 (M = 4 in forebody wake) and stagnation temperatures to 760°F are reported in Reference 16. Concurrent with and subsequent to this testing, Kevlar and nylon hemisflo ribbon parachutes, 5 ft in diameter were tested behind rocket propelled sleds at dynamic pressures as high as 6,000 psf. The data and comparison of nylon and Kevlar-29 parachute performance is documented in Reference 17. Additionally, a series of drop tests from aircraft of solid cloth, nylon parachute canopies (C-9 and T-10 types), which were fitted with Kevlar-29 suspension systems and tested over a range of canopy loadings, produced data which established the feasibility of replacing nylon suspension lines and risers with lighter, less voluminous Kevlar-29 materials of equivalent strength. This comparative data, showing no excessive snatch or opening forces (relative to nylon) for deployment velocities of 140 and 160 knots equivalent airspeed, is reported in Reference 18.

2. DESIGN CRITERIA TESTING

FDL efforts to develop a Kevlar-29 MARS drag parachute (see Appendix D) set the stage for developing military specifications for the decelerator materials and for conducting a series of in-house design criteria tests utilizing 15.3 ft D_0 continuous ribbon, 20 degree conical parachutes. The objectives of these tests were to develop and demonstrate a MARS drag parachute prototype, to obtain performance data for Kevlar-29 ribbon parachutes, and to generate or conform design criteria to be utilized in choosing materials for Kevlar-29 ribbon parachutes. Early material developments were utilized in fabrication of the first MARS prototype test items. Experience in fabrication, joint development, and test results were utilized as feedback to the materials development, design criteria, and materials testing programs. The choice of the 15.3 ft D_0 continuous ribbon, 20 degree conical parachute as the single design criteria test item configuration was motivated by the MARS drag parachute requirement and facilitated multiple benefit from the MARS test results.

a. Parachute Test Item Description

(1) Common Characteristics

All Kevlar-29 test items incorporated the common characteristics contained in Table 5. Canopies with 32, 28 and 24 gores were utilized in the early designs but 16 of the 20 Kevlar test items were construcuted with 28 gores. Typical gore arrangements are shown in Figure 1. Horizontal ribbon spacing (constant for each canopy) was adjusted to compensate for deviations (less than .062 inches) from the nominal 2 inch ribbon width to maintain geometric porosity between 15.3 and 17.2 percent.

Horizontal ribbon free lengths were restricted by vertical tapes to a 3-inch maximum except for the lower ribbons of test items 3 and 4 where free lengths adjacent to the radial ribbons were as great as 4.5 inches.

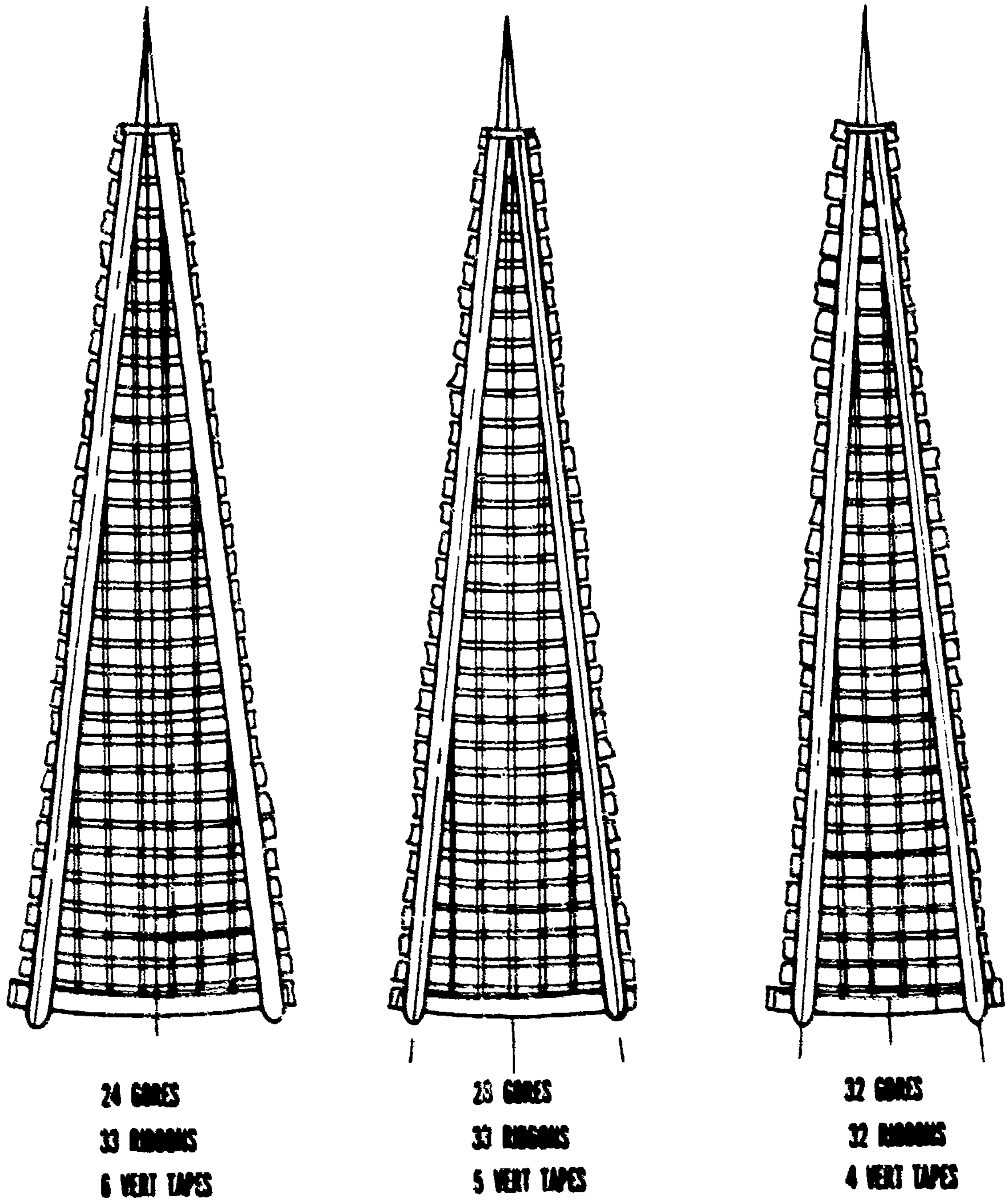


Figure 1. Kevlar-29 Parachute Test Item Gore Arrangements 15.3 ft D_0, 20 Degree Conical Continuous Ribbon

TABLE 5

TEST ITEM COMMON CHARACTERISTICS

Nominal Diameter - D_o = 15.3 ft

Canopy Type - 20 degree conical ribbon

Construction - Continuous ribbon with 2 ply radial and vertical tapes

Horizontal and Radial Ribbon Width - 2 in.

Vertical Tape, Width - .5 inches, nominal strength - 250 lb

Evenly Distributed Ribbon Spacing

Suspension Line of Braided Cord

Suspension Line Length - 15 ft, 10 in.

Over Strength Kevlar Riser - 100,000 lb

Riser Length - 50 in. (19 in. from the riser confluence point to the line loops)

Vent Area - 1.0 percent of nominal canopy area

Vent Band Wdith - .75 in.

Skirt Band Width - 1.75 in.

Reefing Rings Attached at Radial Ribbons

(2) Parachute Component Materials

Table 6 indicates tensile strength of materials chosen for the major components of each test item. A rough chronological order of test item design is indicated by the progression of the test item columns from left to right. Relatively few of the materials used for early test items are represented exactly in the military specification materials which were mostly developed after these items were fabricated. Later test items utilized more materials which are the same as or nearly identical to specification materials.

COMPONENT STRENGTH (lbs)

Test Item No. Number of Gores	1 32		2 32		3 MARS EVOLUTION 24		4 24		5 28		MARS 6 thru 10 28		IH-1 28		IH-2 28		IH-3 28		IH
Material Strength	Est Req	Used	Est Req	Used	Est Req	Used	Est Req	Used	Est Req	Used	Est Req	Used	Est Req	Used	Est Req	Used	Est Req	Used	Est Req
Suspension Lines	1528	2000 2275	1528	2000 2275	2037	2000 2275	2037	2000 2275	1746	1500 1703	1746	1500 1722	2079	2000 2234	2079	2000 2284	2079	2000 2284	2079
2" Horizontal Ribbons (Continuous)	509	1000 1001	509	1000 1001	679	900 980	679	900 980	582	600 797	582	1000 1038 800 804	693	540 650 *400 480	693	*400 480	693	[illegible] [illegible] *100 480	693
2 in Radial Tapes	764	1000 1001	764	1000 1001	1019	900 980	1091	900 980	873	600 797	873	800 801	1040	1000 1145	1040	1000 1145	1040	1000 1145	1040
1 3/4" Skirt Band	657	2500 2691	657	2500 2691	876	2500 2691	876	2500 2691	751	1200 1282	751	3600 4700	894	1200 1282	894	1200 1281	894	1200 1282	894
3/4" Vent Band	1680	3000 3057	2500 2691	3000 3057	2241	4000 4121	2241	4000 4121	1921	4000 4121	1921	3000 3300	2287	3000 3300	2287	3000 3300	2287	3000 3300	2287
Vent Lines	1528 T	2300 Nylon	1528 T	3000 3057	2037 T	3000 3057	2037 T	3000 3057	1746 T	3000 3057	1746 C	1500 1722	2079 C	2000 2284	2079 C	2000 2284	2079 C	2000 2284	2079 C
3/4" Reinforcement HR11	--	--	--	--	--	--	--	--	--	--	--	3000 3300	--	--	--	--	--	--	--
HR12	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Reefing Line	1680	1500 1703	1680	1500 1703	1680	1500 1703	1680	2000 2275	1680	2000 2275	1680	1500 1722	2000	2000 2284	2000	2000 2284	2000	2000 2284	2000

Test Item No.	1	2	3	4	5	MARS 6 thru 10	IH-1	IH-2	IH-3	IH
Max Design Load (lbs)	16,300	16,300	16,300	16,800	16,300	16,800	20,000	20,000	20,000	20,0
Geometric Porosity λ_g	17.2	17.2	16.1	16.3	15.3	15.3	15.3	15.3	15.3	15
Finished Weight (lbs)	13.6	13.6	11.4	11.5	11.0	11.9	11.3	11.2	11.3	14.
Reference Test Number XXXXXX D - Drop XXXXXX S - Sled M - Modified Test Item R - Repaired Test Item	141175 D 171275 DM 310877 SM	231275 D 080377 S 270777 S 270977 SM	270476 D	160876 D 150176 DR 031276 DM	171176 D	250577 DM 021277 D 080378 D 030578 D 041278 D 260578 D 150878 D	080377 D	150377 D	270178 D	1611 1002 0405

TABLE 6

PARACHUTE TEST ITEM MATERIALS, DESIGN DATA, AND TEST REFERENCE

	IH-3 28		IH-5 28		IH-6 28		IH-7 28		IH-? 28		IH-? 28		WP-1 28		WP-2 28		WP-3 28		WP-4 28		WP-5 28		WP-6 28	
...ed	Est Req	Used	Est Req	Used	Est Req	Used	Est Req	Used	Est Req	Used	Est Req	Used	Est Req	Used	Est Req	Used	Est Req	Used	Est Req	Used	Est Req	Used	Est Req	Used
...000 ...284	2079	2000 2284	2079	2000 2284	2079	2000 2284	2079	2000 2244	2079	2000 2284	2079	2000 [illegible]	3636	3500 4650	3636	3500 4650	2183	2000 2350	2183	2000 2350	2183	2000 2350	2183	2000 2350
*400 480	693	[illegible] *1 0 480	693	1000 [illegible]	693	1000 1038	693	*200[a] 456	693	*400[a] 456	693	*4[illegible][b]	1213	*1000 1090	1213	*1000 1090	728	600 694	728	600 694	728	750 620	728	750 620
...000 ...145	1040	1000 1145	1040	[illegible]	1040	1000 1038	1040	1000 1034	1040	1000 1034	1040	[illegible]	1819	1500 1530	1819	1500 1530	1092	*1000 1090	1092	*1000 1090	1092	*1000 1090	1092	*1000 1090
...200 ...281	494	1000 1282	494	[illegible]	494	6500 7400	494	4500 4342	494	4500 3342	494	4500 [illegible]	1564	*4000 4400	1564	*4000 4400	939	*2500 2990	939	*2500 2990	939	*2500 2990	939	*2500 2990
...700 ...300	2287	1000 3300	2287	[illegible]	2287	4000 4121	2287	*3000 3390	2287	*3000 3300	2287	*[illegible]	4002	*4000 4080	4002	*4000 4080	2401	*3000 3148	2401	*3000 3148	2401	*4000 4080	2401	*4000 4080
...000 ...284	2079 C	2000 2284	2079 C	[illegible] 2284	2079 C	2000 2294	2079 C	2000 2284	2079 C	2000 2284	2079 C	2000 2284	3638 C	3500 4650	3638 C	3500 4650	2100 C	*2000 2350	2100 C	*2000 2350	2000 C	*2000 2350	2000 C	*2000 2350
...**	--	--	--	3000 3300	--	3000 3300	--	3000 3300	--	3000 3300	--	3000 [illegible]	--	*3000 3300	--	*3000 3390	--	*3000 3148	--	*3000 3148	--	*3000 3148	--	*3000 3148
...**	--	--	--	3000 [illegible]	--	3000 3300	--	3000 3300	--	3000 3300	--	[illegible]	--	*3000 3300	--	*3000 3300	--	*3000 3148	--	*3000 3148	--	*3000 3148	--	*3000 3148
...000 ...284	2000	2000 2284	2000	2000 2284	2000	*2000 2284	2000	*2000 2284	2000	*2000 2284	2000	*[illegible]	[illegible]	*2000 2350	3500	*2000 2350	2100	*2000 2350	2100	*2000 2350	2100	*2000 2350	2100	*2000 2350
...3	20,000		20,000		20,000		20,000		20,000		[illegible]		35,000		35,000		21,000		21,000		21,000		21,000	
...3	15.3		15.3		15.3		[illegible]		15.2		[illegible]		15.3		15.3		15.3		15.3		15.3		15.3	
...7	14.3		14.3		14.1		[illegible]		13.2		[illegible]		[illegible]		13.0		13.0		12.55		13.7		11.6	
...D	270178 S		161177		1003778 S		123978 D		210878 S		100978 S		140679 S		190779		170879 S		060379 S		270979S		151079 S	
			100278 S		230678 SR																			
			240878 SM																					

NOTES

Top value for used component strength is nominal strength
  Bottom value is average of tested sample strengths
Superscript a (test items IH-7 and IH-8) denotes 50 percent concentration
  Genton Ribbon coating
Superscript b (test item IH-9) denotes 100 percent Genton coating
  Letters * and C denote tape or [illegible] used for vent line materials
Mark 6 utilized stronger materials for lower horizontal ribbons and radials. Breaking
strength 318 lbs.

*Indicates Military Specification material see references 1 through 10 or Tables 1 through 4

Selection of material strength for various components for test items were influenced by the design criteria of Reference 17 and by the desire to isolate failures to specific components. Risers were in all cases over-designed with total tensile strength in the 100,000 pound range when the expected maximum loads were less than 30,000 pounds. Chosen skirt band strengths were always greater than the estimated requirements to prevent catastrophic canopy failures and to help distribute concentrated loads imposed by reefing systems. Test items identified with prefixes "IH" and "WP" often reflect over- or underdesign in horizontal ribbons in selected areas of the canopies to establish design criteria for specific components. Test items IH-7 through IH-9 utilize coated horizontal ribbon material and were used to test coating effects on yarn migration or slippage in this material. The coatings consisted of concentrations of a water dispersed nylon (marketed as Genton, see Reference 2) which were applied to the ribbon prior to fabrication through a w[illegible] and drying process. Selection of component materials for tes[illegible] 1 through MARS 10 reflect optimization of the Kevlar-29 MARS prototypes.

Choices of suspension line strength generally reflect a safety factor and degradation factors which result in a design factor (Reference 1) of 2.91. Suspension line, skirt bands, and riser failures were not [illegible]jectives of the design criteria testing.

The actual strength of materials used in the various items included in Table 6 are the result of tensile testing of materials usually from the same lot of material used in construction. Tensile testing techniques used were not always optimum but generally were the same as those used in establishing joint efficiencies. Often materials of the same nominal strength resulted in different actual strengths. These differences may reflect variations in material lots, variations in the construction of materials of similar nominal strength or variations in tensile testing methods.

Design loads listed in Table 6 were for reference in materials strength selection and served as a guide in selecting test conditions for demonstration of structural integrity or promotion of failure in specific components.

(3) Geometric Porosity

Geometric porosity is the ratio of open area in a single gore to the total area of the gore accounting for vent lines, vertical tapes across slots, radial tapes and horizontal ribbons. Deviations from the two-inch ribbon width were also accounted for when applicable. Test item gore geometry and arrangement are depicted in Figure 1.

(4) Parachute Weight

The finished weights listed in Table 6 are actual weights of parachutes with weight for a 1.0 pound riser swivel deducted where applicable. Each weight includes an overstrength riser weighing 1.7 pounds and the appropriate reefing system. These weights do not include deployment bags, pilot parachutes, or pilot parachute risers which add approximately .9 pounds to the packed parachute weight. Nylon test item weight (see paragraph (6)b.) reflects MARS design load (16,800 lb) and can be directly compared with Kevlar-29 MARS items in Table 6.

(5) Packing

All test items were deployed from an unlined bag made from Kevlar-29 fabric and reinforcing webbing. These bags conformed to the shape of the conical tail cones of contemporary Remotely Piloted Vehicles (RPV). The bag shape was that of a right conical frustrum, 20 inches along its axis with base diameters of 10.5 and 3.5 inches. The volume of the bag was .49 cubic feet. Resulting pack densities ranged from 22.5 to 27.8 pounds per cubic foot.

Parachutes were forced into the bags manually and no packing forms were used. Hydraulic force was used on the heavier parachutes but packing pressures were low relative to pressure packing techniques.

The deployment bag configuration provided a lines-first deployment with canopy restraint which was removed after deployment of all suspension lines. Deployment of the test items was aided by a 24 inch diameter, 8 vaned pilot parachute utilizing Kevlar-29 suspension lines and a nylon riser connecting the pilot parachute to the aft end of the deployment bag.

(6) Test Number Referencing

Table 6 also includes test numbers for each test item which allows indexing and referencing of the test items to Tables 7 and 8 which contain test conditions and results.

b. Nylon Parachute Test Items

Not included in Table 6 are two nylon test items. Both of these parachutes were production 15.3 ft D_o, 20 degree conical MARS drag parachutes. These parachutes have 20 gores, a geometric porosity of 20 percent, and are constructed by assembling individual gores (i.e., ribbons are not continuous). Horizontal and radial ribbons are 2" wide. The horizontal ribbons have a nominal strength of 300 pounds. Suspension lines and risers have the same geometry as the Kevlar-29 test items with a suspension line strength of 1850 pounds.

The nylon test item used in test 270978S retained the production single-stage reefing system. For test 211278S a two-stage reefing system was installed. The nylon parachute weight was 15.6 pounds not including the 1.0 pound riser swivel, deployment bag, or pilot parachute.

3. TEST ITEM REEFING

All test items, exclusive of IH-1, IH-2 and IH-3 (which were permanently reefed), were fitted with two-stage reefing systems utilizing a 2000 lb Kevlar-29 braided reefing line for each stage which was cut by two pyrotechnic reefing cutters armed by a lanyard pull pin at line stretch. Each reefing line was routed through a separate set of reefing rings attached to the canopy skirt band and radial joint at each radial. Reefing cutters were covered by fabric protective pockets and the reefing lines were thread tacked to each fourth radial to maintain even spacing during handling and packing. An additional thread tack at each fourth radial controlled excess slack for the longer second stage reefing line.

Reefing cutters utilized were designed to cut 2,000 lb braided nylon cord and test firings confirming their effectiveness on 2,000 lb Kevlar braid were conducted prior to testing.

4. DROP TEST DESCRIPTION

Drop testing was conducted at the National Parachute Test Range at El Centro, California and on a test range at Edwards AFB, California.

Cylindrical test vehicles 23 inches in diameter and 140 inches long with cast iron ogive nose sections were ballasted to various weights (see Table 7) from 3,000 to 6,000 pounds and released as an external store from the centerline of an F-4 fighter aircraft. Two seconds after release, a panel closing the aft end of the test vehicle was pyrotechnically separated from the vehicle with sufficient thrust to escape the aerodynamics of the blunt vehicle base. (Table 7 contains all drop test conditions.) This panel extracts the pilot parachute through a nylon tether which breaks away from the apex of the pilot parachute as the pilot parachute riser acquires the mass of the packed parachute located within the test vehicle aft cavity. Initial motion of the parachute deployment bag, relative to the test vehicle, opens the forward end of the bag and the suspension lines are paid out as 24 break ties, nearly evenly spaced along the length of the suspension lines, which progressively fail. Deployment of the last 14 inches of the suspension lines negates restraint of the canopy in the deployment bag and the bag is stripped from the canopy by the pilot parachute as the event defined as line stretch occurs. A minor short duration force peak (see Figure 2) is generated at or near this time which can be defined as the snatch force. The force being applied to the test vehicle mass then increases until a maximum value identified as the opening force peak

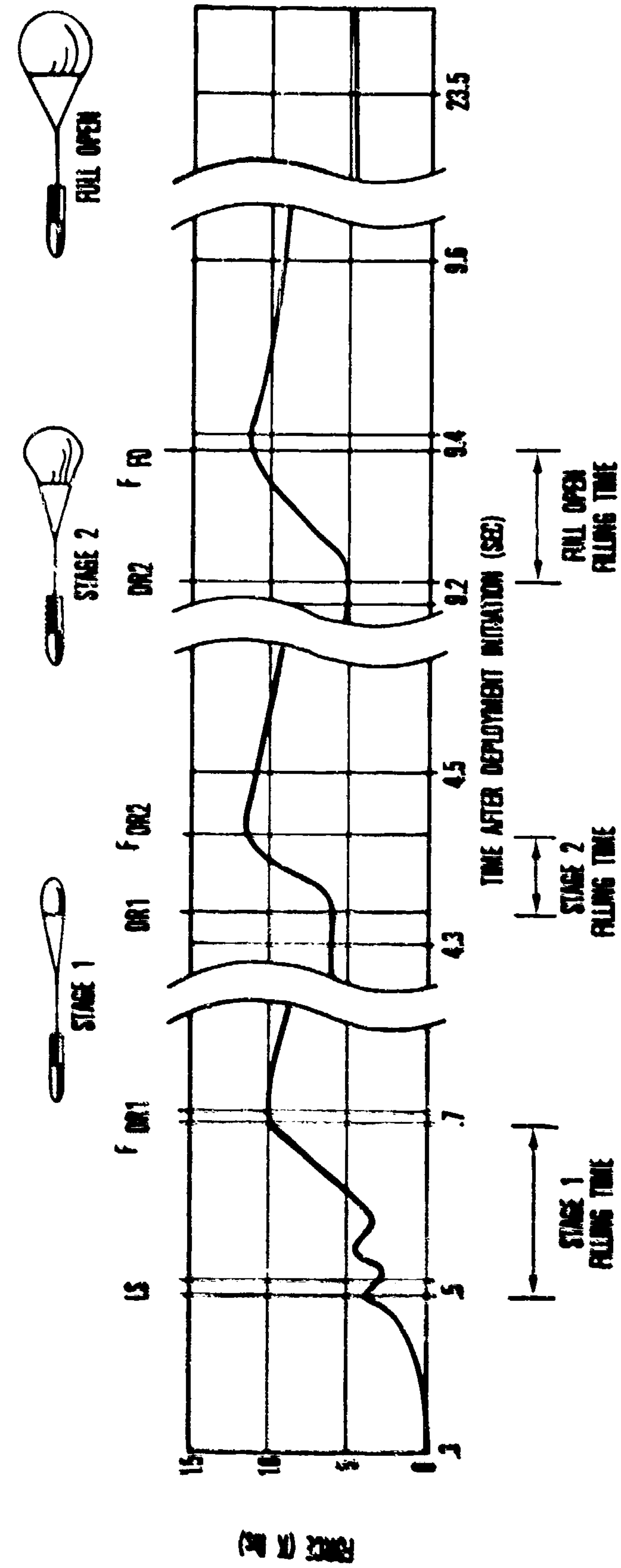


Figure 2. Typical Drop Test Force History and Events

is reached. The test item acquires its first stage size and shape shortly after this force peak and the force decays as the test vehicle is decelerated. After a period of time determined by the reefing cutter delay, the first stage reefing line is severed and the parachute generates an increasing force as it inflates to its second stage. A peak force associated with the changes in parachute area due to disreefing is generated. The vehicle deceleration continues for the second stage, terminating in a third major force peak and the full open parachute which decelerates the vehicle to the point where the near vertical rate of descent is constant and the parachute force is equal to the vehicle weight. Figure 2 displays a typical force time history and identifies some of the events of interest. Programmed separation of the test item from the test vehicle terminates the test approximately 40 seconds after separation from the aircraft. A vehicle recovery system which is independent of the test item then activates to recover the vehicle and on-board instrumentation.

5. SLED TEST DESCRIPTION

Sled testing utilizing the "Bushwhacker" rocket powered sled was conducted at the Holloman AFB track facilities. The "Bushwhacker" sled vehicle, shown in Figure 3, is 15 feet high, 40 feet long, and weighs 12,000 pounds after burnout of on-board rocket propellant. Propulsion for this vehicle is provided by Nike rocket motors contained on-board or on a pusher sled when more than four motors are required to accelerate the sled to require conditions. The packed test item arrangement for sled tests is identical to the drop test arrangement except for the protrusion (for sled tests) of 48 more inches of riser from the forward end of the deployment bag. This facilitates attachment to the sled vehicle at a point 18 inches above and 21¼ inches forward of the center of the aft end of a 15 inch diameter, 31.25 inch long tube attached at its forward end to the trailing edge of the sled. The attachment point for the test item is 180.25 inches above the rail head and approximately 17 feet above the surrounding ground. A complete description of the

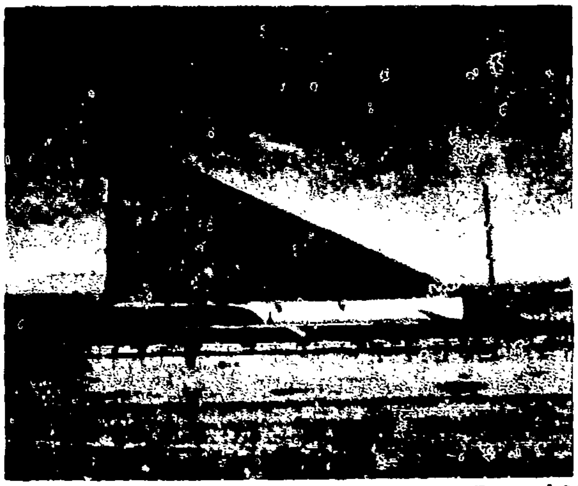


Figure 3a. Bushwhacker Sled Prior to Test 100278S

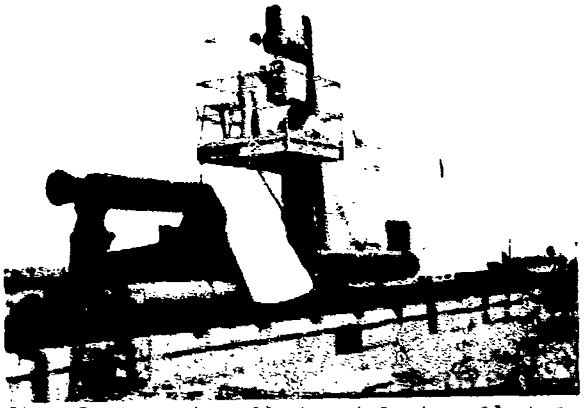


Figure 3b. Bushwhacker Sled and Pusher Sled Prior to Test 270777S

Figure 3c. Bushwhacker Sled with Full Open Test Item Test 040878S

Figure 3. Bushwhacker Rocket Boosted Sled

Holloman AFB track facilities is included in Reference 19. For a typical test, the sled is accelerated by solid fuel rocket motors along a 50,788 foot, 2-rail track on 4 captive slippers. After thrusting of the rockets is complete, the sled is allowed to coast to a predetermined point on the track where parachute deployment is initiated and test item deployment conditions exist. Figure 4 shows a typical sled test force time history and related events.

Test item deployment is initiated by an electrical signal generated when a knife like appendage to the sled strikes a metal screen held stationary with respect to the track. This signal initiates a pyrotechnic thruster which separates an 8 inch diameter, 60 degree metal drag cone or a closure panel at the aft end of the parachute compartment. The cone or closure panel extracts the pilot parachute contained in a nylon envelope (turtle bag) and the remainder of the deployment and test sequence is identical to that described for drop testing with the exception that the aerodynamic decelerating action of the parachute is augmented by the sliding resistance of the slippers on the track and the aerodynamic drag of the sled. The test terminates when the full open parachute is disconnected from the sled while inflated and operating at a low velocity. This disconnect prevents dragging of the test items on the track at very low velocities. Table 8 contains conditions for all sled testing.

6. DATA ACQUISITION

a. Velocity and Dynamic Pressure

Drop test vehicles were tracked continuously and simultaneously by at least three contraves theodolite stations. This tracking arrangement produces synchronized azimuth and elevation data which can be resolved into 30 space position points per second for the test vehicle. Differentation of the position-time data yields vehicle velocity with respect to a reference point on the ground. Dynamic pressure can be calculated from the derived velocity data and air density which is determined at

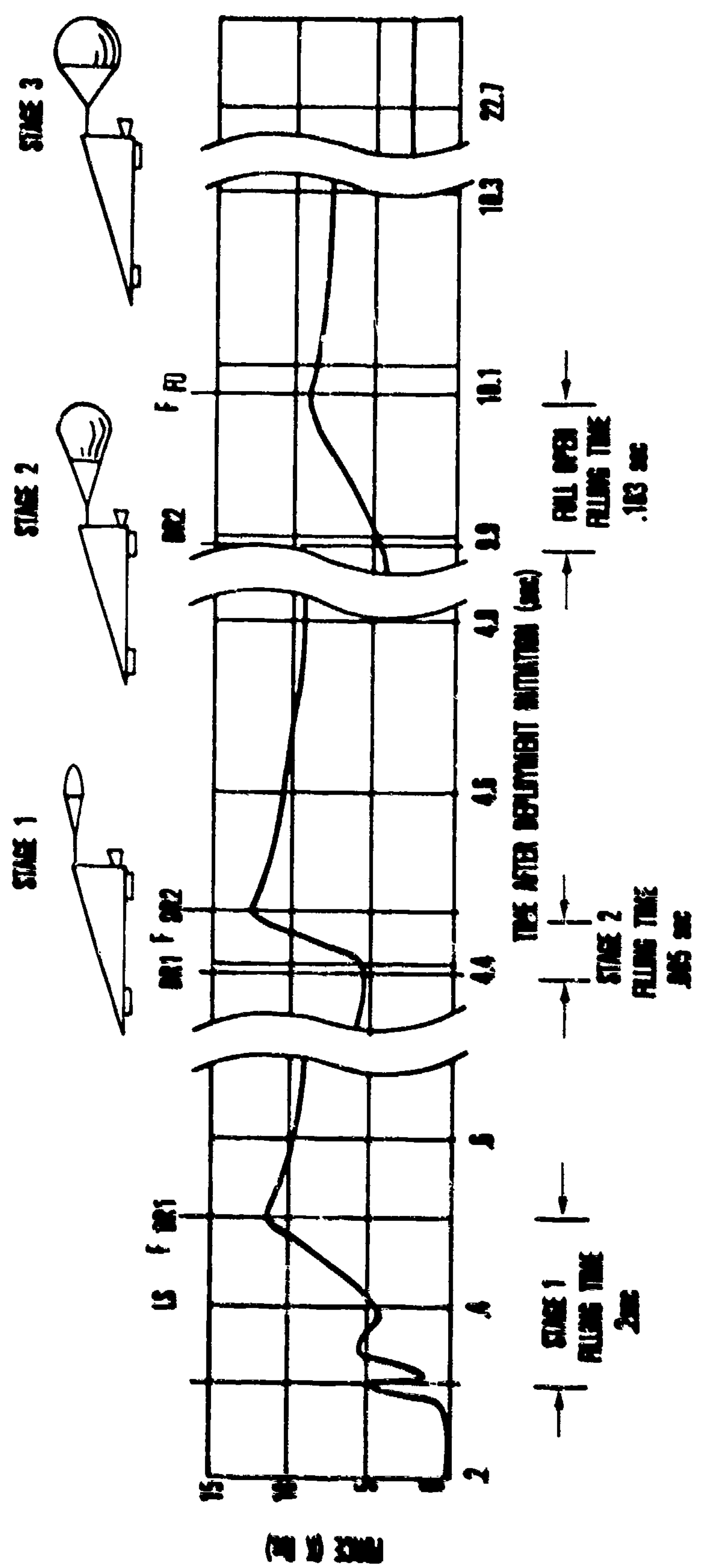


Figure 4. Typical Sled Test Force History and Events (Force-Time History for Sled Test No. 290878S)

altitude by an ascending metrological data measurement package. Effects of wind and other air mass motion with respect to the ground were ignored in obtaining the drop test data. Other important data obtained from the space position data include flight path angle, altitude, and distance along the flight path.

During sled tests the position and velocity of the sled were derived from a recorded history of a point on the sled passing sensors spaced at 13 foot intervals along the track. Dynamic pressure is based on true airspeed (obtained by utilizing measured surface winds and the derived ground velocity) and air density obtained from measured atmospheric data.

b. Force

Forces generated by the parachute and applied to the test vehicles were sensed by strain gauged metal force transducers during both drop and sled tests. The drop test force transducer is a tensile link located in a nylon riser which connects the test item riser to load bearing structure in the forward section of the cylindrical test vehicle. On the sled, a similar transducer is a tensile link in the metal load path from the test item Kevlar riser to the sled structure. In both systems the force data is telemetered to a remote station where the data is recorded on magnetic tape. Analog and digital force records are later created from the tapes for analysis.

c. Photographic Data

On-board high speed 16mm motion picture cameras were common to both sled and drop tests. Four cameras are carried on the sled for close-up observation of specific components of the test items and for overall coverage which can be utilized to obtain projected area growth and variations. Drop test vehicles carry only one camera for overall coverage.

Excellent views of the sled test items side profiles and observations of staging are obtained from the stationary cameras with film planes parallel to the track. Drop test side profiles are not usually obtained but chase aircraft films supply coverage of deployment and early staging operations.

d. Data Syncronization

Telemetered data includes the output of on-board timing generators used to place timing marks (100 per second) on the on-board films. Common range binary timing is utilized to synchronize all ground based cameras and is recorded simultaneously on telemetered tape records. These timing conventions permit accurate determinations of test events during both sled and drop tests.

7. TEST CONDITIONS AND RESULTS

Test conditions and results from the drop tests and sled tests are presented in Tables 7 and 8. The altitude of the sled track is 4070 ft. MSL.

a. Parameter Definitions

Tables 7 and 8 contain measured data and parameters derived from the measured test data. Definitions of these parameters are presented in the following list:

(1) Test Vehicle Weight

The measured weight of the cylindrical test vehicle is just prior to the loading on the aircraft for drop testing. This weight includes the weight of the packed test item with pilot chute, and the test vehicle aft closure or door. The vehicles were ballasted and an error of not more than $\pm$ 25 pounds would be reasonable.

(2) Reefing Ratio (RR)

The ratio of the diameter of a circle with circumference equal to the reefing line length to the nominal test item diameter (i.e., reefing line length divided by π and 15.3).

TAB

DROP TEST CONDITIONS AND RESULTS

CONICAL CONTINUOUS

		141175D	171275D	231275D	270476D	160876D	151076D	171176D	091276D	250577D
	Test Number	141175D	171275D	231275D	270476D	160876D	151076D	171176D	091276D	250577D
	Test Item	1	1M	2	3	4	4R	5	4M	MARS 6M
	Vehicle Weight (lb)	3760	4766	6266	4750	4750	4750	4750	4750	5000
REEFING	Stage 1 Ratio	.219	.219	.320	.219	.219	.219	.219	.219	.221
	Stage 1 Delay (sec)	6	6	5	5	6	6	6	6	4
	Stage 2 Ratio	.352	.352	.410	.320	.320	.320	.320	.320	.337
	Stage 2 Delay (sec)	12	12	12	12	12	12	12	12	7.5
LINE STRETCH	Velocity TAS (fps)	611	740	569	810	776	836	794	830	621
	Mach Number m	.57	.70	.53	.76	.73	.78	.74	.78	.58
	Altitude MSL (ft)	15000	15000	15000	15000	15500	15000	15000	15000	5000
	Q (psf)	268	430	258	494	440	514	449	527	276
	Snatch Force (lb)	3376	1964	2717	6759	6825	1468	7125	5326	4156
STAGE 1	Peak Force F_{OR1} (lb)	9170	17333	13800	12394	15097	15218	14973	15683	8852
	X_{R1}	1.17	1.37	1.43	1.08			1.10	1.28	1.22
	C_DS	29	29	37	22			30	23	26
	At Disreef Q (psf)	129	219	166	252			226	265	190
	At Disreef Force (lb)	3760	6425	6194	5651			6367	6115	5000
STAGE 2	Peak Force F_{OR2}	9515	16469	11120				12236	13316	12366
	X_{R2}	1.48	1.50	1.29				1.24	1.32	1.37
	C_DS	50	50	52				44	38	48
	At Q (psf)	71	100	104	Reefing Malfunction Both lines cut at first disreef	Premature test item release	Premature test item release	111	137	112
	Disreef Force (lb)	3540	5022	5397				4853	5228	5338
FULL OPEN	Peak Force F_{OFO} (lb)	11203	15509	14163				17503	17606	15711
	X_{FO}	1.51	1.52	1.46				1.76	1.35	1.37
	Equilibrium C_DS	104	101	94				93	105	102
	Equilibrium Q (psf)	36	47	67				51	45	49
	C_D	.57	.55	.51				.51	.57	.56
	Damage	one reefing cutter attach failed - no textile component failure	None	None	susp lines fail at unknown load	minor 2 ribbon breaks top three	None	None	no breaks strain evidence in radials	lower edge ribbon 1[illegible] had 7 partial breaks

TABLE 7

S AND RESULTS FOR 15.3 FT D_o KEVLAR-29 20 DEGREE
CAL CONTINUOUS RIBBON PARACHUTES

250577D	021277D	080378D	030578D	260578D	180878D	041278D	080377D	150377D	270178D	120978D
MARS 6M	MARS 6	MARS 7	MARS 8	MARS 10	MARS 10	MARS 9	IH-1	IH-2	IH-3	IH-7
5000	3000	4500	5000	3000	5000	5000	4750	4750	4750	4750
.221	.221	.221	.221	.221	.221	.221	.300	.300	.219	.219
4	4	4	4	4	4	4	permanent	permanent	5	5
.337	.337	.337	.337	.337	.337	.337	N/A	N/A	.352	.352
7.5	7.5	7.5	7.5	7.5	7.5	7.5	N/A	N/A	10	10
621	1007	825	745	244	715	729	626	635	680	740
.58	.99	.78	.67	.23	.75	.76	.59	.60	.65	.70
5000	26500	14500	5350	20135	40000	41500	14500	14500	15500	15500
276	489	517	512	31	(150)	140	297	299	345	402
4156	--	NO	6667	150	961	3586	3353	3350	9917	4631
8852	15227	FORCE	15833	910	5270	5378	13596	11679	14161	10311
1.22	1.33	DATA	1.11	.91	--	.90	1.20	1.10	1.25	.96
26	23		28	32	--	42	38	35	33	27
190	241	278	291	39	--	120	N/A	N/A	200	235
5000	5636		8125	1260	4335	4975			6577	6251
12366	12909	NO FORCE	20278	3080	3540	7507			14675	11885
1.37	1.42	DATA	1.42	1.62	--	1.30			1.58	1.06
48	38		49	43	--	50			47	48
112	101	123	144	45	--	104			101	116
5338	3818	NO	7083	2170	5533	5154			4698	5557
15711	10727	FORCE	19722	7769	13423	13109			10612	10914
1.37	1.06	DATA	1.37	1.73	--	1.40	N/A	N/A	1.14	.98
102	100	98	100	100	--	101	38	35	92	96
49	30	46	50	30	--	50	104	108	52	50
.56	.54	.53	.54	.54	--	.55	.21	.19	.50	.52
lower edge ribbon 11 had 7 partial breaks	minor - 2 isolated ribbon breaks #12 and #16	no breaks, partial breaks and vertical strains lower third all gores	None (As observed on film)	None	None	None	no breaks severe yarn slippage lower ribbons	no breaks severe yarn slippage partial breaks	no breaks severe yarn slippage ribbons 18 thru 33 all partially broken	no breaks severe yarn slippage throughout

Test Number			080377S	270777S	310877S	270977S	161177S	100278S	300378S
Test Item			2	2	1M	2M	IH-5	IH-5	IH-6
REEFING	Stage 1	Ratio	.219	.219	.219	.219	.219	.219	.219
		Delay (sec)	5	5	5	5	5	5	5
	Stage 2	Ratio	.352	.352	.352	.352	.352	.352	.352
		Delay (sec)	10	10	10	10	10	10	10
LINE STRETCH	Velocity TAS (fps)		777	856	815	696	751	841	887
	Mach Number		.70	.74	.71	.61	.67	.75	.65
	Q (psf)		628	702	653	482	571	723	793
	Snatch Force (lb)		4916	9053	5701	7325	4920	11637	4597
STAGE 1	Peak Force F_{OR1} (lb)		21404	23444	24117	17101	21618	23658	26049
	X_{R1}		1.18	Swivel Failure	1.12	1.17	1.28	1.09	1.12
	At Disreef	C_DS	29		33	30	30	30	29
		Q (psf)	311		310	271	293	356	393
		Force (lb)	9165		10344	8174	8643	10683	11481
STAGE 2	Peak Force F_{OR2} (lb)		20152		29156	18712	20332	23934	26283
	X_{R2}		1.35		Reefing Failure	1.33	1.37	1.37	1.44
	At Disreef	C_DS	48			53	51	49	47
		Q (psf)	117			104	115	128	140
		Force (lb)	5656			5474	5846	6326	6536
FULL OPEN	Peak Force F_{OFO} (lb)		16212			14067	17159	17497	18633
	Y_{FO}		1.33			1.30		1.34	1.29
	Equilibrium	C_DS	105			105	Early Disconnect	104	104
		Q (psf)	52			42		88.1	93
		C_D	.57			.57		.57	.57
Damage			None	one partially broken crown ribbon	all radials fail at 23,620	11 breaks in top 6 ribbons	None	minor ribbons #3 and #4 broken near #3 splice scattered partial breaks	no breaks many partial breaks lower 12 ribbons

TABLE 8

SULTS FOR 15.3 FT D_0 KEVLAR-29 (NYLON) 20 DEGREE
ONTINUOUS RIBBON PARACHUTES

←NYLON—

290578S	190978S	140679S	190779S	170879S	060979S	270979S	181079S	270978S	21127
IH-8	IH-9	WP-1	WP-2	WP-3	WP-4	WP-5	WP-6	NYLON MARS	NYLON M MODIFIE
.219	.219	.219	.219	.219	.219	.219	.219	.350	.219
5	5	5	5	5	5	5	5	5	5
.352	.352	.352	.352	.352	.352	.352	.352	N/A	.352
10	10	10	10	10	10	10	10	N/A	10
604	608	941	939	868	841	840	815	610	596
.53	.54	.82	.83	.77	.74	.74	.73	.54	.54
371	367	870	874	755	694	699	675	365	381
5446	6626	6099	6390	7494	7433	4563	5238	4839	5802
12058	11649	25504	29964	25209	25227	22744	23290	20149	11777
1.22	1.11	1.08	1.37	1.28	Reefing Failure	1.23	1.27	Riser Failure	1.1
27	29	27	26	26		26	27		2
221	212	401	408	391		345	309		20
5900	6068	10850	10523	10185		9127	8403		561
12998	13155	24416	25460	22933		20005	19046		1283
1.34	1.31	1.29	1.49	Vent band and vent lines failure		1.38	1.27		1.3
44	48	48	42			42	47		4
102	110	181	180			214	158		9
4506	5252	8609	7628			9057	7415		452
9498	11180	20212	20421			16286	17099		1122
1.07	1.14	1.15	1.32			.98	1.15		1.3
89	92	99	89			85	97		[illegible]
56	62	143	110			94	67		[illegible]
.48	.50	.54	.48			.46	.53		[illegible]
ribbon splices broken in #8,#7&#6 ribbon 5 also broken severe yarn slippage	no breaks severe yarn slippage	vent band failed during first stage inflation crown ribbon fails first	vent band failed during first stage inflation crown ribbon failures first	vent band failed during first stage inflation followed by vent lines & crown ribbons	two crown ribbons fail first all suspension lines fail at 25,933 lbs vent band did not	upper ribbons in one gore fail during first stage inflation then vent band fails	vent band fails during inflation at first stage after 4 crown ribbon failures	riser failed at 2014916	nor

(3) Reefing Delay (Seconds)

Nominal time for burn of the time delay powder train in the pyrotechnic cutters which sever reefing lines. Initiation of powder train burning is accomplished by a lanyard anchored to the suspension lines in a position which applies tension to an initiating pin at the completion of suspension line deployment from the deployment bag.

(4) Velocity (ft/sec)

The true airspeed or velocity of the cylindrical test vehicle relative to the ground or of the sled relative to the air mass through which it is moving.

(5) Mach Number

The ratio of the velocity to the speed of sound in the air mass through which the test vehicle is moving. Calculated from the atmospheric conditions at the time of testing and vehicle velocity.

(6) Dynamic Pressure (Q, pounds per square ft)

A quantification of the potential of an air mass to exert forces on a body moving through it. (Product of the square of the velocity (ft per sec) and one half of the air density (slugs per cubic foot)).

(7) Line Stretch (LS)

An event which occurs as test item deployment terminates and inflation to the first stage begins. Determined by observation of high-speed films showing grouped suspension lines becomming taut and the parachute skirt emerging from the deployment bag.

(8) Snatch Force (lb)

First recognizable peak in the force trace after deployment initiation and prior to the first stage inflation peak force. When two or more such peaks of approximately the same magnitude appear the first is identified as the snatch force.

(9) Peak Inflation Force (F_{OR1}, F_{OR2}, F_{FO}, lbs)

Maximum force recorded as the test item achieves its inflated size, shape and final force producing configuration for either the first reefed stage, the second reefed stage, or the full open or unreefed condition. Force values for these peaks are read from analog displays of the recorded telemetered force time data where time scales are nominally 10 inches per second.

(10) Shock Factor (X_{R1}, X_{R2}, X_{FO})

A factor used to predict peak loads when drag area and dynamic pressure can be determined. Shock factors developed from the reported test data as design criteria were obtained for each stage as follows:

$$X_{R1} = \frac{F_{OR1}}{(C_D S)_{R1} \quad Q_{LS}} \qquad \text{(first reefed stage)}$$

$$X_{R2} = \frac{F_{OR2}}{(C_D)_{R2} \quad Q_{DR1}} \qquad \text{(second reefed stage)}$$

$$X_{FO} = \frac{F_{FO}}{(C_D S)_{FO} \quad Q_{DR2}} \qquad \text{(full open)}$$

(11) Drag Area ($C_D S$, Square feet)

Effective area of the parachute at the end of each inflation stage. For the reported test data, drag area is calculated as the ratio of test item drag force to dynamic pressure at a specific time.

(12) Disreef

Events initiated by the firing of pyrotechnic reefing cutters which sever a reefing line. Times for the disreefing events are determined by identifying an on-board film frame which depicts first growth in test item projected area at the beginning of the second or full open stage.

(13) Equilibrium

For drop testing: Condition in which the sum of the parachute force and vehicle aerodynamic drag is equal to the total weight of the vehicle and parachute and in which velocity is both constant and near vertical. Staging times or test item disconnects normally preclude reaching this condition precisely, especially for reefed stages where conditions just prior to disreef were interpreted as "equilibrium conditions" for purposes of calculating reefed drag coefficients and drag areas.

For sled testing: Equilibrium conditions are considered to exist at the end of each stage or in the full open condition at a time following final disreef where acceleration of the sled was minimal.

(14) Drag Coefficient (C_D)

Factor by which parachute areas and dynamic pressure are multiplied to obtain drag force. (Drag Force = (C_DS) (Q)). The equilibrium drag coefficients contained in Tables 7 and 8 are equal to the ratio of the force measured at equilibrium conditions to the product of dynamic pressure and parachute area.

8. DISCUSSION OF TEST RESULTS AND EFFECTS OF REEFING

a. Peak Forces

Peak forces, which occur at or near the time when maximum projected area for each of three inflated stages, were measured and are included in Tables 7 and 8 for drop and sled tests respectively. In Figures 5, 6, and 7, values for force peaks and coincident dynamic pressure are plotted for the reefed stages and full open stage of each test. Symbols on the plotted data points represent damage to the test items or unique test item configurations. Figures 5 and 6 indicate that noncatastrophic damage does not significantly disturb the linearity of the data for the first and second stages respectively. In Figure 7, the plot for the full open stage, several points which represent damage to test items are below a reasonable line drawn through the undamaged or less severely damaged test item data points.

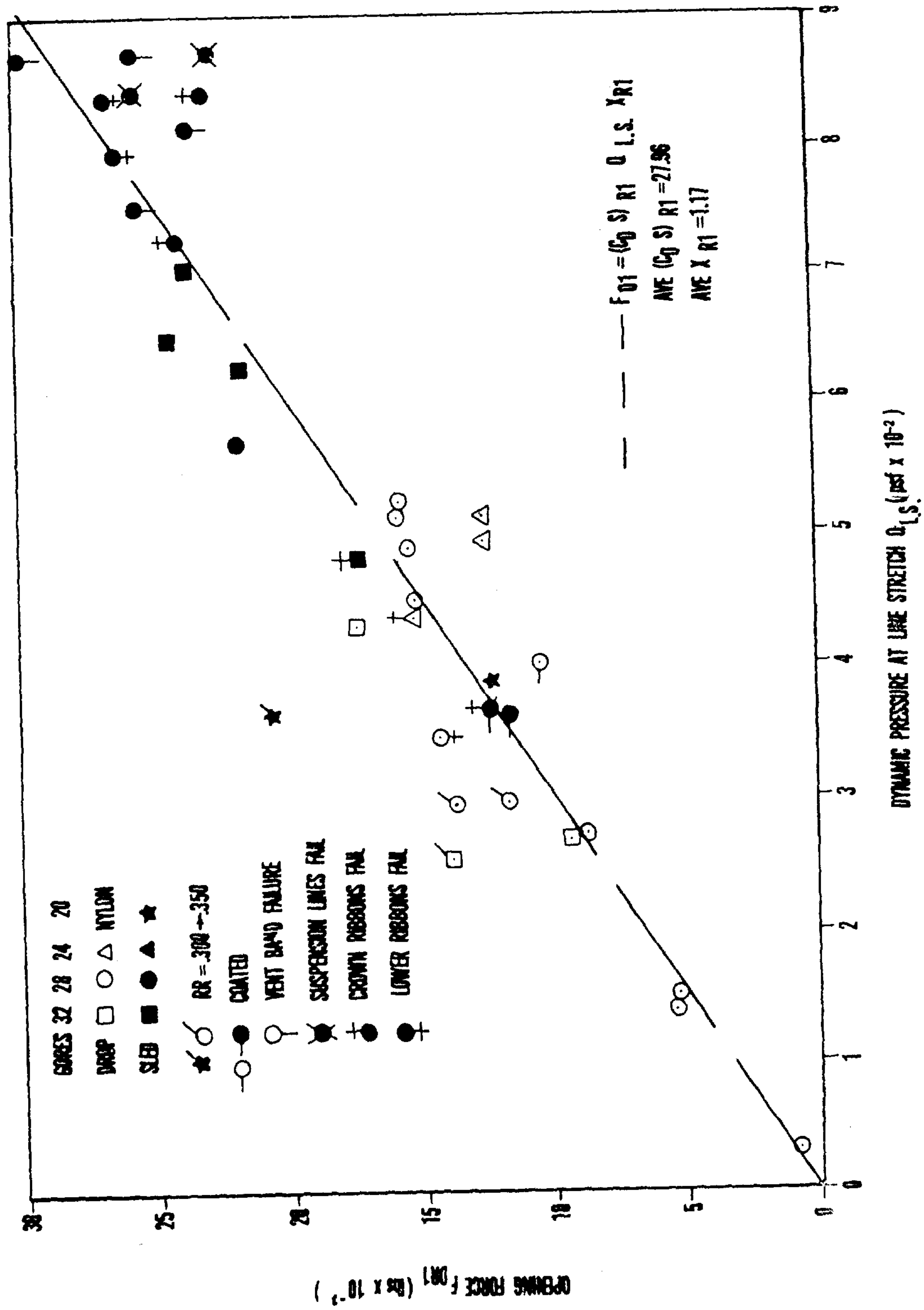


Figure 5. First Stage Peak Force vs Line Stretch Dynamic Pressure .219<RR<.221 and noted

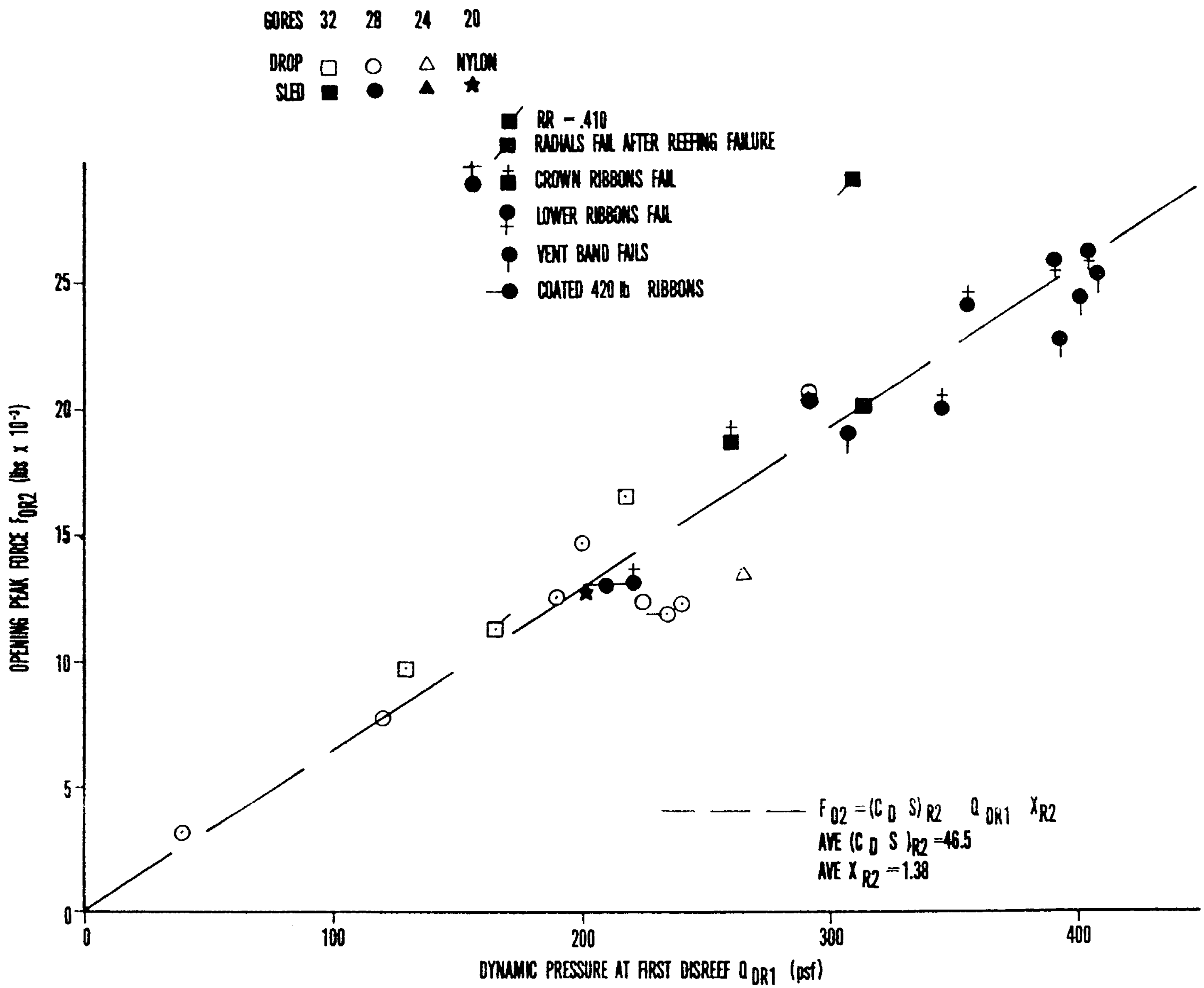


Figure 6. Second Stage Peak Force vs Dynamic Pressure at First Disreef

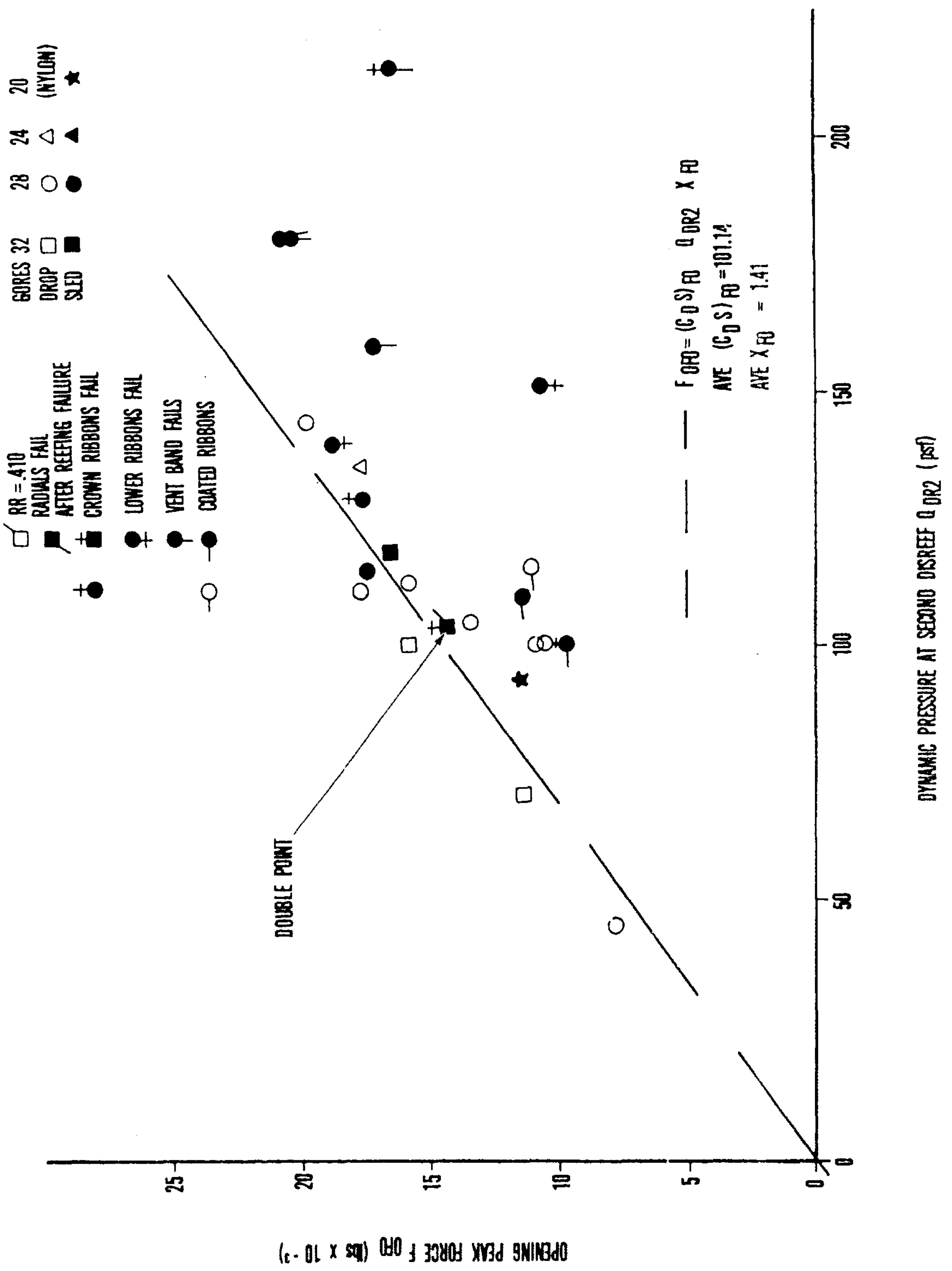


Figure 7. Full Open Peak Force vs Dynamic Pressure at Second Disreef

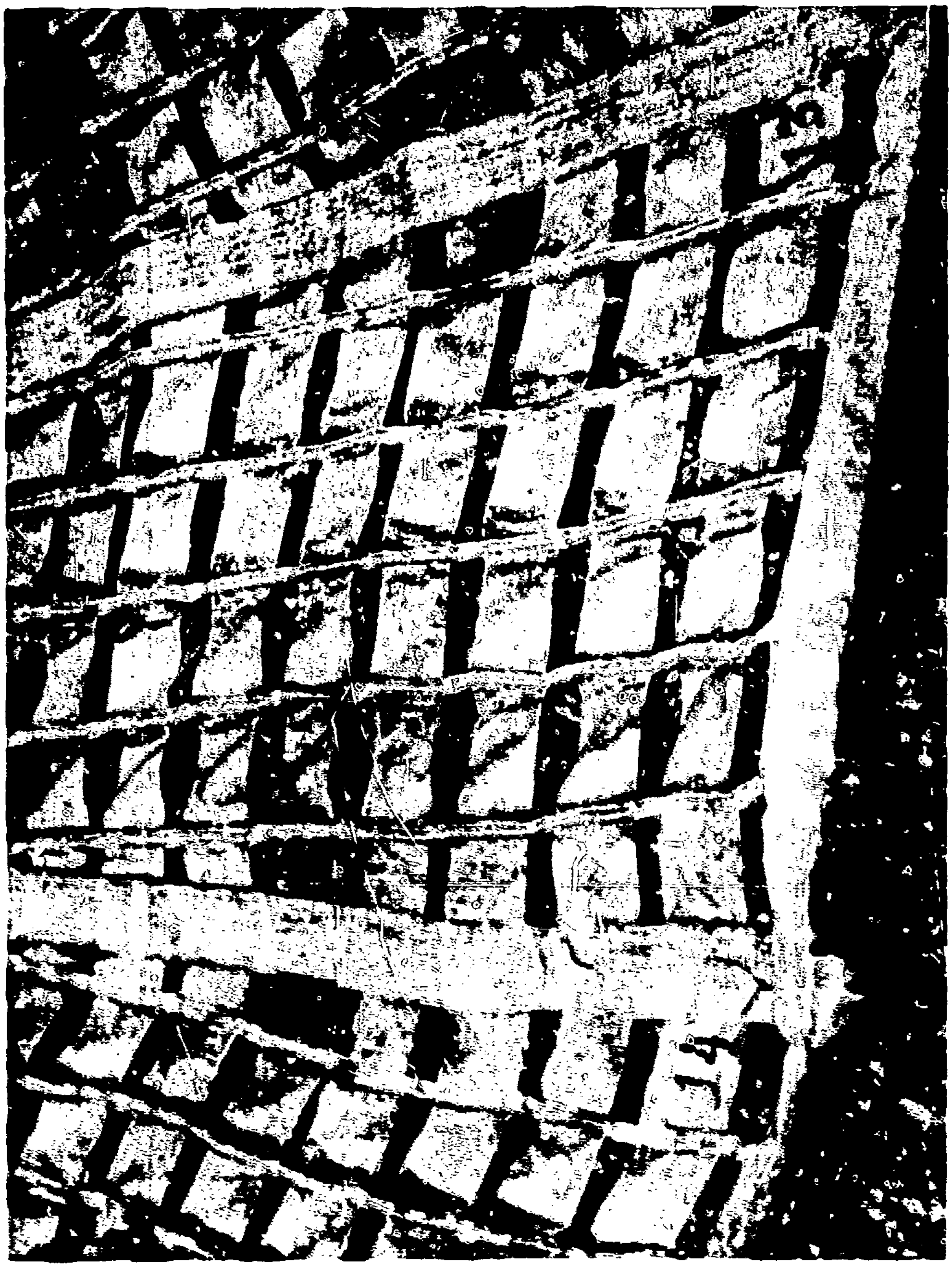


Figure 8. Typical Coated 400 lb Ribbon Yarn Migration

Peak forces generated by the staging to full open of test items IH-3, IH-7, IH-8 and IH-9 which utilized 400 lb tensile strength horizontal ribbons were lower than the line representing test data for the full open stage in Figure 7. Since damage to test items was primarily yarn migrations and not tensile failure (even though ribbons were coated in IH-7 and -9) it appears that ribbon configurational changes are the primary cause for the lower forces. Figure 8 shows the post test condition of 400 lb ribbons and the ineffectiveness of the coating relative to preventing yarn slippage or migration. The ribbon condition depicted in Figure 8 is typical for both coating concentrations.

When sled and drop tests involved staging at similar dynamic pressures, good agreement in the peak forces obtained by these two test methods was observed.

b. Drag Area

Drag area values contained in Tables 7 and 8 were averaged for test item stages. These average values, quantity of data, and the data dispersion (standard deviation) are presented in Table 9. Stage 1 averaged data represent reefing ratios of .219 and .221. Stage 2 averaged data represent reefing ratios of .352, .337 and .320. Observation of Figure 7 and values making up the averaged data populations suggested that tests involving extensive damage and test items based on the 400 lb horizontal ribbons should not be included in the drag area data representing the full open stage. When these data are omitted from the full open stage data population, the last column in Table 9 results. These selected data are considered representative of obtainable drag area.

Sled test and drop test averaged drag areas indicate that these categories can be represented by the combined drag area average values.

TABLE 9

REPRESENTATIVE DRAG AREAS, $C_D S$ (sq. ft)

	Stage 1 All Data			Stage 2 All Data			FULL OPEN STAGE All Data			FULL OPEN STAGE Selected Data*		
	RR = .219 or .221			RR = .352, .337 or .320								
	Data Points	Average Value	Std Dev	Data Points	Average Value	Std Dev	Data Points	Average Value	Std Dev	Data Points	Average Value	Std Dev
DROP TESTS	14	28.4	2.02	12	46.9	3.40	11	96.2	7.55	4	104.5	.58
SLED TESTS	11	27.5	3.67	10	46.0	4.55	13	98.9	4.09	10	99.8	3.88
COMBINED TESTS	25	28.0	2.84	22	46.5	3.89	24	97.7	5.95	14	101.1	3.92

*Data related to test items utilizing 400 lb ribbon or severely damaged test items were omitted from "selected data".

Figure 9 contains plotted points representing the averaged C_DS values for each drop and sled test reefing ratio. The reefing ratio value RR = .67 is indicative of the full open Kevlar-29 test item profile as scaled from films. Also plotted are average values for eight 15.3 ft nylon conical ribbon RPV drag parachutes tested under a preceeding program (results unpublished). The Kevlar data matches these and the data resulting from the single sled test (see Table 8) of the nylon parachute. It should be noted that the nylon parachute canopy contained 20 gores.

c. Opening Shock Factors

Opening shock factors which resulted from dividing the peak force for a given inflation stage by the drag area at the end of the stage and by the dynamic pressure at the initiation of the stage were taken from Tables 7 and 8 and averaged to obtain representative values. Table 10 contains the representative values following the practice utilized to obtain the drag area representative values of Table 9. The results of this averaging process (Table 10) indicate that sled and drop test data for the first two stages can be reasonably combined, but that drop tests produce higher and more scattered full open shock factors.

Utilizing the commonly used Reference 1 relationship for predicting peak loads,

$$F_o = (C_DS)\ Q\ X$$

and the combined test average values for C_DS and X (for a given stage) from Tables 9 and 10, the dashed straight lines on Figures 5, 6, and 7 were plotted.

The effect of reefing on opening shock factor is shown in Figure 10. The plotted average values for the first two stages are representative of relatively closely grouped data populations even though a large range of test conditions is represented. All data, except those resulting from tests of items using 400 lb horizontal ribbons were included. The full

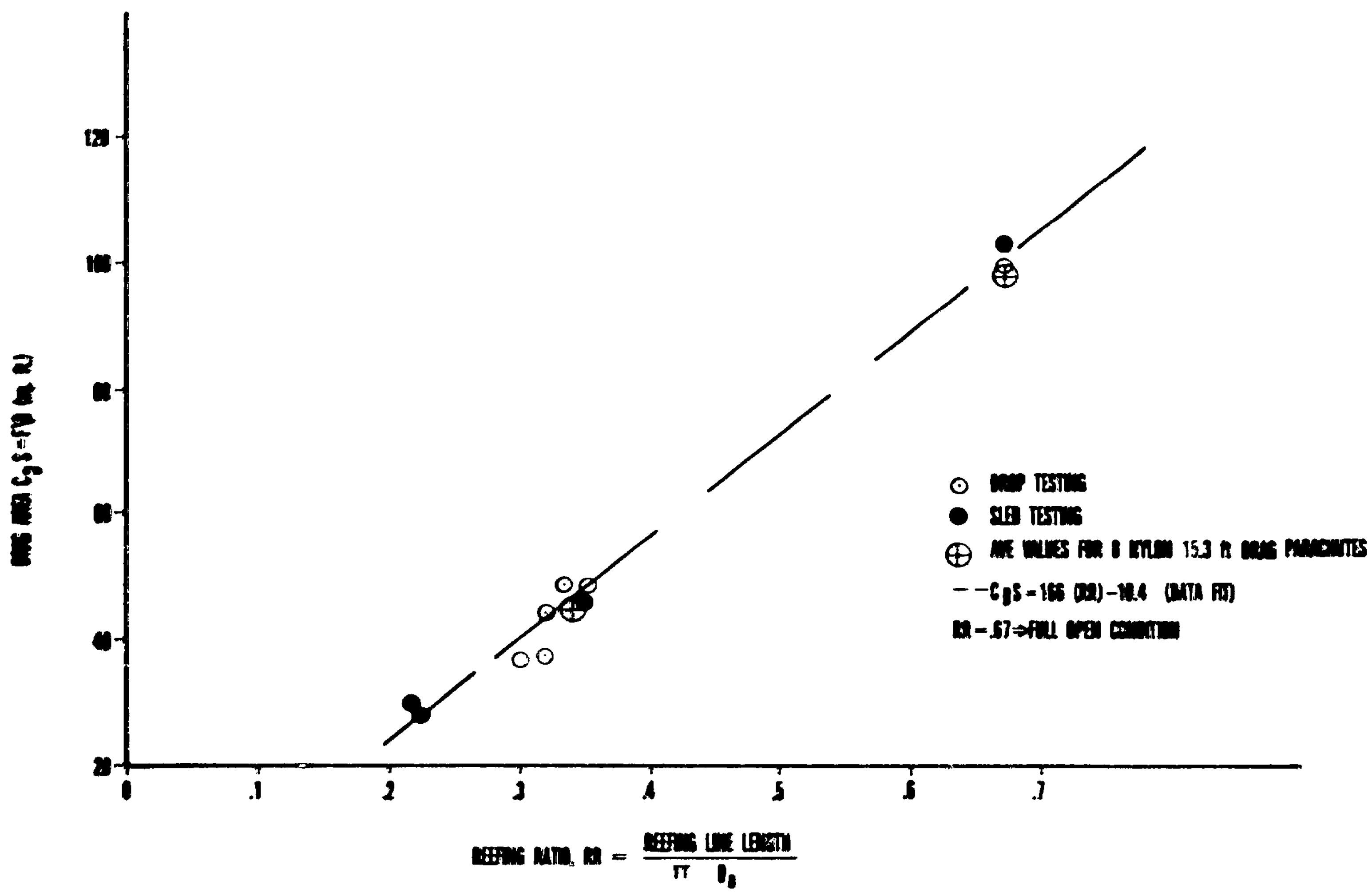


Figure 9. Average Drag Area vs Reefing Ratio for 15.3 ft D_0, 20 Degree Conical Kevlar-29 Parachute

TABLE 10

REPRESENTATIVE OPENING SHOCK FACTORS

	X_{R1} Stage 1 All Data			X_{R2} Stage 2 All Data			X_{FO} FULL OPEN STAGE All Data			X_{FO} FULL OPEN STAGE Selected Data*		
	PR = .219 or .221			PR = .352, .3370 or 320								
	Data Points	Ave Value	Std Dev	Data Points	Ave Value	Std Dev	Data Points	Ave Value	Std Dev	Data Points	Ave Value	Std Dev
DROP TEST	15	1.16	.16	12	1.38	.16	12	1.39	.24	9	1.45	.21
SLED TEST	14	1.19	.09	12	1.37	.07	12	1.22	.12	4	1.32	.02
COMBINED TESTS	29	1.17	.13	24	1.38	.12	24	1.31	.20	13	1.41	.19

*Data related to test items utilizing 400 lb ribbon or severely damaged test items were omitted from "selected data".

open shock factor data for sled tests is also a closely grouped population (data from tests with damage are omitted as per discussion on peak forces), but drop test data has a wide dispersion as indicated in the figure. The average value for full open drop test opening shock factor is 1.45 which represents a population of 9 data points with a standard deviation of .21 and a range of data from X_{FO} = 1.06 to 1.76. Interpreting the data to produce a relationship based on the test data which could be used for design resulted in the dashed line on Figure 10 which is biased toward the high values for shock factor in the staging to full open.

Single points on Figure 10 represent odd reefing ratios and test items made with 400 lb horizontal ribbons. Except for the first stage of the two sled tests, test items with 400 lb ribbons produced much smaller opening shock factors. These results are believed to reflect changes in permeability due to slippage of filling yarns in horizontal ribbon free lengths. Figure 8 shows coated 400 lb ribbons after test 290878S. No indication that either concentration of the Genton coating prov[illegible] mprovement in this material was observed.

d. Inflation (Filling) Times

The times required for test items to transition from one stage to another (inflation of the canopy from the line stretch condition to completion of first stage inflation (Stage 1), the inflation which occurs between the first disreef and the completion of second stage inflation (Stage 2), or inflation which occurs between second disreef and the full open condition) are referred to as filling times. Events marking the initiation of each inflation stage were clearly defined on high-speed motion picture films or on oscillograms containing force traces. These two data sources were also syncronized utilizing timing marks which were recorded simultaneously on film and oscillograms.

The end of inflation periods are commonly defined as the time when the projected area first equals the steady-state or equilibrium projected area for

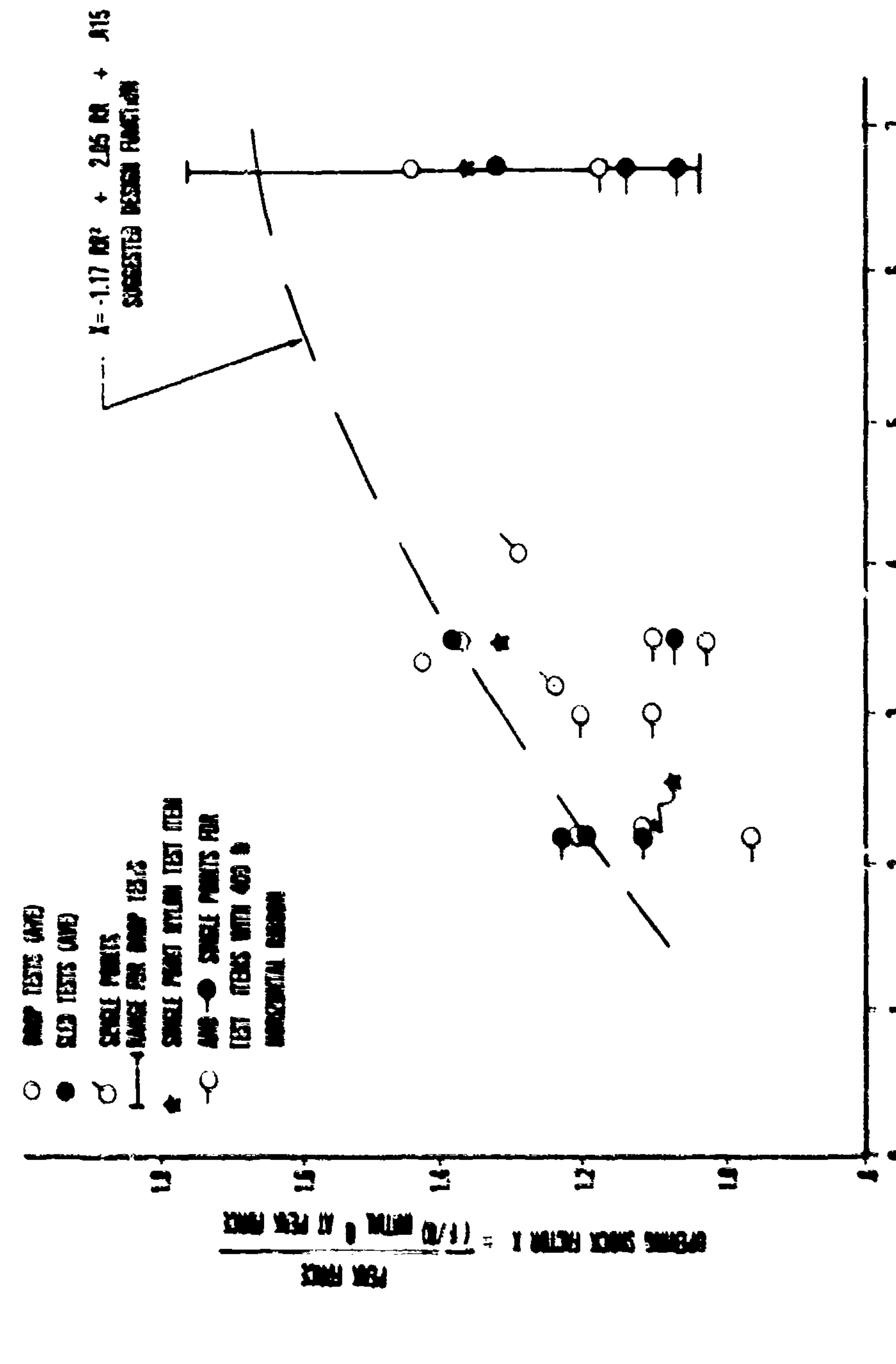


Figure 10. Opening Shock Factor Average Value vs Reefing Ratio for 15.3 ft D_o, 20 Degree Conical Kevlar-29 Parachute

a given reefing stage or the full open condition. For the testing discussed here, motion picture frame rates (300-500 frames per second), high rates of area growth, and precision in obtaining projected area data from images, yielded uncertainties which led to adopting the time of occurrence of peak forces as the end of inflation or filling intervals. Figures 2 and 4 show the definition of filling intervals.

Tables 11 and 12 contain filling times for drop and sled tests respectively. Test items and test numbers can be cross-referenced with Tables 7 and 8 to obtain additional information relative to test item configuration, test conditions and test item damage.

Figures 11, 12 and 13 are plots of filling times and dynamic pressure for indicated reefing ratio ranges with odd reefing ratios noted. Also noted in the symbols for data points are seriously damaged test items. Segmented lines drawn on each of these figures are "eyeball" faired and considered representative of the measured data.

Filling times for test items based on 400 lb ribbon are greater than the general trend of data for the first and full open stages, while the second stage filling times for these test items are in agreement with other data.

Test items with vent band failures produced relatively large scatter in the filling time data which was confined to the inflation to full open, although failures in vent bands occurred early in the first stage inflations.

e. Projected Area

Projected areas of test items were obtained from on-board motion picture films. These areas are the maximum frontal profile areas, the planes of which (for the reefed inflated stages) are significantly aft of the test item skirt. Projected area data were not obtained for every test as high quality, high-speed sideview film which could be syncronized

TABLE 11

PROJECTED AREA, FILLING TIME AND DYNAMIC PRESSURE FOR DROP TESTS

Test Nr. Test Item Nr.	DYNAMIC PRESSURE (lb/ft^2) Line Stretch	First Disreef	Second Disreef	PROJECTED AREA (ft^2) Stage 1	Stage 2	Full Open	FILLING TIME (sec) Stage 1	Stage 2	Full Open
1411750 1	268	129	71	28.7	44.1	80.3	.149	.083	.102
1712750 1M	430	219	100	29.3	49.3	82.0	.114	.038	.062
2312750 2	258	166	104	47.5	63.7	81.3	133	.009	.043
2704760 3	494	252	--	27.0	--	--	.050	--	--
1608750 4	440	--	--	27.9	--	--	.105	--	--
1711760 5	449	226	111	30.0	44.0	96.0	.290	.030	.111
0912760 4M	527	265	137	30.0	46.0	95.0	.121	.063	.091
2505770 MARS 6M	276	190	112	27.0	47.0	80.0	.150	.038	.065
0212770 MARS 6	489	241	101	--	--	--	.124	.040	.064
0305780 MARS 8	512	291	144	--	--	--	168	.033	.083
2605780 MARS 10	31	39	45	--	--	--	.492	.063	.09[illegible]
1808780 MARS 10	150	--	--	--	--	--	.160	.030	.080
0412780 MARS 9	140	120	104	--	--	--	.180	.030	.050
0803770 IH-1	297	--	--	42.0	single	stage	.479	--	--
1503770 IH-2	299	--	--	45.0	single	stage	.675	--	--
2701780 IH-3	345	200	101	26.0	46.0	90.0	.140	.011	.210
1209780 I[illegible] 7	402	235	118	--	--	--	.180	.140	.170

TABLE 12

PROJECTED AREA, FILLING TIME AND DYNAMIC PRESSURE FOR SLED TESTS

Test Nr Test Item Nr	DYNAMIC PRESSURE (lb/ft^2)			PROJECTED AREA ($ft)^2$			FILLING TIME (sec)		
	Line Stretch	First Disreef	Second Disreef	Stage 1	Stage 2	Full Open	Stage 1	Stage 2	Full Open
080377 S 2	628	311	117	26.0	44.0	82.5	.121	.036	.072
310877 S 1M	653	310	--	26.6	--	--	.105	.077	--
270977 S 2M	482	271	104	25.2	46.0	--	.133	.045	.069
161177 S IH-5	571	293	115	25.7	42.5	90.0	.132	.026	.080
100278 S IH-5	723	356	128	26.5	46.0	90.0	.135	.013	.065
300378 S IH-6	793	393	140	26.0	42.5	90.0	.124	.027	.074
040878 S IH-5M	840	404	151	26.5	46.0	95.0	.118	.029	.073
290878 S IH-8	371	221	102	22.0	42.5	88.0	.200	.035	.183
190978 S IH-9	367	212	110	23.0	45.0	85.0	247	.036	.101
140679 S WP-1	870	401	181	26.0	47.5	91.0	.107	.026	.082
190779 S WP-2	874	408	180	27.0	47.0	92.5	.134	.056	.107
170879 S WP-3	755	391	--	27.5	--	--	.110	--	--
270979 S WP-5	699	345	214	26.0	46.0	85.0	.139	.036	103
181079 S WP-6	675	309	158	27.5	45.0	90.0	105	.033	.017
211278 S Nylon	551	[illegible]	93	25.0	46.0	90.0	190	035	140

TABLE 13

SUMMARY OF AVERAGED PROJECTED AREA DATA

	STAGE 1			STAGE 2			STAGE 3		
	Data Points	Average Value (ft^2)	Std Dev (ft^2)	Data Points	Average Value (ft)	Std Dev (ft^2)	Data Points	Average Value (ft^2)	Std Dev (ft^2)
DROP TESTS	8	28.2	1.50	5	46.1	2.21	5	86.7	8.1
SLED TESTS	12	26.3	.62	10	45.3	1.74	9	89.6	3.74

NOTE: Test data for test items with 400 lb coated ribbons omitted from data (See Table 6).

Odd reefing configurations (tests 231275D, 080377D and 150377D) omitted from data (See Table 7).

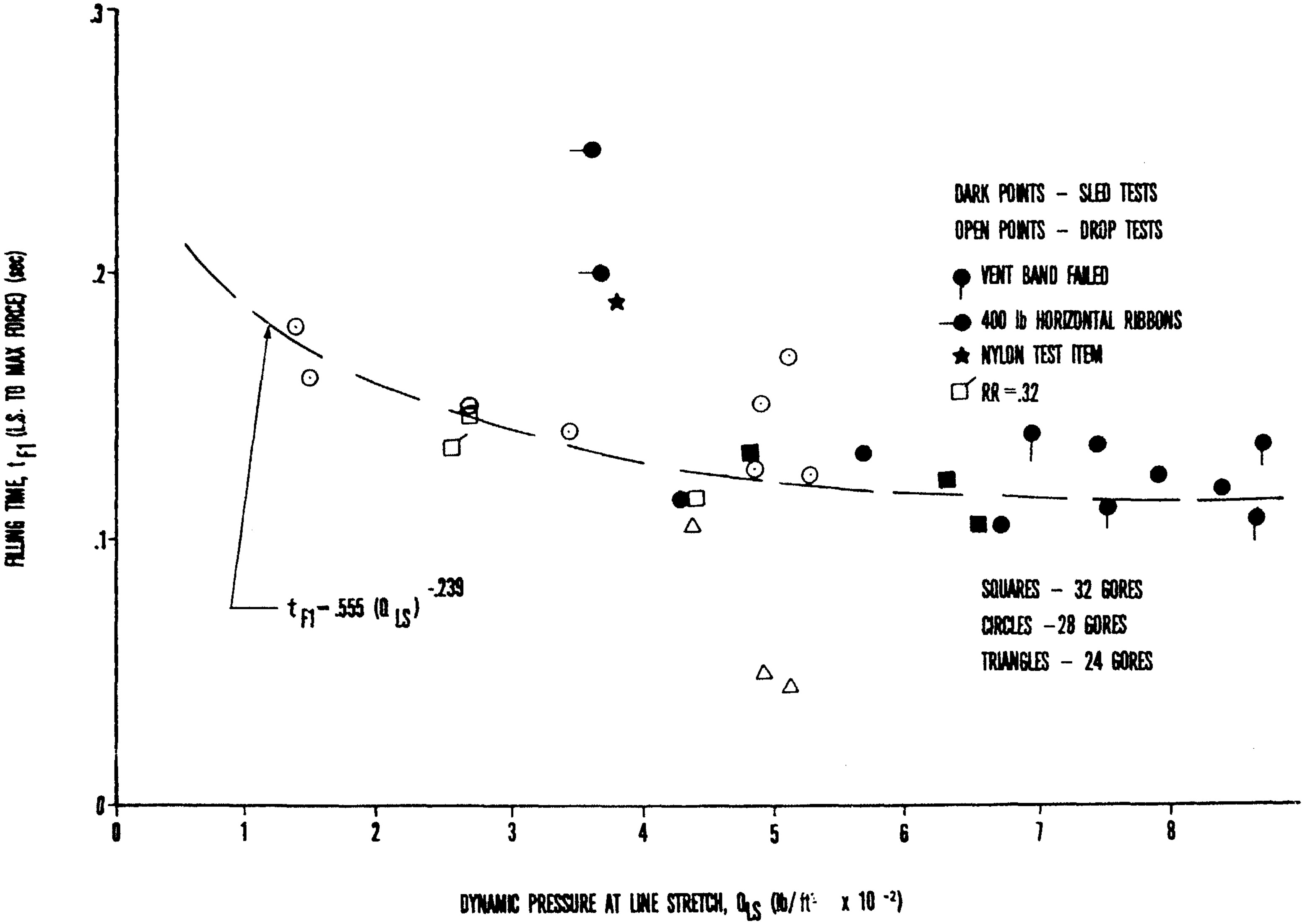


Figure 11. First Stage Filling Time vs Dynamic Pressure at Line Stretch .221>RR>.219

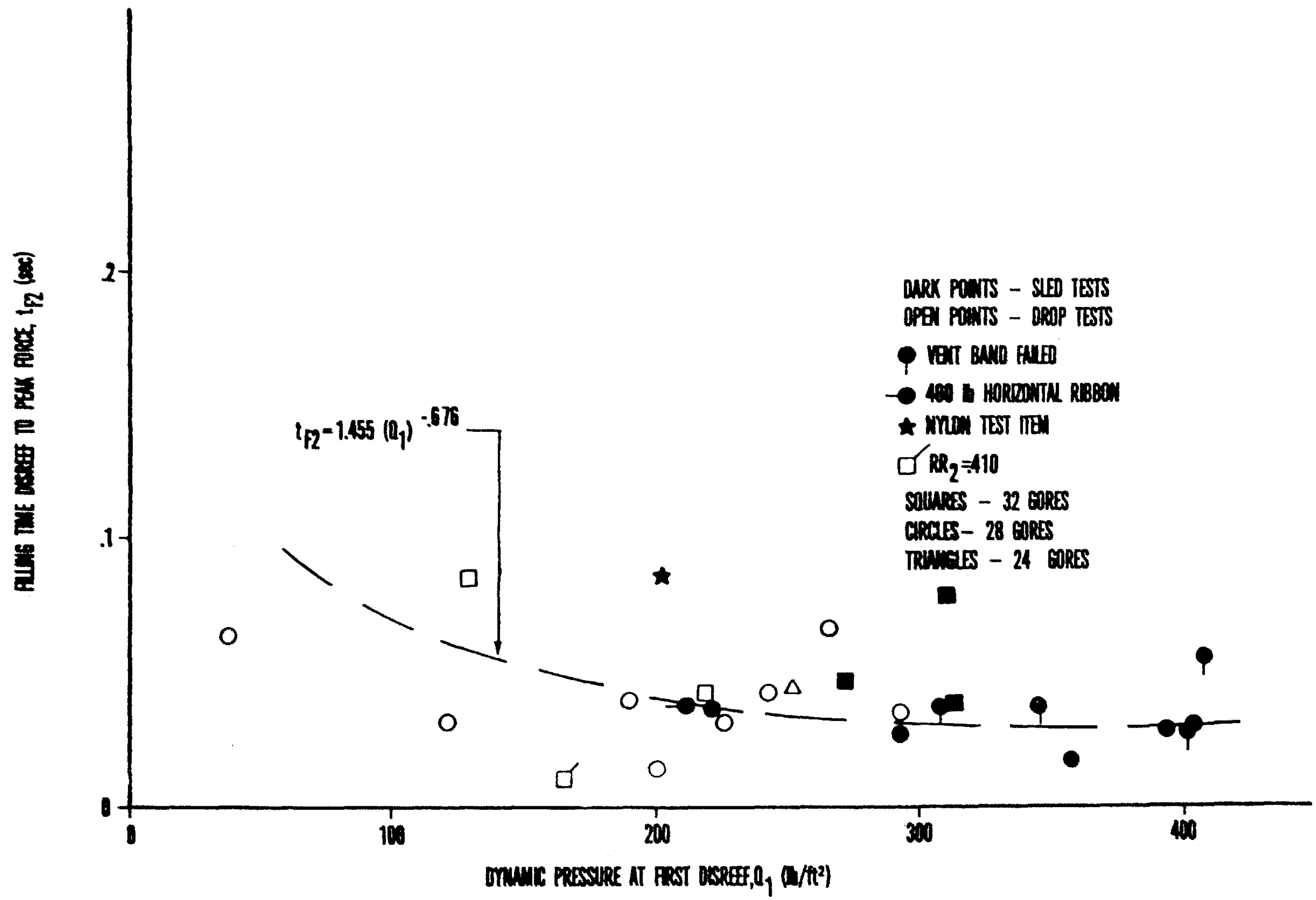


Figure 12. Second Stage Filling Time vs Dynamic Pressure at First Disreef .352>RR_2>.320

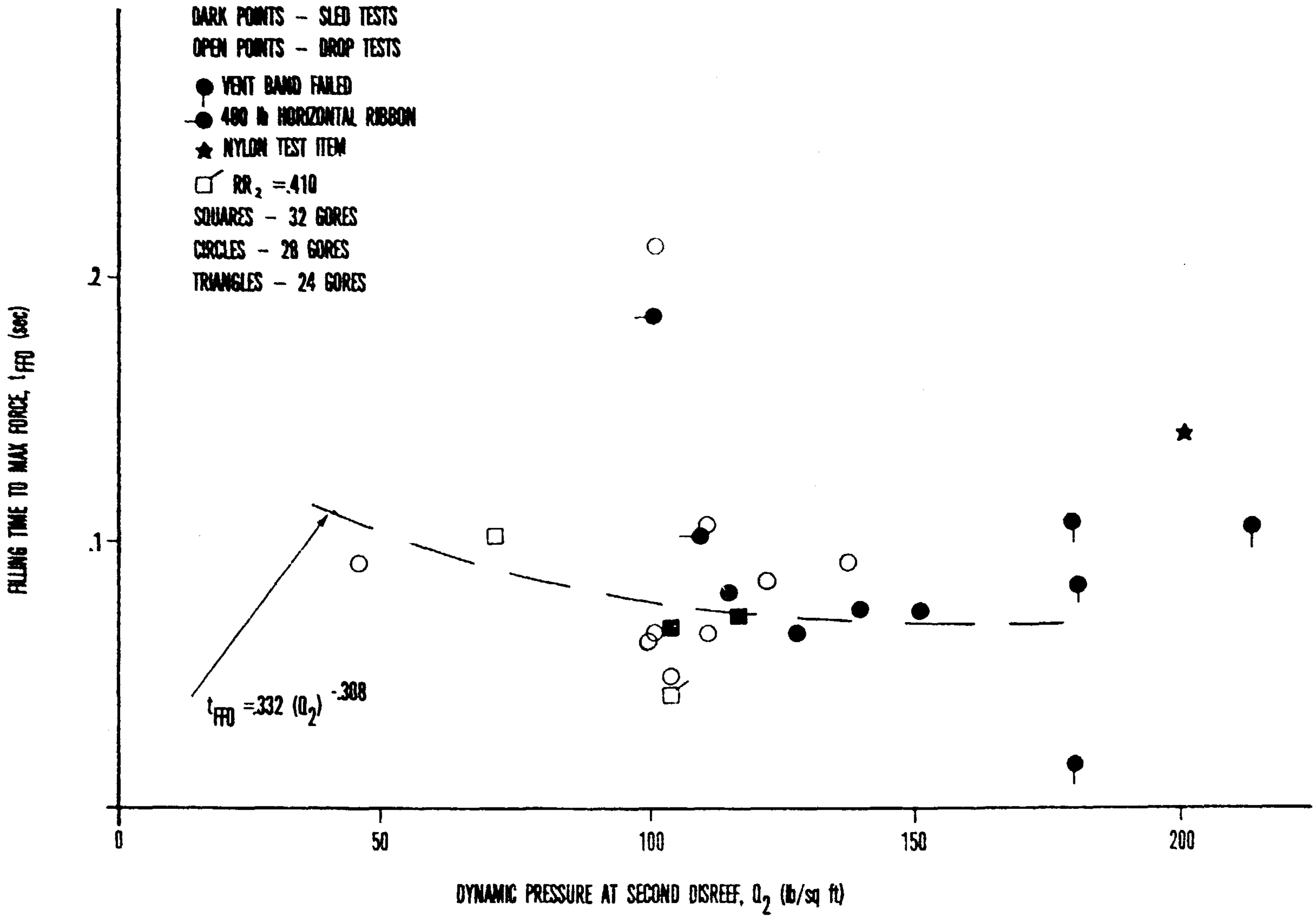


Figure 13. Filling Time - Second Stage to Full Open vs Dynamic Pressure at Second Disreef $.352 > RR_2 > .320$

with on-board film and oscillograms was not always available (especially for drop testing). This film is necessary for determination of the distance from the maximum projected area plane to the focal plane of the on-board cameras for developing area scale factors.

Observation of the body of projected area data contained in Tables 11 and 12 reveals that projected areas were nearly independent of dynamic pressure and, in most cases, test item configuration. A notable exception to the configurational independence are test items IH-8 and IH-9 which were fabricated with 400 lb coated horizontal ribbons. These two test items produced projected areas which were smaller than all other configurations in the first stage and projected areas comparable with the lowest values for the second and full open stages.

Table 13 summarizes the projected area data. Higher dispersions (standard deviations) were noted for drop test data where film quality and side view film was poor relative to that available for sled tests.

Average values of projected area for various reefing ratios are plotted in Figure 14 where a linear relationship can be seen. Odd reefing configuration data and data resulting from tests of items with the 400 lb coated ribbon material are also plotted and are in general agreement with the linear relationship represented by the segmented line drawn through the average points.

(1) Overinflation Area

Overinflation area, the difference between the equilibrium (or end of stage) projected area and the maximum projected area achieved during a given stage, was observed in most of the tests. The time of occurrence of maximum area was subsequent to the time for maximum force in the first stage in all but 4 of the 24 drop and sled tests for which data was available. In the second stage this was true for all but 3 of 21 tests. In the inflation to full open, maximum area was reached before

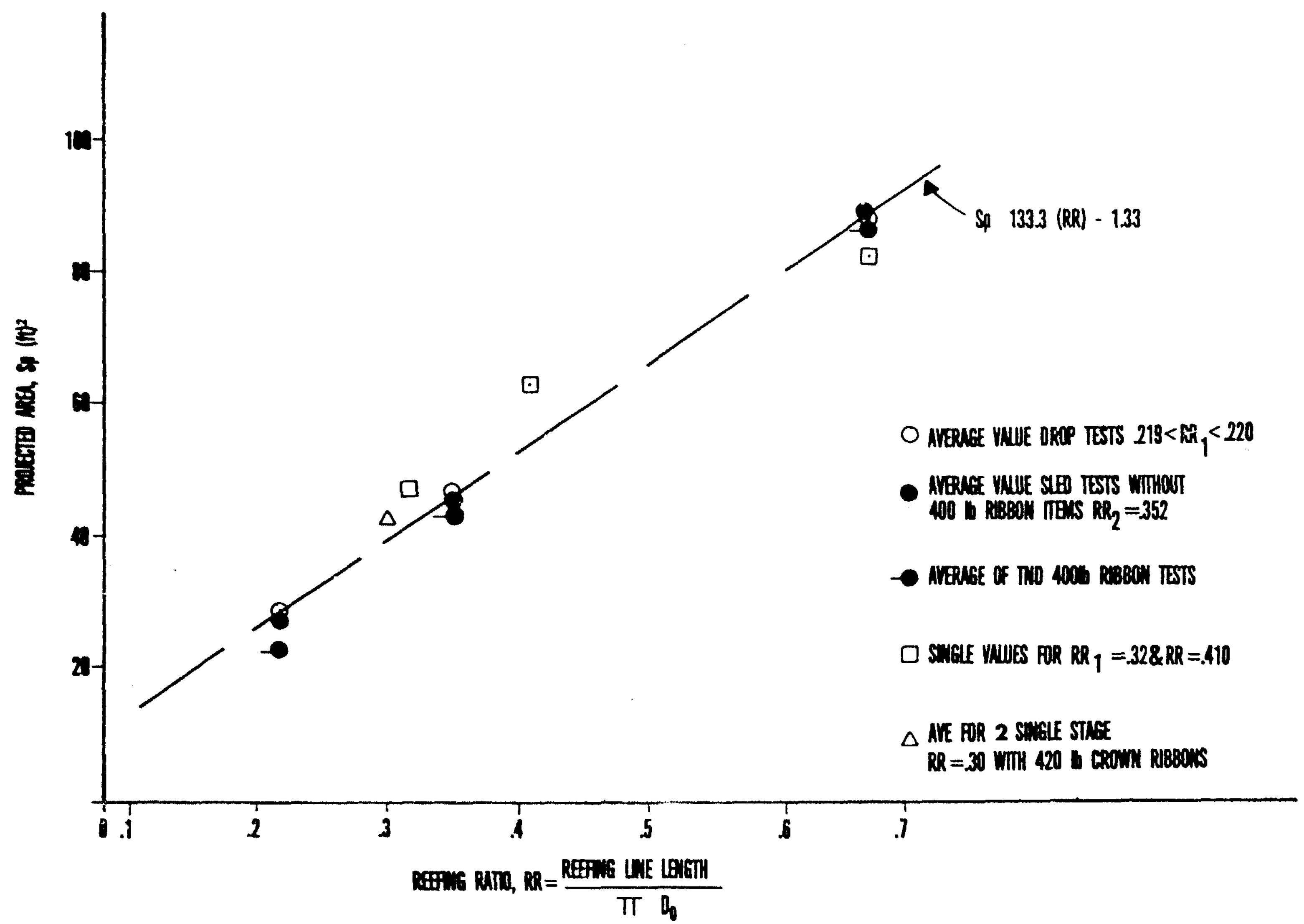


Figure 14. Projected Area vs Reefing Ratio for 15.3 ft D_0 20 Degree Conical Kevlar-29 Ribbon Parachutes

maximum force for 6 of the 18 tests for which data is available. Average values for overinflation area in drop tests were 3.2, 5.1 and 7.3 percent of end of stage areas for first, second and full open stages respectively. For sled tests overinflation area averaged 2.9, 4.4 and 7.5 percent for the three stages respectively. No correlation between number of gores or any other configurational property and overinflation area could be identified.

f. Inflated Profiles

Inflated profiles typical of the Kevlar-29 test items with $RR_1 = .219$ and $RR_2 = .352$ are shown in Figures 15, 16, and 17. These sideviews were taken from films exposed by fixed cameras located 1,040 ft from the track centerline and timed to run as the sled passes the camera station. The side profiles were traced from frames exposed when the sled was at the same track station as the camera, producing a true view. Views traced as representative were also chosen at times when frontal areas were nearly circular. The full open and second stages always produced nearly circular frontal areas, but the first stage frontal shapes oscillated from circular to elliptical during the inflated period.

Dimensions of the canopy side profiles were obtained by deriving a scale factor for each film frame from known distances along the sled track and measured dimensions for these distances made on tracings of film projections.

The suspension system, from the confluence point to the parachute skirt consisted of 22½ inches of 12,000 lb (2 plies) lower riser leg, 190 inches of braided coreless cord, and 3 inches of radial tapes termination at the skirt for a total nominal length of 215.5 inches. Values shown in the sideviews reflect elongation in the suspension system equal to 2.42, .89 percent and 3.16 percent of the 190 inch suspension line length for stages 1, 2 and full open respectively. Loads in each (2000 lb nominal strength) suspension line at the time of the sideview tracings

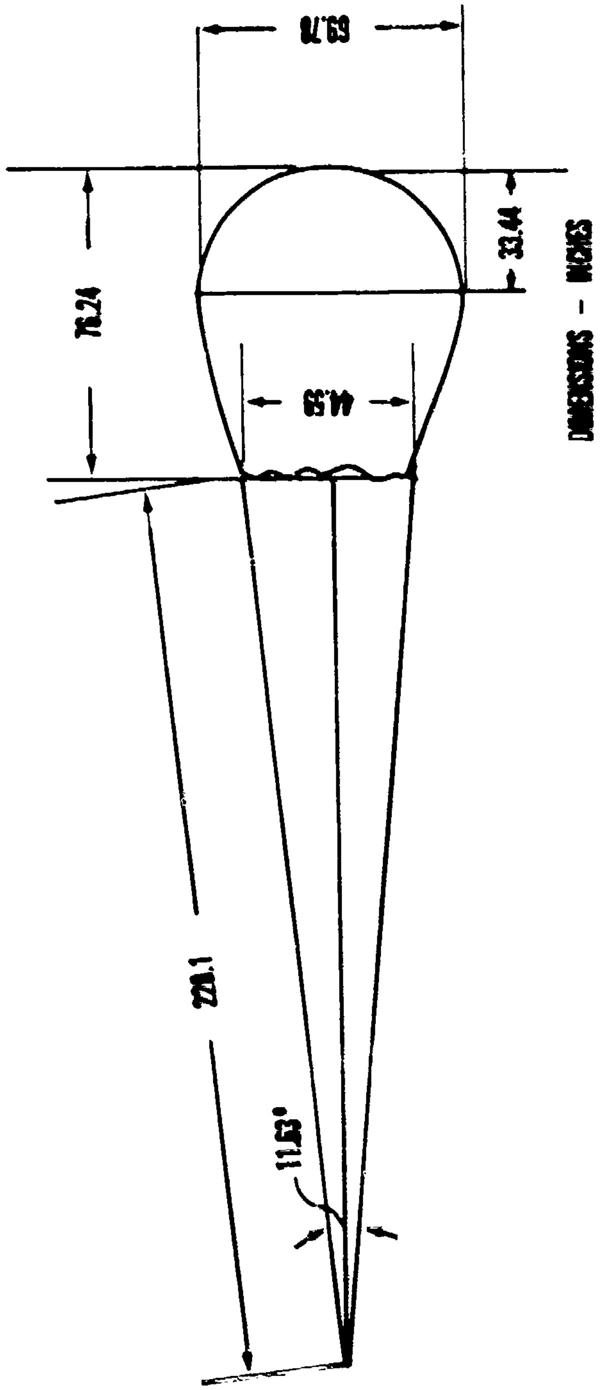


Figure 15. Typical First Stage Inflated Profile

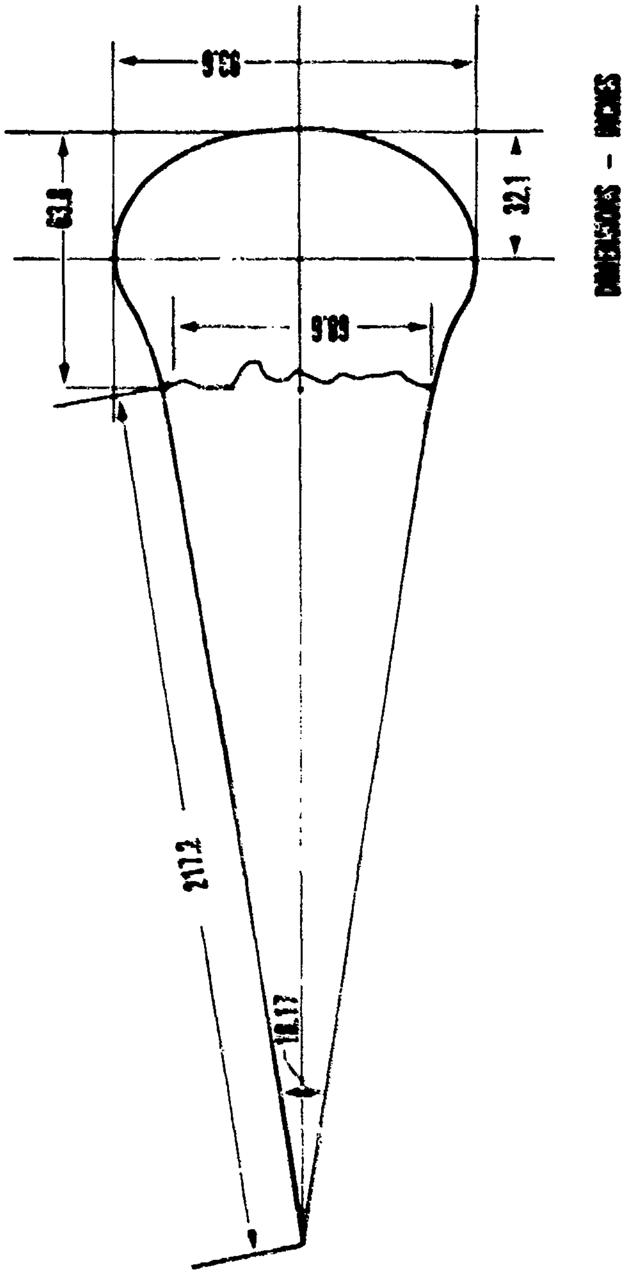


Figure 16. Typical Second Stage Inflated Profile

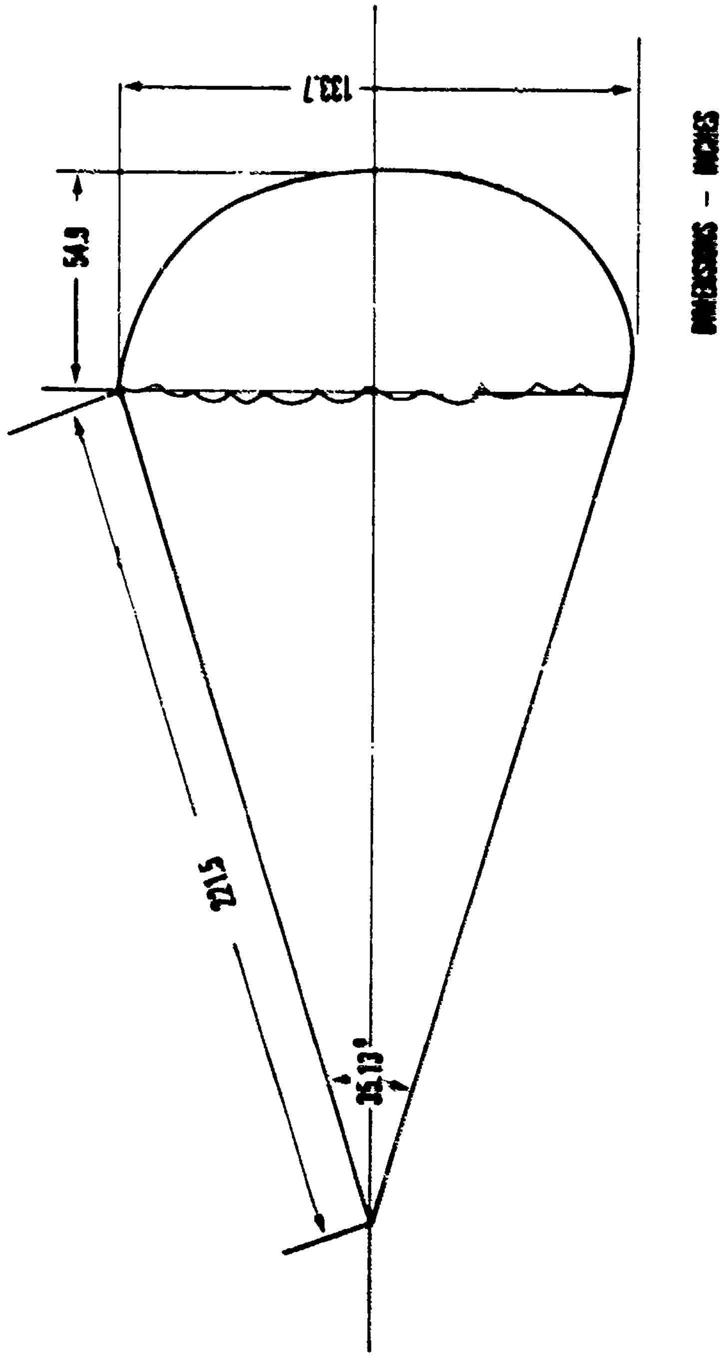


Figure 17. Typical Full Open Inflated Profile

were approximately 600 lb for each stage. The uncertainty in determining the suspension system length from photographs and in the fabricated suspension system length is estimated at $\pm$ 4.5 inches for 2.4 percent of the 190 inch suspension line length which precludes meaningful conclusions relative to elongation data.

g. Test Item Oscillation

Parachute oscillation was defined as motion of the parachute which resulted in displacement of the canopy vent center from an axis parallel to the testing vehicle relative air velocity vector and through the test item attachment point. For purposes of evaluating oscillation, the velocity vector was assumed parallel to the test vehicle flight path (or sled track) since wind vectors were small relative to vehicle velocities at the times when oscillation is of interest.

Motion pictures from on-board cameras viewing the inflated test item frontal area were used to evaluate test item oscillation. Pitching instabilities in the drop test vehicle about axies located within the vehicles precluded the provision of a steady base for the on-board cameras and only qualitative comments based on air-to-air and ground-to-air film data can be made. The sled test on-board film was obtained from cameras on stable mounts and excursions from the center of the film frames could be quantitatively ascertained. General observation of film from both drop tests and analysis of films from sled testing revealed that reefed stages for all test items were quite stable with oscillations of four degrees or less. When filling to the full inflated stage, significant oscillations were encountered for all test items at all conditions in both drop and sled tests. These oscillations (as high as 12 degrees in sled tests) were quickly damped and the full open test item configurations exhibited oscillation angles of less than 8 degrees subsequent to the damping which typically was complete in less than .75 seconds.

h. Material Suitability and Structural Adequacy

(1) Suspension Lines

Suspension line failure was encountered in three tests, one test (230678S) where the primary failure was suspension lines and two tests (270476D and 060979S) where suspension lines failed subsequent to failure of the reefing system and premature inflation to large areas at high dynamic pressures. The suspension line primary failure case was the second test of test item IH-6 which had in the first test, been subjected to peak inflation loads of 26,049, 26,283 and 18,633 lbs. Suspension line failure occurred immediately subsequent to the first stage inflation during which a peak load of 22,655 lbs had been encountered. Failures of these suspension lines occurred at the loop eye splices attaching them to riser legs.

Figure 18 describes the envelope of suspension line strength and peak inflation loads which was covered by the drop and sled testing. The failure points shown represent tests 230678S and 060979S which involved 28 gore test items. A point for the suspension line failure during test 270476D was not included because a reasonable value for the failure load could not be determined from the force recording. In addition to the failure points shown, the envelope encloses 84 suspension line peak inflation points which did not result in suspension line failures.

(2) Horizontal Ribbons

Damage to horizontal ribbons was considered separately for the ribbons in the top of the canopy from the vent through ribbon 12, known as the "crown" ribbons, and for the ribbons 13 through the skirt ribbon, called the "lower" ribbons. Figure 19 shows the location of ribbon 12 relative to inflated shapes.

Horizontal ribbon tensile failures which were not the result of failure in some other parachute component occurred primarily in the crown area and nearly always before or at the time when the first stage

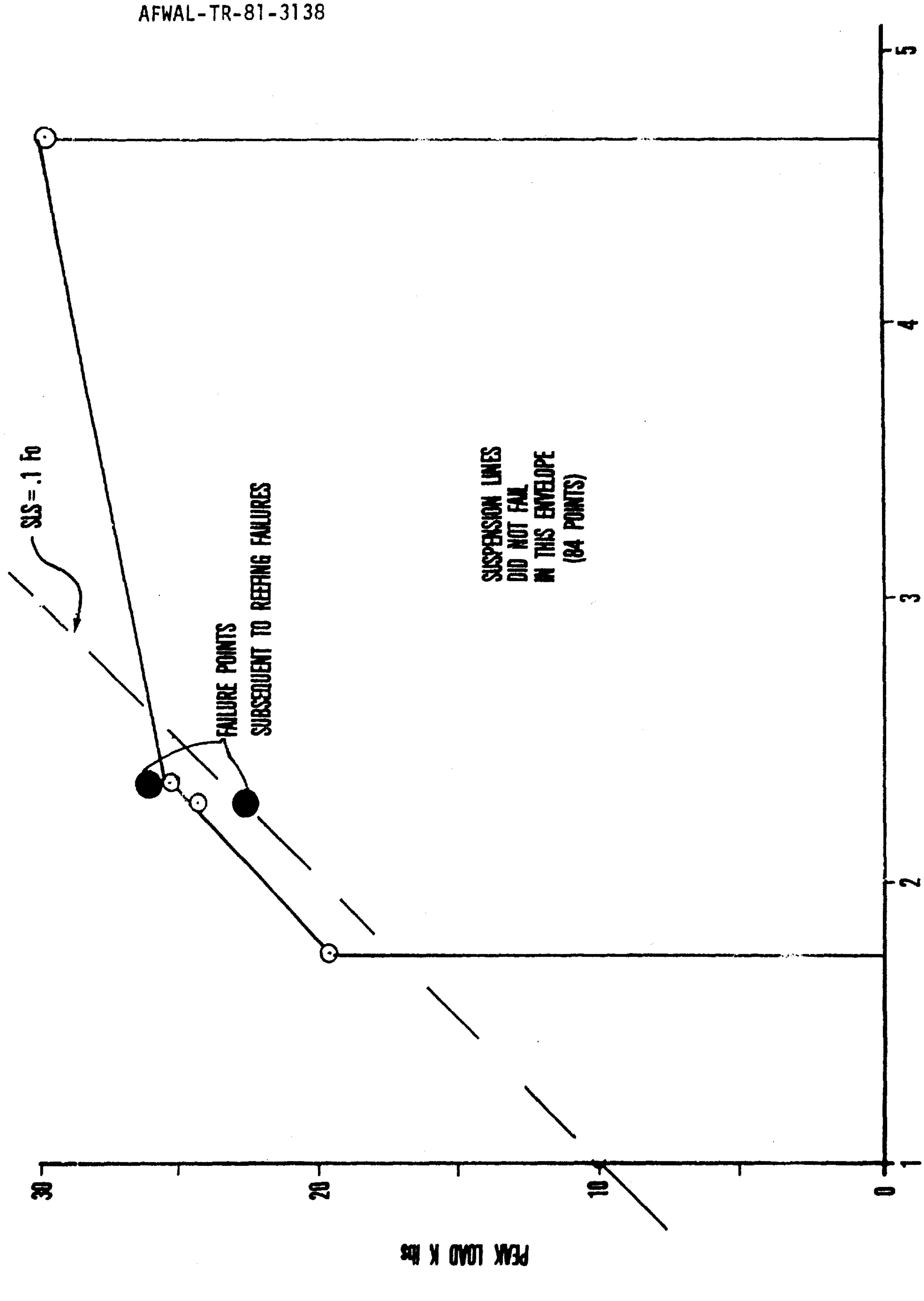


Figure 18. Demonstrated Suspension Line Structural Adequacy Envelope

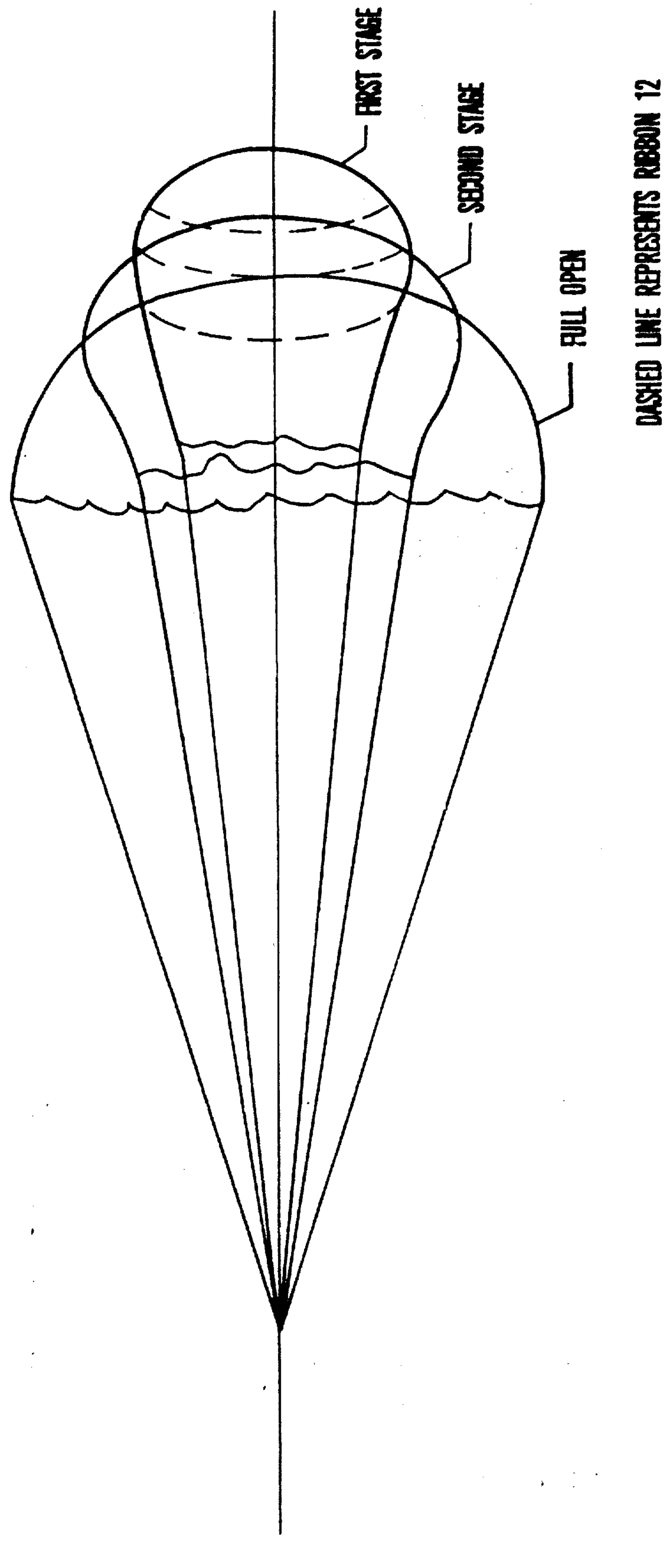


Figure 19. Location of Ribbon No. 12 Relative to Inflated Profiles

reefed inflated shape was attained. Observation of the crown ribbons often revealed isolated breaks in the early portion of first stage reefed inflation.

Horizontal ribbon structural adequacy is displayed in Figure 20 where measured horizontal ribbon material breaking strength is plotted with peak opening force. The peak opening force is not necessarily the load at which ribbon tensile failures occur. This parameter was chosen because peak forces often govern selection of component material strength. Many combinations of peak force and ribbon strength (not involving failure), which were significantly below the range where ribbon failures occurred, were not plotted. For the plotted points in Figure 20, indication of damage is made only for complete tensile failures in ribbons where these failures are not believed to be the consequence of the failure of other test item components or the reefing system. Minor damage implies that relatively few ribbon tensile breaks occurred in the test items and that these breaks were sufficiently scattered that entire gores were not split from the vent ribbon to the eleventh ribbon from the vent. Major damage consists of enough tensile breaks to cause one or more gores to be split from the vent to ribbon eleven. It is important to recognize those points in Figure 20 which represent failures in horizontal ribbons which occurred in previously tested test items. Previously tested parachutes often suffered ribbon failures related to lower peak forces than the test item was exposed to previously with no damage. Table 14 summarizes horizontal ribbon failures and includes the plotting symbol code for points in Figure 20. Indication of the test and loading histories for various test items can be obtained from Table 7 and 8 and Appendix G which contains summaries of test item configurations test abnormalities, and structural damage.

It should be noted that most of the horizontal ribbon failures represented in Figure 20 did not change the performance of the test items appreciably and might not be construed as test item failures in many single use applications.

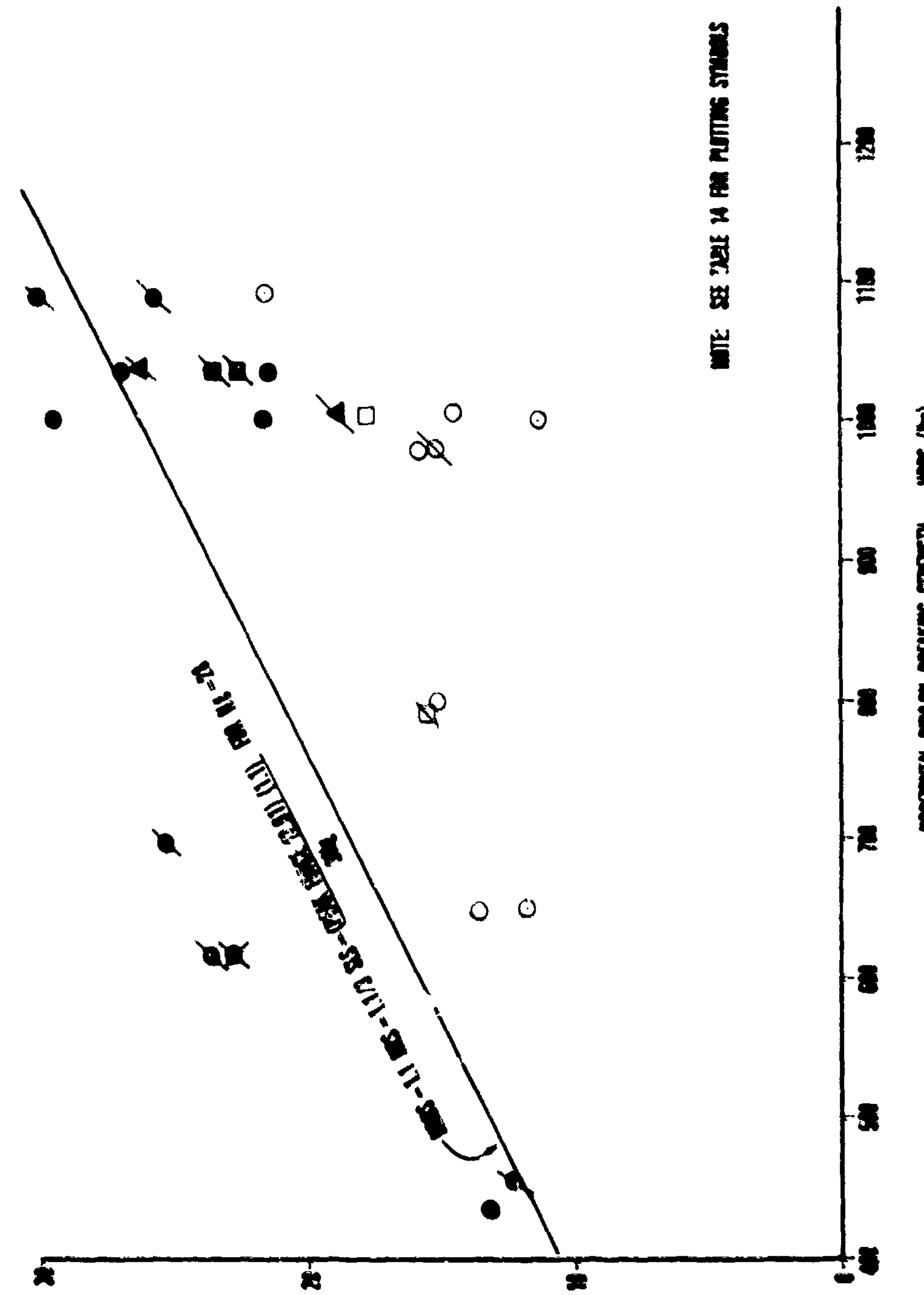


Figure 20. Peak Inflation Force (Test Data) vs Horizontal Ribbon Breaking Strength

TABLE 14

HORIZONTAL RIBBON FAILURE SUMMARY

Test Nr.	Test Item	Ribbon Breaking Strength (Measured (lb) Crown/lower	Peak Force (lb)	Previous Tests	Plotting Symbol Figure 17	Failure Comments	
160876 D	4	980	15079	No		Two breaks in top three ribbons test item inadvertently released before first disreef no other damage.	1.4
250577 D	MARS 6M	1038/793	15711	No	Not Plotted	Lower edge of ribbon 11 had 7 partial breaks. No reinforcement band.	1.66
021277 D	MARS 6	1038/793	15227	1		One break each in ribbons 12 and 16. Reinforcement band on ribbon 11	1.31
270977 S	2M	1001	18712	3		Eleven breaks in top six ribbons. Two of three previous tests exposed to higher loads without ribbon breaks.	1.54
100278 S	1M-5	1038	23658	1		One break each in ribbons 3 and 4.	1.11
300378 S	1M-6	1038	26283	No		Many partial breaks in lower 12 ribbons.	1.00

TABLE 14 (Cont'd)

Test Nr.	Test Item	Ribbon Breaking Strength (Measured (lb) Crown/lower	Peak Force (lb)	Previous Tests	Plotting Symbol Figure 17	Failure Comments	
230678 S	IM-6R	1038	22655	1		Minor crown ribbon. Failures before suspension lines failed.	1.15
040878 S	IM-5M	1038	26125	2		Scattered lower ribbon failures	1.00
290878 S	IM-6	456	12058	No		Ribbons 6, 7 and 8 broken once each at splice #5 also broken once.	.95
140679 S	MP-1	1090	24504	No		Top ribbon failed once just before vent band failure	1.12
190779 S	MP-2	1090	29964	No		Ribbon 4 failed before failure of vent band.	.92
170879 S	MP-3	700	25209	No		Crown ribbon failures were subsequent to vent band failures.	.70
060979 S	MP-4	700	25227	No		Three breaks in top four ribbons before suspension lines fail at 25,933 lbs load.	.70
270979 S	MP-5	620	22744	No		Ribbons of one gore fail down to #11 then vent band fails	.69
181079 S	MP-6	620	23290	No		Four ribbon breaks in top five ribbons.	.67

The line plotted on Figure 20 is representative of the criteria used to obtain the estimated requirement for horizontal ribbon nominal strength contained in Table 6. Ribbon material measured average strength is assumed to be 10 percent greater than nominal strength. Ribbon failure points in Figure 20 indicate minor damage occurring below this line for two cases of initial testing. One of these points, for ribbon with 1090 lb breaking strength, included one break in the top ribbon which occurred within 10 milliseconds of the failure of the vent band which was stitched to the top ribbon and may have influenced the plotted ribbon failure. The other low initial point on Figure 20 was the breaking of 980 lb ribbons, numbers 2 and 3, each in one place during a drop test (No. 160876D) that was inadvertently released from the test vehicle just before the second disreef. The time of occurrence of these breaks could not be determined from the low quality on-board film which was too overexposed to show detail. Repairs were made to these ribbons and there were no failures in a subsequent drop test of the same test item. The possibility of some circumstance other than loading during inflation being responsible for this ribbon failure point seems likely but no evidence to refute the data was found.

When a second, a third, and in one case, a fourth test of the same test item is considered, several instances of test item minor damage due to ribbon failure (as shown in Figure 20) are well below the design criteria line. It should be emphasized that the minor damage to these test items did not appreciably affect parachute performance and it was not apparent that these ribbon failures caused failures in other parachute components.

The point coded as major damage in Figure 20 is from test No. 270979S during which the crown ribbons of an entire gore failed followed by failure of the vent band at this gore forming a large hole in the canopy which contributed to low, full open drag.

Ribbon damage outside the scope of Figure 20 was in the form of partial breaks and weave distortion. Partial breaks of horizontal ribbons were characterized by broken selvage yarns and tensile failure of some, but not all of the ribbon warp yarns. Most partial breaks occurred in the lower ribbons which were subject to untensioned fluttering during the reefed stages. The point of intersection of the horizontal ribbons, vertical tapes, and radial ribbons (at ribbons 11 and 12) was a prime area for the occurrence of partial breaks in test items 1 through MARS 6M. Failures at this location prompted placing circumferential reinforcement bands in this area on subsequent test items. It is also believed that assembly of vertical tapes normal to the horizontal ribbon edges contributed to this damage.

All test items which utilized the 400 lb nominal strength ribbon, with and without coating, experienced damage in the form of weave distortion or filling yarn slippage which in general did not result in tensile failures, but did affect performance as discussed previously.

Ribbon splices were usually not consistent locations for ribbon failures except for test 290878S during which three crown ribbons failed at the splice. This failure is further discussed in Section VI, paragraph 3.

(3) Vent Bands

Five of six of the WP series of test items -1, -2, -3, -5 and -6 experienced failure of vent bands while attaining the first stage inflated shape. A definite reason for these failures has not been identified but a discussion of some of the circumstantial evidence is presented in the following text.

Table 15 summarizes pertinent information related to the vent band failures in the WP series test items and some data for testing of other configurations at similar peak loadings where failure of the vent bands did not occur.

TABLE 15

VENT BAND STRUCTURAL ADEQUACY

TEST ITEM	TEST NR	PEAK OPENING FORCE (lbs)	VENT BAND MATERIAL STRENGTH (NOMINAL) (lbs)	VENT DIAMETER[1] - VENT LINE LENGTH (inches)	SUSPENSION LINE STRENGTH (lbs)	VENT BAND FAILED	VENT BAND DID NOT FAIL	COMMENT
WP-1	1406795	25604	4000 1800	0	3500	X		
WP-2	1903795	29964	4000 1000	1	3500	X		
WP-3	1708795	25[illegible]69	3000 694	0	2000	X		
WP-4	0609795	25[illegible]27	4000 694	1	2000		X	All suspension lines failed during first stage inflation
WP-5	1709795	22744	4000 620	1/2	2000	X		
WP-6	1810795	28190	4000 620	0	2000	X		
3M-[illegible]	3005785	26049	4000 1038	1	2000		X	
[illegible]-6R	2306785	22655	4000 1038	1	2000		X	Suspension lines fail after peak force
3M-6	2306785	28656	4000 1038	1	2000		X	
3M-5M	0408785	28[illegible]25	4000 1038	1	2000		X	
1	0508775	21404	3000 1001	1	2000		X	
2	1708775	28444	3000 1001	1	2000		X	
1M	3108775	24117	3000 1001	1	2000		X	Radials failed at skirt in second stage

1. Finished vent diameter based on measurement of vent circumference.

The length of vent lines relative to vent finished diameter does not appear to be a likely cause for failure since three different length differentials were involved in failures, one of which was used in test items which did not experience vent band failures.

The WP series test items differed from all the other test items in that they were fabricated with tucks in the top crown ribbons to reduce inherent continuous ribbon upper edge fullness as discussed in Section VII, paragraph 1.b.

(4) Reefing Components

Failure of reefing lines was not observed in any of the sled or drop tests and it is therefore known that the force in the line did not exceed the breaking strength of the braided cords used. The measured breaking strengths (Table 6) for these materials were obtained using tensile testing apparatus which resulted in tensile breaks at the tensile testing jaw. The strengths of these Kevlar-29 braided cords may have been higher than the reported values if the tensile testing methods described in Appendix C had been used.

Failures in reefing systems (Tests 310877S and 060979S) were catastrophic in both cases. These failures occurred at high loadings and began by separation of reefing lines from the radials at the skirt band due to failure of the reefing ring attachment tape stitching or possibly of the reefing rings. For testing subsequent to 310877S, special high strength heat treated reefing rings fabricated from 4130 steel (heat treated to 153,000 psi) were used. Average failure loads for these rings in tensile testing machines was 833 lb compared to 480 lb for the previously used rings. No evidence that any of the heat treated rings failed or elongated during tests was found.

Test 270476D terminated in a reefing malfunction which is not considered a reefing structural failure. Observation of on-board film indicates that both reefing lines were cut at the normal time for first disreef. This malfunction could have been caused by a rigging error.

SECTION V

GENERAL KEVLAR-29 DESIGN CONSIDERATIONS

1. WEIGHT, VOLUME AND COST

Utilization of Kevlar-29 materials should be considered when attaining lightweight, low volume, high strength or strength at high temperatures. These conditions justify the cost of this material relative to conventional fibers (nylon, polyester, Nomex, etc). Cost comparisons should be made based on length requirements for finished materials of given breaking strength since Kevlar-29 is usually lighter than materials of similar strength based on other fibers. Reference 1 and Tables 2, 3, and 4 can be used to obtain unit weights and other characteristics.

2. LIMITATIONS IMPOSED BY YARN AVAILABILITY

When decelerator loading dictates tensile strength less than 250 lbs per inch over the canopy surface, Kevlar-29 materials based on presently available yarns may not be available in a reasonable air permeability range, or may produce a decelerator with adequate tensile strength but limited reuse application due to yarn migration and possible distortions at joints. Ribbon parachutes utilizing 2 inch wide, 400 lbs horizontal ribbons (Type XI, Class 3), (see Table 6) were flight and sled tested over a wide loading range without horizontal ribbon tensile failures but with extensive distortions in ribbon weave which included slipping of filling yarns to the ends of ribbon free lengths. Figure 8 shows typical post test ribbon conditions. Utilization of woven Kevlar-29 materials of 200 lbs per inch of width also dictates more attention to design and fabrication of joints, possibly requiring several iterations to develop desired joint efficiency. Application of the above mentioned porous ribbons may dictate accounting for permeable ribbons in calculation of porosity. Reference 6 contains data indicative of permeability values for Kevlar-29 materials and Reference 1 includes a method for adding permeability to geometric porosity to estimate total porosity.

3. ABRASION RESISTANCE

Kevlar-29 woven and braided materials offer abrasion resistance superior to similar nylon, Nomex, or polyester materials, if the relative velocity between abraiding elements is high enough or of sufficient duration to cause heating of the materials. If decelerator system components will be subjected to low-speed abrasion where material damage would result from mechanical surface interactions, most Kevlar-29 materials are equivalent in abrasion resistance to similar strength nylon materials. Applications which place components in loading cycles ranging from compression to maximum tension at high frequency for long durations are not well suited to Kevlar-29. Reference 20 contains results of Kevlar-29 and nylon abrasion testing and describes conditions and relative abrasion resistance of Kevlar-29 and nylon materials. FDL experience includes tensile failures in vent lines which appear to have been caused by abraiding of braided cords under high tension at the center of the vent. When vent lines were fabricated from flat webbing these failures were not encountered.

4. ANTI-FRAY PROTECTION

Cut ends of Kevlar-29 woven or braided materials which cannot be enclosed inside joints or seams should be treated to resist fraying during handling, packing, and during operation of the decelerator. This is particularly necessary in components subject to aerodynamic flutter and to items which must be reused. Since the basic fiber does not melt in the manner of nylon and polyester, the customary technique of searing ends is not applicable to Kevlar-29. A product marketed by the General Plastics Corporation of Bloomfield, NJ under the tradename "Sergene" has been used by FDL on Kevlar-29 ribbon parachute test items for drop and sled testing. Application of Sergene retards fraying by causing yarns to adhere to each other.

SECTION VI

RIBBON PARACHUTE DESIGN

1. GEOMETRIC ARRANGEMENT

Subsequent to determination of parachute type and size, maximum loads, staging, and equilibrium or steady-state performance to meet system requirements, canopy and gore geometry must be determined. These determinations will include gore dimensions, ribbon spacing and a number of horizontal ribbons, vent geometry, a number of vertical tapes, radial tape width, suspension line and riser lengths.

a. Porosity Calculations

A technique for calculating geometric porosity (or total porosity if permeability of horizontal ribbons is appreciable) should be devised which permits iteration of the number of horizontal ribbons and yields the parachute porosity desired to meet performance requirements. Appendix D contains a sample calculation of these geometry related items for the MARS drag parachute.

b. Vent Geometry

In many applications the vents in nylon parachutes are designed so that the vent lines are loaded and elongated prior to the loading of the vent circumferential members. For most of the Kevlar-29 test item (see Table 6) parachutes fabricated and tested by FDL, vent lines were made one inch shorter than the finished vent diameter. WP series test items were made with varying vent line lengths but failures in vent lines or vent circumferential members due to constructed dimensions were not conclusively shown. Low elongation of Kevlar-29 suggests vent line length equal to the vent diameter.

c. Vertical Tapes

The number and location of vertical tapes applied to the canopy parallel to the gore centerline (these tapes can be applied in a radial direction as in Reference 21) to maintain ribbon spacing over the gore length should be chosen to limit horizontal ribbon free length particularly near the skirt and lower portions of the canopy which may be subject to extensive high frequency flutter during reefed stages or early stages of inflation. Promotion of positive inflation, maintenance of porosity, and limiting yarn migration or sleaziness of Kevlar-29, 2-inch ribbons in the lower strength ranges, suggests a maximum horizontal ribbon free length of 3 to 3 1/2 inches. This practice was successful in the FDL testing reported here (and in Reference 4). Continuous ribbon designs for Kevlar-29 materials accentuate the need for small horizontal ribbon free length due to the combination of low elongation and the fullness in the upper ribbon edge (if not corrected by constructed tucks under radials). The 20 degree conical design of Appendix D includes 11.8 inches of fullness (total around canopy circumference) in the top edge of all horizontal ribbons.

d. Radial Tapes

The width of radial tapes which form gore edges, attachment points for suspension lines, and carry radial loads, is an important influence on geometric porosity, horizontal ribbon free length and integration of horizontal ribbon splices. Utilization of wide radial tapes increases the portion of the canopy surface under tensile load during early inflation and reefed stages thus minimizing the area subject to flutter damage and deflection which might cause variance in geometric porosity. Two-inch wide materials were used on the FDL effort reported in Section IV with good results.

2. STRUCTURAL REQUIREMENTS AND MATERIAL SELECTION

a. Peak Opening Forces and Design Factor

Design criteria for selecting material tensile strength for various components are expressed in terms of the peak opening force (F_o) and a design factor (D.F.).

Design Component Strength = (D.F.) (F_0)

Peak opening forces are predicted using the relationship

$$F_0 = (C_D S)\ Q\ X$$

Where the drag area ($C_D S$) and opening shock factor (X) reflect a given reefing condition. The dynamic pressure (Q) reflects the aerodynamic conditions at the time of deployment or staging. Figure 21 shows the relationship between reefing ratio, drag area, and opening shock factor when full open drag area is known. The plotted functions in Figure 18 are representative of the lines faired through test results plotted in Figures 9 and 10. It should be noted that the opening shock factor function is somewhat conservative for larger reefing ratios. A feeling for the magnitude of this conservation can be obtained by reviewing the data and faired curve of Figure 10 and Paragraph 8.c. in Section IV. Reference 17 contains similar data for unreefed Kevlar-29 ribbon parachutes tested at Mach numbers up to 2.2.

The (D.F.) as described in References 1 and in Reference 22 typically incorporates a chosen safety factor, various strength degradation factors and a confluence factor applicable to suspension lines and risers. The safety factor should represent a margin over the ultimate strength of the parachute component and is chosen to reflect the parachute application.

$$\text{D.F.} = \text{Safety Factor}\left(\frac{1}{A_p}\right)$$

Where A_p is the product of strength degradation factors which may include joint efficiency, abrasion losses, fatigue, effects of moisture, temperature, effects of vacuum, unequal loading, and confluence convergence. For convenience in discussing the Kevlar-29 design criteria suggested by the testing reported in Section IV, an ultimate factor (U.F.) equal to $\frac{1}{A_p}$ is defined.

In the ideal situation, the strength degradation factors have been determined by experiment or are known from previous experience.

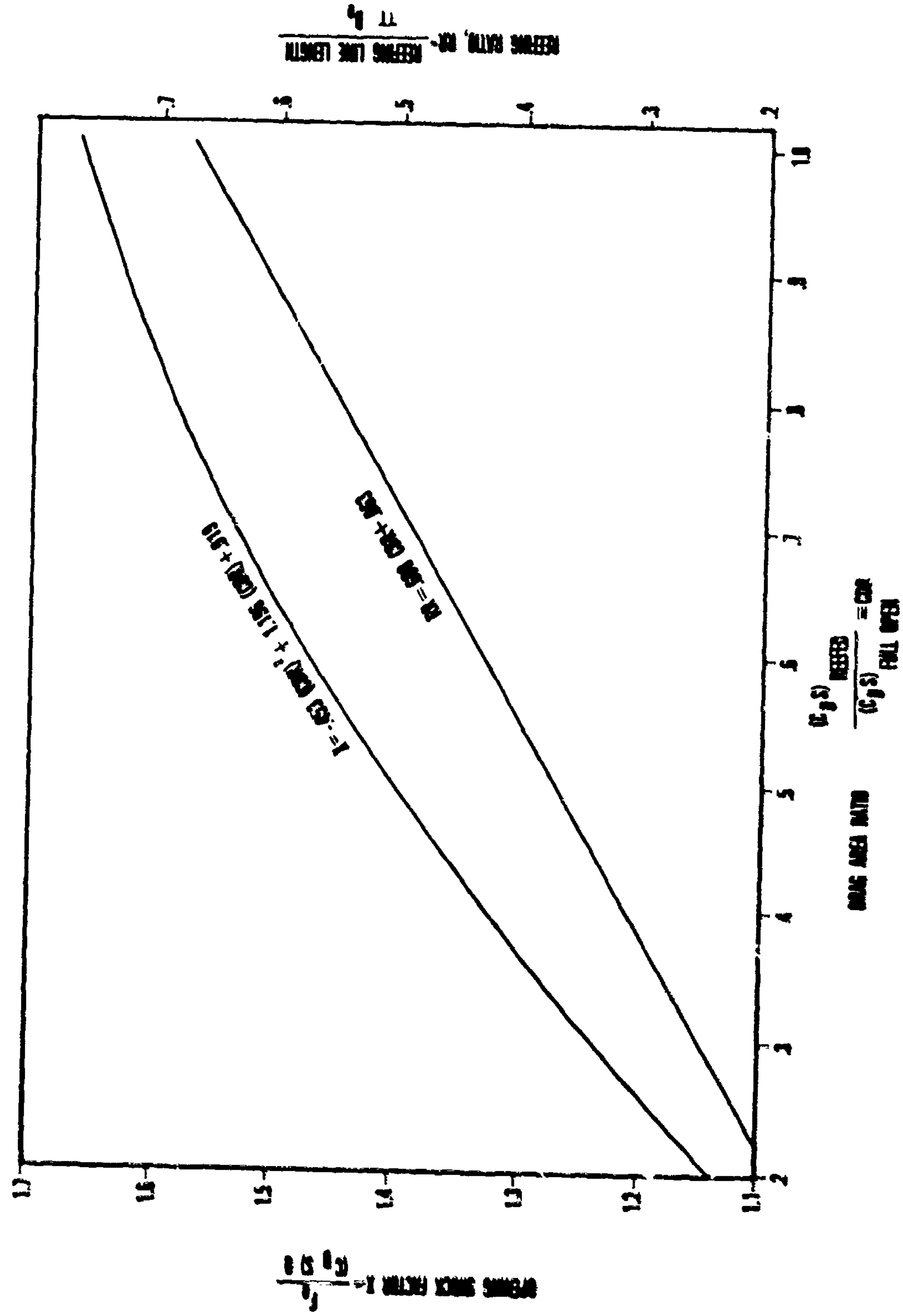


Figure 21. Criteria for Calculating Peak Opening Forces for Kevlar-29 Conical Ribbon Parachutes

In reality, however, values for all of these factors reflecting specific design conditions and materials are rarely known.

Design criteria for determining major Kevlar-29 ribbon parachute component nominal strength are discussed in the following paragraphs and summarized in Table 18.

b. Suspension Lines

Summarizing the test data reported in Section IV indicates that a peak opening force of approximately 26,000 lbs produced near ultimate loads in 28 suspension lines made from 2,000 lb nominal strength cord. This suggests that an ultimate factor for suspension lines would have the value

$$U.F. = \frac{2,000(28)}{26,000} = 2.15$$

and that the product of the degradation factors would be 1/U.F. = .46. A combination of strength degradation factors which would produce this U.F. is listed in Table 16.

In order to select a material strength for suspension lines, a value for F_o which includes the effects of dynamic pressure, appropriate opening shock factor, and drag area (from Figure 18 and known full open drag area) is divided by the number of gores, multiplied by the U. F. of Table 16 (including other degradation factors as appropriate) and multiplied by a safety factor chosen by the designer reflecting the parachute application.

A typical result for a Kevlar-29 parachute reefed from $(C_DS)_{F_o}$ = 100 to (C_DS) = 26 sq ft and deployed at a dynamic pressure of 600 psf follows:

$$F_o = (C_DS)\ Q\ X = 26(600)1.2 = 18,720 \text{ lbs}$$

(X = 1.2 from Figure 21)

The suspension line strength, SLS, is then:

$$SLS = \frac{F_o}{Ng}\,(U.F.)\;S_F = \frac{18720}{28}\,\left(\frac{1}{.46}\right)\,1.5 = 2180 \text{ lbs}$$

Where the product of U.F. and S_F can be considered the D.F. of Reference 1, and $S_F = 1.5$ was arbitrarily chosen.

If after checking subsequent staging of this parachute, the example condition produces the maximum F_o value, selection of Type IX coreless cord having a 2000 lb nominal breaking strength would be m-d- from Table 4.

c. Horizontal Ribbons

Test results for horizontal ribbon failures (Table 14, Figure 20 and Paragraph 8.h.(2) of Section IV), were used as a base from which the ultimate factor values of Table 17 were derived. These values are representative of the specific test items discussed in Section IV and apply to two-inch wide continuous ribbons. Application of the Table 17 ultimate factor is as follows:

$$HRS_{ult} = \frac{F_o}{Ng}\;(U.F.)$$

and

$$HRS = \frac{F_o}{Ng}\;(U.F.)(S_F)$$

It is important to note that the Type XI, Class 3 (400 lb nominal strength) ribbons (Reference 10 and Table 2) are not recommended for parachutes designed for repeated use.

Also included in Table 17 are ratios which rebate horizontal ribbon nominal strength (HRS) with suspension line strength from the previous paragraph.

TABLE 16

STRENGTH DEGRADATION FACTORS FOR KEVLAR-29
CORELESS CORD SUSPENSION LINES

(Reference 1, page 414)

Category	Value	Comments
Joint Efficiency	.80	Testing of line termination splices suggest this is a meaningful value
Abrasion	1.00	No evidence of abraided material was found on suspension lines in failure areas
Moisture	1.00	Test items were essentially dry
Temperature	1.00	Temperatures were in range of negligible strength loss
Vacuum	1.00	Not applicable
Convergence (cos ϕ)	.99	Representative of second stage. First stage and full open stage values are .995 and .953 respectively, see Figures 15 thru 17
Fatigue		
Unequal Loading	.58	Specific values unknown combined value reflects experience
Other		
A_p	.46	Product containing all values as factors
U.F. $= \frac{1}{A_p}$	2.15	Definition of the ultimate Factor

TABLE 17

DESIGN CRITERIA FOR TWO-INCH HORIZONTAL RIBBONS
IN
KEVLAR-29 CONTINUOUS RIBBON REEFED PARACHUTES

Application	Ultimate Factor U.F.	In Terms of SLS
Crown Ribbons		
Single Use	1.0	HRS = .46 SLS
Repeated Uses*	1.2	HRS = .55 SLS
Lower Ribbons		
Single Use	.8	HRS = .37 SLS
Repeated Use*	1.2	HRS = .55 SLS

*400 lb Type XI, Class 3 ribbons should not be used in items designed for reuse.

d. Radial Ribbons

Radial ribbon strength (one of two plies) equal to one half the suspension line strength did not result in failures during the testing except during one test (Test 310877S, Table 8) where radial ribbons failed after sustaining a total opening force of 29,156 lbs incurred due to a reefing failure. Ignoring the uneven loading caused by the reefing failure an ultimate factor based on this condition is:

$$U.F. = \frac{\text{Radial Nominal Strength}}{F_o/Ng} = \frac{1000}{29156/32} = 1.10$$

inferring RRS = .506 SLS

which supports the practice of choosing total (2-ply) radial ribbon strength equal to the suspension line strength.

e. Skirt Band

Tensile loads in the skirt band are not the driving factor in choosing the strength of skirt band material. In reefed parachutes, bulk and ability to withstand concentrated loading at the stitching which attaches reefing hardware (rings and cutter brackets) are of primary consideration. Additionally, stiffness and local strength to withstand loadings at radial attachment joints and aerodynamic fluttering during reefed stages is important but has not been quantified.

Although reefing failures experiences during the testing reported in Section IV could not be conclusively related to local failures of the skirt bands, if skirt band failures were assumed, the resulting ultimate factor would be approximately 2.7 which results in the following relationship for skirt band nominal strength:

$$SBS = \frac{F_o}{Ng} (2.7) (SF) = 1.25 \text{ SLS}$$

The two-inch wide skirt ribbon which is plied with the skirt band adds tensile strength but is not considered in the selection of the skirt band. This ribbon is usually relatively thin and has little resistance to local concentrated loads.

f. Vent Band

The lowest peak force which resulted in failure of a 4000 lb vent band in the 28 gore parachute was 22,744 lbs (Test 270979S, Tables 8 and 15). This result and several other tests where vent band failure occurred at somewhat higher peak forces suggests

$$U.F. = \frac{\text{Vent Band Nominal Strength}}{F_o/Ng} = \frac{4000}{22744} 28 = 4.92,$$

$$VBS = \frac{F_o}{Ng} (4.92) (SF) \qquad \text{and } VBS = 2.27 \text{ SLS}$$

Vent bands are normally plied to the vent or top ribbon. The strength attributable to a 3/4 inch portion of this ribbon is neglected as it is small relative to the vent band strength and since the plying stitching may slightly degrade the vent band strength.

g. Vent Lines

Test experience did not include vent line tensile failures that could not be attributed to some previous failure of some other component. The practice of choosing vent line strength equal to the suspension line strength seems equitable. There was evidence of abrasion damage to vent lines where they cross at the vent center when braided cords (2,000 and 3,50C lbs nominal strength) were used and when high loadings were encountered. It is suggested that the thickness of 14 vent lines stacked at the vent center may effect appreciable normal loads which aid abrasion degradation. This could be prevented by utilizing webbing for vent lines or by increasing the ultimate factor when braided cord must be used. For choosing vent line nominal strength then,

VLS = 1.0 SLS	for webbing type material
VLS = 1.5 SLS	for braided cords when tensile strength is greater than 1,500 pounds.

3. DESIGN DETAILS

a. Splices and Plying

(1) Horizontal Ribbon

Continuous, two-inch wide ribbons each have one splice which is sandwiched between two radial ribbon plies. Figure 22 shows a typical arrangement and Appendix F describes in detail those splicing configurations used in the test items discussed in Section IV and many other splice arrangements which did not meet efficiency requirements. Joint efficiency for horizontal ribbon splices used in test items ranged between 86 and 100 percent based on tensile testing machine unidirectional loading to failure along the axis of the ribbons. Details describing the make-up of these joints and the results of joint sample tests are contained in Appendix F.

Splices in horizontal ribbons were staggered in a manner which separated the splices of adjacent ribbons by one gore width.

Splices in the extreme upper crown ribbons were covered by more than one radial ribbon pair, but this condition was not considered in the development and testing of the horizontal ribbon splice.

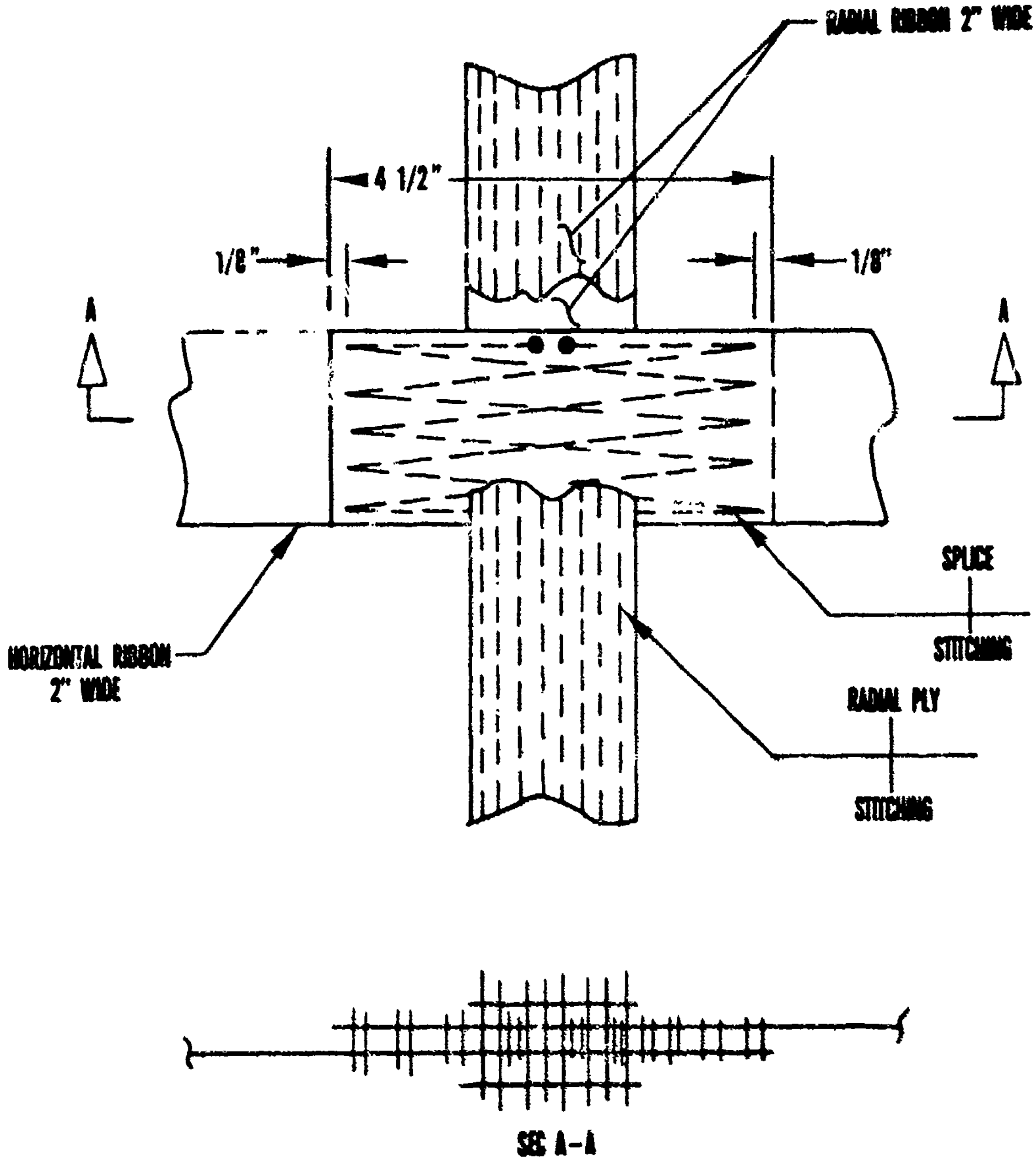


Figure 22. Typical Horizontal Ribbon Splice

TABLE 18

DESIGN CRITERIA FOR SELECTING KEVLAR-29
RIBBON PARACHUTE COMPONENT MATERIAL STRENGTHS

Component	Column 1 Strength Relative to $(S_F)F_o/Ng$	Column 2 Factors Relative to SLS
Suspension Lines SLS	$\frac{1}{A_p}$	-
Horizontal Ribbons HRS		
Crown single use	1.0	.46
repeated use	1.2	.55
Lower single use	.8	.37
repeated use	1.2	.55
Radial Ribbons RRS each of two plies	1.1	.51
Skirt Band SBS	2.7	1.25
Vent Band VBS	4.9	2.27
Vent Lines VLS Webbing	-	1.00
Vent Lines VLS Cord	-	1.50

$$\text{Component Nominal Strength} = \frac{F_o}{Ng}(S_F)\underset{\text{Column 1}}{(\text{Strength Factor})}$$

or

$$\text{Component Nominal Strength} = \text{SLS}\underset{\text{Column 2}}{(\text{Strength Factor})}$$

(2) Skirt Band

Figure 23 shows a typical skirt band splice arrangement. The 1 3/4 inch skirt band webbing was stitched to the bottom horizontal ribbon and spliced with lap stitching through the ribbon and vertical tapes which had been previously stitched to the ribbon with ends folded back between skirt band and ribbon. Skirt band splices were located at the midpoint of one gore of the canopy assembly.

High efficiencies (above 90 percent) were routinely obtained for this joint and no failures occurred during parachute testing.

(3) Vent Band

Splices in the three-fourth inch wide vent bands were made by stitching a 3 point pattern through a 5 1/4 inch lap, the top ribbon, and the vent terminations of 3 radial ribbons. Stitching for attaching the vent lines also is through the vent band and three sets of this stitching is through the lap. Figure 24 shows the general arrangement of the vent band splice. Cross-sectional details can be observed in Figure 27b which shows vent termination joints for the radials and vent lines respectively.

Efficiencies greater than 85 percent were obtained when samples were pulled along the axis of a straight vent band in a tensile testing machine.

Vent band failures in parachute testing occurred away from the splices.

(4) Reinforcement Band

Reinforcement bands, three-fourth inches wide were placed at the position of maximum first stage reefed inflation diameter (see Figure 19). These bands are plied to the upper edge of a horizontal ribbon at this location. Splices are formed in a manner similar to

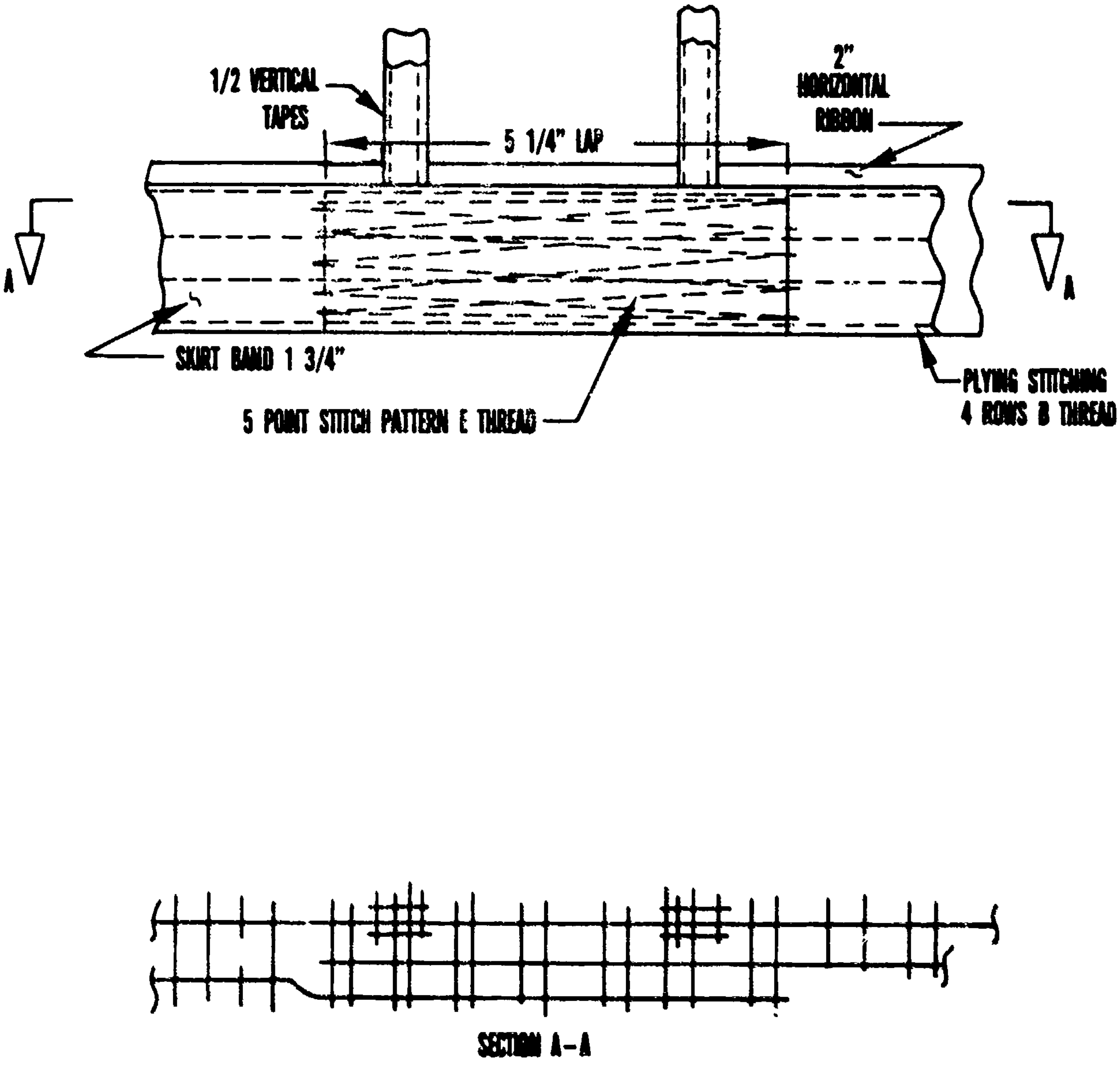


Figure 23. Typical Skirt Band Splice

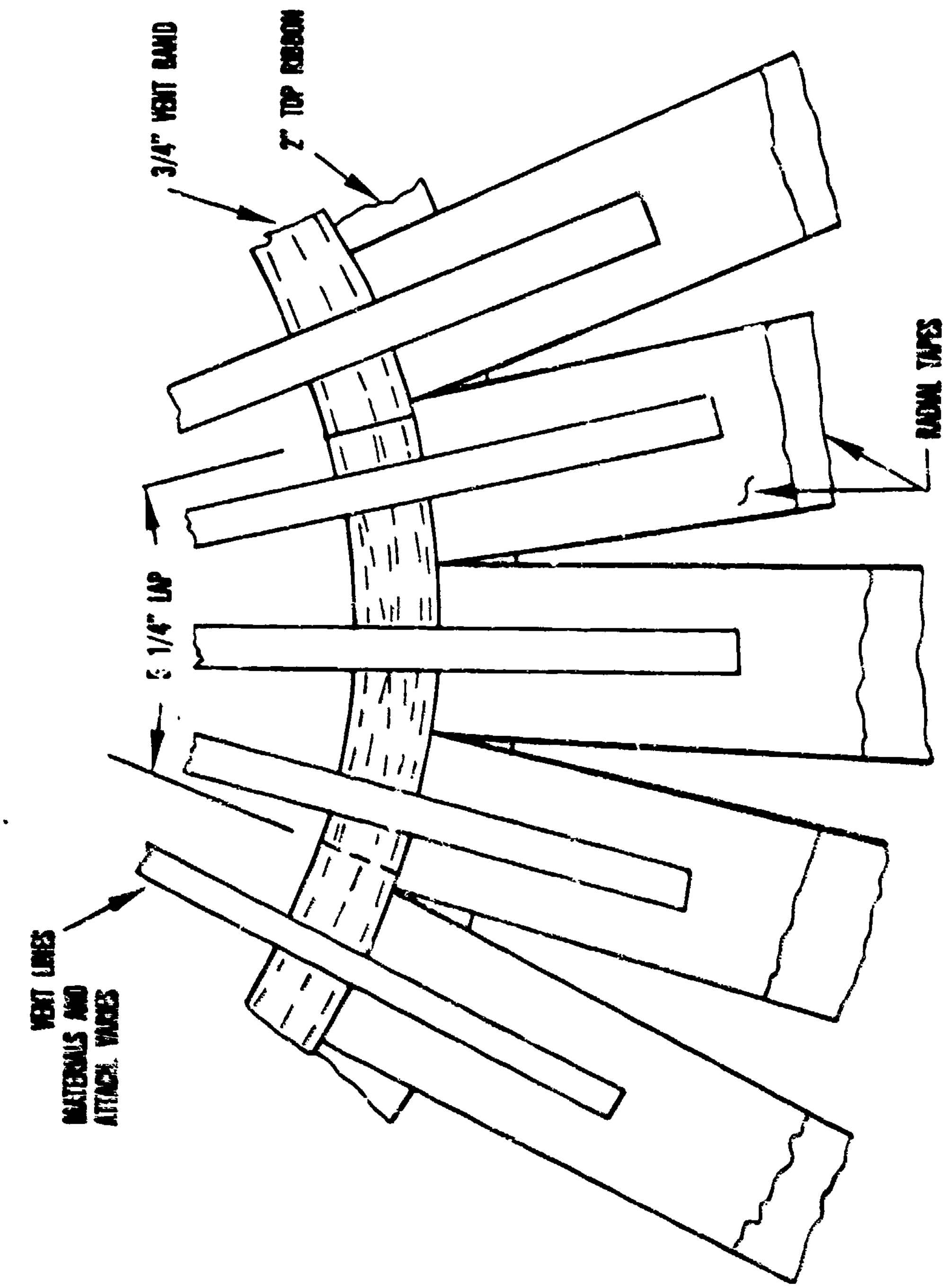


Figure 24. Typical Vent Band Splice

the vent band splice of Figure 24 with plying and lap stitching through horizontal ribbon, vertical tapes and radial ribbons. Three point lap stitching patterns are used and high efficiency (90 percent and greater) is commonly obtained in test samples. Laps for splices are centered on a radial ribbon.

Reinforcement band failures did not occur in parachute testing (Section IV).

(5) Radial Tapes

Plying of the two ribbons, which make-up radial tapes and which sandwich between them the horizontal ribbons, is shown in Figure 25. Eight rows of straight stitching shown, applied by two passes of a four needle sewing machine, evolved as the most efficient plying technique.

Several stitching techniques were tried in tensile test samples, including various thread sizes and stitch spacing, fewer rows, and various combinations of zig-zag and straight stitching.

Tensile testing of plied samples usually indicated appreciable strength degradations when results were compared to two times the strength of the radial ribbon material. Testing of a sample which consisted of 2 ribbons without stitching indicated that the test methods and apparatus used yielded only 80 to 90 percent efficiency for the unstitched configuration. When stitched test sample results were compared to the unstitched results, acceptable efficiencies were evident.

The absence of failures in radial tapes during parachute testing confirms the plying technique indicated in Figure 25.

b. Terminations and Joints

(1) Radial to Suspension Line

Suspension lines are attached to the parachute skirt through beckets (loops) formed from the ends of radial ribbons extended below the skirt. Figure 26a shows the finished configuration of this joint

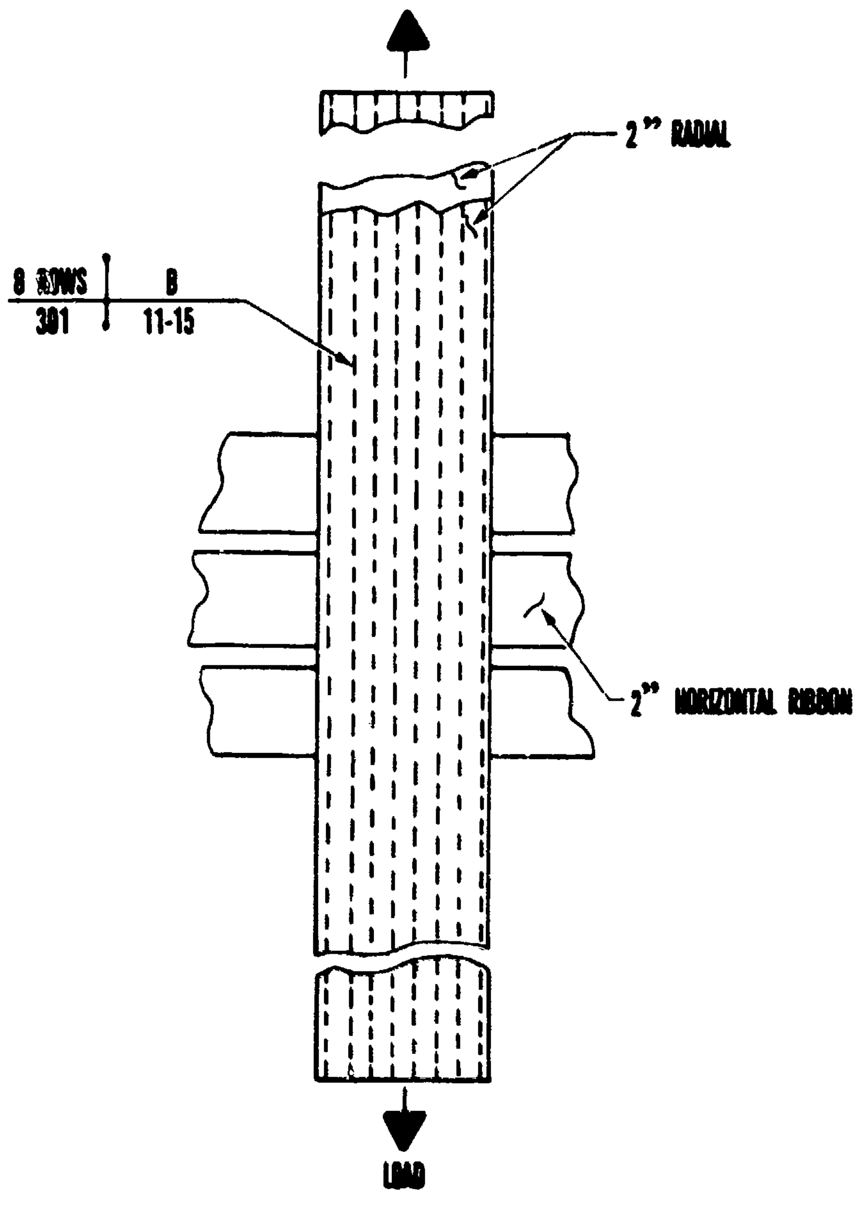


Figure 25. Radial Ribbon Plying

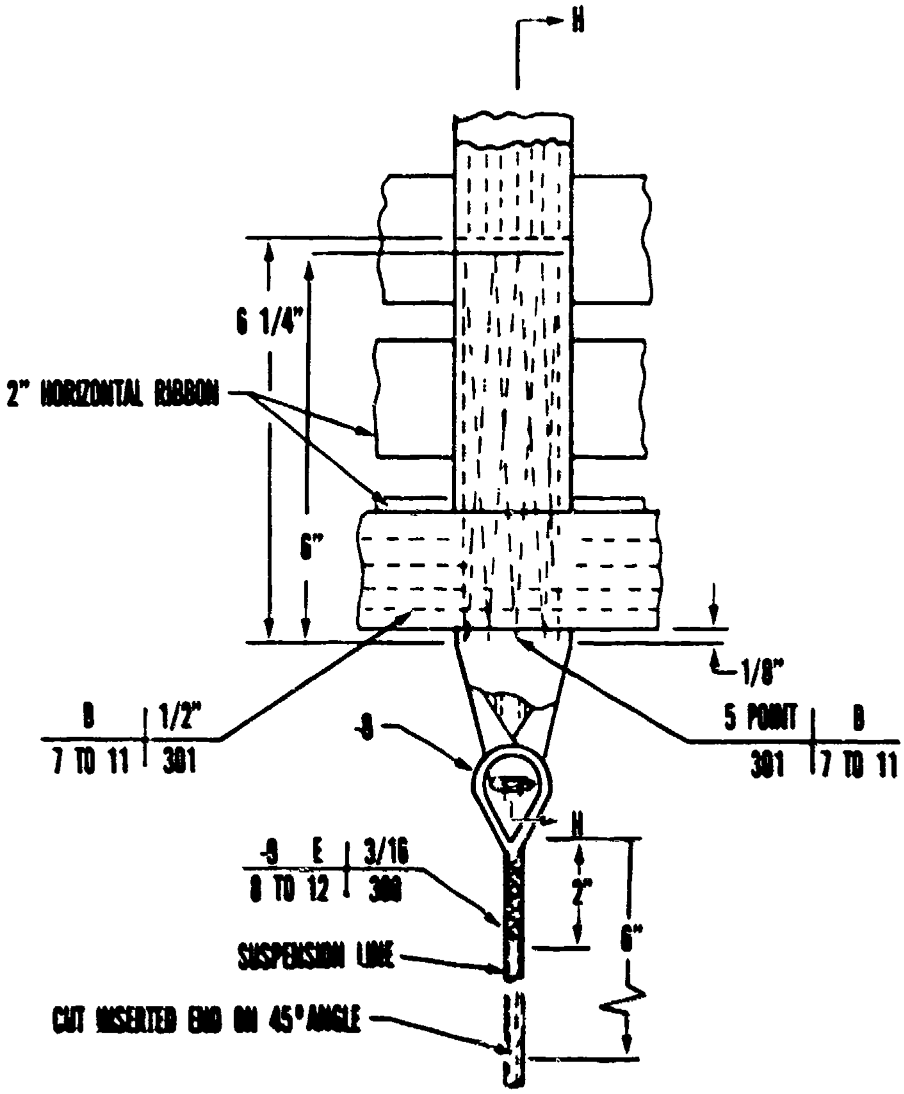


Figure 26a. Radial to Suspension Line Joint

and the eye spliced termination of the coreless cord suspension line. Details of the inner construction and a section are shown in Figures 26b and 26c.

An internal three-fourth inch, 3,000 lb reinforcement absorbs concentrated loading, but no anti-abrasion buffer is included.

Eighty to ninety percent of the total radial strength is retained in tensile test samples of this joint. When lower strength radial materials are used, efficiency is in the lower portion of this range. An additional interlayer of material similar to or stronger than the radial ribbon can be placed in the folded-up ends of the radials before installing the five point lap stitching to improved efficiency when lower strength radial materials are involved.

Parachute testing (reported in Section IV) did not result in failures in this joint or in evidence of abrasion to the suspension line loop or becket.

(2) Radial to Vent Line

The general configuration for the joint which terminates the radials at the vent and provides for attachment of the vent lines is shown in Figures 27a and 27b. Figure 27b shows the location of two separate reinforcement pieces necessary to distribute the vent line load across the width of the radials. The internal reinforcement must be in place when the radial plies are sewn over the horizontal ribbons. The vent band can then be sewn on and spliced with radial folds as shown. Next, the outer reinforcement is applied with appropriate folding and stitching through all components. Lastly, the ends of the vent lines are attached using stitching and reinforcement techniques appropriate for the vent line material.

When lower strength radial materials were used it was necessary to retain higher strength materials (800 to 1,000 lb nominal strength) for the inner and outer reinforcement pieces.

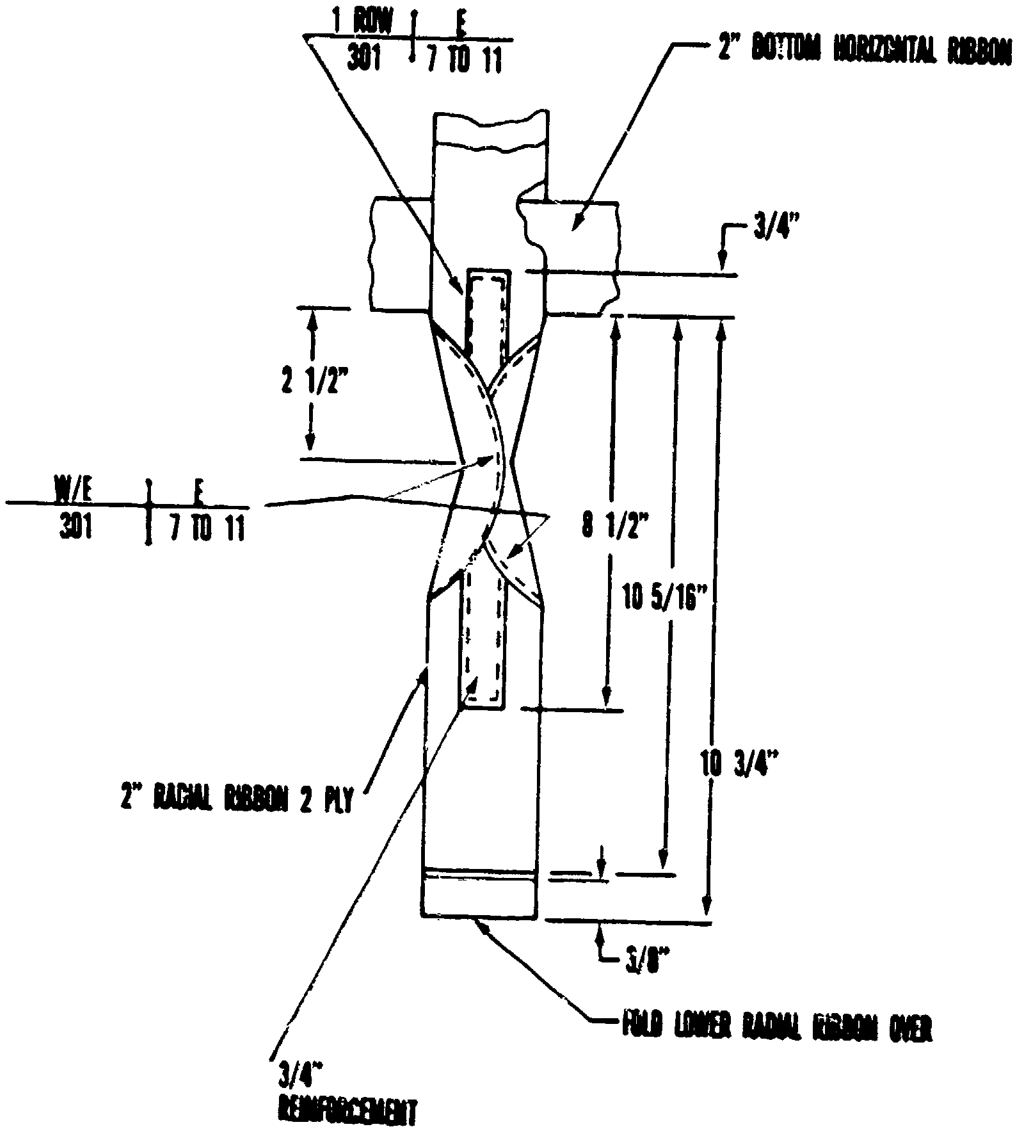


Figure 26b. Radial to Suspension Line Joint Becket and Reinforcement Detail

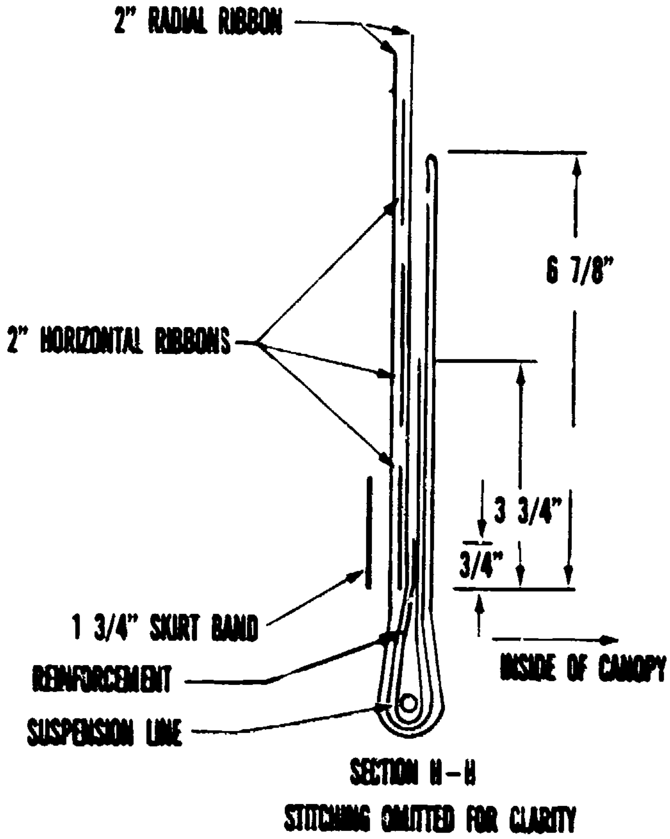


Figure 26c. Radial to Suspension Line Joint Section Details

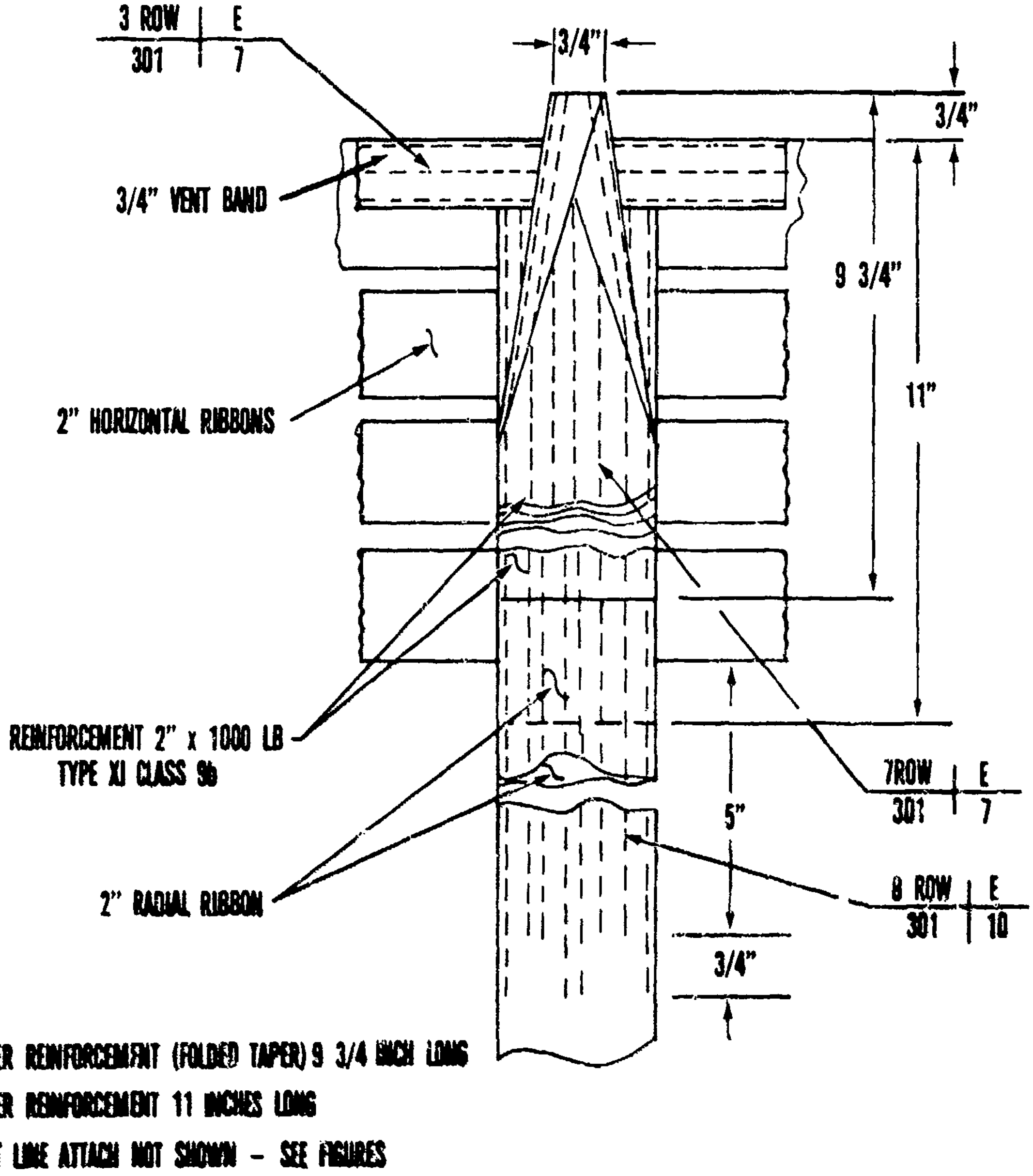


Figure 27a. Vent Line to Radial Joint Before Vent Line Attachment

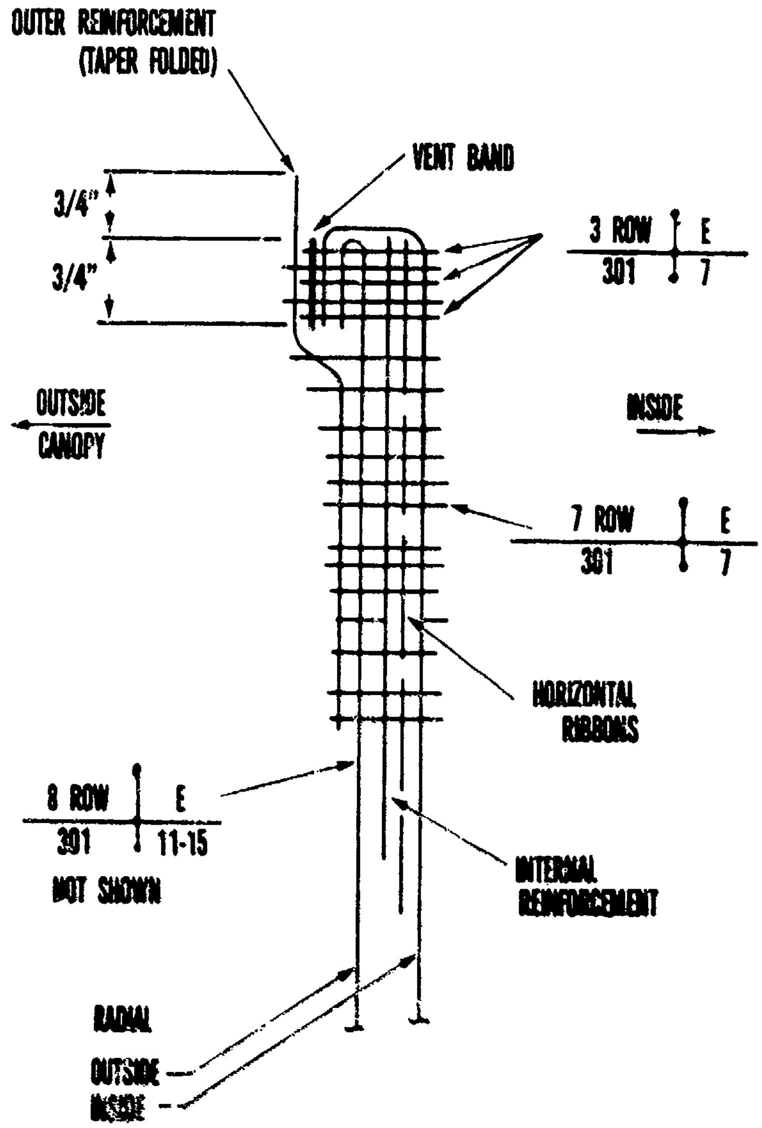


Figure 27b. Vent Line to Radial Joint Cross Section Detail Before Attachment of Vent Line

Figures 28, 29, and 30 show three variations for attaching vent lines. Each of these involve double throw zig-zag stitching through all components in the section of Figure 27b.

When coreless braided cords are used, a length of the cord is inserted into the end of the vent line as a reinforcement which prevents failure of the line at the end of the attaching stitching, and in the case of the "Y" attachment (Figure 28), provides the second leg for the "Y". Tapering of the end of the inserted end of the reinforcement is necessary for good tensile efficiency (see Appendix C). The tapering technique used in the parachute test items (Section IV) was a simple 45 degree cut.

Joints without the outer reinforcement were successfully used when vent lines were made of 9/16 inch tubular webbing and when 1,000 lb radial and horizontal ribbons were used. When lower strength radial materials were used, efficiencies greater than 80 percent could not be obtained in tensile test samples.

While considerable time and effort was often expended in developing efficient joint arrangements, with final results usually less than 85 percent of the vent line strength, no failures of this joint were encountered during the parachute testing (Section IV).

(3) Suspension Line

Suspension lines on adjacent gores can be made from a single piece of coreless braided cord by forming the loop at the riser termination shown in Figure 31. The opposite ends of these lines can be attached to the canopy as shown in Figure 26a.

Very high efficiencies were routinely obtained for the loops formed in coreless cord tensile test samples (95 percent and higher).

Tapering the inserted ends in the eye splices at the canopy ends of lines is important to attaining good efficiencies. Refer to Appendix C for more information on eye splices in Kevlar-29 coreless cord.

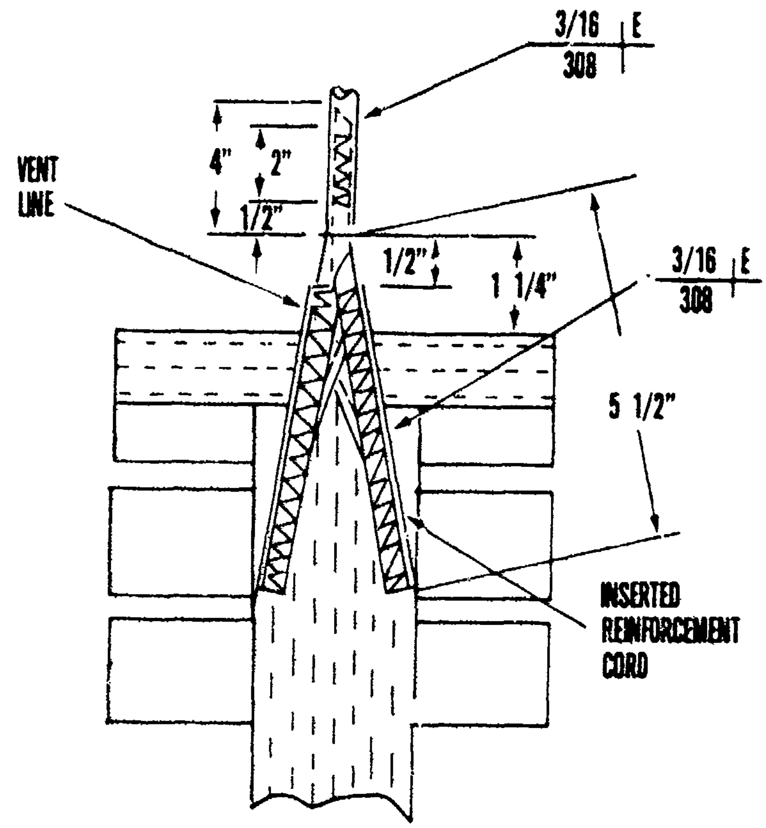


Figure 28. Vent Line to Radial Joint "Y" Attachment for Coreless Cord Vent Lines

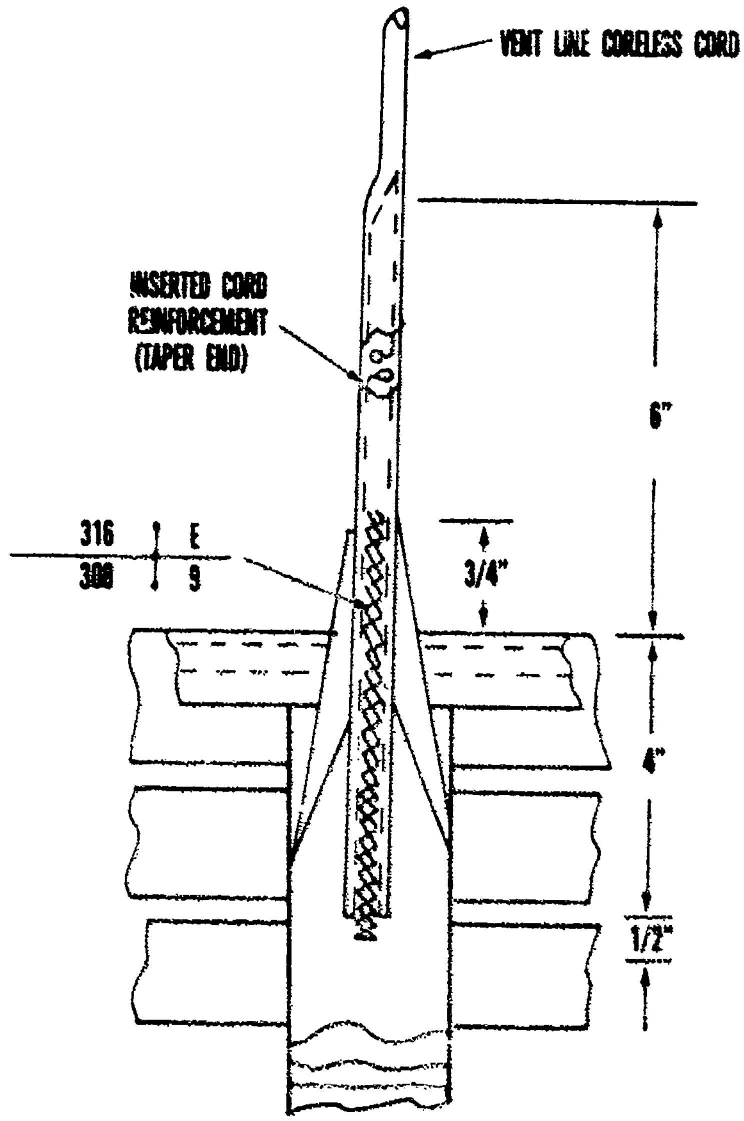


Figure 29. Vent Line to Radial Joint Attachment for Coreless Cord Vent Lines

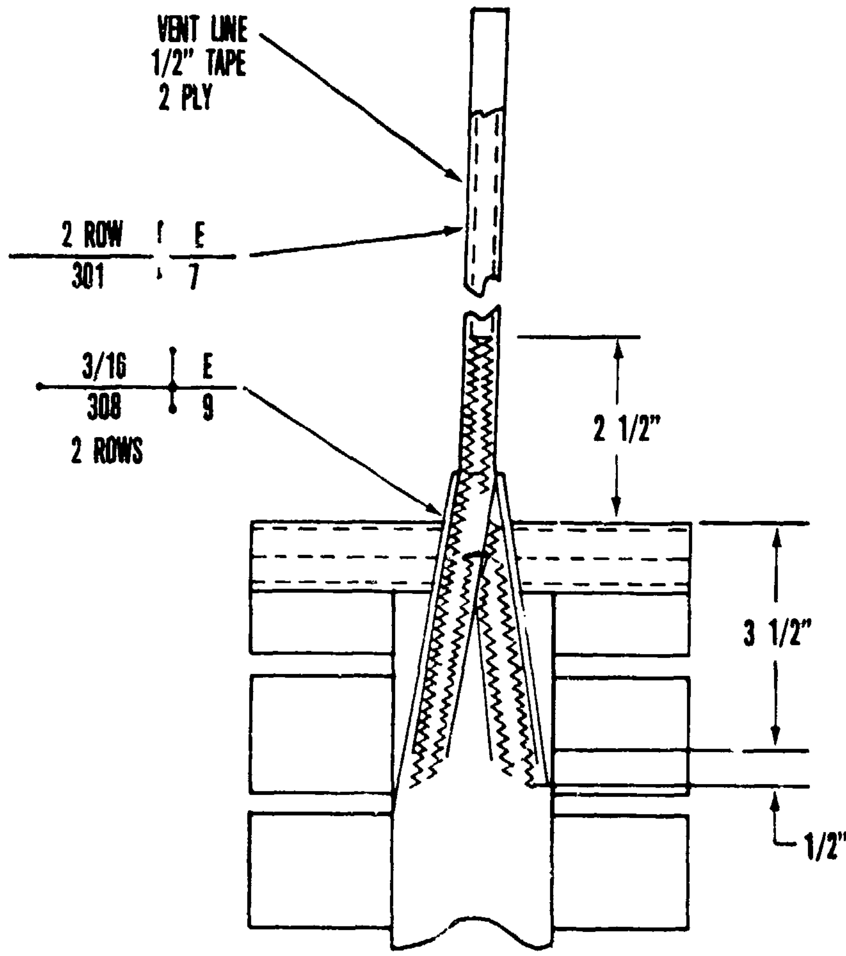


Figure 30. Vent Line to Radial Joint Attachment for Two-Ply Tape Vent Lines

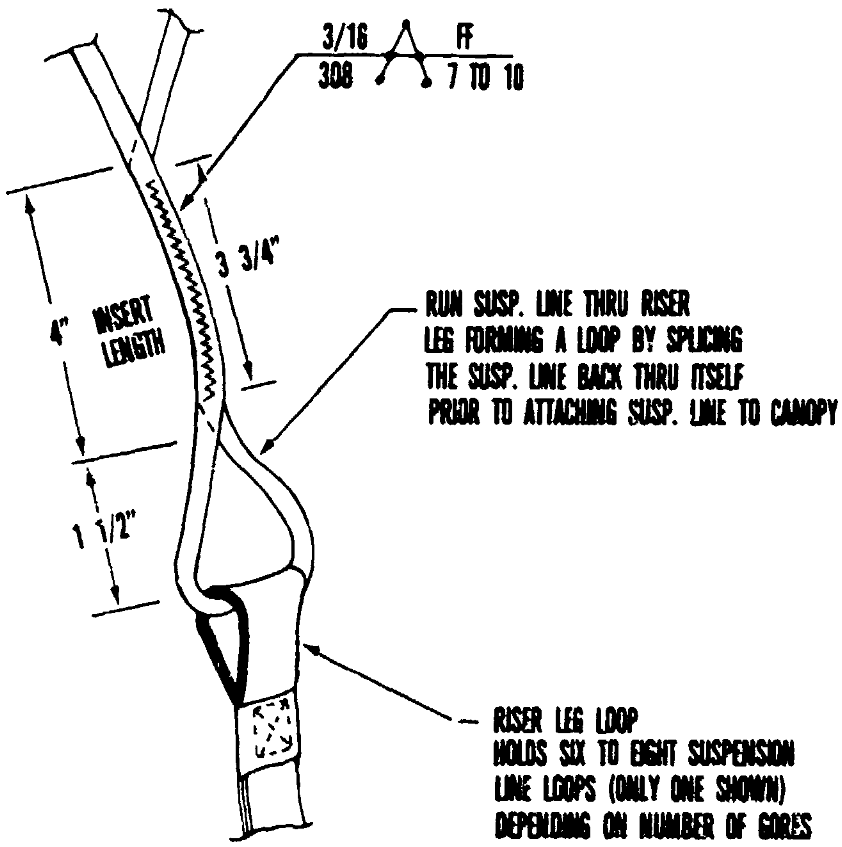


Figure 31. Coreless Braided Cord Suspension Line Termination at Riser

SECTION VII

FABRICATION

1. PATTERNS

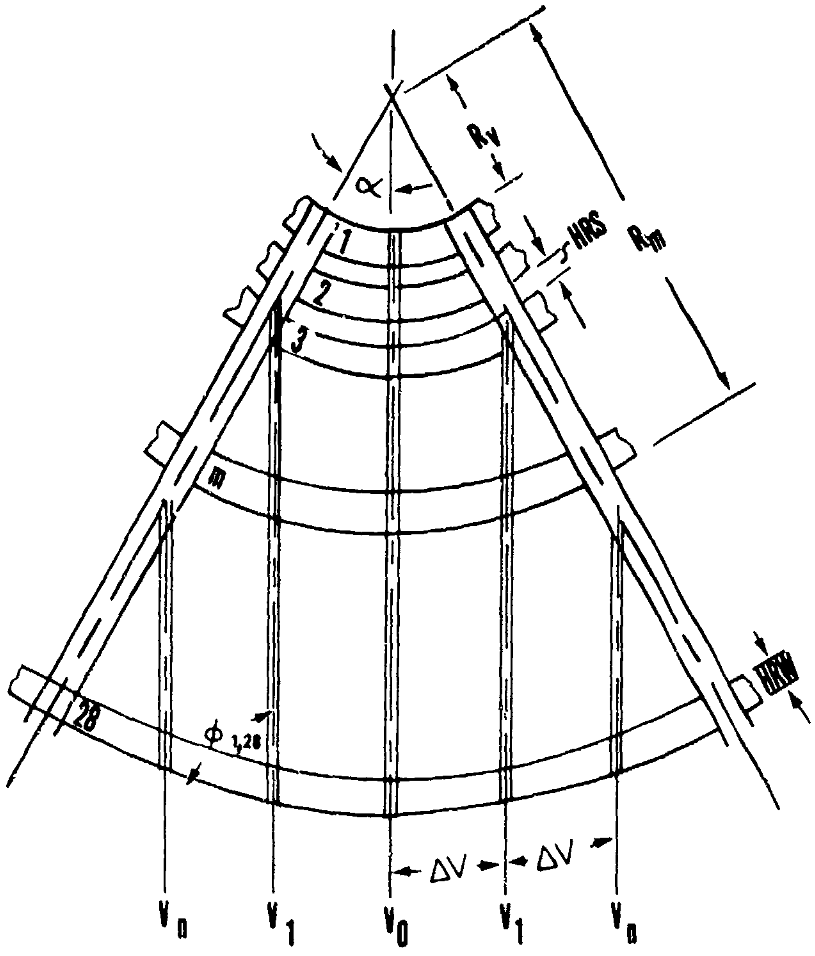
Given selected material strengths and design geometry, patterns are used for cutting and marking components prior to sewing operations which form joints at all component intersections and terminations.

a. Relative Position of Components

Patterns for marking materials at cutting points and at positions where components are to be folded or sewn into position are necessary to facilitate and maintain construction consistency.

Marking slots or edges which match parachute geometry and dimensions are cut into hard, stiff card stock or pattern paper. These patterns are positioned above or beside material lengths under nominal tension and marks for cutting and positioning are made on the material.

For continuous ribbon Kevlar-29 parachutes, effective component joining often requires close control of assembled component relative position. An important consideration in this area is the angle between the continuous horizontal ribbons and the radial ribbons and vertical tapes. Normal nylon construction practice is to stitch all vertical components at right angles to ribbons in the same manner as radial ribbons (or vertical tapes located on gore center lines) where intersections are perpendicular to the horizontal ribbons). Non-centered vertical tapes positioned parallel to gore centerlines intersect the horizontal ribbons at angles which vary with distance from the centerline and with radial distance measured from the vent center. These relationships and formulae for determining the intersection angle between vertical tapes and tangents to the bottom edge of each horizontal ribbon at the vertical tape intersections are shown in Figure 32. Table 19 contains values for these angles considering 2-inch ribbon width, a .601 inch ribbon spacing and 3 inches between vertical tapes. Figure 33 shows a simulated horizontal ribbon marking pattern for positions of radials and vertical tapes in one gore. Layout of the marking slots in this pattern are



$$\phi_{nm} = 90 - \text{ARC SIN} \frac{n \Delta V}{R_m}$$

$$R_m = R_v + m\ (HRW) + (m-1)\ HRS$$

m – RIBBON NUMBER

n – VERTICAL TAPE NUMBER

$\phi_{om} = 90°$

Figure 32. Position Angles Between Continuous Horizontal Ribbons and Vertical Tapes

TABLE 19

ANGLES FOR POSITIONING VERTICAL TAPES ON CONTINUOUS HORIZONTAL RIBBONS

Ribbon Nr m	Angle $\Phi_{n,m}$ (deg.) Vertical Tape Nr n: 0	1	2
1	90.0		
2			
3			
4			
5			
6			
7			
8		84.2	
9		84.7	
10		85.1	
11		85.4	
12		85.7	
13		86.0	
14		86.2	
15		86.4	
16		86.6	
17		86.8	
18		86.9	
19		87.1	84.1
20		87.2	84.3
21		87.3	84.6
22		87.4	84.8
23		87.5	85.0
24		87.6	85.1
25		87.7	85.3
26		87.8	85.5
27		87.8	85.7
28		87.9	85.8
29		88.0	85.9
30		88.0	86.0
31		88.1	86.2
32		88.1	86.3
33	90.0	88.2	86.4

VALUES APPLY TO:

Two-inch Wide Horizontal Ribbons

.601 inch Ribbon Spacing

Three-inch Vertical Tape Spacing

Five Vertical Tapes

Vertical Tapes Intersect Radial Centerlines at Ribbons 8 and 19 and are Terminated

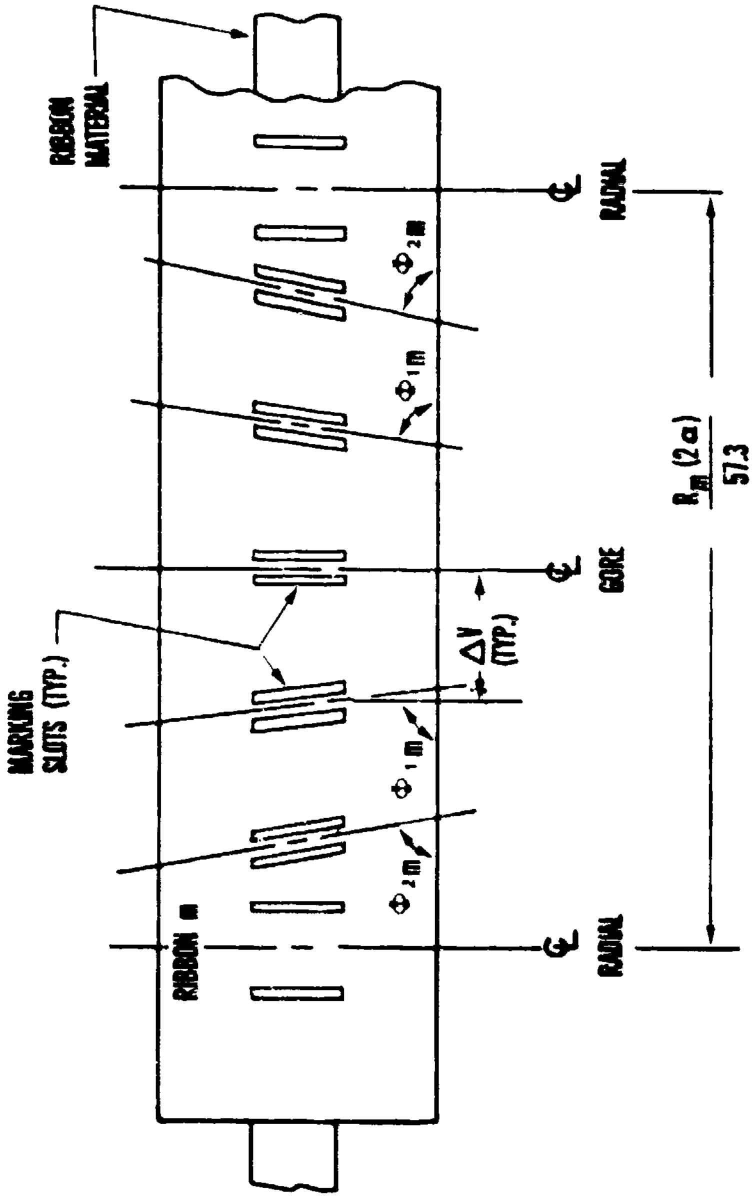


Figure 33. Typical Horizontal Ribbon Marking Pattern

based on the ribbon bottom edge along which spacing is measured and from which angles are measured. Usually one piece of pattern material contains marking slots for several gores. The pattern is placed over ribbon material under tension ($\approx$ 30 pounds for at least 30 seconds) and position marks made through the slots using colored pencils coded for center vertical, off-center verticals, and radials.

b. Fullness in Continuous Ribbons

Due to the geometry of the continuous ribbon conical parachute, the difference in circumference of the conical surface at the top and bottom edges of the ribbon is:

$$\Delta C = \frac{N_g (2\ \alpha)}{360} 2\pi \text{ (Horizontal Ribbon Width)}$$

For a 20 degree conical canopy (α = 6.04 degrees) and with 2 inch wide ribbons this difference in length is 11.81 inches (constant for all ribbons). Since ribbons are cut to the bottom edge dimensions, appreciable fullness in the top edge, especially for the crown ribbons, results. To alleviate concentrated loading in the lower edges of continuous ribbons caused by geometric fullness and aggravated by low elongation Kevlar material, tucks in the ribbon upper edges may be utilized. When this is desired, patterns for marking these tucks can be made to produce marks on ribbons as depicted in Figure 34. Tucks are formed by sewing the tuck lines together at the center of each radial location which positions the radial locating lines perpendicular to the ribbon bottom edge. Tuck angles are determined by dividing the difference in ribbon edge lengths to be compensated for by the number of gores and using the ribbon width to define the angle. In the top ribbon, some of the differential can be compensated for by take-up in stitching on the vent band since it is narrow relative to the ribbons. Compensation for differential in ribbon edge length may be limited to the crown ribbons where it is a relatively high percentage of the total ribbon length.

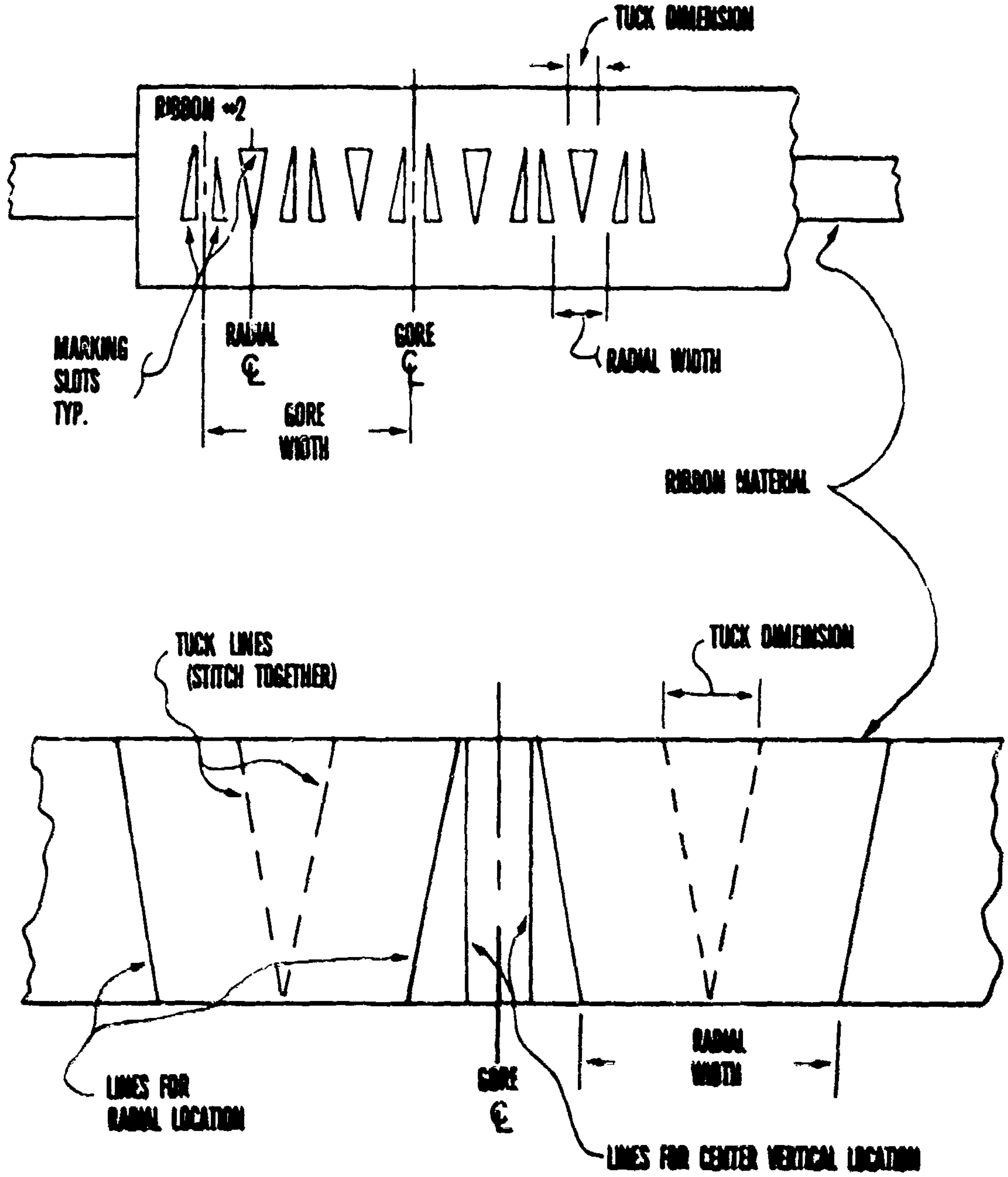


Figure 34. Continuous Horizontal Ribbon Marking Pattern for Control of Top Edge Fullness in Upper Crown Ribbons

c. General Kevlar-29 Marking Considerations

Patterns for marking components other than horizontal ribbons generally follow techniques used for conventional materials. Low elongation of Kevlar materials de-emphasizes the importance of consistency of tension in material being marked allowing marking of several pieces simultaneously. As an example, a simple clamp capable of holding 10 ends of vertical tape material can be used to load 10 vertical tapes for simultaneous marking of ribbon location and cutting lines. If take-up due to stitching is to be accounted for in component layout, take-up should be experimentally determined using personnel and sewing machines to be used in production.

2. CUTTING MATERIALS

In general, Kevlar-29 textile decelerator materials can be cut by conventional manual methods. Cutting edges of normal manual shears dull rapidly. Special shears with edges developed and coated for cutting Kevlar fabrics were used effectively. Materials for the last six test items in Table 6 were cut with shears from Penn Associates, Inc. (Wilmington, Delaware) which performed satisfactorily.

3. SEWING

Sewing Kevlar-29 materials can be accomplished using machines and techniques generally applicable to other synthetic materials. Machine operators and setup personnel should be aware of the difference in strength of Kevlar-29 threads which are nearly the same size as typical nylon threads. Damage to sewing machine components can result from improper tension adjustments when larger thread sizes are used.

Sewing experience has shown a tendency of the Kevlar-29 materials to dull needles rapidly relative to nylon. Potential excessive strength degradation due to needle penetration exists if materials are sewn with dull needles.

SECTION VIII

CONCLUSIONS AND RECOMMENDATIONS

1. CONCLUSIONS

a. General Conclusions

(1) Kevlar-29 textile materials can be successfully applied to various decelerator system components including risers, suspension lines, reefing lines, deployment bags, and geometric porosity type parachutes where unit canopy tensile loading is greater than 200 lbs per inch.

(2) While existing Kevlar-29 textile materials developed for decelerator system application are generally applicable, the nonavailability of yarns smaller than 200 denier imposes important limitations when material strengths less than 200 lbs per inch of width are required.

(3) High joint efficiency (80 to 90 percent of base material strength) can be obtained in Kevlar-29 materials joint construction based on unidirectional tensile testing. Some materials combinations may require several iterations of thread size, stitching patterns, and joint arrangement to obtain efficiencies at these levels.

(4) Kevlar-29 threads described in MIL-T-87128 (Reference 8) are compatible with standard sewing machines. Sewing machine adjustments should be made carefully as these high strength threads can impose high stresses in machine parts.

b. Conclusions Based on Parachute Test Results

Conclusions based on 15.3 ft D_o Kevlar-29 ribbon parachute test experience within the ranges of test conditions in Tables 7 and 8 are as follows:

(1) Drop tests and sled tests produced drag area and force data which are equivalent and which exhibit similar trends relative to reefing stages and dynamic pressure.

(2) Reuse of Kevlar-29 ribbon parachutes has been demonstrated when higher strength horizontal ribbons were used (i.e., ribbons without the loose weaving imposed by yarn denier limitations).

(3) Two stage reefing of Kevlar-29 15.3 ft D_o, 20 degree conical continuous ribbon parachutes has been demonstrated as a reliable and predictable method for drag area and opening force control.

(4) Reefing line cutters normally used for cutting nylon lines were successful in cutting similar strength Kevlar-29 reefing lines.

(5) Peak forces occurring at the end of inflation to a given stage vary linearly with dynamic pressure at the beginning of the stage and the slope of this variation is the product of the average opening shock factor for this stage and the average drag area evaluated at the end of the stage.

(6) Breaks in vent bands which occurred early in the inflation to the first stage did not cause significant degradation in the peak force associated with the two reefed stages, but resulted in smaller force peaks associated with the full open stage.

(7) Average opening shock factors for Kevlar-29 test items including both sled and drop test results were 1.17, 1.38 and 1.41 for first, second and full open stages respectively. Individual values show independence on dynamic pressure at staging initiation. Although values for opening shock factor for a single test of a comparison nylon parachute were 4 to 5 percent lower than the averages for Kevlar-29 test items at each stage, this difference is considered insignificant relative to scatter in Kevlar-29 based shock factor data.

(8) Drag area expressed as the ratio of drag force measured at stage termination (Or after reaching full open quasi-equilibrium condition) to the dynamic pressure at these conditions can be expressed in terms of the reefing ratio by the expression,

$$C_DS = F/_Q = 166\ (RR)\ -10.4$$

and is independent of dynamic pressure over the range of test conditions.

(9) Representative times required for Kevlar test items to inflate to reefed stages and full open are .125, .035, and .070 seconds respectively for most dynamic pressures. A few data points at the lower dynamic pressure values for each stage indicated longer filling times.

(10) Average values for projected area at each stage resulted in the linear relationship with reefing ratio as follows:

$$S_p = 133.3 \text{ (RR) } -1.33$$

Overinflation in each of the stages was indicated but could not be identified as a direct factor in generating the staging force peaks.

(11) Oscillation of the Kevlar-29 test items with respect to the direction of travel through the air mass was small (less than 4 degrees) for the first two stages. Significant oscillations, triggered by inflation to full open, damped to 8 degrees or less (based on short full open times) during sled testing.

(12) All test items utilizing 400 lb tensile strength horizontal ribbons exhibited severe filling yarn migrations in ribbon free lengths based on post test inspections. This weave instability is inherent at the lower limit of tensile strength per unit width imposed by 200 minimum yarn denier. This material does not produce undue tensile failures but the migration of yarns would prohibit its use in decelerators which must be reused.

(13) Test utilizing 400 lb horizontal ribbon material produced low values for peak forces in the full open stage, low values for opening shock in the second and full open stages, and longer filling times in the first and full open stages. The Genton coating, tried on the ribbons used in test items IH-7, IH-8 and IH-9, was ineffective in preventing weave distortions or changing performance characteristic of items utilizing 400 lb horizontal ribbons.

(14) Vertical tapes parallel to gore centerlines (but off the gore centerline) should not be sewn perpendicular to the edges of horizontal ribbons, but should form angles which preserve correct geometric shape and prevent stress concentrations (see Section VII).

2. RECOMMENDATIONS

Kevlar-29 materials should be considered in decelerator system design when requirements include minimum weight, low volume, high strength, or strength at high temperature.

Based on the results of testing efforts utilizing the test items and testing described in Section IV, the design criteria for Kevlar-29 ribbon parachute component materials (see Table 18) were derived. These criteria are recommended for similar parachute designs.

Since no prospect for availability of Kevlar-29 yarns smaller than 200 denier is evident, it is recommended that further effort be conducted to develop a coating for woven materials with tensile strengths less than 300 lbs per inch of width (yarn migrations (slippage) and joining problems were observed in 2-inch wide ribbons having tensile strengths less than 600 lbs). This coating should add little weight, hold yarns in place in sewn joints and during aerodynamic fluttering, and be compatible with pressure packing and environmental requirements.

Appendix A

Draft

Tentative Military Specification

for

CLOTH, PARACHUTE, CARGO AND DECELERATION,

PARA-ARAMID, INTERMEDIATE MODULUS

This specification is mandatory for use by all Departments

and Agencies of the Department of Defense.

1. SCOPE

1.1 Scope. This specification covers canopy fabrics made from para-aramid, intermediate modulus yarn for fabrication of parachutes.

1.2 Classification. The cloths shall be of the following types as specified (see 6.2):

Type I - 3.0 ounces per yard, maximum weight.

Type II - 2.0 ounces per yard, maximum weight.

2. APPLICABLE DOCUMENTS

2.1 The following documents of the issue in effect on date of invitation for bids or request for proposal, form a part of this specification to the extent specified herein.

SPECIFICATIONS

Federal

PPP-P-1133 Packaging and Packing of Synthetic Fiber Fabrics

STANDARDS

Federal

FED-STD-191 Textile Test Methods

Cloth, Parachute, Cargo and Deceleration
Para-aramid, Intermediate Modulus

Military

MIL-STD-105 Sampling Procedures and Tables for Inspection by Attributes

(Copies of specifications, standards, drawings, and publications required by suppliers in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

2.2 Other Publications. The following document forms a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.

Laws and Regulations

Rules and Regulations under the Textile Fiber Products Identification Act

(Copies may be obtained from the Federal Trade Commission, Washington DC 20580.)

3. REQUIREMENTS

3.1 Material.

3.1.1 Kevlar Yarn. The yarn used in the manufacture of all types of parachute cloth shall be a para-aramid, intermediate modulus type (see 6.6).

3.1.1.1 Denier and Twist. The yarn used in the manufacture of the cloth shall be of the denier and twist specified in Table I. (Note: A twist designation of zero signifies that no twist is to be added to the producer's twist as delivered.)

3.2 Weave.

3.2.1 Type I. The weave pattern for Type I and II cloths shall be a plain weave.

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Cloth, Parachute, Cargo and Deceleration
Para-aramid, Intermediate Modulus

3.3 Physical Properties. The physical properties of the finished cloth shall conform to Table I.

TABLE I

PHYSICAL REQUIREMENTS

	Type I	Type II
Yarns per inch (min)		
warp	48	36
filling	48	34
Yarn denier	200	200
Yarn ply		
warp	single	single
filling	single	single
Yarn twist		
warp	5.0	0
filling	0	0
Weight (oz/sq yd) (maximum)	3.0	2.0
Breaking strength (lb/inch) (minimum)		
warp	350	230
filling	350	220
Air permeability (cu ft air/min/sq ft at 1/2 inch water pressure)	50 to 90	50 to 90

3.3.1 Dimensions.

3.3.1.1 Width. Unless otherwise speci.ied, the overall width of the finished cloth shall be 36.5 $\pm$ 0.5 inches (see 6.2).

3.3.1.2 Length and Put-up. Unless otherwise specified, the cloth shall be in continuous pieces, each not less than 50 yards. The pieces shall be put up on rolls as specified in PPP-P-1133 (see 6.2). Shorter cuts may be included in accordance with the following schedule:

75 percent of total yardage in cuts 50 to 150 yards
15 percent of total yardage in cuts 25 to 50 yards
10 percent of total yardage in cuts 15 to 25 yards.

3.4 Fiber Identification. Each piece shall be labeled or ticketed, and invoiced for fiber content in accordance with the rules and regulations under the Textile Fiber Products Identification Act (see 4.2.1.1.2).

3.5 Identification of Product. Each roll of finished cloth shall be marked for identification in accordance with PPP-P-1133. In addition, each piece of cloth in each roll shall be clearly and legibly marked with the finisher's roll number or code, and each roll shall have attached a durable tag on which the finisher's roll number or code is listed. The date of manufacture of the cloth shall be included on the tag attached to each roll.

3.5.1 Age. The cloth shall not be more than two years old from date of manufacture of the yarn to date of delivery of the cloth.

3.6 Workmanship. The finished cloth shall be clean and evenly woven and shall conform to the quality and grade of product established by this specification, and the occurrence of defects shall not exceed the applicable acceptable levels.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection. Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified in the contract or order, the supplier may use his own or any other facilities unless disapproved by the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.1.1 Certification of Compliance. The supplier shall submit certificates of compliance for the following characteristic:

Characteristic	Requirement Paragraph
Age of cloth	3.5.1

4.2 Inspection for Acceptance. Sampling for inspection shall be in accordance with MIL-STD-105, except where otherwise indicated herein.

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Cloth, Parachute, Cargo and Deceleration
Para-aramid, Intermediate Modulus

4.2.1 Examination of Product.

4.2.1.1 Yard-by-Yard Examination. A sufficient number of rolls shall be selected at random from an inspection lot so that the required sample yardage will be obtained by inspecting approximately 25 consecutive yards out of each sample roll. The required yardage of each piece shall be examined and the visual defects classified as listed in Table II. The sample size shall be in accordance with inspection level III of MIL-STD-105. The acceptable quality level expressed in defects per 100 units (yards) shall be 2.5 for major defects and 10 for total defects. The lot size shall be expressed in units of one yard each. The unit of product for this examination shall be one linear yard (i.e., increment of one yard on the measuring device of the inspection machine).

4.2.1.1.1 Flagging of Defects. Each major defect shall be flagged by a red string sewn in the selvage. A continuous defect shall be flagged by a single red string sewn into the selvage for each yard containing the defect.

4.2.1.1.2 Examination for Compliance with the Textile Fiber Products Identification Act. During the yard-by-yard examination each roll shall be examined for fiber identification. The lot shall be unacceptable if two or more rolls in the sample are not labeled in accordance with the rules and regulations under the Textile Fiber Products Identification Act.

4.2.1.2. Overall Examination. During the yard-by-yard examination, each piece shall be examined for overall defects. The unit of product for overall examination shall be one piece. Each piece shall be examined and, should any piece contain any of the following defects, the lot represented shall be rejected:

a. Objectionable odor
b. Uncleanliness throughout
c. Uneven weaving.

4.2.1.3 Examination for Length.

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Cloth, Parachute, Cargo and Deceleration
Para-aramid, Intermediate Modulus

4.2.1.3.1 Individual Rolls. During the yard-by-yard examination, each roll shall be examined for length. Any roll length found to be less than the minimum specified, or more than two yards below the length marked on the ticket, shall be considered a defect with respect to length.

4.2.1.3.2 Total Yardage. The lot shall be unacceptable if the total of the actual lengths of roll examined is less than the total of the lengths marked on the ticket.

4.2.2 Samples for Testing of End Item. An inspection lot will consist of the finished para-aramid, intermediate modulus cloth of one type, made under essentially the same conditions and presented for inspection at the same time. The lot size shall be expressed in units of one yard. The sample unit shall be four continuous yards, full width of the finished cloth. The sample size shall be in accordance with level S-2 of MIL-STD-105. The acceptable quality level shall be 1.5 percent defective. Except for lot sizes up to 3,200 yards, the sample size shall be 3, acceptance number 0, and lots 3,201 to 10,000 yards, the sample size shall be 5, acceptance number 0.

TABLE II. CLASSIFICATION OF DEFECTS

Defect	Description	Major	Minor
Abrasion mark	Any abrasion mark showing fuzziness	X	
Biased filling	More than two inches from horizontal at greatest point of bias	X	
Bowed filling	Filling bow more than two inches in height (as measured from a straight line cord to highest point of arc).	X	
Broken or missing end	Two or more contiguous regardless of length	X	
	Single, more than 18 inches missing	X	
	Single, 18 inches or less missing		X
Broken or missing pick	Two or more contiguous regardless of length	X	
	One pick full width		X

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Cloth, Parachute, Cargo and Deceleration
Para-aramid, Intermediate Modulus

TABLE II. CLASSIFICATION OF DEFECTS (cont)

Defect	Description	Major	Minor
Coarse filling bar	Clearly noticeable 1/ and extending for more than one inch in the length direction of the cloth	X	
	Clearly noticeable 1/ and extending for one inch or less in the length direction of the cloth		X
Crease	Hard, embedded crease	X	
Cut, hole or tear	Any	X	
Distortion or slippage of threads	Any distortion or slippage of warp or filling threads that cannot readily be reset by hand	X	
Fine filling bar, thin or light place or light set mark	Any clearly noticeable 1/ fine filling bar, thin or light place, or light Set mark	X	
Floats or skips	Any multiple float three-sixteenth inch square or more	X	
	Single floats one-fourth inch or more in length	X	
	Contiguous floats or pin floats 2/ the sequence of which measures one inch or more in length	X	
	Any multiple float up to three-sixteenth inch square		X
	Single floats up to one-fourth inch in lengths		X
	Contiguous floats or pin floats 2/ the sequence of which measures less than one inch in length		X
Heavy filling bar or heavy place	Over one-eighth inch in width and varying 10 percent or more from normal pick count	X	
	Over one-half inch in width and varying less than 10 percent for normal pick count	X	
	One-eighth inch or less in width and varying 10 percent or more from normal pick count		X
	One-half inch or less in width and varying less than 10 percent from normal pick count		X

Cloth, Parachute, Cargo and Deceleration
Para-aramid, Intermediate Modulus

TABLE II. CLASSIFICATION OF DEFECTS (cont)

Defect	Description	Major	Minor
Hitchback (warp catch)	Resulting in a thin place three-eighth inch or more in combined warp and filling direction	X	
Jerked-in filling or slough-off	Two or more additional yarns in the shed	X	
	One additional yarn in the shed		X
	Note: One-half inch or less shall not be considered a defect		
Loops, kinks, or snarls (except selvage)	All over one-eighth inch long	X	
	Three or more (in any linear yard) up to one-eighth inch in length	X	
	Up to two (in any linear yard) one-eighth inch or less in length		X
Mispick or double pick	Three or more additional picks in the shed	X	
	Two picks		X
Misweave	Pattern not conforming to specified weave	X	
Pick-out mark	Resulting in a clearly noticeable 1/ thin or thick place	X	
Pinholes or yarn deformations	Over six pinholes or yarn deformations occurring within an area equal to a six-inch diameter circle	X	
	Three to six pinholes or yarn deformations occurring within an area equal to a six-inch diameter circle		X
Selvage cut, broken torn, or scalloped	Any cut, broken torn or scalloped selvage	X	
Selvage slack or wavy	Clearly noticeable 1/ waviness along selvage edge when viewed without tension		X
Selvage stringy or loopy	More than three inches of continuous stringy or loopy selvage projecting one-eighth inch or more	X	
	Continuous stringy or loopy selvage projecting up to one-eighth inch		X

Cloth, Parachute, Cargo and Deceleration
Para-aramid, Intermediate Modulus

TABLE II. CLASSIFICATION OF DEFECTS (cont)

Defect	Description	Major	Minor
Selvage tight	Any clearly noticeable 1/ roll of edge or edges when tension is released	X	
Slubs or strip back3/	More than five over one-fourth inch in length	X	
	Two up to and including five over one-half inch in length	X	
	One over one inch in length	X	
	Five or less over one-fourth inch but not exceeding one-half inch in length		X
	One over one-half inch but not exceeding one inch in length		X
Smash	Any smash	X	
Spot, strain or streak (not applicable to dye streaks)	Single ends or picks 15 inches or more in length	X	
	Double ends or picks eight inches or more in length	X	
	Over two ends or picks five inches or more in length or a clearly noticeable1/ area more than one-fourth square inch in area, whichever is greater	X	
	Single ends or picks 2-1/2 inches up to 15 inches in length		X
	Double ends or picks 2-1/2 inches up to 8 inches in length		X
	Over two ends or picks less than five inches in length or a clearly noticeable area1/ one-fourth square inch or less in area, whichever is greater		X
Weak place	Any weak place	X	
Width	Beyond specified tolerances	X	
Wrong draw	Resulting in a clearly visible1/ warpwise streak more than 18 inches in length	X	

1/ Clearly noticeable at normal inspection distance (3 feet).

2/ A pin float is defined as a float measuring one-eighth inch or less. Single pin floats shall not be considered a defect.

3/ A strip back is defined as a broken filament(s) wrapped around the remaining yearn forming an enlarged area resembling a slub.

Cloth, Parachute, Cargo and Deceleration
Para-aramid, Intermediate Modulus

4.2.3 Testing of the End Item.

4.2.3.1 Testing Methods. The methods of testing in FED-STD-191, wherever applicable, as listed in Table III, and as specified herein shall be followed. The physical values specified in Section 3 apply to the average of determinations made on a unit of product for test purposes as specified in the applicable test methods.

TABLE III. TEST METHODS

Test Characteristics	Requirement Paragraph	Test Method
Weave	3.2	Visual
Yarns per inch	Table I	5050
Yarn Ply	Table I	Visual
Weight	Table I	5041
Breaking strength1/	Table I	4108
Air Permeability2/	Table I	4.2.3.1.1
Width	3.3.1.1	5020

1/ Except that there shall be a five-inch unsupported length between the jaws, and the speed of the pulling jaw shall be 2 ± 1/2 inches per minute.

2/ The air permeability requirements shall be tested at one-half inch of water differential pressure.

4.2.3.1.1 Air Permeability. The test specimen shall be seven inches long and the full width of the cloth. The air permeability test shall consist of five individual readings made in accordance with Method 5450.1 of FED-STD-191. The individual readings shall be equally spaced across the width (between selvages) of the test specimen except that no readings shall be taken within an area from the selvage equal to 10 percent of the specimen width. The air permeability of the test specimen shall be the arithmetic mean or average of the five individual readings.

4.3 Examination and Preparation for Delivery. An examination shall be made in accordance with the provisions of PPP-P-1133 to determine that packaging, packing and marking requirements of Section 5 of this specification are complied with.

5. PREPARATION FOR DELIVERY

5.1 Packaging. Packaging shall be level A or C as specified (see 6.2).

5.1.1 Levels A and C. The cloth, put-up as specified, shall be packaged in accordance with the applicable requirements of PPP-P-1133.

5.2 Packing. Packing shall be level A, B, or C as specified (see 6.2).

5.2.1 Levels A, B, and C. The cloth shall be packed in accordance with the applicable requirements of PPP-P-1133.

5.3 Marking. In addition to any special marking required by the contract or order, shipments shall be marked in accordance with the applicable requirements of PPP-P-1133.

6. NOTES

6.1 Intended Use. The para-aramid, intermediate modulus cloth is intended for use in the manufacture of cargo and deceleration parachutes.

6.2. Ordering Data. Procurement documents should specify the following:

a. Title, number and date of this specification.
b. Type and class (1.2).
c. Quantity.
d. Width, if other than specified in 3.3.1.1.
e. Length and put-up (3.3.1.2).
f. Selection of the applicable levels of packaging and packing (5.1 and 5.2).

6.3 Twisting Precautions.

1. Feed roll speed should be as follows for various para-aramid, intermediate modulus yarns and twist levels:

Yarn Denier	Twist (tpi)	Feed Roll Speed (yards per min)
200	5.0	70
400	4.0	90
1000	4.0	60
1500 and greater	1.8	20

2. Slightly heavier travelers than those used for nylon yarn should be used.

3. High humidity should be maintained to minimize electrostatic charge between filaments.

6.4 Winding Precautions. "Anti-wear" wide tension gates (Leesona Corporation), or their equivalent, should be used.

6.5 Weaving Precautions.

1. PTFE coated heddles (precision Coating Co., Inc., Dedham, Mass.), or their equivalent, may be used to minimize yarn abrasion.

2. Warp line should be level.

3. Loom(s) selected for weaving para-aramid, intermediate modulus yarns must be in good running condition with minimum wear or "play" in various mechanical components.

4. Warp beam should not be more than one-half inch wider than required width of finished fabric.

5. Friction take-up rolls should be as smooth as possible, consistent with maintaining tension. Cork or rubber may be used for fine denier yarns and, if necessary, fine sandpaper for heavier deniers.

6. Due to the low extensibility of para-aramid, intermediate modulus yarn it is important that uniform yarn length be maintained at all times across the entire set of warp yarns.

7. Avoid contact of para-aramid, intermediate modulus yarn with rough surface or sharp edges in order to minimize damage.

8. High humidity should be maintained during weaving.

6. Kevlar-29 yarn manufactured by the E. I. DuPont deNemours and Company and identified as 200-134-0 Type 964 is an acceptable yarn.

APPENDIX B

DRAFT SPECIFICATION FOR KEVLAR-29 TENSILE TESTING

The following text and drawings are taken directly from Reference 12 and are included here due to the importance associated with proper testing techniques and apparatus required for many Kevlar-29 materials.

Draft Specification for Tensile Testing of Kevlar Materials

These paragraphs are proposed as an insertion into Section 4.4 of the Military Specifications for tapes and webbings, MIL-T-87130 and for tubular webbings, MIL-W-87127 (References 7 and 10). In each specification, the test method reference in Table IV under breaking strength should be changed from 41082/ to 4.4.1, and footnote 2 should be deleted.

4.4.1 Tensile Tests

4.4.1.1 Jaw Design. All tensile tests must use double pin jaws of the design specified in Figure 15.

4.1.1.2 Machine Adjustment. Mount the jaws with careful attention to rotational and axial alignment. Set the speed of the moving jaw at 1 ± 1/4 inch per minute (2.5 ± 0.5 cm/min), and the initial jaw separation such that the distance between the tangent points where the specimen first touches the primary (large diameter) pins is 12 ± 0.1 inch (30 ± 0.2 cm). (See Figure 16. This should read Figure 2 for MIL-T-87130 and Figure 1 for MIL-W-87127.)

4.4.1.3 Specimen Size and Number. Each specimen shall be the full width of the tape or webbing and 60 inches (150 cm) long. Test five specimens, or enough to get five acceptable breaks.

NOTE: An acceptable break can only be defined as one which occurs in the unsupported length of the specimen between the primary pin tangent contact points or at the contact points, but not within the material which is wrapped around each double pin jaw, and which is characteristic of the material being tested. Ideally, all the warp yarns should break simultaneously and cleanly and, when warp yarn tensions are carefully balanced in weaving, subsequent handling and testing, this will occur. Because of Kevlar's low elongation and high modulus, however, warp yarn tension unbalance can easily occur. This leads to a break in which the yarns fail sequentially or in groups, and may initiate a tearing type of failure. Breaks of this nature give a low value for breaking strength. If this type of break occurs in only one or two of the five specimens, it should be considered untypical and the test result discarded, and additional specimens tested to obtain 5 acceptable breaks. If more than two of the five breaks involve sequential yarn failure, or other undesirable breaking mode, and no testing inadequacies can be identified, weaving nonuniformities may be indicated, and the failure mode must be considered typical for the material being tested. In this case, even if all of the breaking load values exceed the specified strength, acceptance of the material or decision to reweave in an attempt to improve the failure mode must be subject to the discretion of the buyer.

It is essential that the nature of each break be carefully observed and recorded, in order that an assessment can be made of whether unacceptable breaks are due to deficiencies in weaving or in testing.

4.4.1.4 Specimen Mounting. Wrap the specimen around the primary and secondary pins of each jaw as shown in Figure 16. (This should read Figure 2 for MIL-T-87130 and Figure 1 for MIL-W-87127.) Be careful to keep all legs of the specimen in alignment with the direction of stress application, and successive wraps exactly in line. This is important to ensure uniform stress distribution in the specimen. For materials having a strength less than 500 pounds per inch of width, or for stronger materials which are not breaking acceptably, insert a double layer of cotton fabric (2-1/8" x 10", 4.4 cm x 25 cm) (cloth, silesia, cotton, MIL-C-326) between the two layers of Kevlar which pass around the primary pin in both top and bottom jaws.

4.4.1.5 Report. Report the average breaking load obtained from five acceptable breaks, as well as the highest and lowest values observed. If the breaks are not all acceptable, identify and describe the nature of each unacceptable break. NOTE: Such descriptions may be "individual warp yarn breaks scattered throughout the free length of the specimen"; "break initiated at the edge(s) of the specimen followed by a rapid failure of the remaining warp yarns"; "break initiated at one edge of the specimen, followed by sequential warp yarn breaks proceeding across the specimen in the manner of a tear"; "several unbroken warp yarns remain after an otherwise acceptable break."

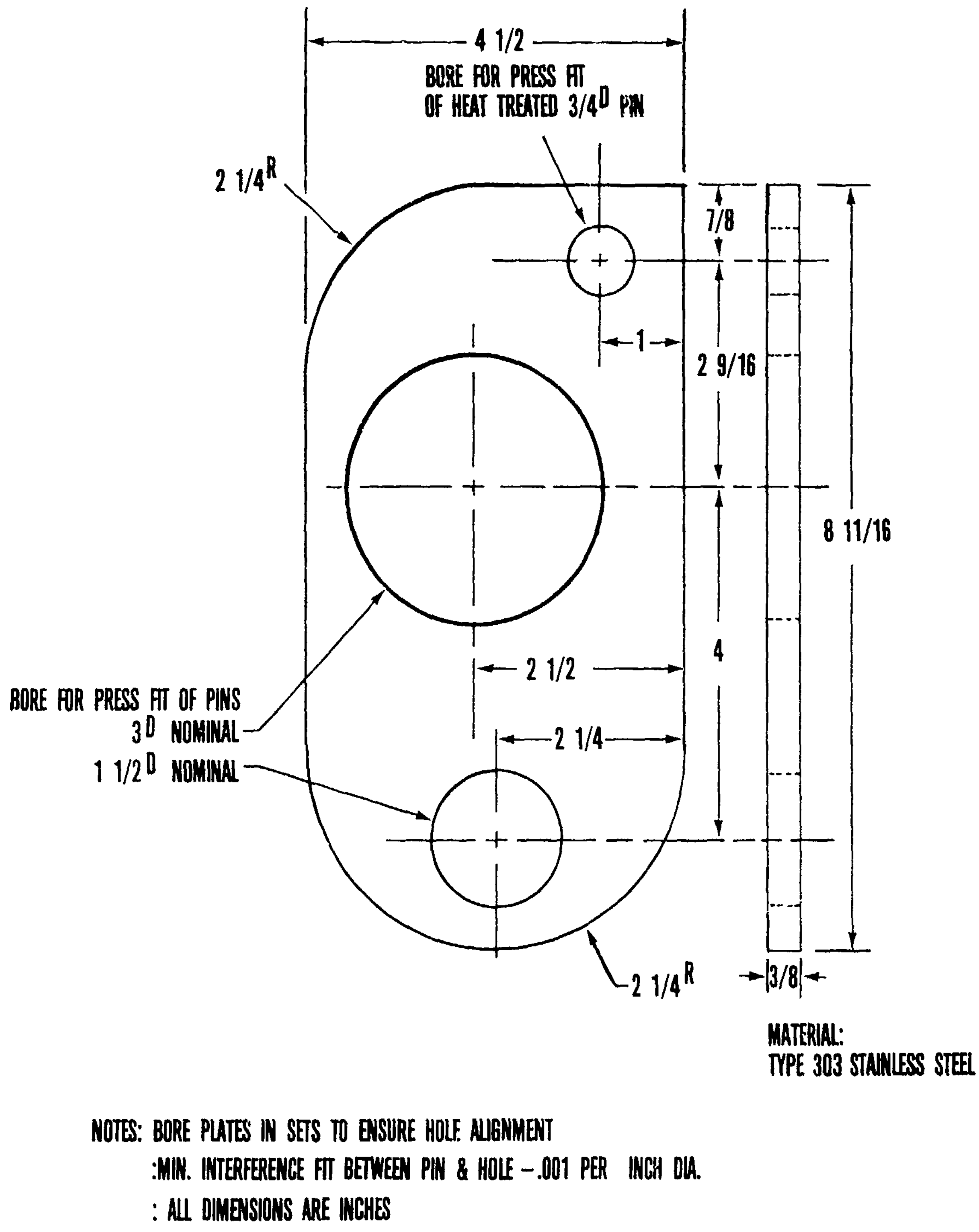


Figure 15. Double Pin Jaw (Sheet 1 of 7)

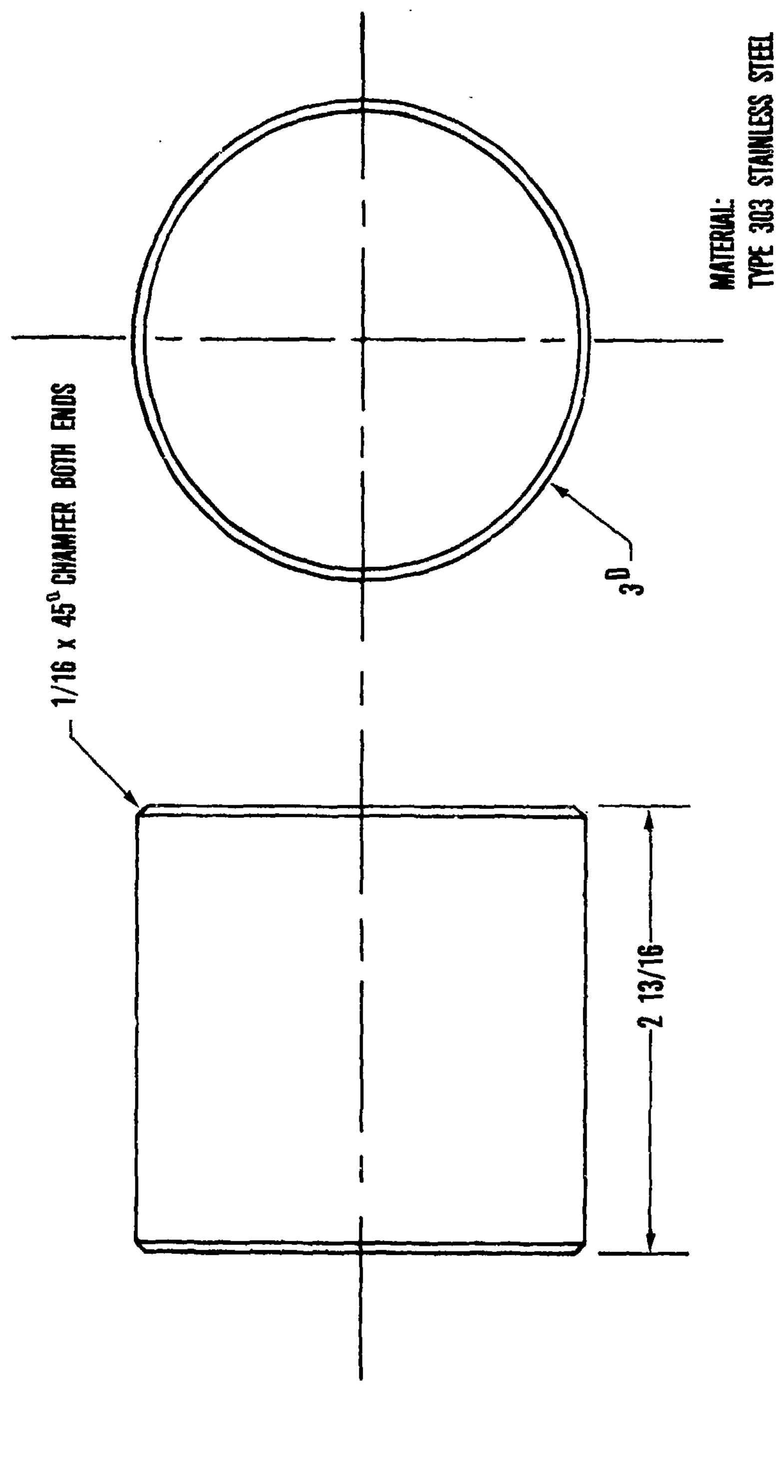


Figure 15. Double Pin Jaw - Primary Pin (Sheet 2 of 7)

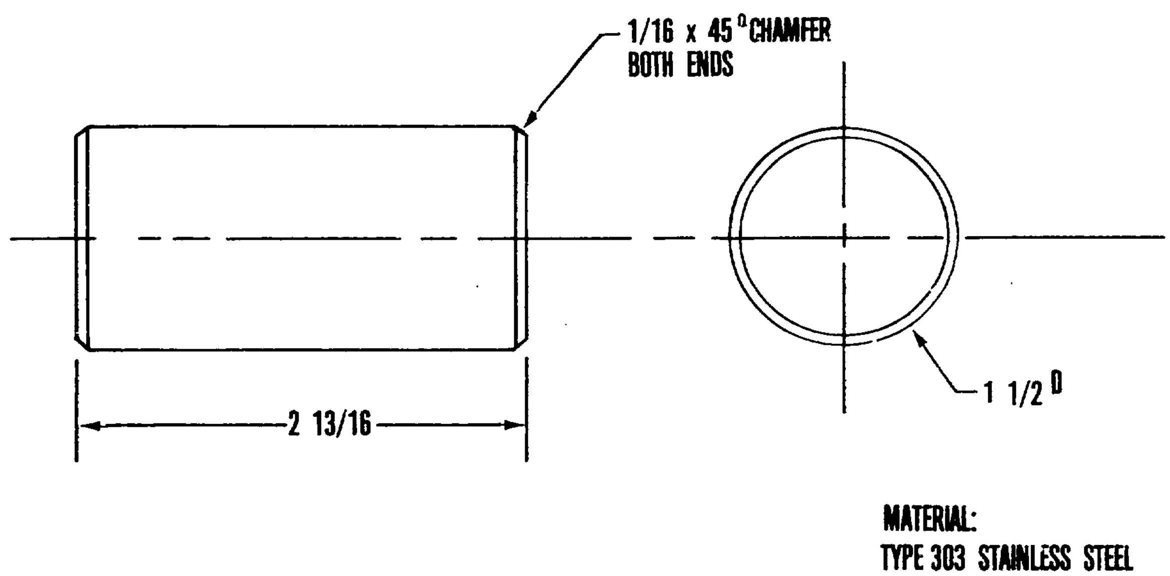


Figure 15. Double Pin Jaw - Secondary Pin (Sheet 3 of 7)

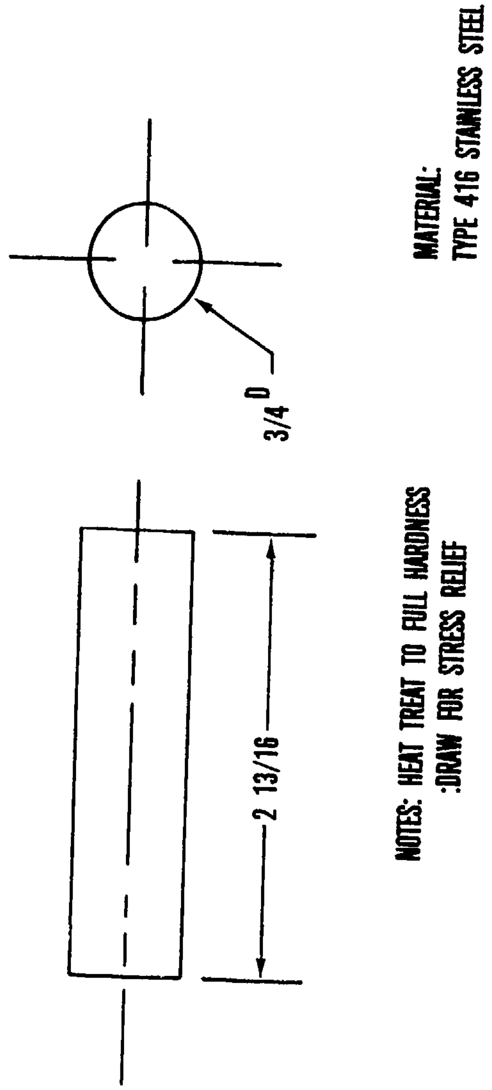


Figure 15. Double Pin Jaw - Attachment Pin (Sheet 4 of 7)

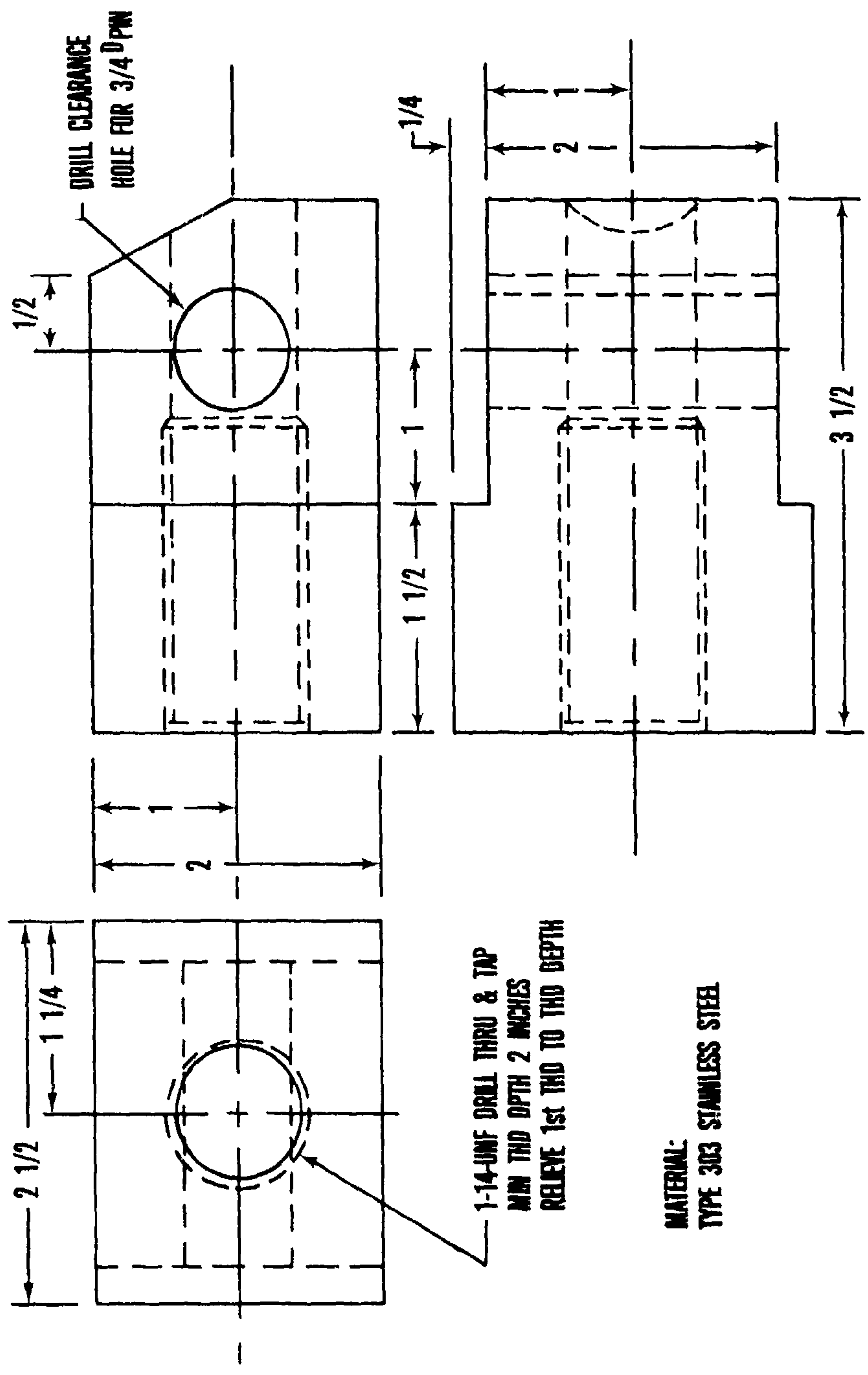


Figure 15. Double Pin Jaw - Attachment Block (Sheet 5 of 7)

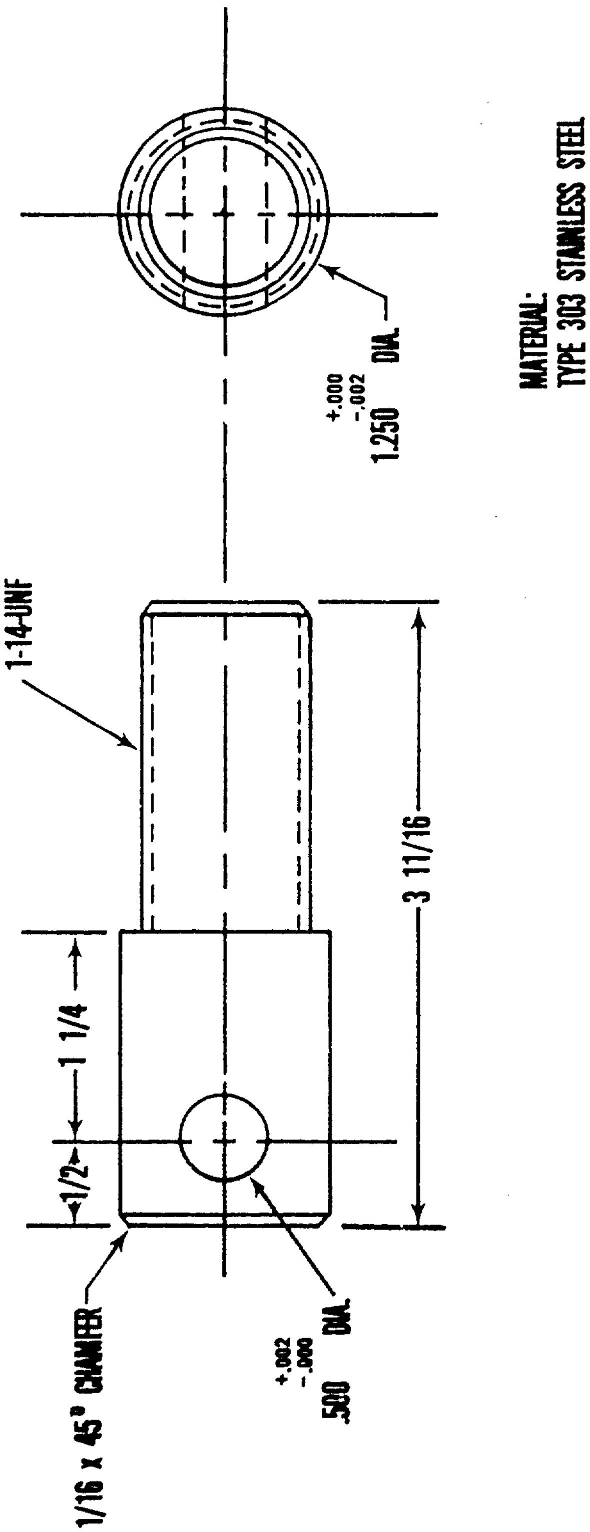
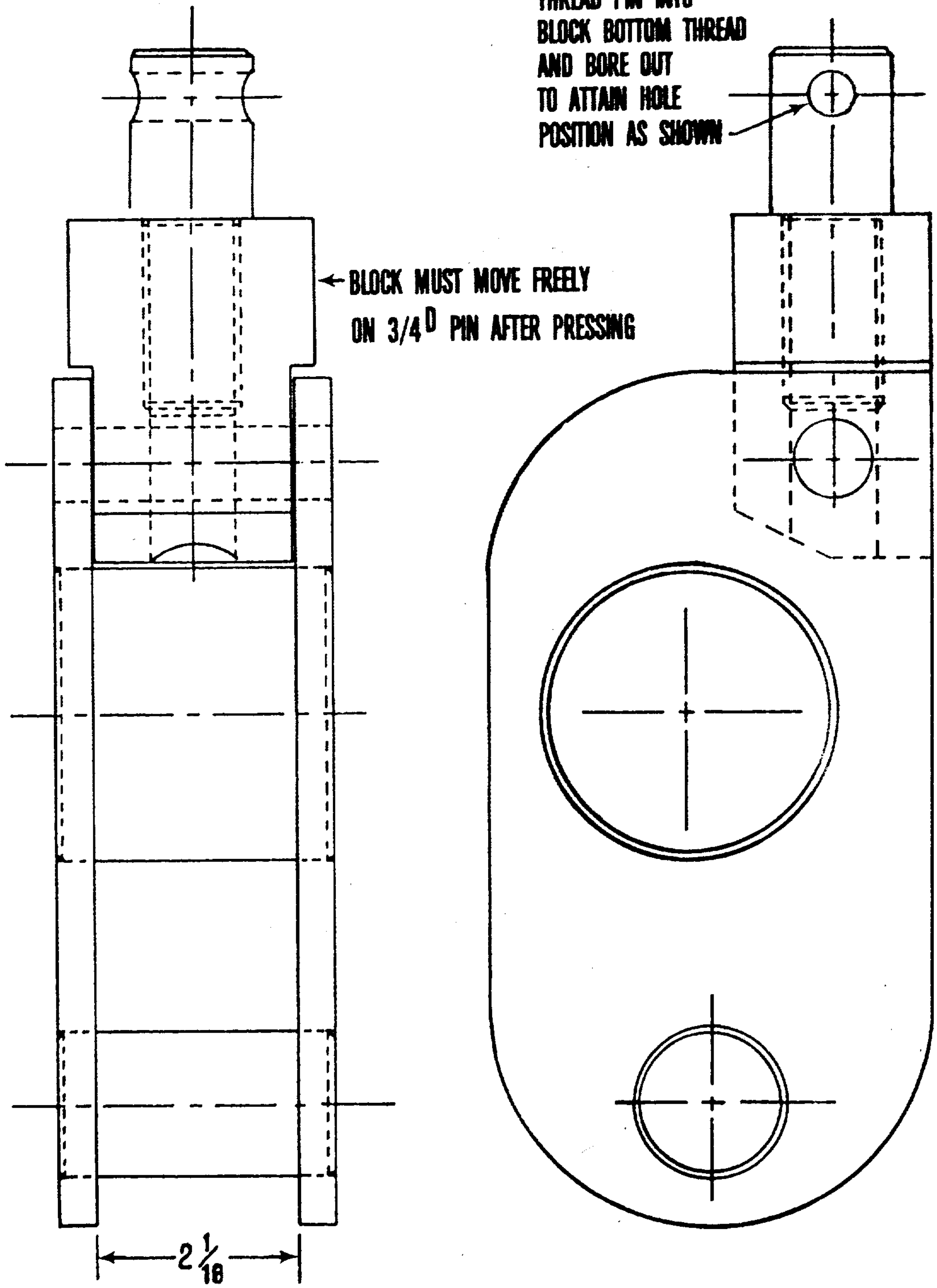


Figure 15. Double Pin Jaw - Instron Connector Pin (Sheet 6 of 7)



PRESS SIDE PLATES ONTO PINS TO ATTAIN DESIRED SEPARATION.

PINS MUST BE PARALLEL, SIDE PLATES MUST BE PARALLEL,
& PINS MUST BE PERPENDICULAR TO SIDE PLATES AFTER PRESSING.

ENDS OF PINS SHOULD BE FLUSH WITH OUTSIDE SURFACE OF SIDE PLATES AFTER PRESSING.

Figure 15. Double Pin Jaw - Assembly (Sheet 7 of 7)

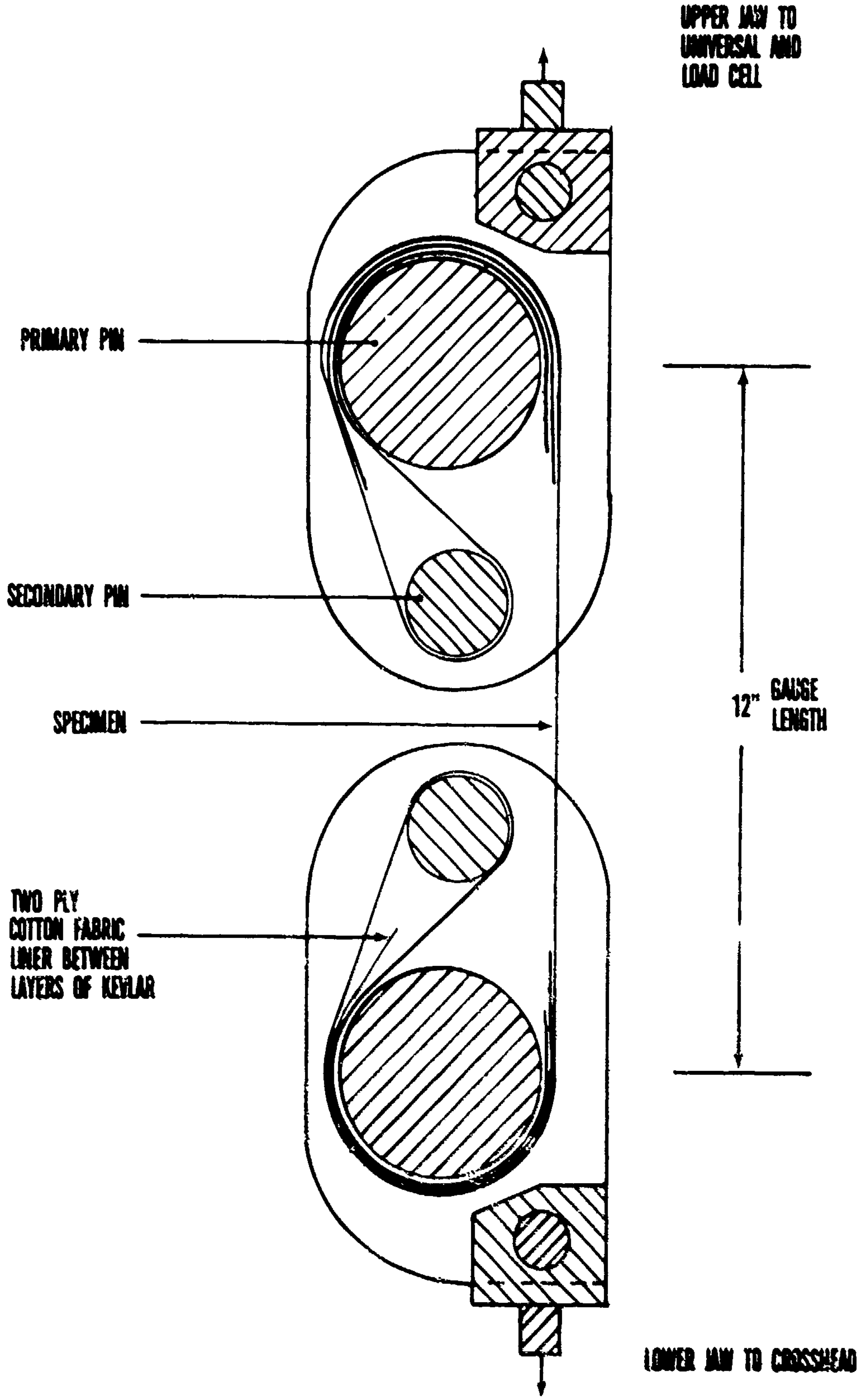


Figure 16. Test Configuration for Double Pin Jaws

AFWAL-TR-81-3138

AFWAL-TM-81-60 FIER
(UPDATED VERSION)

APPENDIX C

TENSILE TESTING METHODS FOR KEVLAR-29 CORELESS BRAIDED CORD

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January 1982

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AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

AFWAL-TM-81-60 FIER

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SECTION I

INTRODUCTION

1. BACKGROUND

A lightweight, high strength fiber developed by the DuPont Company and sold under their trade name, "Kevlar-29," has been used as a basis for many decelerator materials including broad fabric, webbing, ribbons, sewing thread and braided cord. Kevlar decelerator materials offer the decelerator systems designer the potential for weight and volume reductions of 50 percent when compared to nylon systems of equivalent strength and 70 percent strength retention at the melting temperature of nylon. The Flight Dynamics Laboratory and the Materials Laboratory of the Air Force Wright Aeronautical Laboratories have sponsored efforts to develop woven, braided and twisted materials based on DuPont yarns.

During development of Kevlar woven materials it became apparent that apparatus commonly used for tensile testing similar nylon materials were not suitable for the thinner, high modulus materials. Tensile testing of Kevlar-29 cord done as a part of efforts to develop materials and to study the effects of abrasion on tensile strength has utilized split capstan or double pin jaws. The results produced during these efforts have included few tensile breaks in test sample free lengths with most failures occurring at the departure or tangent point where the sample free length begins. Additionally, results have yielded unreasonably low failure values which were usually discarded. Efforts to develop suitable tensile test sample termination apparatus (Reference 12) resulted in configurations suitable for narrow fabrics but did not address Kevlar braided cord. Kevlar braided cords have been used successfully for parachute suspension lines but the effect of the decelerator loads on strength is unknown, so an effort was needed not only to establish suitable test apparatus and methods but also to determine the effects, if any, of parachute opening loads (the largest decelerator loads) on the strength of the Kevlar suspension lines.

AFWAL-TM-81-60 FIER

2. SCOPE

The purpose of this work was to determine the best of several test sample termination configurations. In doing so, a data base would be established which could then be compared with data from tensile testing of suspension lines taken from parachutes previously tested by the Flight Dynamics Laboratory; the effects of decelerator loads on strength degradation could then be determined.

A total of 174 tensile tests were conducted to establish failure loads for 3 types of Kevlar-29 coreless braided cord with rated strengths of 1500, 2000 and 3500 pounds. A total of 10 test sample termination configurations in conjunction with 3 different termination apparatus were compared. Three different crosshead speeds were compared to determine their effects on breaking strength. Suspension lines fabricated from the same 3 cord types were removed from drop and sled tested parachutes and 27 tensile tests were run for indications of strength loss.

SECTION II

TENSILE TESTING

1. EQUIPMENT

All testing at Wright-Patterson Air Force Base was done using the Instron Model TT-C tensile testing machine (Figure 1) operated by AFWAL/MLBC in Building 32, Area B. Samples were loaded onto the machine utilizing various termination arrangements and elongated constantly from zero load to rupture.

An integral strip recorder continuously recorded load data in the following manner. Graph paper was fed vertically at some constant rate past a marking pen that travels horizontally in a track. The distance the pen travels from the right edge of the graph varies linearly with the

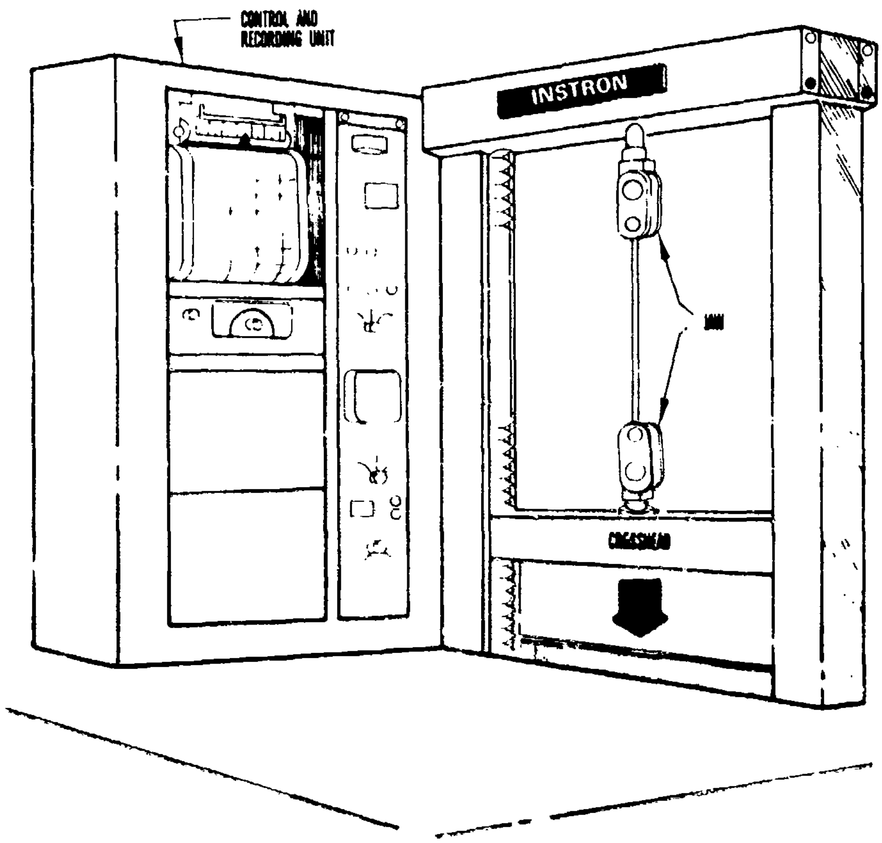

Figure 1. Instron Tensile Testing Machine

load on the test sample. Because paper speed and crosshead speed are both constant, the resulting plots can be interpreted as load vs time or load vs elongation. A representative plot is shown in Figure 2.

Equation for time:

$$\text{time (min)} = \frac{\text{length of paper (in.)}}{\text{paper speed (in./min)}}$$

Equation for elongation:

$$\text{Elongation (in.)} = \text{Crosshead speed (in./min)} \times \text{time (min)}$$

$$= \text{Crosshead speed} \times \frac{\text{length of paper (in.)}}{\text{paper speed (in./min)}}$$

The paper began motion at the beginning of loading and was stopped after rupture so that total time to rupture is equal to the total length of paper fed past the pen (for that one test) divided by the paper speed. Crosshead speeds of 0.2, 1.0 and 1.5 in./min were used to determine the effects of elongation rate on breaking strength and breaking strength variance.

Four inch drum diameter split capstan jaws (Reference 6), double pin jaws (Reference 12), and three-fourth inch pins were used for test sample termination (Figure 3).

2. MATERIALS

The Kevlar-29 coreless braids used for data base and termination configuration testing were of Types VIII, IX, And X as described in MIL-C-87129 (USAF) (Reference 9) and were manufactured by FWF Industries, Inc, in May and June 1979. These have rated breaking strengths of 1500, 2000, and 3500 lbs respectively. All samples of the same type braid were taken from the same spool. Sections of braids with spliced carriers or visible irregularities were not used.

Suspension lines of the same types as those used for data base testing were taken from parachutes previously tested by the Flight Dynamics Laboratory. These samples were tested to determine the effect of parachute opening loads on strength degradation.

3. METHODS

Connection of test specimens to the Instron was accomplished with double pin jaws, split capstan jaws or three-fourth inch pins inserted through finger-trapped eye splices in each end of the sample. Cord samples were arranged in termination configurations to have a free length of approximately 18 inches. When jaws configurations were used, free length was defined as the distance between tangent points where specimens depart from cylindrical surfaces. For the eye splice/pin termination the free length is the distance between the inserted ends of the cord.

A total of 18 samples were tested using the double pin jaws. Ten were wrapped in configuration P_1 (see Table 1) as shown in Figure 3. Stop knots were required when tying the tail to the length of material between the primary and secondary pins to prevent slippage of the double half hitches during loading. Eight samples were wrapped in configuration P_2 (see Table 1) as shown in Figure 3. Stop knots were also used to prevent slippage. Eighteen samples were pulled on the split capstan jaws (configuration S in Table 1) as seen also in Figure 3. One hundred thirty-eight samples were tested by first splicing a loop in each end and then connecting them to the Instron with three-fourth inch pins inserted through the eye splices (see Figure 3). The 27 samples taken from the drop and sled tested parachutes were also connected with eye splices.

AFWAL-TM-81-60 FIER TABLE 1

DESCRIPTION AND KEY TO SYMBOLS OF TEST SAMPLE TERMINATION CONFIGURATIONS AND BREAK POINTS

	Symbol	Description
	S	Split capstan jaws.
Jaws Configurations (Fig 3)	P_1	Double pin jaws wrapped so that no wraps cross on the primary pin.
	P_2	Double pin jaws wrapped so that free length contacts primary pin between other two turns and crosses under second turn on opposite side of pin.
	A	Untapered
	B	Eight carriers removed at even intervals.
	C	Twelve carriers removed at even intervals
Eye Spliced Configurations (Fig 4, 5, 6)	D	Taper was accomplished by fraying the end four inches and cutting to produce an even taper.
	E	Eight carriers were cut four-inch from end. Seven more were cut at even intervals to the end.
	F	End was "split" before insertion by cutting up the middle of the end for two inch to insure cutting all carriers. Scrap was then pulled off leaving a short smooth taper. Insertion length varied uncontrolled from three inch to six inch (applicable to three samples only).
	G	End was tapered in the same manner as "F" above except that insertion length was controlled to six inch.
	T	Tangent point of contact of free-length to jaw drum. (applicable only to jaws configurations).
Break Points	I	End of insertion (applies to eye spliced configurations only.
	M	Free length.

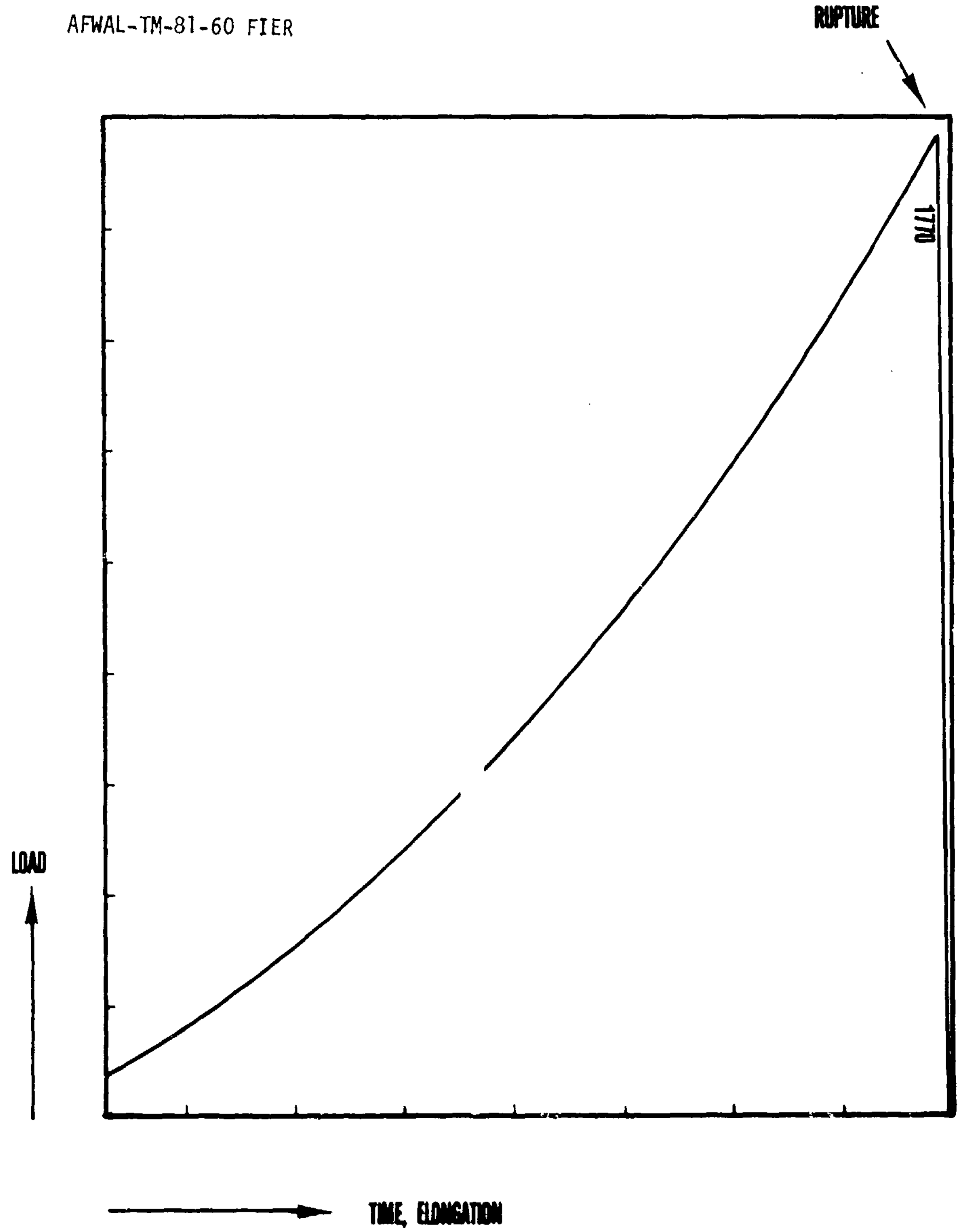

Figure 2. Representative Plot from Instron

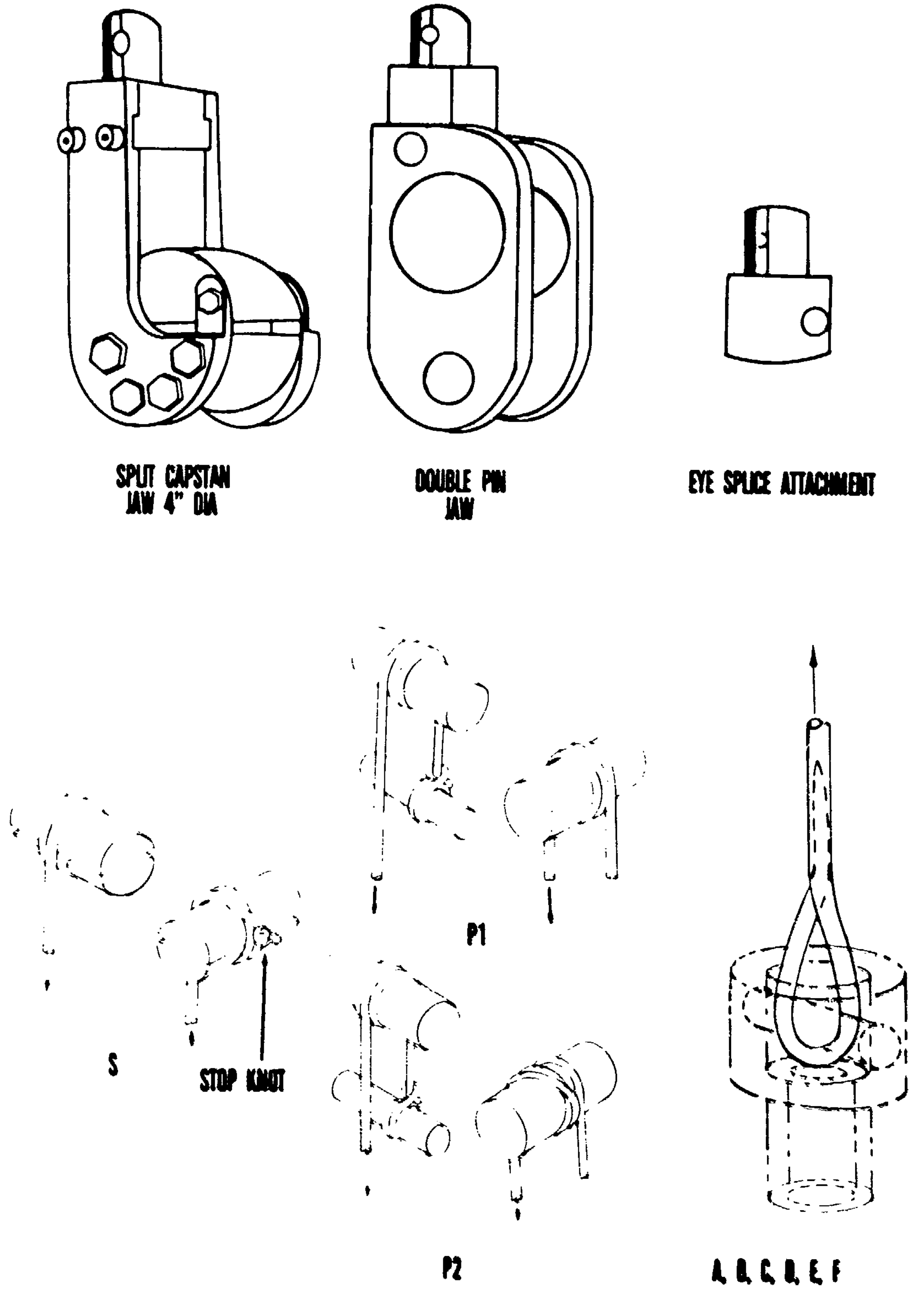

Figure 3. Test Sample Termination Apparatus with Respective Attachment Configurations

Sample preparation for split capstan or double pin jaws merely consists of cutting from the spool a 96 inch length of braid. The general procedure used for the preparation of the eye-spliced samples is illustrated in Figure 4 as follows.

Step 1. A 52 inch length of braid is cut from the spool and ink marks are placed at 6, 11, and 18 inches from each end.

Step 2. A 2-foot length of 0.04 inch diameter steel wire is folded in half and inserted folded end first into the braid at one of the 18 inch marks and out at the corresponding 11 inch mark. Care should be taken to part the carriers cleanly at the entrance and exit points so as to avoid splitting yarns with the folded wire.

Step 3. The end of the sample is then wedged into the fold in the wire and pulled back into the braid center by withdrawing the wire back through the section between the 11 and 18 inch marks.

Step 4. The end now protruding from the 18 inch mark can be tapered in accordance to one of the taper configurations as described in Table 1 and shown in Figure 6.

Step 5. At this point, the 6 inch and 11 inch marks are held firmly together to prevent slippage while the outer sleeve (section between the 11 inch and 18 inch marks) is "massaged" so as to fit snugly around and completely enclose the insertion.

Step 6. A stitch of nylon E thread is now hand sewn through the outer sleeve and insertion about an inch from the 11 inch mark to prevent the insertion from slipping about inside the outer sleeve.

These steps are performed for both ends and result in a sample length of approximately 34 inches with about 18 inches of free length between

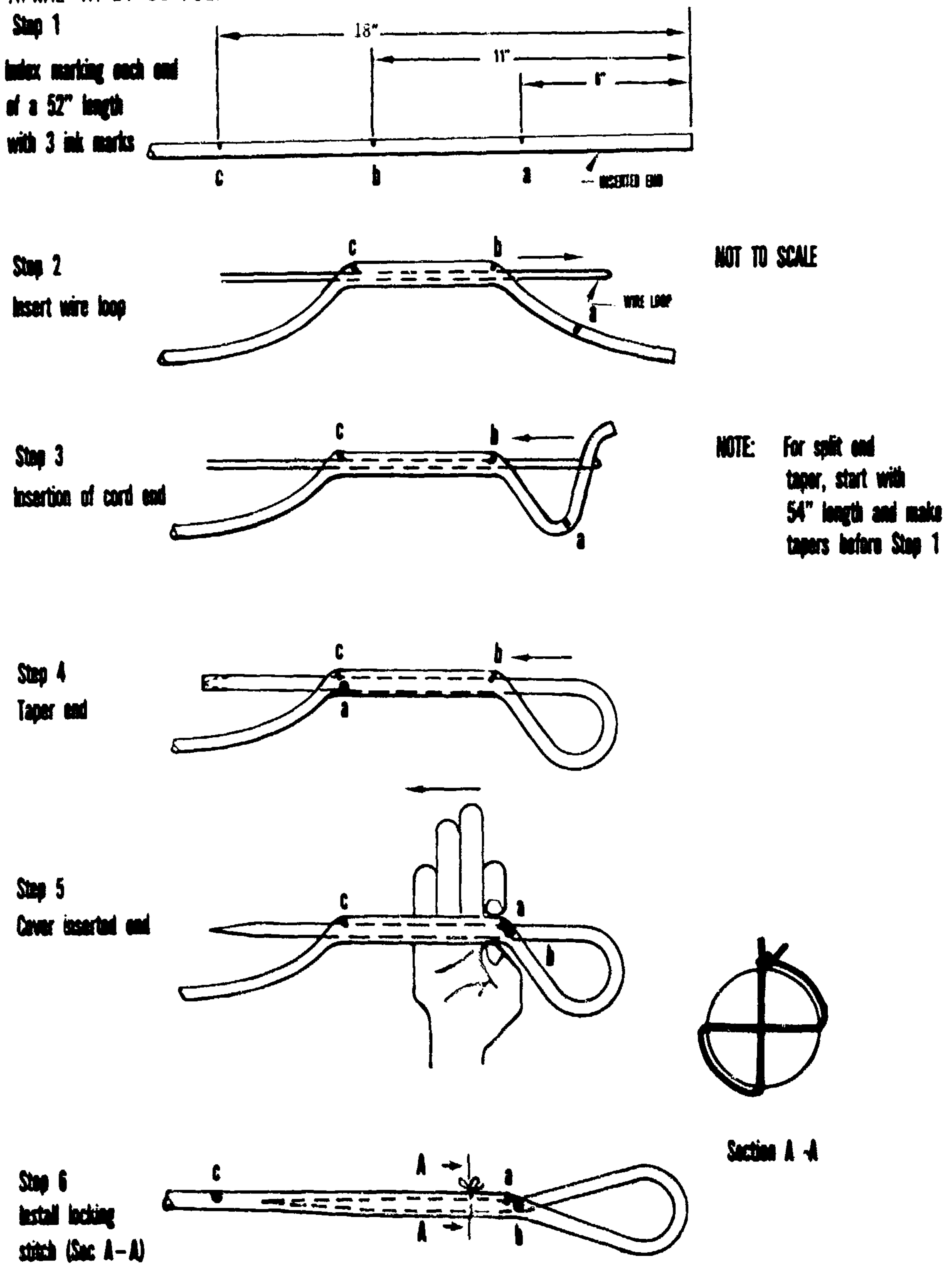

Figure 4. Procedure for Forming Eye Splices

the ends of insertions. The circumference of the loop (eye splice) is five inches; a completed eye splice is shown in Figure 5.

Eye splices with "split end" tapers (configurations F and G are constructed using this same method with the following exceptions.

a. A 54 inch length of braid is initially cut from the spool.

b. The ends are tapered before insertion.

c. After tapering, ink marks are placed at 6, 11, and 18 inches from each end and then the ends are inserted as per Step 2 in the general procedure discussed on the previous page.

Except where otherwise noted, the end four inches of the six inch inserted ends were tapered in accordance with one of the configurations described in Table 1 (Figure 6). Except for split end tapers, a specified number of carriers were pulled out at specified intervals along the four inch end section and cut off as close as possible to the braid to accomplish the taper.

Elongations of the free length of nine samples were obtained by measuring the distance between two ink marks on the free lengths at various loads; data is listed in Table B-3. Except where otherwise noted, crosshead speed was 1.0 in./min.

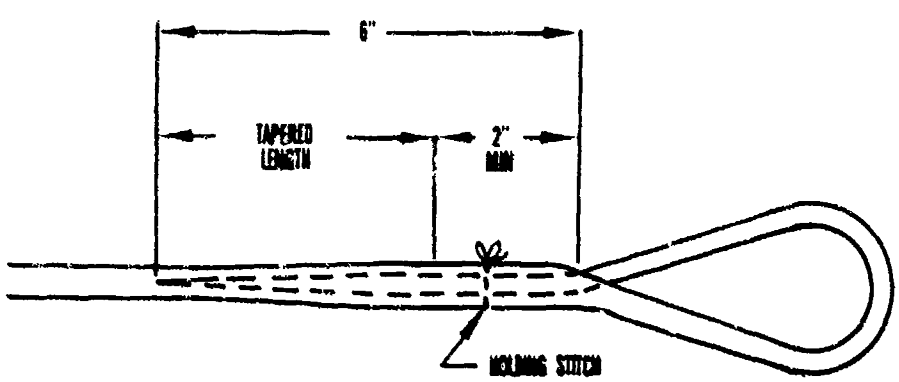

Figure 5. Completed Eye Splice

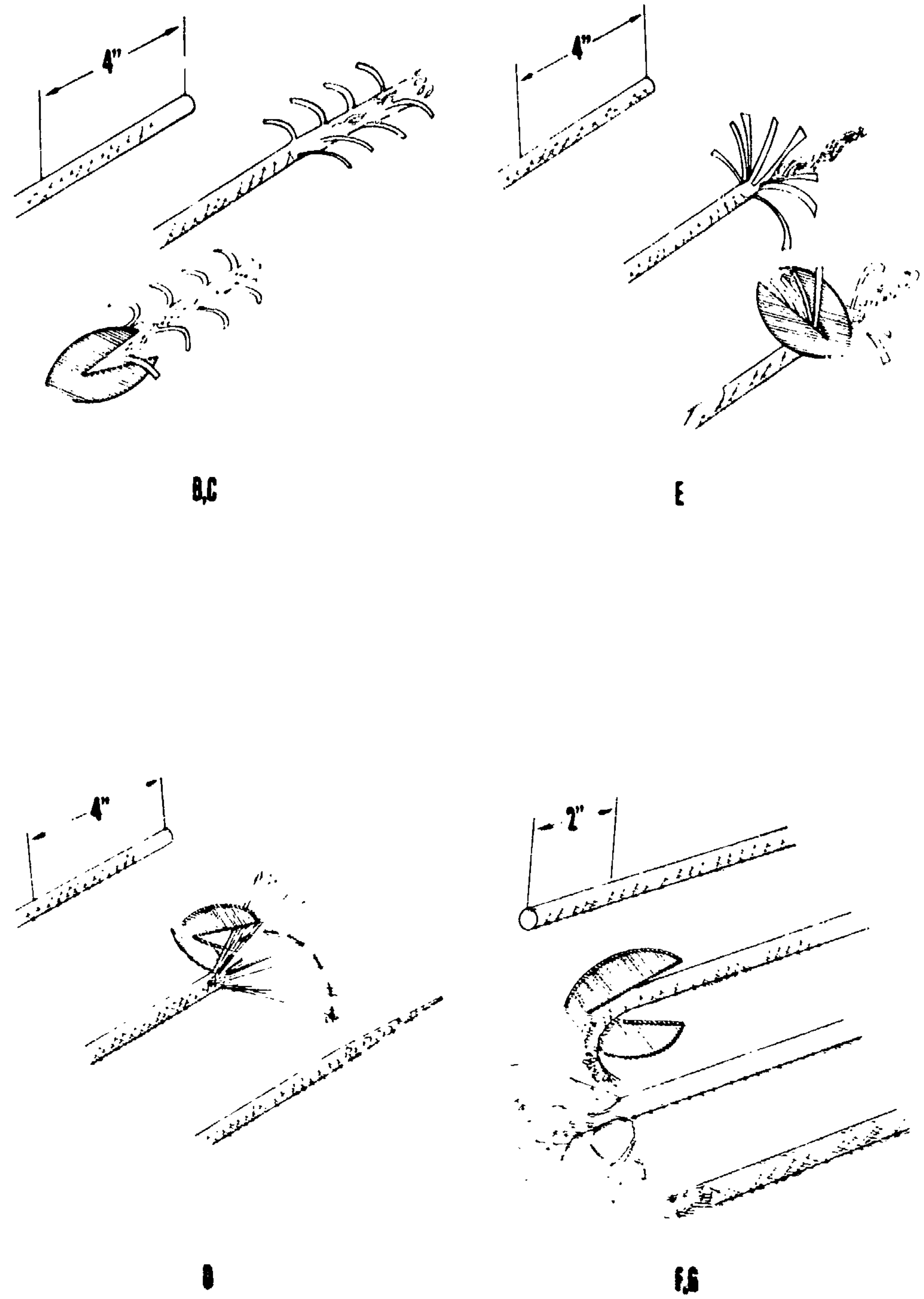

Figure 6. Procedures for Forming Tapers for Eye Splices

SECTION III

RESULTS

1. TEST DATA

Individual test data are listed in Appendix B in Tables B-1a, 1b, and 1c according to braid type, crosshead speed, and jaw or taper (attachment) configuration; the symbols used in these tables are listed and defined in Table 1. Tables B-2a and b contain data from the parachute suspension line tests. Free length elongation data is listed in Table B-3.

$$\text{Elongation (in.)} = \text{length (in.)} - \text{initial length (in.)}$$

$$\text{Percent elongation} = \frac{\text{elongation}}{\text{initial length}} \times 100 \text{ percent}$$

The above definitions are correct when initial length is unstrained length. Since the samples were loaded slightly (see Table B-3) during the measurement of initial length, the initial length is not quite equal to unstrained length. There was no way around this discrepancy, however, and the error introduced is small when using the above definitions for slightly strained initial lengths.

2. DATA SUMMARY

Average breaking strength, standard deviation, and coefficient of variation for each group are listed in Tables 2 and 4 and were calculated using the following equations.

$$\text{Average breaking strength (lbs)} = \frac{\Sigma X}{N}$$

where X = breaking strength (lbs) and N = population

$$\text{Standard deviation} = \sqrt{\frac{\Sigma X^2 - \frac{(\Sigma X)^2}{N}}{N - 1}}$$

$$\text{Coefficient of Variation} = \frac{\text{Standard Deviation}}{\text{Average Breaking Strength}} \times 100\%$$

SECTION IV

DISCUSSION

1. CROSSHEAD SPEED

The effect of crosshead speed on breaking strength was not very pronounced except that those samples tested at 2.5 in./min had much less data scatter than those pulled at the two lower speeds of 0.2 and 1.0 in./min. Coefficients of variation for breaking strength values of sample pulled at 2.5, 1.0, and 0.2 in./min were 3.70, 7.91, and 8.72 respectively.

The average value of breaking strength for the samples pulled at 0.2 in./min was slightly less than the average values for the other two crosshead speeds by about one standard deviation (see Table 2). Included in this average is an extremely low value of 3700 lbs for test 72 (see Table B-1c) which is lower than the average by 1.74 standard deviations. Had this value been left out, the average would be 4492 lbs and standard deviation would be 224 to give a coefficient of variation of 4.98 percent.

None of the samples pulled at 0.2 in./min broke in the free length while the percentage of free length breaks at the other two speeds of 1.0 and 2.5 in./min were about the same at 37 percent and 33 percent respectively.

Obviously, those samples pulled at higher or lower crosshead speeds took proportionally shorter or longer times from zero load to rupture since the rupture loads were about equal.

2. SPLIT CAPSTAN JAWS VS DOUBLE PIN JAWS

Samples pulled using the split-capstan jaws (configuration S) had in all cases higher breaking strength values by over three standard deviations than those pulled using the double pin jaws. Coefficients of variations were lower for split capstan jaws than for double pin jaws in all cases but one (Type IX, Jaw Configuration P_2).

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TABLE 2

SUMMARY OF TEST DATA

Braid Type	Termination Configuration	Average Breaking Strength (lbs)	Population	Standard Deviation (lbs)	Coefficient of Variation
VIII	P_1	1533	4	59	3.82
	S	1694	5	24	1.42
	A	1613	3	47	2.93
	B	1807	3	38	2.10
	C	1840	3	20	4.09
	D	1727	3	74	4.27
	E	1817	3	21	1.15
	F	1763	6	110	6.26
	G	1753	12	42	2.39
IX	P_1	2043	3	93	4.55
	P_2	2092	5	66	3.18
	S	2360	5	77	3.25
	A	2323	3	32	1.38
	B	2300	3	191	8.30
	C	2427	3	59	2.41
	F	2397	3	32	1.34
	G	2343	12	79	3.36
X	P_1	4143	3	125	3.02
	P_2	3983	3	180	4.51
	S	4604	8	138	3.00
	A	4460	3	157	3.52
	B	4706	18	325	6.91
	B CROSSHEAD SPEED = 0.2 in./min	4360	6	380	8.72
	B CROSSHEAD SPEED = 2.5 in./min	4593	6	170	3.70
	C	4943	3	166	3.36
	F	4633	3	505	10.90
	G	4821	15	190	3.94

There was no significant difference in breaking strength between the two double pin jaws wrap configurations, P_1 and P_2. For Type IX braid, configuration P_1 had a slightly higher coefficient of variation although breaking strength average was almost the same. For Type X braid, P_1 had a lower coefficient of variation and a higher breaking strength average by one standard deviation. Configuration P_2 was not used for testing the Type VIII braid.

In all but two tests using jaws, break point was at the tangent point of departure of the free length from the drum face. There was one break in the free length (Test 11, configuration P_1) and one break at the point on the split capstan jaws drum where the first turn crosses under the second turn.

Total testing time is the sum of specimen preparation time, time for wrapping or connecting specimen to Instron, time from zero load to rupture, and time to disconnect or unwrap the ruptured sample from the machine. A representative total testing time for double pin jaws in both configurations is 12 minutes, over twice the representative total testing time of 5 minutes for split capstan jaws. Both jaws have about the same time from zero load to rupture but the wrapping procedure for double pin jaws is much more tedious and time consuming.

3. EYE SPLICED CONFIGURATIONS

Seven different tapers (including configuration A which is actually untapered) were experimented with. To produce a sample that would break in the free length rather than at the end of the insertion was the motivation for the wide variety of tapers (configurations). This variety reflects an effort to minimize the inherent discontinuity at the end of the insertion thereby increasing the chance of a free-length break.

For all eye-spliced configurations except A, breaking strength averages ran about the same. Configuration C produced the highest average breaking strengths for all three braids but these values fell within one standard deviation of most of the other tapers. Coefficients of variation were effected greatly by single high or low values as were averages since populations often consisted of only three samples. Configuration F resulted in inconsistent data because the insertion length was uncontrolled and in 3 of 12 tests the splices pulled out. The same taper was used for G but the insertion length was controlled to six inches and data became much more consistent.

Of 138 tests using eye splices for sample termination, there were 31 free length breaks, 3 tests where the splice pulled out, and 104 breaks at the end of the insertions. Configurations C, F, and G produced a higher percentage of free length breaks although average breaking strengths were not significantly higher. The average breaking strength of all the samples for each type that broke in the free length was virtually the same as the average breaking strengths for configurations C, F, and G.

A representative total testing time for configuration C is 15 minutes while the representative time for configuration G is half that at 7½ minutes. Most of this time is taken for sample preparation since it takes only 2½ minutes to connect an eye spliced sample to the Instron, rupture it, and disconnect it. Total testing time for A and F is about 7 minutes while total testing time for B, D, and E is about 14½ minutes.

4. SPLIT CAPSTAN JAWS VS CONFIGURATION G

For Type VIII and X braid, configuration G load averages were slightly higher than split-capstan jaws (configuration S) breaking strength averages; differences were a little more than one standard deviation. For Type IX braid, these averages were about the same. Coefficients of variation were slightly less for split capstan jaws than for configuration G.

There were no free length breaks for the samples terminated with split capstan jaws while 7 out of 39 of the tests using configuration G eye splices resulted in free length breaks.

TABLE 3

PERCENT ELONGATION OF THE FREE AND TOTAL LENGTHS OF EYE SPLICED TEST SAMPLES AT A 3000 LB LOAD.

	Percent Elongation	
Test	Free Length	Total Length
96	4.1	4.7
97	3.9	4.7
98	4.3	4.8

Total testing time for split-capstan jaws was about 5 minutes as opposed to approximately 7½ minutes for eye-splice G.

For a split capstan jaws test 96 inches of braid was needed while 54 inches was needed to produce an eye-spliced sample of configuration G.

5. ELONGATION

From the data in Table B-3 load vs elongation plots were drawn to the same scale of and compared to the Instron plots. It was found that the strain in the free length of eye-spliced samples was approximately equal to the strain in the entire sample when length of entire sample is defined as distance between the centers of the pins when the sample is taut but unstrained (See Table 3).

6. LOAD ONSET RATE

The slope of the load vs time curve at any point on that curve is the load onset rate at that point. Slope can be determined graphically or by curve fitting an equation to the data and differentiating it with respect to time. The latter was chosen and a second-order polynomial was fit using the method of least squares approximation (Appendix A). The resulting equation fit the data closely as the slopes of the actual and fitted curves were virtually the same at all points so that differentiation of the polynomial yielded accurate load onset rates. These were plotted against load as seen in Figure 7.

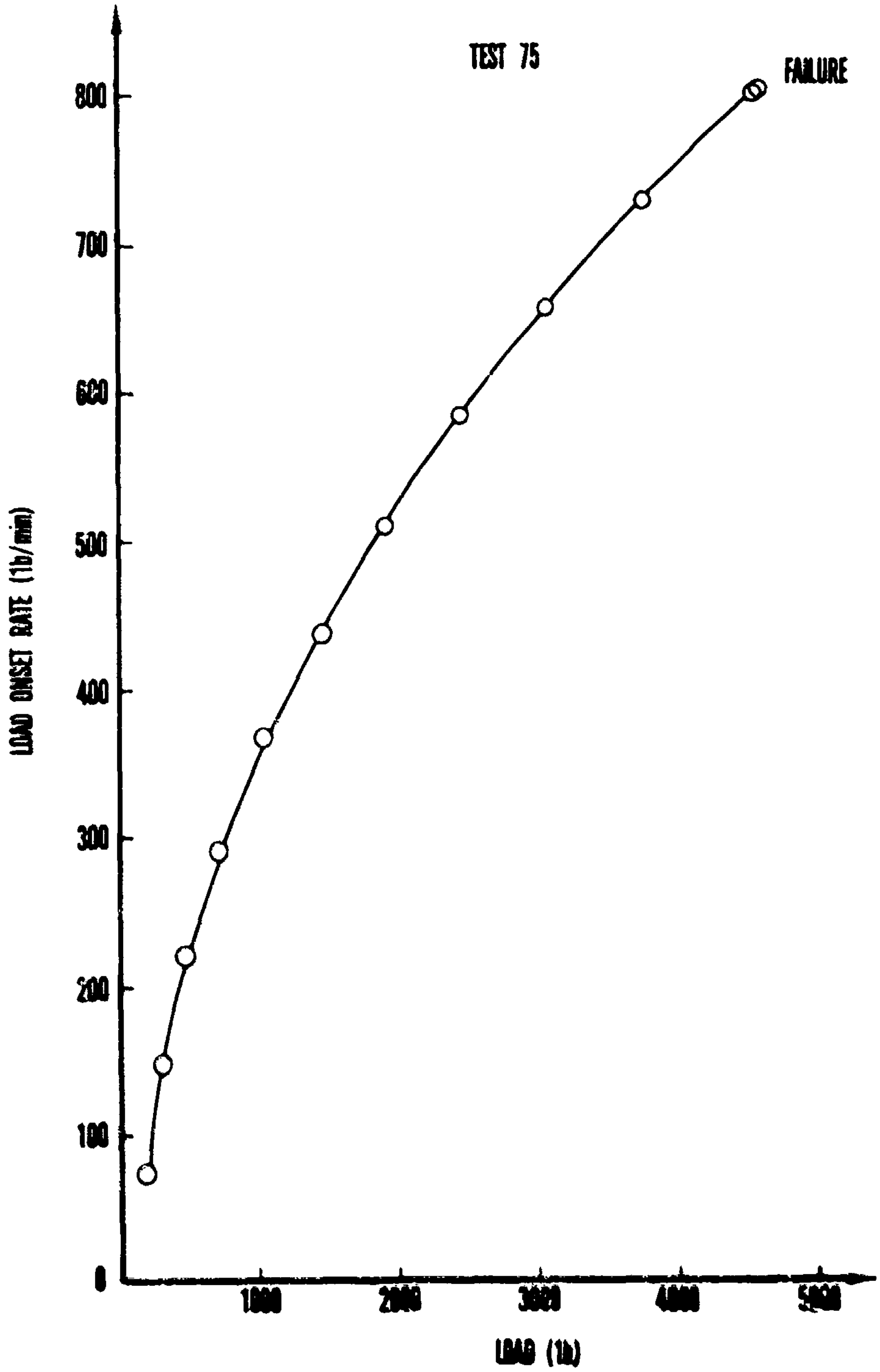


Figure 7. Load Onset Rate vs Load

7. SUSPENSION LINES FROM PREVIOUSLY TESTED PARACHUTES

All the samples taken from the suspension lines were tested with tapered insertion eye-splice configuration G so that all comparisons are with braid tested in configuration G. From each of the 3 parachutes 9 samples were taken for a total of 27 tests; data is listed in Tables 4, B-2a, and B-2b. Samples of Type X braid taken from parachute A had an average breaking strength of 3931 lbs which is over 4½ standard deviations and 18 percent lower than 4821 lbs, the average breaking strength of the Type X braid taken, unused, from the spool. Type IX braid, taken from test parachute B had an average breaking strength of 2641 lbs which is 12 2/3 percent and over 3½ standard deviations higher than the same type braid taken from the spool. Type VIII braid taken from parachute C had about the same breaking strength as the same braid taken from the spool.

TABLE 4

SUMMARY OF PARACHUTE SUSPENSION LINE TEST DATA

Parachute	Average Line Breaking Strength (lbs)	Standard Deviation (lbs)	Coefficient of Variation
A	3931	198	5.02%
B	2641	36	1.37%
C	1719	39	2.24%

SECTION V

CONCLUSIONS

Split capstan jaws are superior to double-pin jaws for testing Kevlar-29 coreless braided cords. In all cases, the average breaking strength of samples pulled on the split capstan jaws were higher by three standard deviations than those pulled on the double-pin jaws. Tests took less than half as long and there was less data scatter for the split capstan jaws.

It was found that the strain of the entire eye-spliced sample was about equal to the strain in the free length. This is significant in that strain data can be taken directly from the Instron rather than from the tedious method of measuring, at various loads, the distances between two ink marks on the free length.

Of the seven eye-spliced configurations, configuration G produces a relatively high frequency of free length breaks and, next to A and F is the easiest and fastest to splice. For these reasons, it was chosen for data base testing for the parachute suspension lines.

There is no clear "better configuration" between the split-capstan jaws and eye splice configuration G. Breaking strength averages are about the same as are the coefficients of variation. Configuration G has a longer total test time but uses less material so that almost twice as many tests can be done on a given length of material.

Based on the 27 tests of cord samples taken from suspension lines of the 3 previously tested parachutes, no conclusions can be drawn concerning the effect of parachute opening loads on strength degradation of these lines since no significant trends were indicated by the test data.

APPENDIX A

CURVE FITTING ELONGATION DATA

All curve fitting was accomplished using a least squares approximation algorithm programmed into an HP-97 calculator. This algorithm yields the three coefficients for a second-order polynomial.

EXAMPLE

For test 75, the equation produced from the least squares approximation is

$$P = 36.17t^2 + 76.98t + 146.57$$

where P is load in pounds and t is time in munutes. Values of load obtained from the above expression are compared in Table A-1 to the actual load data obtained from the Instron plot. Differentiation of this polynomial gives

$$P' = 72.34t + 76.98$$

where P' is load onset rate in pounds per minute.

TABLE A-1

COMPARISON OF CURVE FIT TO ACTUAL LOAD DATA

Time t (sec)	Actual Loads (lbs)	Load P (lbs)	Percent Error
0.0	100	147	47.0
1.0	240	260	8.3
2.0	450	445	1.1
3.0	830	703	15.3
4.0	1070	1033	3.5
5.0	1460	1436	1.6
6.0	1800	1910	6.1
7.0	2430	2458	1.1
8.0	3030	3077	1.6
9.0	3760	3769	0.2
10.0	4600	4533	1.5

APPENDIX B

DATA

TABLE B-1a. TEST DATA FOR TYPE VIII KEVLAR BRAIDED CORD

TEST	TERMINATION CONFIGURATION	BREAKING STRENGTH (lbs)	BREAK POINT AND COMMENTS
10		1500	T; much knot slippage-no stop knot
11		1620	M
12	P_1	1510	T
13		1500	T
128		1680	T
129		1700	T
130	S	1660	T
131		1720	T
132		1710	T
1		1560	I
2	A	1630	I
3		1650	I
20		1790	I
21	B	1780	I
22		1850	I
23		1840	I
24	C	1820	I
25		1860	I
38		1700	I
39	D	1810	I
40		1670	I
41		1840	M
42	E	1800	I
43		1818	M
44		1740	Splice pulled out
45		1560	Splice pulled out
46		1770	I
47	F	1880	M
48		1810	I
49		1820	M
84		1800	I
85		1800	I
86		1730	I
87		1800	M
88		1760	I
89		1710	I
90	G	1730	M
91		1770	I
92		1680	I
93		1710	I
94		1800	I
95		1800	I

AFWAL-TM-81-60 FIER TABLE B-1b

TEST DATA FOR TYPE IX KEVLAR BRAIDED CORD

TEST	TERMINATION CONFIGURATION	BREAKING STRENGTH (lbs)	BREAK POINT AND COMMENTS
14		1980	T
15	P_1	2000	T
16		2150	T
123		2010	T
124		2070	T; one yarn intact
125	P_2	2150	T
126		2170	T
127		2060	T
133		2330	T
134		2450	T
135	S	2250	T
136		2410	T
137		2360	T
4		2310	M
5	A	2360	I
6		2300	I
26		2280	I
27	B	2500	I
28		2120	I; failed one carrier at a time
29		2450	M
30	C	2360	I
31		2470	M
50		2410	I
51	F	2360	M
52		2420	M
99		2390	I
100		2290	I
101		2320	I
102		2380	M
103		2360	I
104	G	2340	I
105		2270	M
106		2500	M
107		2460	I
108		2300	I
109		2260	I
110		2250	I

AFWAL-TM-81-60 FIER

TABLE B-1c

TEST DATA FOR TYPE X KEVLAR BRAIDED CORD

TEST	TERMINATION CONFIGURATION	BREAKING STRENGTH (lbs)	BREAK POINT AND COMMENTS
17		4230	T
18	P_1	4200	T
19		4000	T
178		3780	T
179	P_2	4050	T
180		4120	T
138		4670	T
139		4330	T; one yarn intact
140		4520	T
141	S	4720	T
142		4670	T; one yarn intact
181		4700	T
182		4510	Failed at Crossover point
183		4710	T
7		4570	I
8	A	4280	I
9		4530	M
32		4950	M
33		4850	M
34		4930	M
59		4290	I; one carrier failed first
60		5080	M
61		4610	I; one carrier failed first
62		4020	I
63		4300	I
64		5000	M
65	B	5080	I
66		4610	I
67		4770	I
68		4320	I; one carrier failed first
69		4820	I
70		5000	I
96		4310	I
97		4870	M
98		4900	M
71		4610	I; one carrier failed first
72	B; Crosshead speed = 0.2 in./min	3700	I; 3 carriers intact
73		4650	I
74		4420	I
75		4650	M; one carrier intact
76		4130	I
77		4280	I
78	B; Crosshead speed = 2.5 in./min	4600	I
79		4750	M
80		4610	M
81		4580	I
82		4740	I

AFWAL-TM-81-60 FIER

TABLE B-1c

TEST DATA FOR TYPE X KEVLAR BRAIDED CORD (Continued)

TEST	TERMINATION CONFIGURATION	BREAKING STRENGTH (lbs)	BREAK POINT AND COMMENTS
35		5120	M
36	C	4920	I
37		4790	M
53		4730	M
54	F	4050	Splice pulled out
55		4920	I
56		4910	I
57		5270	I
58		4730	I
111		4840	M
112		5000	I
113		4910	I
114	G	4600	I
115		4800	M
116		4820	M
117		4910	I
118		4950	I
119		4530	I
120		4820	I
121		4610	I; one carrier failed 1st
122		4610	I

Samples taken from previously tested parachutes were designated with a four digit label to indicate which parachute, suspension line, and section of the line the sample was taken from. The first digit of the label is a letter identifying which parachute the sample is taken (see Table B-2a). The next two digits are the number of the gore the line was attached to. The last digit is a letter identifying which section or third of the suspension line the sample was taken from; S, M, and R for sections closest to the skirt, middle and riser, respectively.

Example: B09R labels a sample taken from section closest to the riser of the suspension line connected to the ninth gore of parachute B.

TABLE B-2a

PARACHUTE DATA

Parachute Designation	Identification Number	Suspension Line Braid Type	Peak Loads (lbs)
A	308-03 S/N 002	X	29,964 25,460 20,421
B	308-04 S/N 001	IX	25,209 22,933 (Failed)
C	13-11126-2 S/N 005	VIII	First Test 8,852 12,366 15,700 Second Test 15,227 12,909 10,727

AFWAL-TM-81-60 FIER

TABLE B-2b

TEST DATA FOR PARACHUTE SUSPENSION LINES

Test	Sample	Breaking Strength	Break Pt and Comments
151	A01S	3920	M
152	A05R	3950	M
153	A09R	3830	I
154	A13R	4050	I
155	A17R	3900	M
156	A17M	4260	I
157	A17S	3600	I
158	A21R	4120	M
159	A25R	3750	M
160	B01R	2630	I; one yarn intact
161	B05R	2660	M
162	B09R	2650	I
163	B09M	2640	M
164	B09S	2610	I
165	B13R	2650	I
166	B17R	2610	I
167	B21R	2600	M
168	B25R	2720	M
169	C01S	1750	I
170	C05S	1670	M
171	C09S	1680	M
172	C09M	1780	M
173	C09R	1740	I
174	C13S	1720	I
175	C17S	1670	M
176	C21S	1720	I
177	C25S	1740	I

NOTE: All samples were eye-spliced using configuration G; crosshead speed = 1.0 in./min.

TABLE B-3

FREE LENGTH ELONGATION DATA

Test	Load (lb)	Distance Between Two Marks on Free Length (in.)	Elongation (in.)	Percent Elongation
75	450	12.69	0.00	0.00
	1000	12.75	0.06	0.47
	1800	12.88	0.19	1.50
	2100	12.94	0.25	1.97
	2500	13.00	0.31	2.44
	3000	13.06	0.37	2.92
	3500	13.13	0.44	3.47
	4000	13.19	0.50	3.94
76	500	12.84	0.00	0.00
	1000	12.94	0.10	0.78
	1500	13.03	0.19	1.48
	2000	13.15	0.31	2.41
	2500	13.21	0.37	2.88
	3100	13.28	0.44	3.43
	3500	13.31	0.47	3.66
	4000	13.33	0.49	3.82
78	300	12.40	0.00	0.00
	1000	12.56	0.16	1.29
	2000	12.78	0.38	3.06
	3500	12.89	0.49	3.95
79	100	11.60	0.00	0.00
	500	11.70	0.10	0.86
	1500	11.90	0.30	2.59
	2000	11.95	0.35	3.02
	3000	12.05	0.45	3.88
80	100	12.05	0.00	0.00
	500	12.56	0.06	0.48
	1500	12.70	0.20	1.60
	2000	12.85	0.35	2.80
	3000	12.97	0.47	3.76

AFWAL-TM-81-60 FIER TABLE B-3

FREE LENGTH ELONGATION DATA (CONTINUED)

Test	Load (lb)	Distance Between Two Marks on Free Length (in.)	Elongation (in.)	Percent Elongation
83	500	12.10	0.00	0.00
	1000	12.15	0.05	0.41
	1500	12.22	0.12	0.99
	2000	12.30	0.20	1.65
	2500	12.31	0.21	1.74
	3000	12.40	0.30	2.48
	3500	12.48	0.38	3.14
96	50	15.82	0.00	0.00
	500	16.04	0.22	1.39
	1000	16.15	0.33	2.09
	1500	16.24	0.42	2.65
	2000	16.35	0.53	3.35
	2500	16.40	0.58	3.67
	3000	16.46	0.64	4.05
97	50	16.00	0.00	0.00
	500	16.16	0.16	1.00
	1000	16.28	0.28	1.75
	1500	16.38	0.38	2.38
	2000	16.48	0.48	3.00
	2500	16.56	0.56	3.50
	3000	16.62	0.62	3.88
98	50	16.00	0.00	0.00
	500	16.10	0.10	0.63
	1000	16.32	0.32	2.00
	1500	16.45	0.45	2.81
	2000	16.54	0.54	3.38
	2500	16.62	0.62	3.88
	3000	16.68	0.68	4.25

AFWAL-TM-81-60 FIER

APPENDIX C

TENSILE TESTING OF KEVLAR-29 CORELESS BRAIDED CORD BY ALBANY INTERNATIONAL, INC.

During 1978 and 1979 Albany International in Dedham, MA was involved in an effort to determine the effects of abrasion on Kevlar-29 coreless braided cord. In the course of this effort they performed 41 tensile tests from 7 different lots of materials to establish a data base. Type IX braid wrapped on double pin jaws (in configuration P_2) was used for all of the 41 tests. Their data summary is as follows.

Average Breaking Strength	2233 lbs
Standard Deviation	102 lbs
Coefficient of Variation	5.8%

All but four test specimens ruptured clean at the tengent point of departure of the free length from the primary pin. Three broke clean at an upper tangent while a single yarn remained intact during one test; there were no free length breaks.

(NOTE: THIS IS THE LAST PAGE OF AFWAL-TR-81-60 (FIER)

APPENDIX D

SAMPLE KEVLAR-29 RIBBON PARACHUTE DESIGN

1. REQUIREMENT

A 15.3 ft nominal diameter, 20 degree conical, continuous ribbon parachute was chosen as a component of a Mid Air Recovery System (MARS) for remotely piloted vehicles (RPV). Kevlar-29 materials are preferred since volume is limited and high strength is required for a broad deployment envelope. RPV structural limitations dictate that the drag parachute attach point load not exceed 16,800 lbs. Deployment dynamic pressure ranges from 26 to 430 psf and the results of trajectory computations indicated the necessity for a dual reefing system for decelerating a 4,500 lb vehicle to conditions producing a dynamic pressure of 50 psf above a specified altitude.

2. PARACHUTE CANOPY GEOMETRY

Number of gores: $N_g = 28$

Nominal diameter: $D_o = 15.3$ ft

The conical surface area is equal to the nonimal area by definition:

$$S_o = \pi/4\ D_o^2 = 183.85 \text{ sq ft}$$

From Figure D1:

Conical surface area, $S_o = \pi L_o^2 \cos(20) = 183.85$ sq ft

Solving for L_o, the slant height of a 20 degree cone:

$$L_o = 94.7 \text{ in.}$$

Also from Figure D1, the circumference at the base of the cone which is also the parachute skirt is:

$$\text{Skirt circumference} = 2\pi L_o \cos(20)$$

From Figure D2, the flat layout of the 20 degree conical surface,

Skirt circumference = L_o (θ), (θ in radians)

Equating the expressions for skirt circumference and solving for θ yields:

θ = 5.904 radians

or

θ = 338.3 degrees

Selecting a 1 percent vent (based on S_o), dictates a vent slant height:

L_v = .1 (L_o) = 9.47 in (see Figure D3.)

3. GORE GEOMETRY

Gore angle $\beta = \frac{\theta}{N_g}$ = 338.3/28

β = 12.08 degrees

Gore area = (S_o/N_g) 144

= (183.85/28) 144

= 945.53 sq in.

Length of bottom edge of skirt ribbon e_g is:

$e_g = L_o$ (β/57.3)

e_g = 94.7 (12.08)/57.3

= 19.97 in.

Similarly, the top edge of the vent ribbon e_v is:

$e_v = L_v(\beta)/57.3$ = 2.0 in.

ε, the width of slots between ribbons can be calculated from:

$\varepsilon = (L_o - L_v - (BHR)M)/(M-1)$

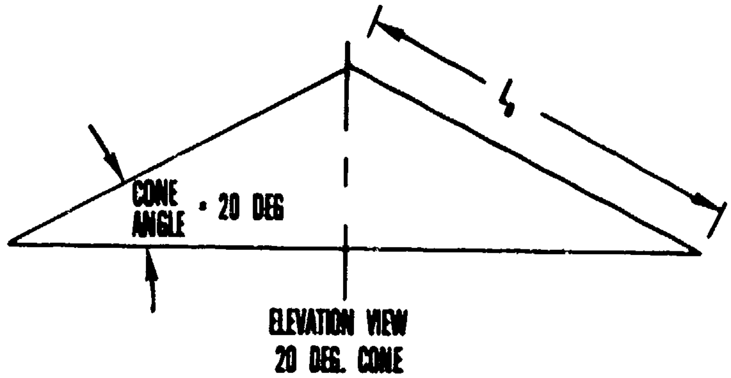


Figure D1. 20 Degree Conical Parachute Canopy Geometry

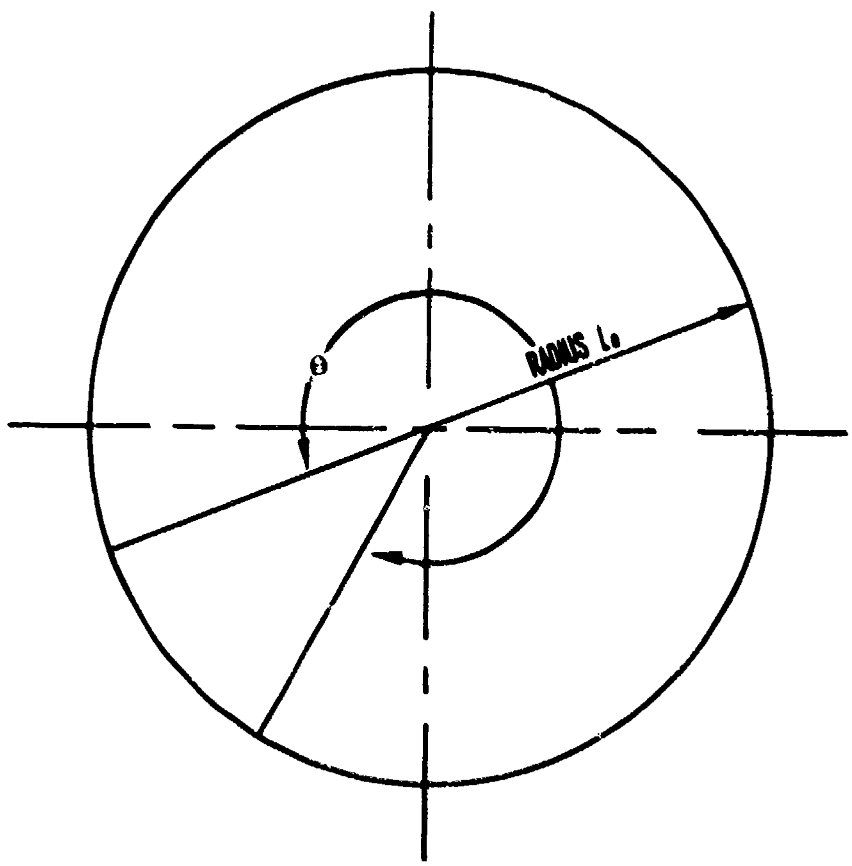


Figure D2. Flat Layout of Conical Surface

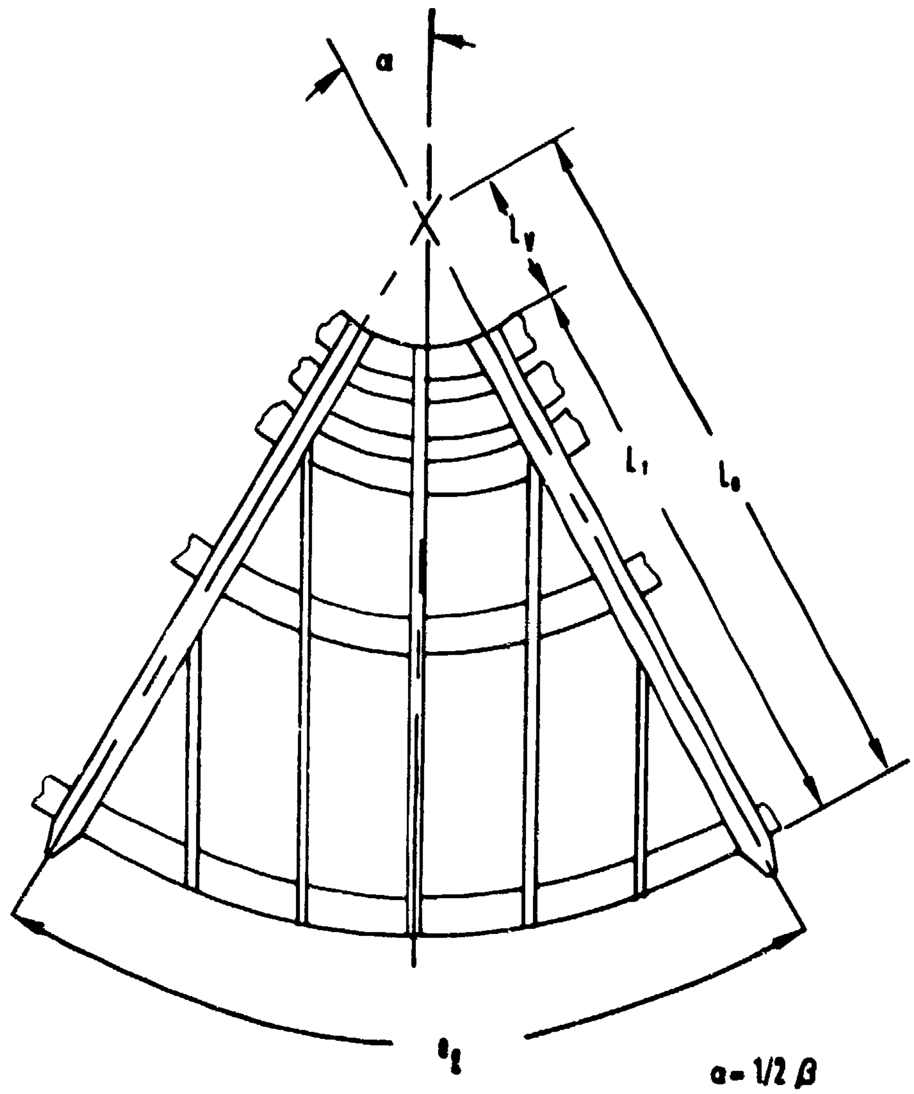


Figure D3. Continuous Ribbon Parachute Gore Arrangement

For integer values of M, the number of horizontal ribbons, and BHR, the width in inches of the horizontal ribbons.

4. GEOMETRIC POROSITY

Geometric porosity, defined as the ratio of open canopy area to the total canopy area, can be calculated by finding the sum of the exposed component area in a single gore, subtracting this from the gore area and then dividing by the gore area. The ratio is usually converted to a percentage of the total area.

For horizontal and radial ribbons 2-inches wide, vertical tapes one-half inch wide, vent lines .563 inches wide, 5 vertical tapes per gore as in Figure D3, and 33 horizontal ribbons, the exposed component area in sq in. is as follows:

$$\text{Radial Ribbon Area} = 2(L_o - L_v)$$

$$= 2(94.7 - 9.74) = 170.46$$

For calculating the exposed horizontal ribbon area, the average length for all ribbons measured along the center of the ribbon is considered.

Length of the skirt ribbon

$$= [(L_o - 1)2\alpha 57.3] - 2 = 17.75$$

Length of the vent ribbon

$$= [(L_v + 1)2\alpha / 57.3] - 2 = .21$$

Average horizontal ribbon length per gore is then:

$$(17.75 + .21)/2 = 8.98$$

And the total exposed horizontal ribbon area per gore is:

$$33(8.98) = 592.72$$

Using the relationship in paragraph 3 above, the width of spaces between ribbons becomes: =.601 in.

For 33 horizontal ribbons 2 in. wide

Referring to the relationships of Figure D4, and using 3.0 in. spacing between vertical tapes, the values for slot area covered are:

TAPE	RADIAL DISTANCE (IN)	SLOTS n	SLOT AREA COVERED (IN^2)
Center	85.2	32	9.62
1	56.7	21X2	12.64
2	28.2	10X2	6.05
		TOTAL AREA	28.31

In order to obtain the exposed surface of vent lines, the entire vent is considered and this area then divided by N_g to obtain this area for one gore. Figure D5 shows the geometry of the vent and includes general equations.

For vent lines .563 inches wide (BVL = 9/16 in), L_v = 9.47 in, and β = 12.08 deg., the equations on Figure D5 produce:

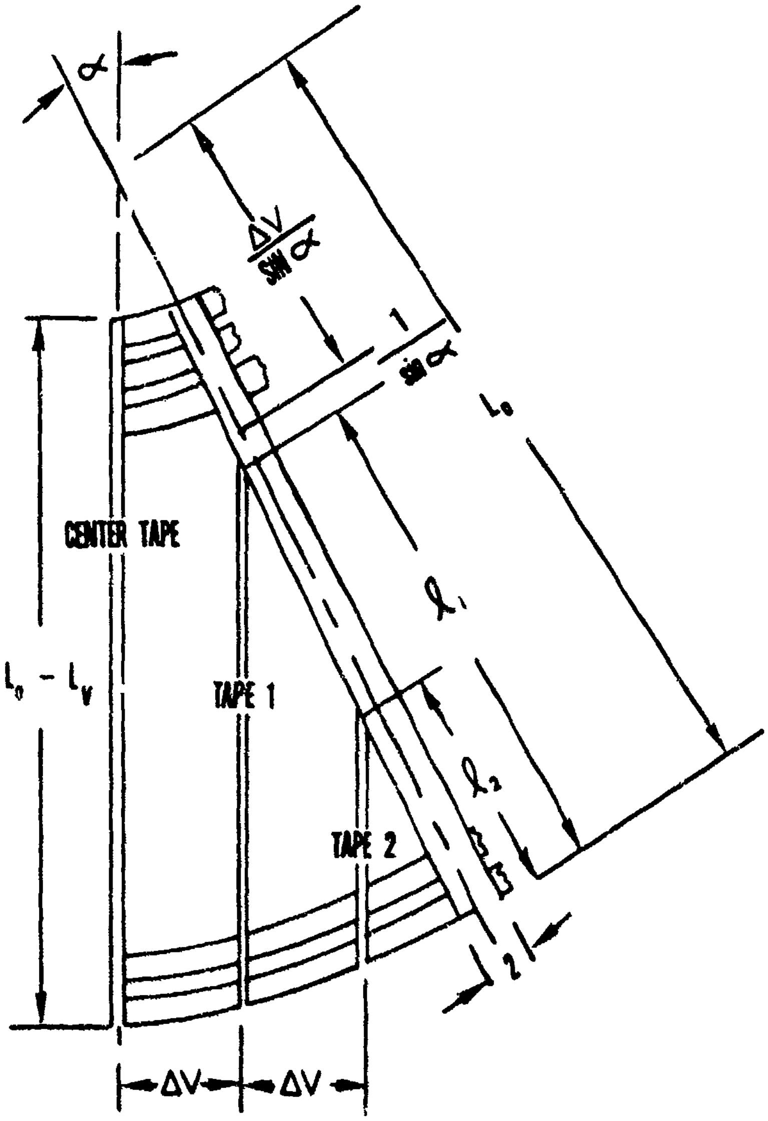
$$R_c = \frac{.563}{2 \sin \frac{(12.08)}{2}} = 2.68 \text{ in.}$$

$$\text{Total vent line area} = \pi/4(2.68)^2 + .563\ (9.47-2.68)28$$

$$= 112.73 \text{ sq. in.}$$

For one gore:

$$\text{Vent line area} = \frac{112.73}{28} = 4.03 \text{ sq in.}$$



$$\ell_1 = L_0 - \left[\frac{\Delta V}{\sin\alpha} + \frac{1}{\sin\alpha}\right]$$

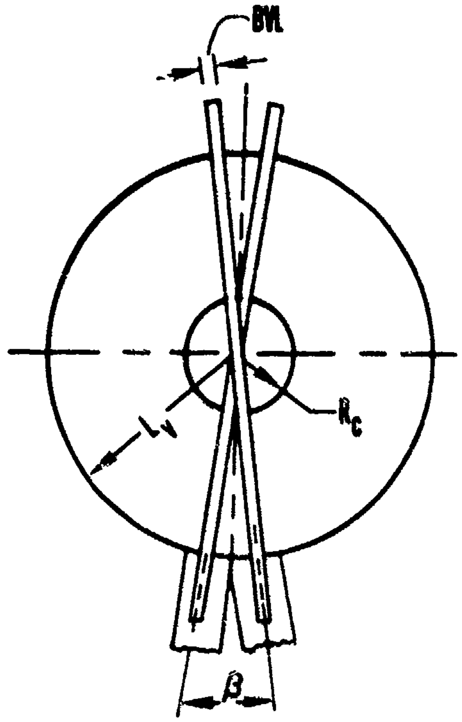
$$\ell_2 = L_0 - \left[2\,\frac{\Delta V}{\sin\alpha} + \frac{1}{\sin\alpha}\right]$$

NUMBER OF SLOTS n WHICH OCCUR IN DISTANCE ℓ ALONG RADIAL IS $n = \dfrac{\ell - 2}{2 + a}$

SINCE $\ell = na + 2(n+1)$

SLOT AREA COVERED BY VERTICAL TAPE IS THEN $= an$ (VERTICAL TAPE WIDTH)

Figure D4. One-Half Gore - Continuous Ribbon Parachute



$$R_C = \frac{BVL}{2 \sin \beta/2}$$

$$\text{TOTAL VENT LINE AREA} = \frac{\pi}{4} R_C^2 + BVL\,(L_V - R_C)\,N_B$$

Figure D5. Basis for Calculation of Exposed Vent Line Area

Summing component exposed area for one gore:

Radial Ribbons	170.46
Horizontal Ribbons	592.72
Vertical Tapes	28.31
Vent Lines	4.03
	795.52 sq. in.

Geometric porosity is then:

$$\lambda_g = \frac{\text{Total gore area - exposed component area}}{\text{Total gore area}}$$

$$= \frac{945.53 - 794.05}{945.53} = .16 \text{ or } 16\%$$

5. SELECTION OF COMPONENT MATERIALS

A safety factor, $S_F = 1.8$ is selected for all components considering the parachute application which is a single use (one deployment) item.

Referring to page 414 of Reference 1, the material degradation factors are chosen as follows:

Category	Value	
Joint efficiency	.80	
Abrasion	1.00	
Moisture	1.00	
Temperature	1.00	
Vacuum	1.00	
Convergence	.99	
Fatigue	.80	Dual reefing involves extensive gluttering in lower portions of canopy
Unequal Loading	.80	

Degradation factor product A_p = .507

Using Table 18, the value for A_p, and the maximum load (F_o = 16,800 pounds), the material selections of Table D1 can be made.

TABLE D1

COMPONENT MATERIALS SELECTION FOR
SAMPLE KEVLAR-29 RIBBON PARACHUTE DESIGN

$$S_F \frac{F_o}{N_g} = 1.8 \ \frac{16,800}{28} = 1080 \qquad A_p = .507$$

Component	Nominal Strength Requirement (Pounds)	Selected Material Width (Inches)	Nominal Strength (Pounds)	Material Description
Suspension Lines	2130	N/A	2000	Coreless Cord Type IX
Horizontal Ribbons Crown (Top 12)	1080	2	1000	Ribbon (Tape) Type XI, Class 9b
Bottom	864	2	800	Ribbon (Tape) Type XI, Class 7
Radial Ribbons each of 2 plies	1188	2	1000	Ribbon (Tape) Type XI, Class 9a
Skirt Band	2916	1 3/4	3000	Webbing Type X, Class 4
Vent Band	5292	1	6000	Webbing Type VI, Class 9
Vent Lines	2130	9/16	2000	Tubular Web, Type III
Vertical Tapes	--	1/2	250	Tape Type I, Class 1

Materials Selection From Tables 2, 3 & 4.

APPENDIX E

DEVELOPMENT OF KEVLAR-29 HORIZONTAL RIBBON SPLICES

1. INTRODUCTION AND SUMMARY

The motivation for all joint trails was to develop combinations of thread size, stitch pattern, anti-fray coating and overlap which would produce a joint tensile breaking strength higher than 85 percent of the horizontal ribbon material. Joint configurations used in actual test item fabrication are identified in the tables by entries in the "used in test item" columns.

The rare occurrence of ribbon splice failures during parachute testing suggests that the requirement for 85 percent efficiency in those joints may be conservative.

All horizontal ribbon materials were woven from the minimum size Kevlar-29 yarn available, 200 denier. This lower limit on available yarn size and the associated loose or "sleazy" weaving in lower strength ribbons is the root of the major problems inhibiting the design and accomplishment of good joints in Kevlar-29 ribbon parachutes. Observation of the trials listed in Tables E1 through E7 indicates that joint efficiency is more and more difficult to achieve as the nominal strength of ribbons decreases. It is also seen that failure modes for the lower strength ribbons is predominately related to raking. Variation of lap stitching patterns in the 400 and 600 lb ribbons is less effective than applying the "sergene" coating which stabilizes the ribbon weave in joints. Conversely, 85 percent joints in the 800 and 1,000 lb ribbons is relatively easy to obtain.

2. DESCRIPTION OF HORIZONTAL RIBBON SPLICE TENSILE TESTING SAMPLES

Splices in horizontal ribbons are formed by overlapping the ribbon ends (usually by 4 1/4 inches) and sewing these ends together with "lap stitching." These splice joints are completed by sewing the lapped ribbon ends between two plies of radial ribbon material using radial plying stitching. Figure E1 shows a typical horizontal ribbon splice test sample.

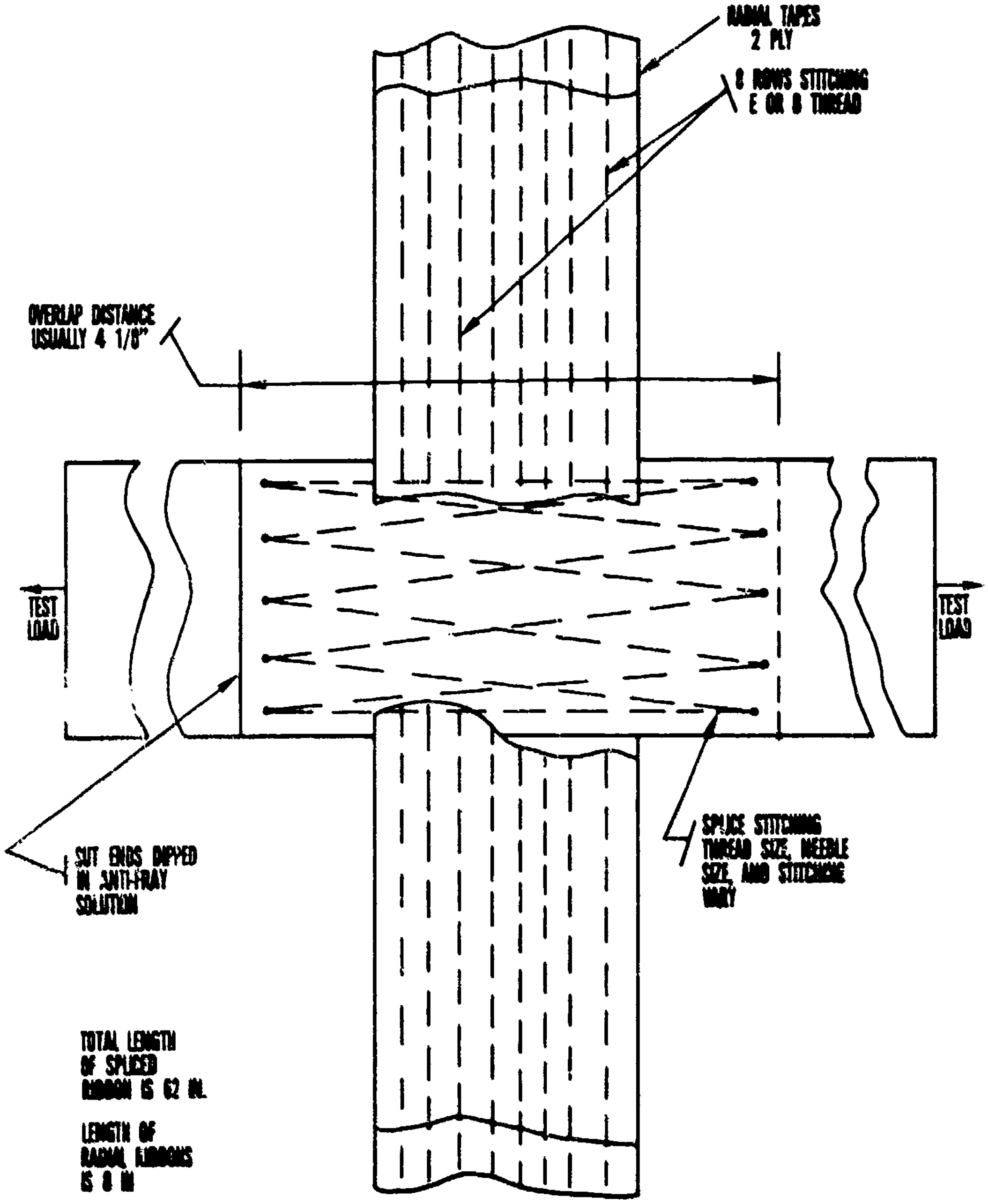


Figure E1. Typical Horizontal Ribbon Splice Test Sample

3. SPLICE SAMPLE TENSILE TESTING

Joint samples were loaded in a single direction by attaching one of the horizontal ribbon ends to a stationary beam of a tensile testing machine and the other and to a moving beam or crosshead. Steady motion of the testing machine crosshead separating from the stationary beam applies load to the joint until the joint fails. Jaw configurations used to attach the ribbon ends to testing machines are shown in Figure E2. The tensile testing jaw in Figure E2b is preferred, but had not yet been developed at the time of much of the splice sample testing. Reference 12 contains the background development and techniques for using this apparatus. Testing apparatus and the crosshead speeds used to obtain the joint breaking strength were also used to obtain the breaking strength for the horizontal ribbon materials which was used to calculate joint efficiency.

4. TENSILE TESTING RESULTS

During trials to achieve 85 percent efficiency, lapping configurations, stitching patterns, thread size, needle size, and anti-fray treatment application area were varied. Tables E1 through E7 and Figures E3 through E33 describe horizontal ribbon splice test samples, the materials used to fabricate these samples, stitching used, anti-fray application, testing apparatus and technique, and tensile testing results.

In order to read the ribbon splice tables, the following coding information is necessary:

a. Material Strength

Nominal strengths of ribbon materials listed in Tables E1 through E7 are often associated with various values for actual strength. Ribbons of the same nominal strength often are of different construction, because they were woven using different yarns, or because the actual strengths may reflect different tensile testing apparatus or technique. The actual strength values for materials were obtained using the same test conditions and apparatus used to test the joints and to determine joint efficiency.

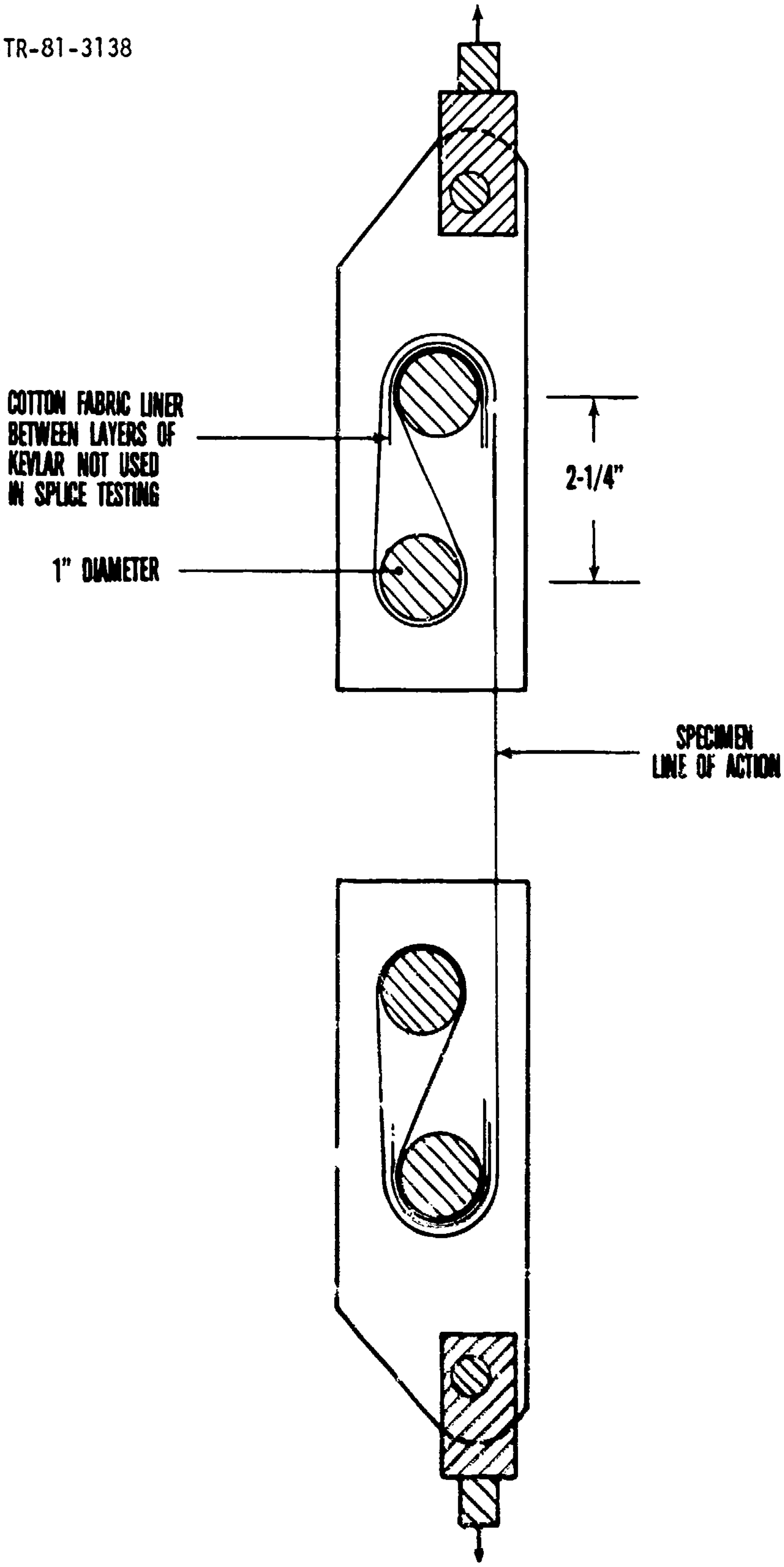


Figure E2a. Equal Diameter Pin Tensile Testing Jaw

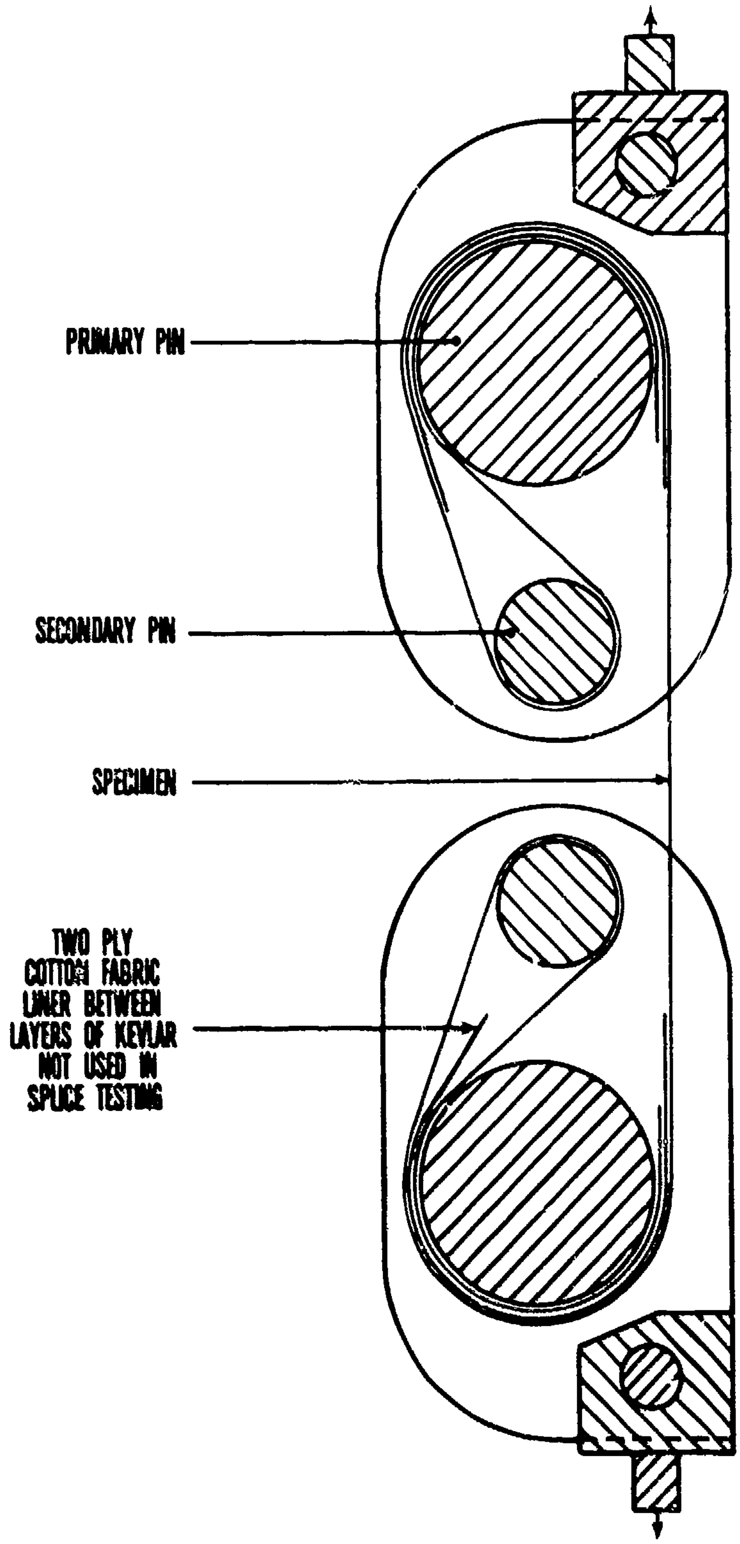


Figure E2b. Unequal Diameter Pin Tensile Testing Jaw

b. Warp and Fill Yarn Count

Yarn count for materials can be used to identify specification materials in Table 2 (MIL-T-87130) listings. Yarn count for non-specification materials can be used as an indicator of similarity to specification materials.

c. Lap Stitching

Table codes for lap stitching are made up of six characters separated into three fields as follows:

XXX	XX-XX	X	XX
designates stitching pattern (Ref Figures)	stitch spacing stitches per inch	thread size	needle size when known

d. Radial Stitching

Similar characters are used to indicate needle and thread size used in the eight straight rows of radial stitching. Radial stitching other than seven to nine stitches per inch will be noted. Radial stitching was accomplished by two passes of a four needle sewing machine.

e. Anti-Fray Treatment

Prior to ribbon splice stitching, the cut ends of horizontal ribbons were usually coated by brushing or dipping with a coating sold commercially as "sergene." This material was applied as a liquid and allowed to cure until dry to the touch before stitching. Tables E1 through E7 indicate the "sergene" treatment by the coated length (measured in inches from the cut end) of the horizontal ribbon.

In a few noted cases additional anti-fray solution was applied as an intermediate step (after the lap stitching but before radial stitching) or as a final step applied to the area of radial and horizontal ribbon intersection. Refer to lap stitch patterns 5P5, 5P6, and 5P7 (Tables E2 through E7).

f. Test Apparatus

Apparatus used to attach the horizontal ribbon sample ends to the testing machine are referred to as jaws. Two types of jaws were used in testing horizontal ribbon samples as shown in Figure E2. The jaw coded as "EDP" (equal diameter pins) in Figure E2a is a forerunner of a jaw configuration developed in the effort reported in Reference 12 and represented here with the code "UDP" (unequal diameter pins). Figure E2b shows the jaw coded "UDP."

Two types of tensile testing machines were used, Dillon Model L, S/N2606 (coded "D" in Tables) or an Instron Model TT-C (Coded "I" in Tables). Crosshead speeds were four and one inches per minute for the Dillon and Instron machines respectively.

g. Joint Sample Tensile Results

Average tensile strengths for joint samples are based on small numbers of tests (typically three). The standard deviation values in the tables were calculated as follows:

$$\text{STD DEV} = \frac{\Sigma(BS)^2 - \frac{(\Sigma BS)^2}{n}}{n-1}$$

Where BS is joint sample breaking strength and n is number of tests. The resulting standard deviation values are not statistically meaningful as the data population is very small. Standard deviation values are included in Tables E1 through E7 to indicate scatter in breaking strength data.

h. Efficiency

$$\text{Joint efficiency} = \frac{\text{Ave Breaking Strength of Joint}}{\text{Ave Breaking Strength of Ribbon Material}} \times 100$$

i. Observed Failure Modes

Tensile tests were continued until the force in test samples decreased or became zero with the crosshead still in motion. Modes of failure could be put into one of several categories as follows:

Table code "N"-failure of horizontal ribbon warp yarns at the lap stitching furthest from the center of the ribbon lap.

Table code "T"-failure of selvage edge at one side of the ribbon at or near the end of lap stitching and subsequent tearing or sequential failure of remaining ribbon warp yarns.

Table code "R"-raking of fill yarns along warp yarns where lap stitches could be envisioned as the tines of a rake between which warp yarns are drawn leaving fill yarns at positions of stitching. This failure mode may occur in combination with "N" or "T" modes.

Table code "C"-failure of ribbon warp yarns at the edge of anti-fray coating application. This mode was limited to some of the joints utilizing coating beyond the lap stitch patterns.

j. 1000 lb Ribbon Trails

Lap stitch patterns based in the five point arrangement (see Table E1 and Figures E3 through E10) generally produced high joint efficiencies with mininal or no anti-fray treatment. The double W arrangement (Trial 13) was also successful while other lap stitching patterns usually involving fewer total stitches (and therefore fewer load concentration points, i.e., 3PI, 8R, 4PI) were less successful (Trials 11, 12 and 14).

Application of anti-fray solution is not necessary with the 1,000 lb ribbon to obtain 85 percent efficiency, although Trial 5 indicates that high efficiency is retained when the entire lapped end is treated.

TABLE E1

RIBBON SPLICES IN 1000 LB KEVLAR-29

Trial Nr	Used in Test Item	Ribbon Strength Nominal Actual (lbs)	Material: Warp Ends	Material: Fill Ends Per (Inch)	Radial Single Ply Nominal Strength (Lbs)	THREAD	Lap Stitching: Pattern	Lap Stitching: Spacing	THREAD	Anti Fray (in)	Test Apparatus: Jaw	Test Apparatus: Machine	NR TESTS	Joint Sample Results: Breaking Strength (Lbs) Ave.	Breaking Strength (Lbs) Std Dev.	Efficiency %	Fail Code	Fig XX	Comment or Note
1	1 & 2	1000 1001	164	56	1000	B	5P1	7-9	E	.5	EDP	D	3	867	29	87	N	E3	
2	3 & 4	900 980	142	51	900	B	5P1	7-9	E	.5	EDP	D	3	950	43	97	N	E3	
3	MARS Top 10	1000 1088	164	56	800	B	5P1	7-9	E	N/A	EDP	D	3	1125	0	108	N	E3	Air Perm 21
4	SARS Not Tested	1000 1088	164	56	1000	B	5P1	7-9	E	N/A	EDP	D	3	967	38	93	N	E3	
5		1000 1088	164	56	1000	B	5P1	7-9	B	5	EDP	D	1	1015	-	98	N	E3	5" Sergene Dip
6	1H-5 & 1H-6	1000 1088	164	56	1000	B	5P1	7-9	B	1	EDP	D	9	951	41	92	N	E3	
7	WP 1 Steinthal	1000 1088	150	45	1500	B	5P1	7-9	E	.5	EDP	D	3	1042	-	96	N	E3	Tests by Contractor
8		1000 1083	164	56	1500	B	5P1	7-9	E	-	UDP	I	4	923	86	85	N	E3	Tests at WPAFB
9		1000 1196	150	45	1500	E	5P1	7-9	21 E	.5	UDP	I	3	927	21	86	N	E3	
10						E	5P1	7-9	21 B	.5	UDP	I	2	970	-	81	N	E3	
11						E	3P1	7-9	E	.5	UDP	I	3	923	110	77	T	E4	
12						E	8R	7-9	23 E	.5	UDP	I	3	987	23	83	N	E5	

Table E1 (Concluded)

Sheet 2 of 2

Trial Nr	Used In Test Item	Ribbon Strength Nominal Actual (lbs)	Material		Radial Single Ply Nominal Strength (Lbs)	THREAD	Lap Stitching		THREAD	Anti Fray (in)	Test Apparatus		Joint Sample Results					Fig XX	Comment or Note
			Warp Ends	Fill Ends Per (Inch)			Pattern	Spacing			Jaw	Machine	NR TESTS	Breaking Strength (Lbs) Ave.	Std Dev.	Efficiency %	Fail Code		
13	WP2	1000 1196	150	45	1500	E	WW	7-9	18 E	.5	UDP	I	6	1085	35	91	N	E6	
14						E	4P1		18 E	.5	UDP	I	3	997	49	83	N	E7	
15						E	5Z		18 E	.5	UDP	I	3	973	21	81	NT	E8	Tests From Failed Selvage
16						22 E	5P3		18 E	.5	UDP	I	3	1013	31	85	N	E9	
17		1000 1196	150	45	1500	E	5P1		18 E	.5	UDP	I	3	993	6	83	N	E3	Compare with same Config. using two-inch needle and B thread
18		1000 1196	150	45	1000	22 E	5P4	7-9	18 E	.5	UDP	I	3	966	71	81	N	E10	
19		1000 1196	150	45	1000	22 E	5P4	7-9	18 B	.5	UDP	I	3	933	67	78	N	E1C	

Using smaller thread (B instead of E) appears to decrease efficiency when other variables are constant (Reference Trials 9 and 10 and Trials 18 and 19).

The high efficiency obtained in Trial 3 cannot be satisfactorily explained unless some unknown disfunction in the testing machine or interpretation of breaking strength is involved. The basic strength of the ribbon used was subsequently confirmed using different apparatus (see Trial 8).

k. 800 Pound Horizontal Ribbon Trials

Trials 21 through 25 (Table E2) were based on a horizontal ribbon material of questionable origin. This ribbon was woven early in the Kevlar-29 materials development efforts and resulted in a very high translational efficiency for the warp yarns. Each 200 denier yarn had a nominal strength of 9.7 lbs and obtaining 915 lbs actual strength for 100 yarns woven into a ribbon (94 percent of total unwoven yarn strength) is unusually high. When the weaver attempted to weave a second quantity of this same configuration, this strength could not be obtained. Instead, the material used in Trial 26 resulted which has a high (83 percent of total yarn strength) translational efficiency but is comparable to other materials of this type.

Joint efficiencies for the super efficient ribbon were not obtained without anti-fray treatment over the entire joint area. Normal ribbon configurations, Trials 20 and 26, were spliced to acceptable joint efficiencies both with and without anti-fray treatment.

The splices in 800 lb ribbons which were used in actual parachute test items (Trials 20, 25, and 26) did not fail during sled or drop tests.

A simplified lap stitch pattern involving only two transverse rows of zig zag stitching was tried in Trial 24 but produced poor joint efficiency.

TABLE E2

RIBBON SPLICES FOR 800 LB KEVLAR-29

Trial Nr	Used in Test Item	Ribbon Strength Nominal Actual (lbs)	Material: Warp Ends	Material: Fill Ends Per Inch	Radial Single Ply Nominal Strength (lbs)	THREAD	Lap Stitching: Pattern	Lap Stitching: Spacing	THREAD	Anti Fray (in)	Test Apparatus: Jaw	Test Apparatus: Machine	NR TESTS	Breaking Strength (Lbs) Ave.	Breaking Strength (Lbs) Std Dev.	Efficiency %	Fail Code	Fig XX	Comment or Note
20	5	600 789	98	55	600	B	5P1	7-9	E	N/A	EDP	D	3	670	20	85	N	E3	Air Perm 65.3
21		800 915	100	52	800	B	5P1	7-9	E	N/A	EDP	D	3	608	14	66	N	E3	First Delivery Bally 2204
22		800 915	100	52	800	B	5P1	7-9	E	N/A	EDP	D	3	640	1	70	N	E3	As above but with special care in sewing lap stitching
23		800 915	100	52	800	B	5P1	7-9	B	1	EDP	D	1	600	-	66	N	E3	
24		800 915	100	52	800	B	2ZZ	8-12	B	1/2	EDP	D	1	375	-	41	N	E11	
25	MARS 6	800 915	100	52	800	B	5P2	7-9	B	5	EDP	D	3	783	14	86	N	E12	
26	MARS 7 thru 10	[illegible] 801	[illegible]	52	800	B	5P1	7-9	B	5	EDP	D	3	725	-	91	N	E3	

TABLE E3

RIBBON SPLICES FOR 600 LB KEVLAR-29

Trial No	Used in Test Item	Ribbon Strength Nominal Actual (lbs)	Material Warp Ends	Material Fill Ends Per (Inch)	Radial Single Ply Nominal Strength (Lbs)	Thread	Lap Stitching Pattern	Lap Stitching Spacing	Thread	Anti Fray (in)	Test Apparatus Jaw	Test Apparatus Machine	NR Tests	Breaking Strength (Lbs) Ave.	Breaking Strength (Lbs) Std Dev.	Efficiency	Fail Code	Fig XX	Comment or Note
27		600 694	96	50	1000	E	WW	7-9	18 E	.5	UDP	I	6	438	34	63	NR	E6	
28						E	WW	7-9	18 B	5			6	407	26	59	NR	E6	
29						E	5P4	7-9	18 E	.5			3	391	6	56	R	E10	
30						E	5P4	7-9	18 B	.5			3	401	20	58	R	E10	
31						E	NIL	N/A	-	.5			3	236	14	34	NR	E14	
32						E	DD1	7-9	18 B	.5			3	463	55	67	NR	E15	
33						E	DD2	7-9	18 B	5			3	540	13	78	NR	E16	
34						E	5P5	7-9	18 B	.5*			3	522	38	75	R	E17	
35						E	5P6	7-9	18 B	2			3	410	10	59	R	E18	
36						E	ST5	5	18 B	.5			3	370	41	53	R	E19	
[illegible]						E	ST5	7-9	18 B	.5			3	370	22	53	R	E19	
38	WP-3	600 694	96	50	1000	E	5P5	7-9	18 E	5*			6	597	23	86	NR	E17	
39	WP-5 WP-6	750 920	100	52	1000	E	5P4	7-9	18 E	.5			2	572	-	92	N	E10	
40	WP-4	600 694	96	50	1000	E	5P7	7-9	E	5**			NO DATA					E21	

* Additional Sergene Application Under Radials
** Additional Sergene Application Over Intersection After Joint Construction

1. 600 lb Horizontal Ribbon Material

A variety of lap stitch patterns was tried using the 600 lb nominal strength specification material (types XI, Class 5) which had an actual strength of 694 lbs. Table E3 lists splice tensile trails using this material.

Trial 31 shows the effect of the radial stitching alone which yielded poor efficiency (34 percent). A variety of attempts to simplify lap stitching and to vary the load concentration points at the ends of stitching rows in Trials 27 through 37 were not successful in attaining the desired 85 percent efficiency. The primary failure mode encountered during these trials was "raking" or the pulling of warp yarns out of the joint leaving fill yarns in the stitching. This raking is combined with failures of some warp yarns usually at the ends of stitching rows. Figure E12 shows a joint sample which failed in this manner.

The force-deflection plot for the pictured sample (Figure E12) is typical of raking failures in that a peak is reached, warp yarns slip while load decreases, then load increases to a subsequent peak and more slippage occurs. The first force peak in this type of failure was considered as the breaking strength for the joint, even if subsequent force peaks are higher. No failures of this type were encountered during sled or drop tests of parachute test items.

Trials 34, 38, and 40 utilized additional sergene anti-fray application subsequent to stitching. The joints tested in Trials 34 and 38 were formed by applying one-half inch of anti-fray solution to the ends of the ribbons, then performing the lap stitching. Additional sergene was brushed on the area of the lap to be covered by the radial material. The radials were then attached using eight rows of straight stitching. A joint efficiency of 86 percent was attained with this construction in Trial 38 which used E thread in lap stitching. In Trial 34, where the smaller B thread was utilized in test item WP-4, included an additional coat of anti-fray solution subsequent to stitching the radials to the splice.

An example of a ribbon joint failure where warp yarn breakage was the primary failure mode (rather than raking) is shown in Figure E20. Here the force deflection plot shows one major peak where warp yarns failed within the joint. Subsequent slippage of the warp yarn ends did not cause secondary major force peaks.

The horizontal ribbon material used in Trial 39 resulted from an intermediate attempt to recreate the super efficient material of Trials 21 through 25. This material, although inefficient (64 percent) based on total yarn strength, produced a good joint efficiency (based on the two samples tested).

m. 400 lb Horizontal Ribbon Material Trials

The 400 lb ribbon (Type CI, Class 3) is the lowest strength, two-inch wide Kevlar-29 ribbon and as such is marginal from a weave stability standpoint. The warp yarn is the minimum size for Kevlar-29 yarns (200 denier). In an effort to prevent fill yarn migrations in the warp yarn direction during parachute operation, a coating was applied to the ribbon after weaving. A nylon dispersion commercially available as Genton 110 (from General Plastics Corporation of Bloomfield, NJ) was chosen as a result of efforts reported in Reference 6. The Genton coating was applied in two concentrations herein discussed as 50 and 100 percent. The Genton added little weight to the ribbon (1 and 2 percent of weight for 50 and 100 percent concentrations respectively). The Genton coating should not be confused with the "sergene" anti-fray adhesive coating which was procured from the same source.

Genton coated average ribbon strength was 456 lbs and 438 lbs for the 50 and 100 percent concentrations respectively.

Several lap stitch patterns tried in Trials 41 through 65 were unsuccessful in attaining desired joint efficiencies unless ribbon ends were coated well past the stitching area. The most successful lap stitching patterns provided a high number of total stitches, where stitching direction was primarily across the width of the horizontal ribbons.

Tensile test failures of 400 lb ribbon joints always involved raking, and yarn breaks were only observed in the most successful lap stitching/anti-fray treatment combinations.

Trials 64 and 65 indicate that efficiencies above 85 percent can be obtained using less lap stitching in the 100 percent Genton coated material.

An entry in Table E7 describes the ribbon splice used in test items IH-1 (bottom 17 ribbons), IH-2 and IH-3 (bottom 17 only). These splices were used without the benefit of pull tests. No ribbon splice failures were observed in these three test items as a result of sled and drop tests.

Actual failures in test item ribbon splices during drop and sled tests were seen only in test item IH-8 where the splices involved anti-fray coating beyond the joint stitching and where failures were located at the edges of the coating. This failure mode was also indicated by partial ribbon failures of this type in test items IH-7 and IH-9 where 400 lb coated ribbons had also been treated beyond the joint with anti-fray solution. Failures at the edge of the coating were not evident in the tensile testing of sample joints and are thought to have resulted from the dynamic conditions and loading in directions other than parallel to the horizontal ribbons.

TABLE E4

Sheet 1 of 2

RIBBON SPLICES FOR 400 LB 50% COATED [illegible]LAR-29

Trial Nr	Used In Test Item	Ribbon Strength Nominal Actual (lbs)	Material: Warp Ends	Material: Fill Ends Per (Inch)	Radial Single Ply Nominal Strength (Lbs)	THREAD	Lap Stitching: Pattern	Lap Stitching: Spacing	THREAD	Anti Fray (in)	Test Apparatus: Jaw	Test Apparatus: Machine	NR TESTS	Joint Sample Results: Breaking Strength (Lbs) Ave.	Breaking Strength Std Dev.	Efficiency %	Fail Code	Fig XX	Comment or Note
41		400 456	60	50	1000	B	5P1	7-9	B	1	EDP	D	5	219	12	48	R	E3	Severe Raking
42		400 456	60	50	1000	B	4P1	7-9	B	1	EDP	D	3	227	6	50	R	E7	
43						B	5P1	7-9	B	5	EDP	D	5	304	4	67	R	E3	
44						B	5P2	7-9	B	1	EDP	D	3	233	23	51	R	E12	1000 lb Ribbon Reinf. Ply in Splice
45						B	BX	7-9	B	5	EDP	D	3	346	12	76	NR	E22	No Failure of Selvage Yarns
46						B	BX	7-9	B	3½	EDP	D	2	358	-	78	R	E22	Center Yarns Slip
47						B	B4R	7-9	B	5	EDP	D	3	323	23	71	NR	E23	
48						B	DBX1	7-9	B	3½	EDP	D	2	375	-	82	R	E24	Center Yarns Slip
49						B	DBX1	7-9	B	5	EDP	D	3	365	40	80	NR	E24	
50						B	DBX1	7-9	B	6	EDP	D	5	299	16	66	NR	E24	
51						B	DBX2	7-9	B	6	EDP	D	3	365	13	80	NR	E25	
52	Delete																		
53						B	B3P	7-9	B	3½	EDP	D	2	305	-	67	R	E26	

TABLE E4 (Concluded)

Sheet 2 of 2

Trial Nr	Used In Test Item	Ribbon Strength Nominal Actual (lbs)	Material Warp Ends	Material Fill Ends Per (Inch)	Radial Single Ply Nominal Strength (Lbs)	THREAD	Lap Stitching Pattern	Lap Stitching Spacing	THREAD	Anti Fray (in)	Test Apparatus Jaw	Test Apparatus Machine	NR TESTS	Joint Sample Results Breaking Strength (Lbs) Ave.	Breaking Strength (Lbs) Std Dev.	Efficiency %	Fail Code	Fig XX	Comment or Note
54		400 456	60	50	1000	B	S5P	7-9	B	5½	EDP	D	3	315	43	69	NR	E27	
55						B	S7P	7-9	B	6	EDP	D	3	360	66	79	NR	E28	
56						B	S9P	7-9	B	6	EDP	D	3	320	53	70	R	E29	
57						B	C12P	7-9	B	6	EDP	D	6	362	29	79	R	E30	
58						B	O12P	7-9	B	6	EDP	D	6	363	36	80	R	E31	
59						B	O12P	7-9	B	.5	EDP	D	3	187	12	41	R	E31	
60						B	O12P	7-9	B	3	EDP	D	1	365	-	80	R	E31	
61						B	C12P	7-9	B	3	↓	↓	11	352	18	77	R	E30	
62						B	O10P	7-9	B	3	↓	↓	3	306	15	67	R	E32	
63	3H7 & 3H8	400 456	60	50	1000	B	C10P	11-13	B	6	EDP	D	3	393	6	86	RN	E33	Used this Joint in Test Items

TABLE E5

RIBBON SPLICES FOR 400 LB 100% GENTON COATED KEVLAR-29

Trial Nr	Used In Test Item	Ribbon Strength Nominal Actual (lbs)	Material Warp Ends	Material Fill Ends Per (Inch)	Radial Single Ply Nominal Strength (Lbs)	THREAD	Lap Stitching Pattern	Lap Stitching Spacing	THREAD	Anti Fray (in)	Test Apparatus Jaw	Test Apparatus Machine	Joint Sample Results NR. TESTS	Breaking Strength (Lbs) Ave.	Breaking Strength (Lbs) Std Dev.	Efficiency %	Fail Code	Fig XX	Comment or Note
E4		400 458	60	50	1000	8	CIOP	11-13	8	6	EDP	D	3	393	25	.90	N	E33	Failed at End of Sergene Coating
E5	3H-9						CIOP	11-13	8	6	EDP	D	3	420	17	.96	N	E33	Stitch Spacing in (Failure as above) Radial changed from 7-9 to 11-13

TABLE E6

RIBBON SPLICES FOR UNCOATED 400 LB KEVLAR-29

Trial Nr	Used in Test Item	Ribbon Strength Nominal Actual (lbs)	Material: Warp Ends	Material: Fill Ends Per Inch	Radial Single Ply Nominal Strength (Lbs)	THREAD	Lap Stitching: Pattern	Lap Stitching: Spacing	THREAD	Anti Fray (in)	Test Apparatus: Jaw	Test Apparatus: Machine	Joint Sample Results: NR TESTS	Breaking Strength (Lbs): Ave.	Breaking Strength (Lbs): Std Dev.	Efficiency %	Fail Code	Fig XX	Comment or Note
	JH 1-B JH 2 JH 3-B	400 480	60	50	1000	B	EP1	7-9	B	5				NO DATA				E3	

TABLE E7

SUMMARY OF RIBBON SPLICES USED IN KEVLAR-29
TEST ITEM PARACHUTES

Used In Test Item	Ribbon Strength Nominal Actual (lbs)	Material		Radial Single Ply Nominal Strength (Lbs)	THREAD	Lap Stitching		THREAD	Anti Fray (in)	Test Apparatus		Joint Sample Results					Fig XX	Comment or Note	Test Item Joint Failure
		Warp Ends	Fill Ends Per (Inch)			Pattern	Spacing			Jaw	Machine	NR TESTS	Breaking Strength (Lbs) Ave.	Std Dev.	Efficiency %	Fail Code			
1 & 2	1000 1001	164	56	1000	B	5P1	7-9	E	.5	EDP	D	3	867	29	87	N	E3		
3 & 4	900 980	142	51	900	B	5P1	7-9	E	.5	EDP	D	3	950	43	97	N	E3		
5	600 789	98	55	600	B	5P1	7-9	E	N/A	EDP	D	3	670	20	85	N	E3		
6M	1000/1038 800/915	164 100	56 52	800 800	B B	5P1 5P1	7-9 7-9	E B	N/A 5	EDP EDP	D D	3 3	1125 783	0 14	108 86	N N	E3 E3		
MARS	1000/1038 800/801	164 100	56 52	800 800	B B	5P1 5P1	7-9 7-9	E B	N/A 5	EDP EDP	D D	3 3	1125 725	0 -	108 91	N N	E3 E3		
IH-1	540/650 400/480	82 60	51 50	1000	B	5P5	7-9	B	.5*	NO DATA							E17		
IH-2	400 480	60	50	1000	B	5P5	7-9	B	.5*	NO DATA							E17		
IH-3	600/780 400/480	90 60	51 50	1000	B	5P5	7-9	B	.5*	NO DATA							E17		
IH-5 IH-6	1000 1038	164	56	1000	B	5P1	7-9	B	1	EDP	D	9	951	41	92	N	E3		
IH-7 IH-8	400 50% 456 Genton Coated	60	50	1000	B	C10P	11-13	B	6	EDP	D	3	393	6	86	RN	E33		At end of Sergene Dips
IH-9	400 100% 438 Genton Coated	60	50	1000	B*	C10P	11-13	B	6	EDP	D	3	420	17	96	N	E33	Failure at ends of Sergene Coating	
WP-1 WP-2	1000/1088 1000/1196	150	45	1500	B E	5P1 WW	7-9	B 18 E	.5	EDP UDP	D I	3 6	1042 1035	? 35	96 91	N	E3 E6		
WP-3 WP-4	600 694	96	50	1000	E	5P5	7-9	18 E	.5*			6	597	23	86	R	E17		
WP-5 WP-6	750 620	100	52	1000	E	5P4	7-9	18 E	.5	UDP	I	2	572	-	92	N	E10		

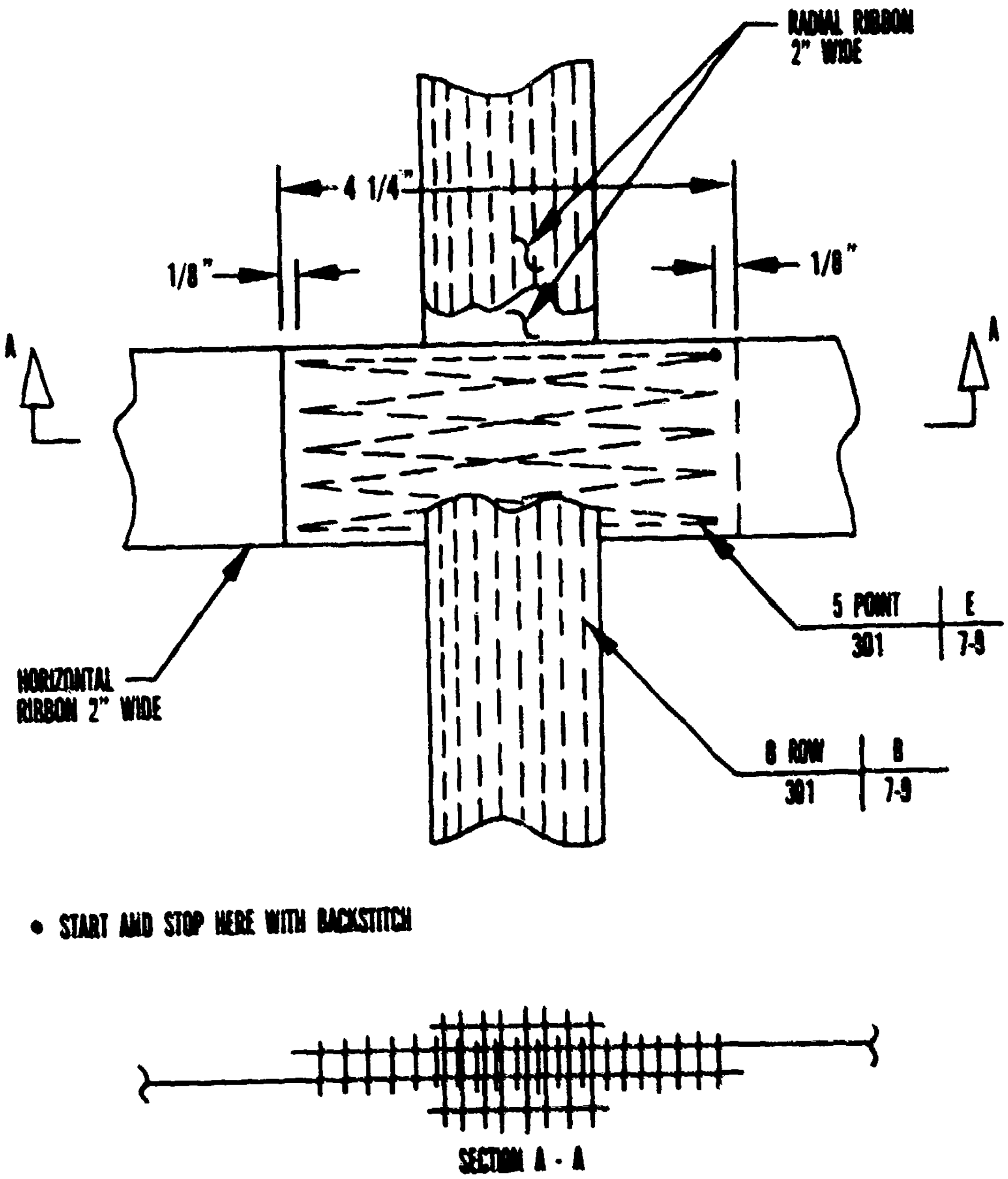


Figure E3 PATTERN 5P1

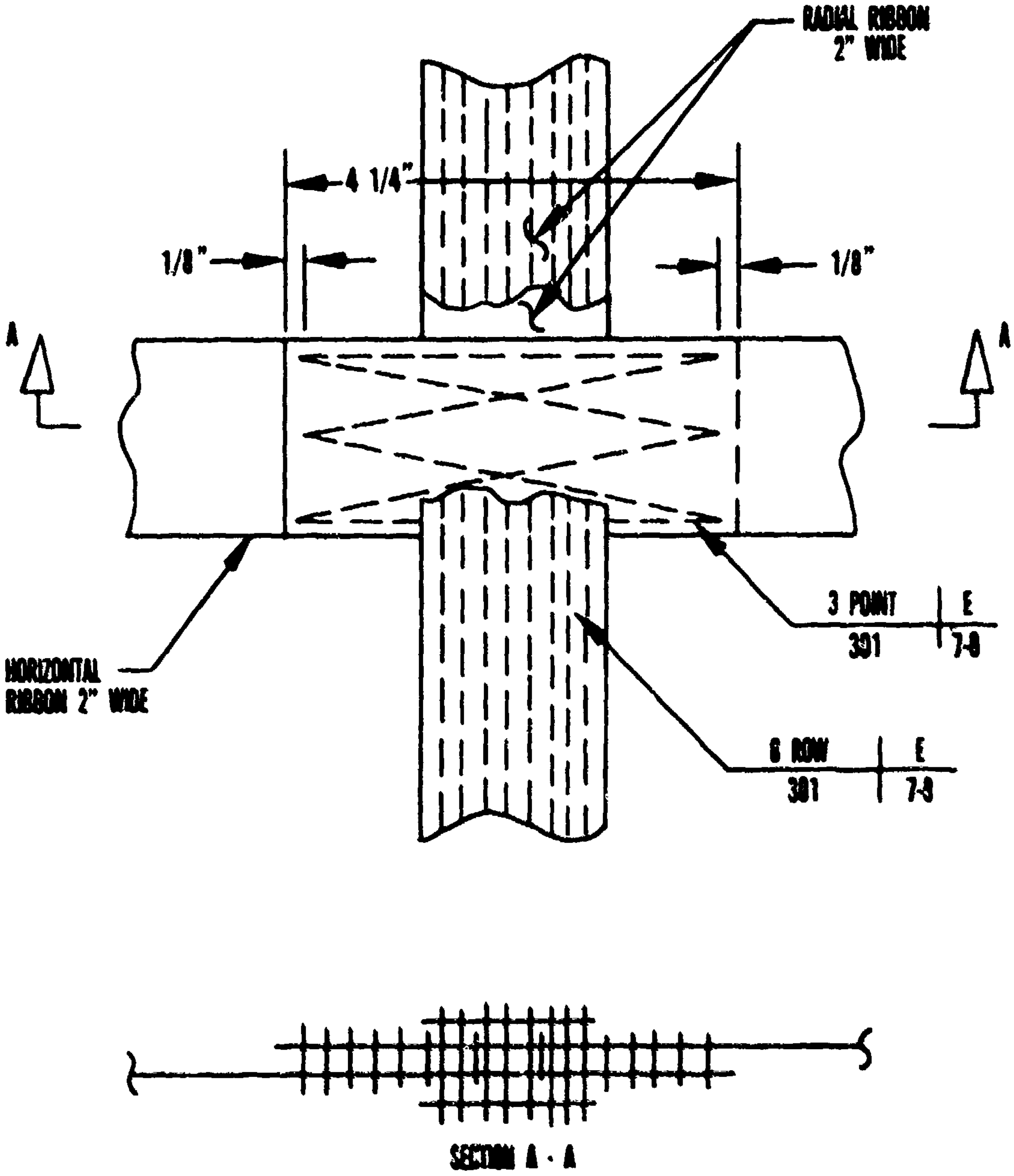


Figure E4 PATTERN 3P1

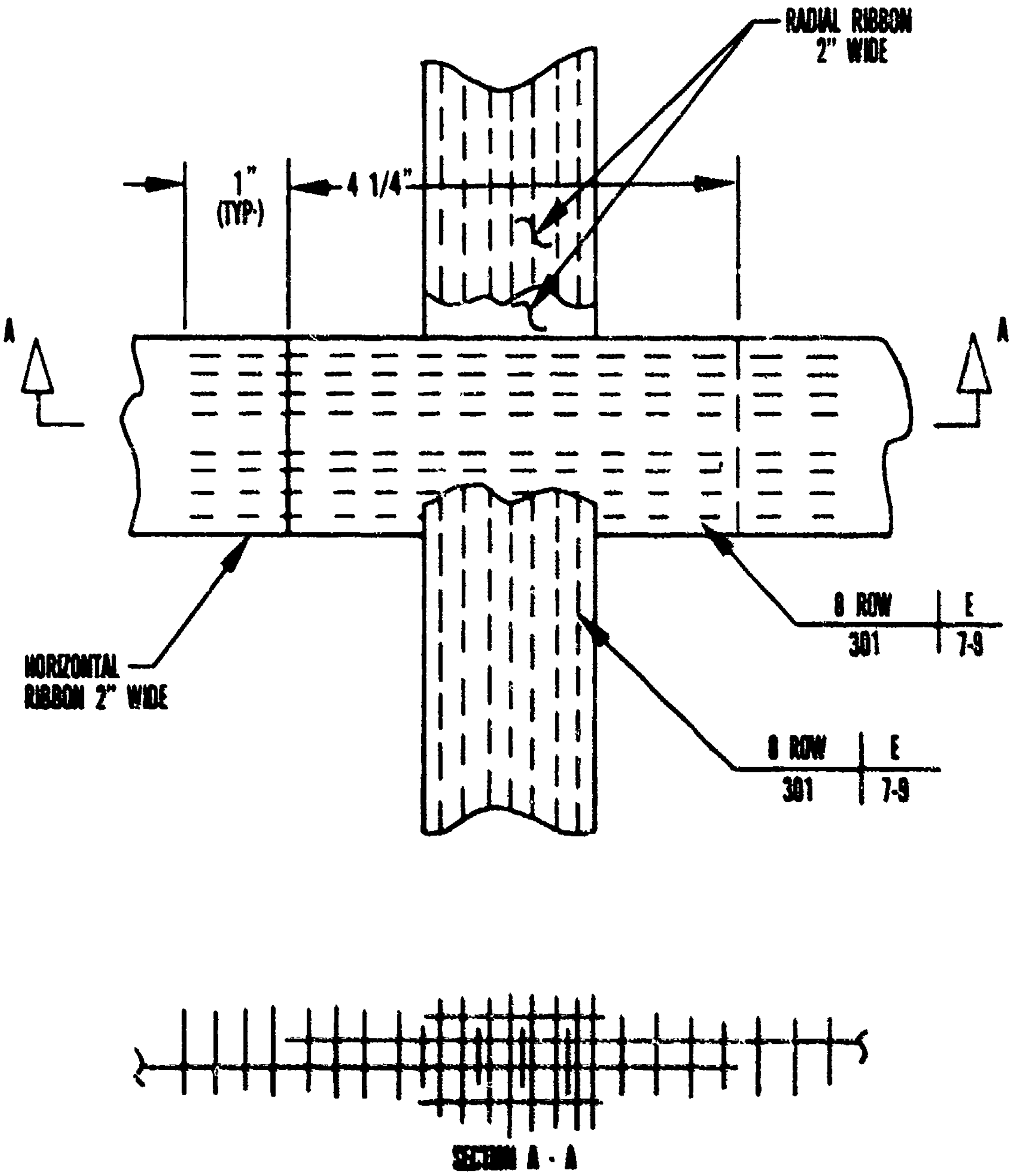


Figure E5 PATTERN 8R

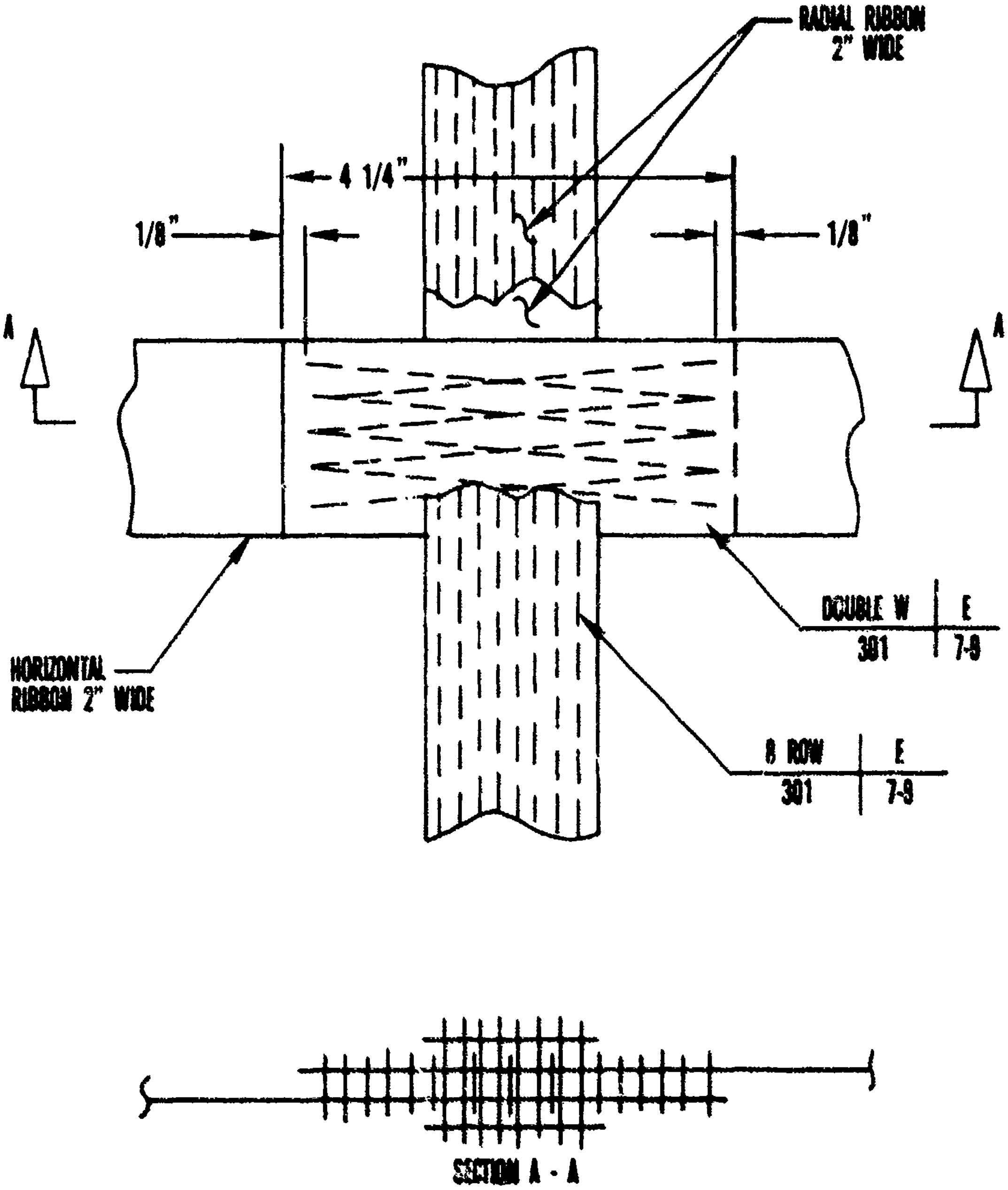


Figure E6 PATTERN WW

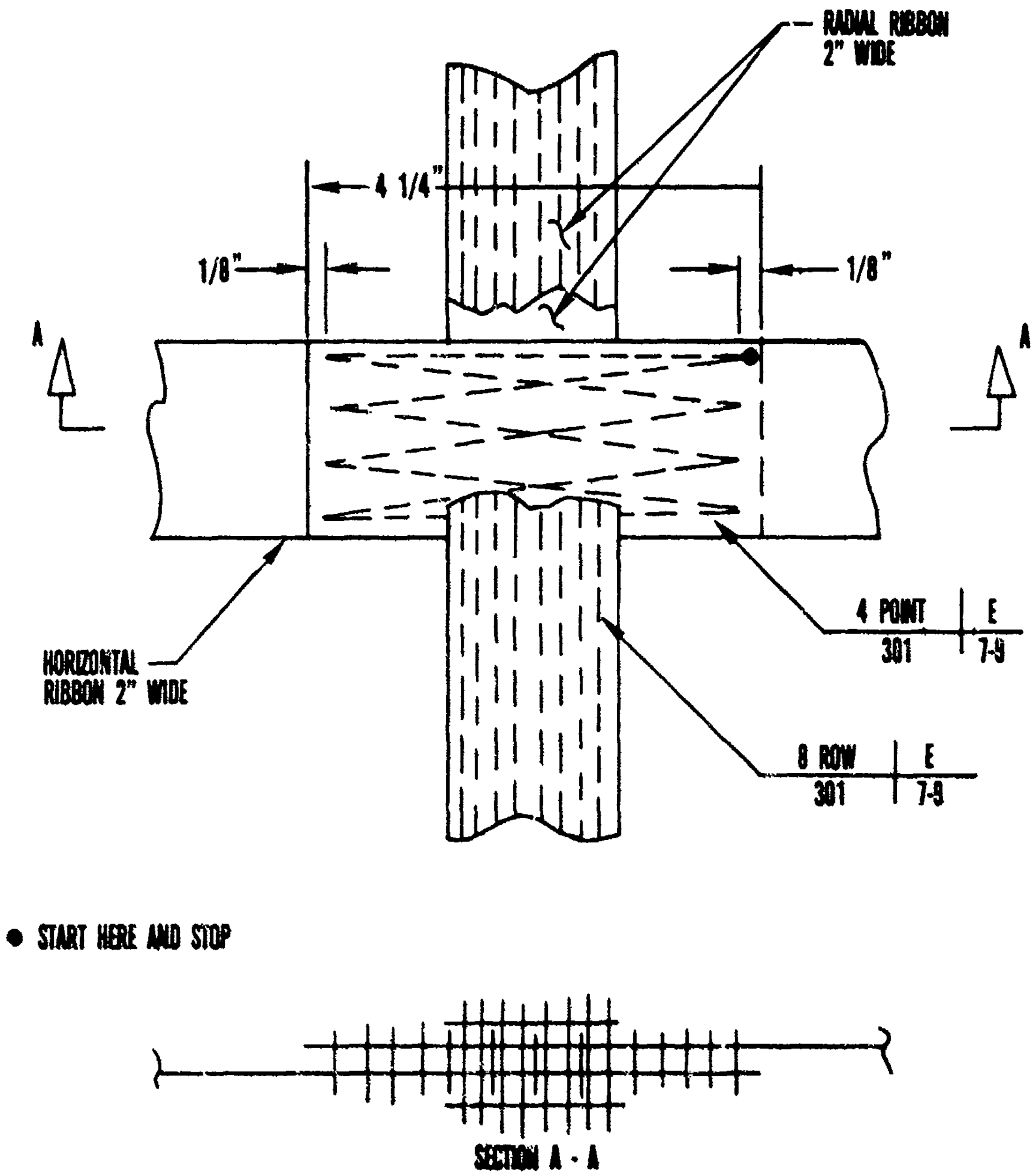
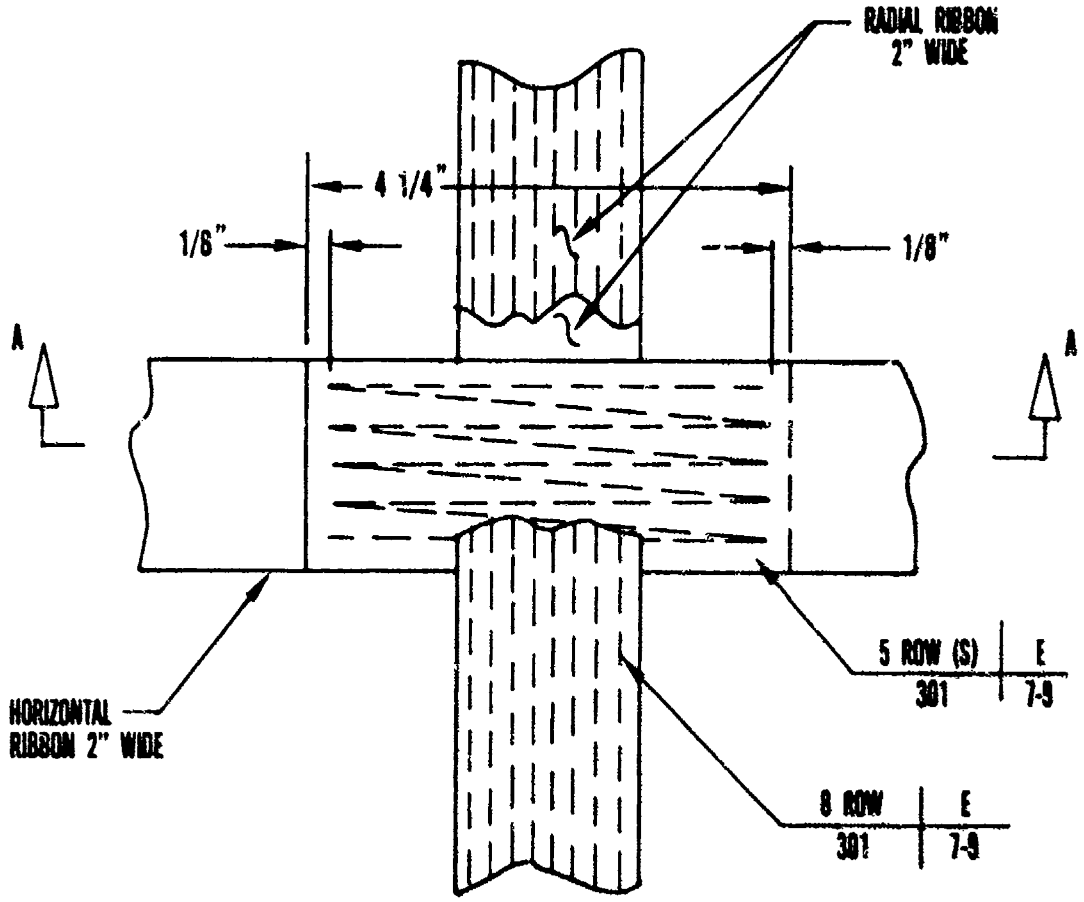


Figure E7 PATTERN 4P1



(S) 5 PARALLEL ROWS OF STITCHING CONNECTED BY DIAGONAL STITCHING

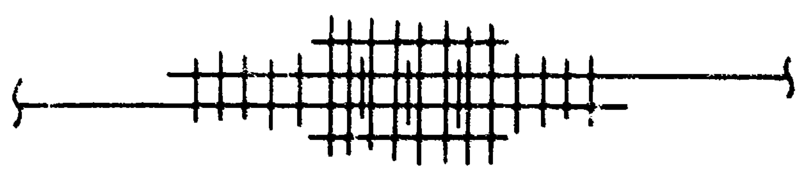


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Figure E8 PATTERN 52

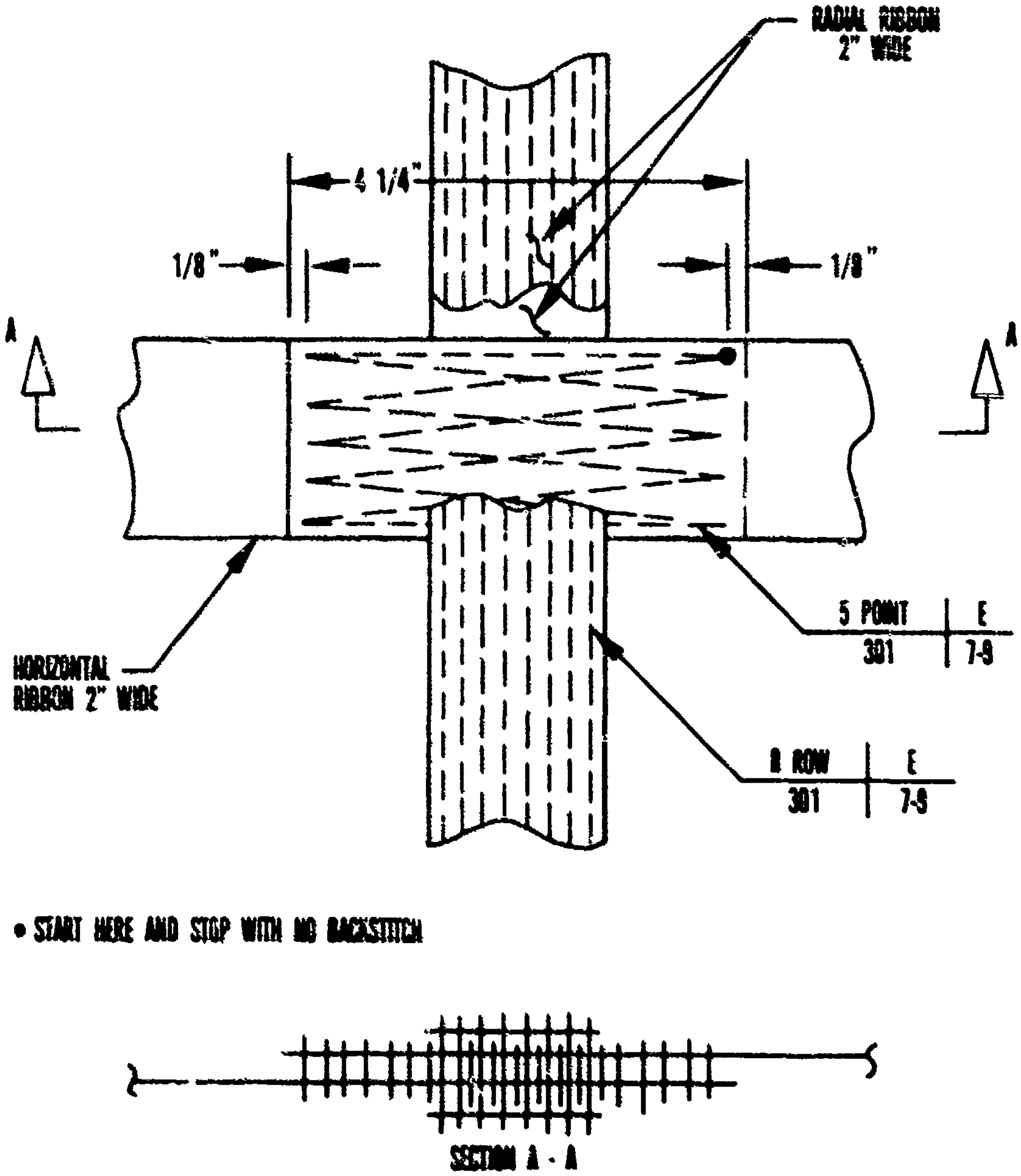
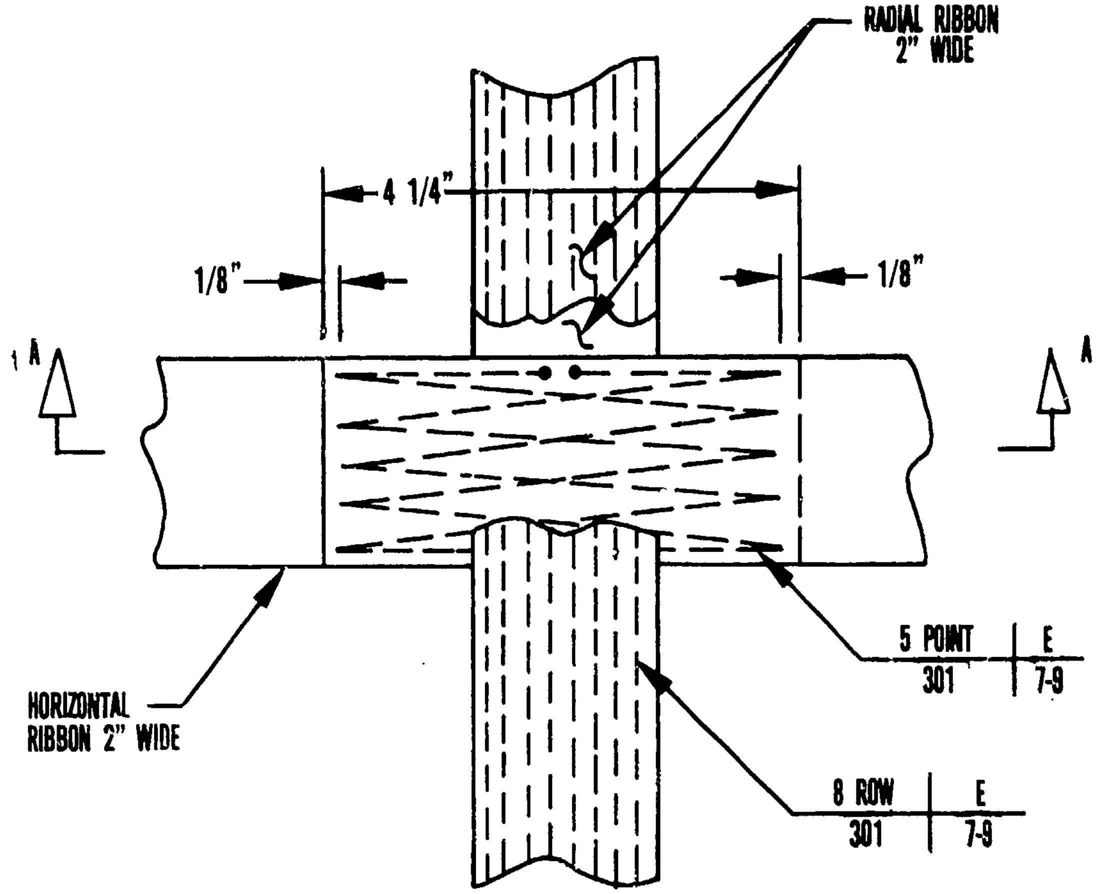


Figure E9 PATTERN 5P3



• START AND STOP AT MID-POINT UNDER RADIAL AS SHOWN. NO BACKSTITCH

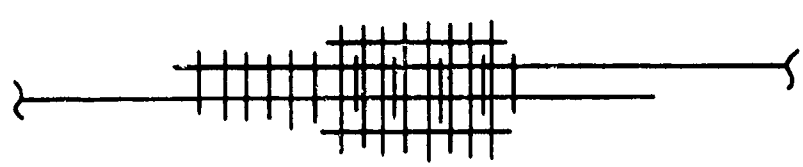


Figure E10 **PATTERN 5P4**

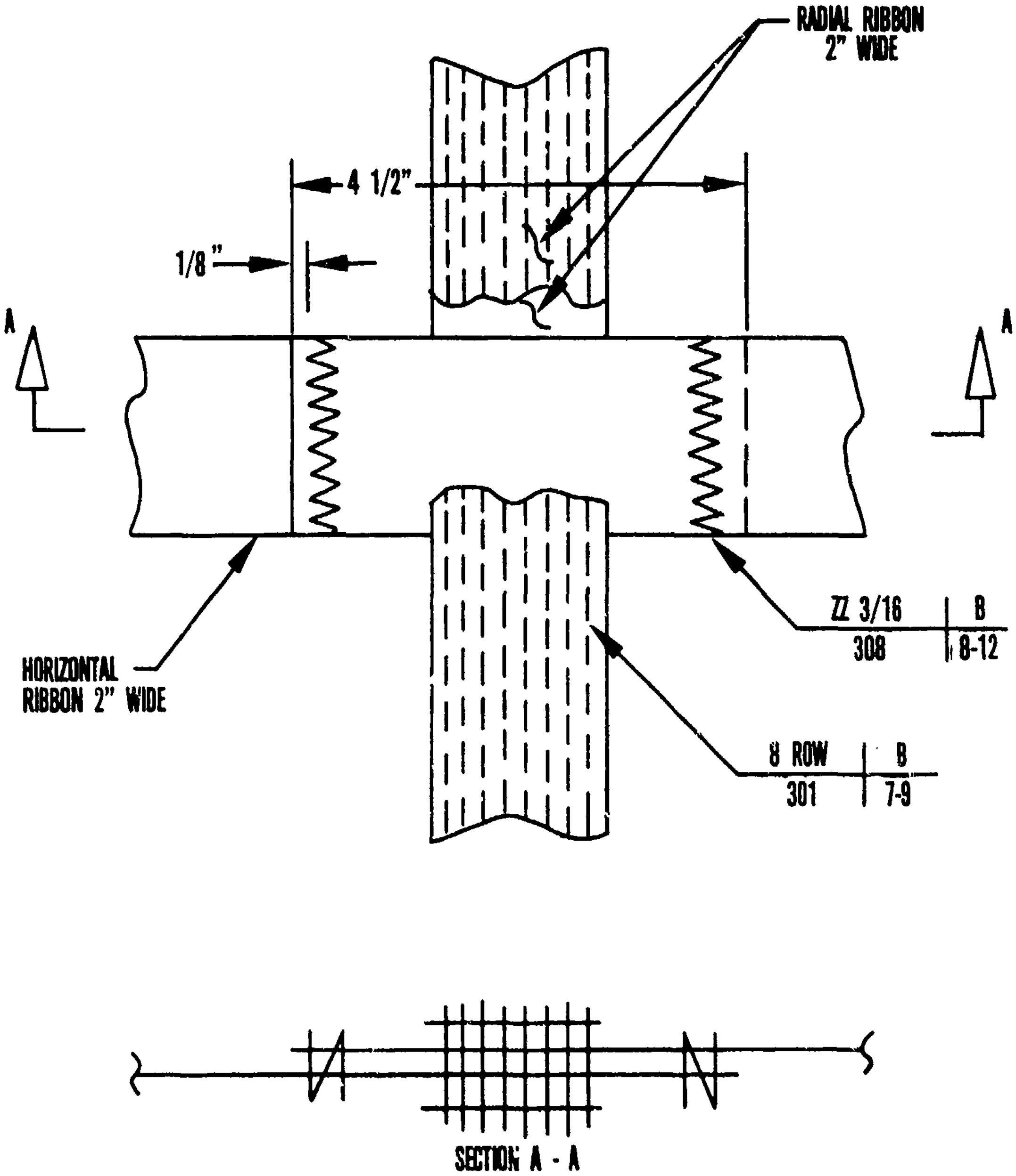


Figure E11 **PATTERN 2ZZ**

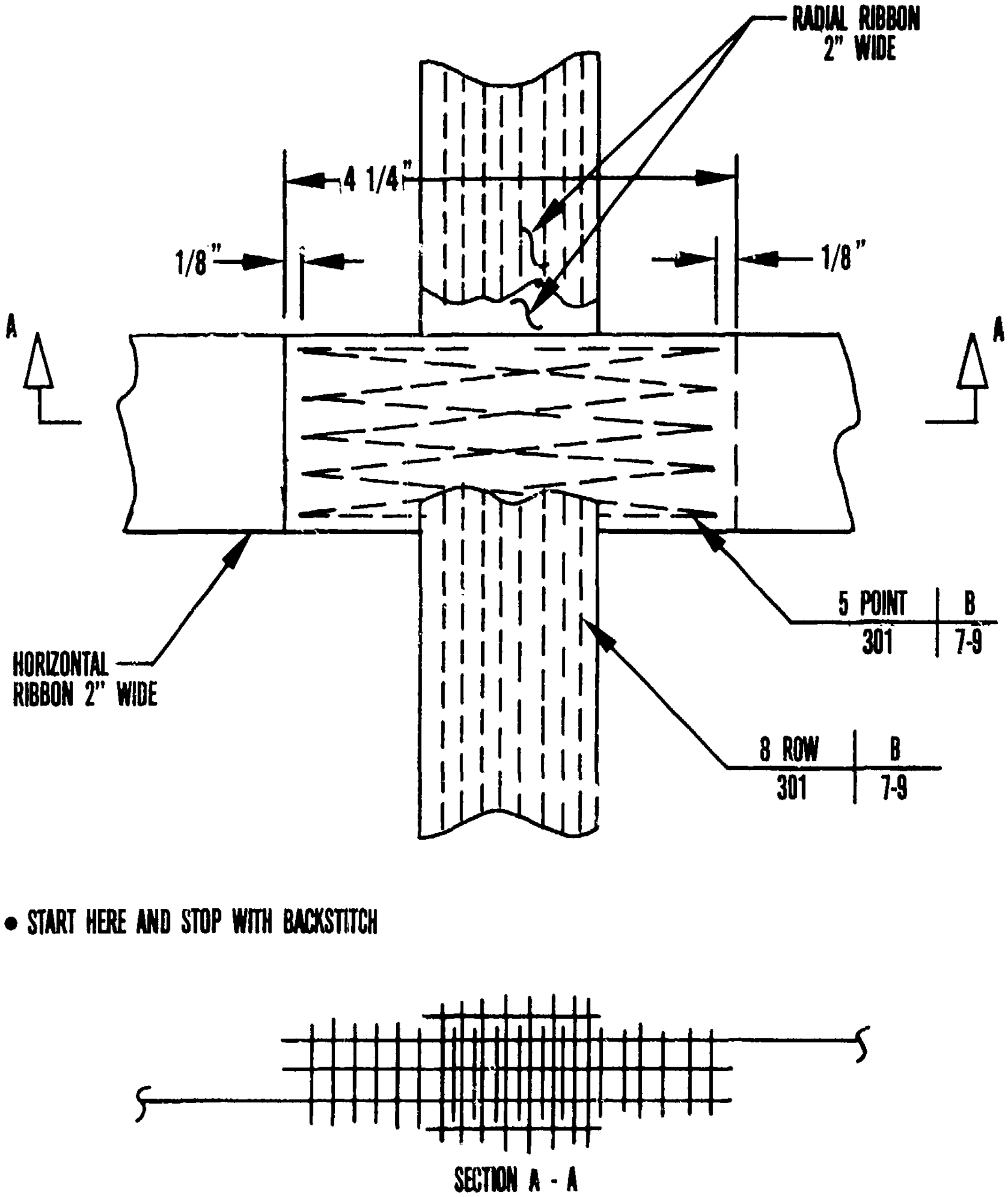


Figure E12 **PATTERN 5P2**

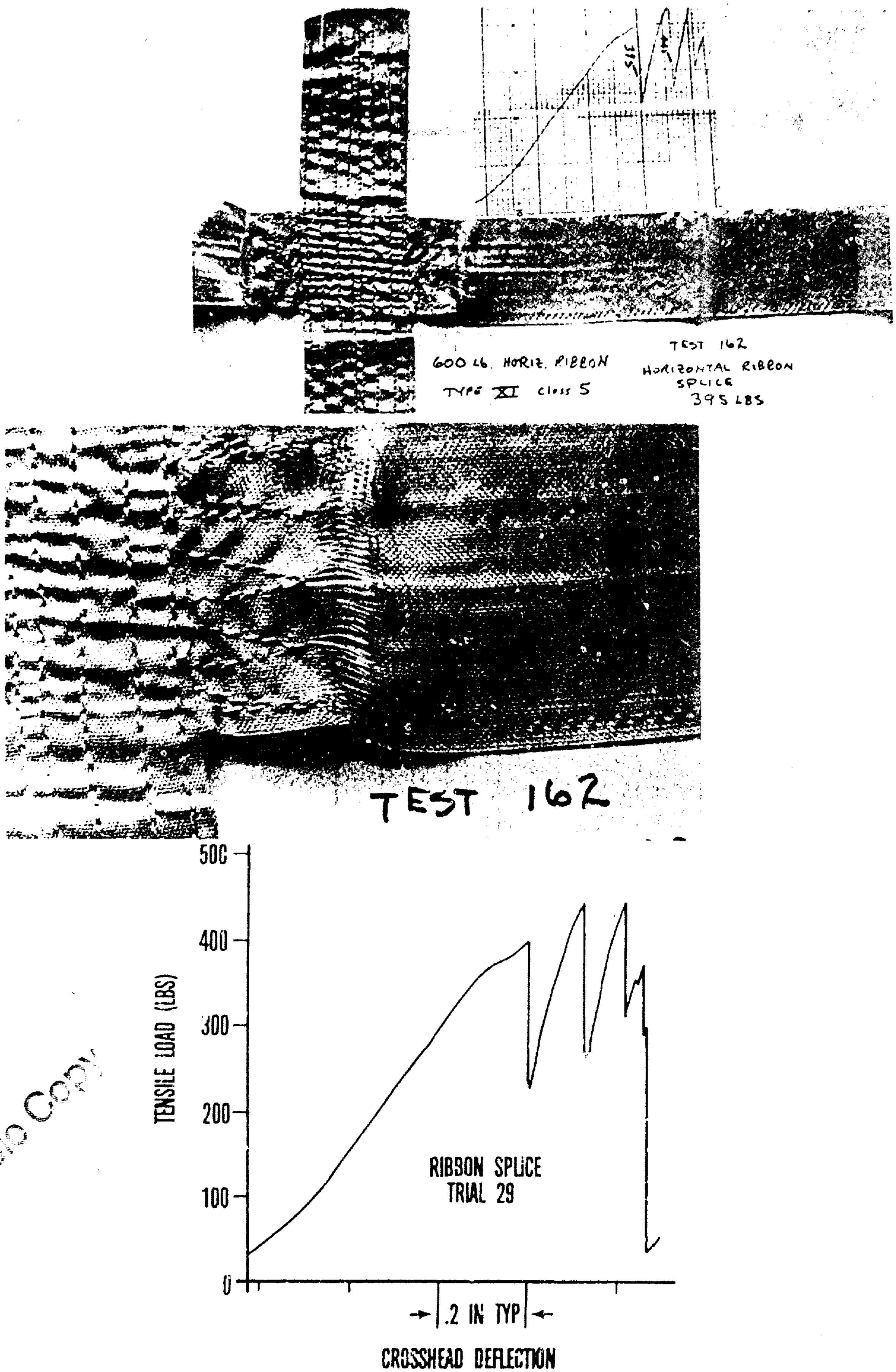


Figure E 13. Horizontal Ribbon Splice Trial 29. Yarn Raking.

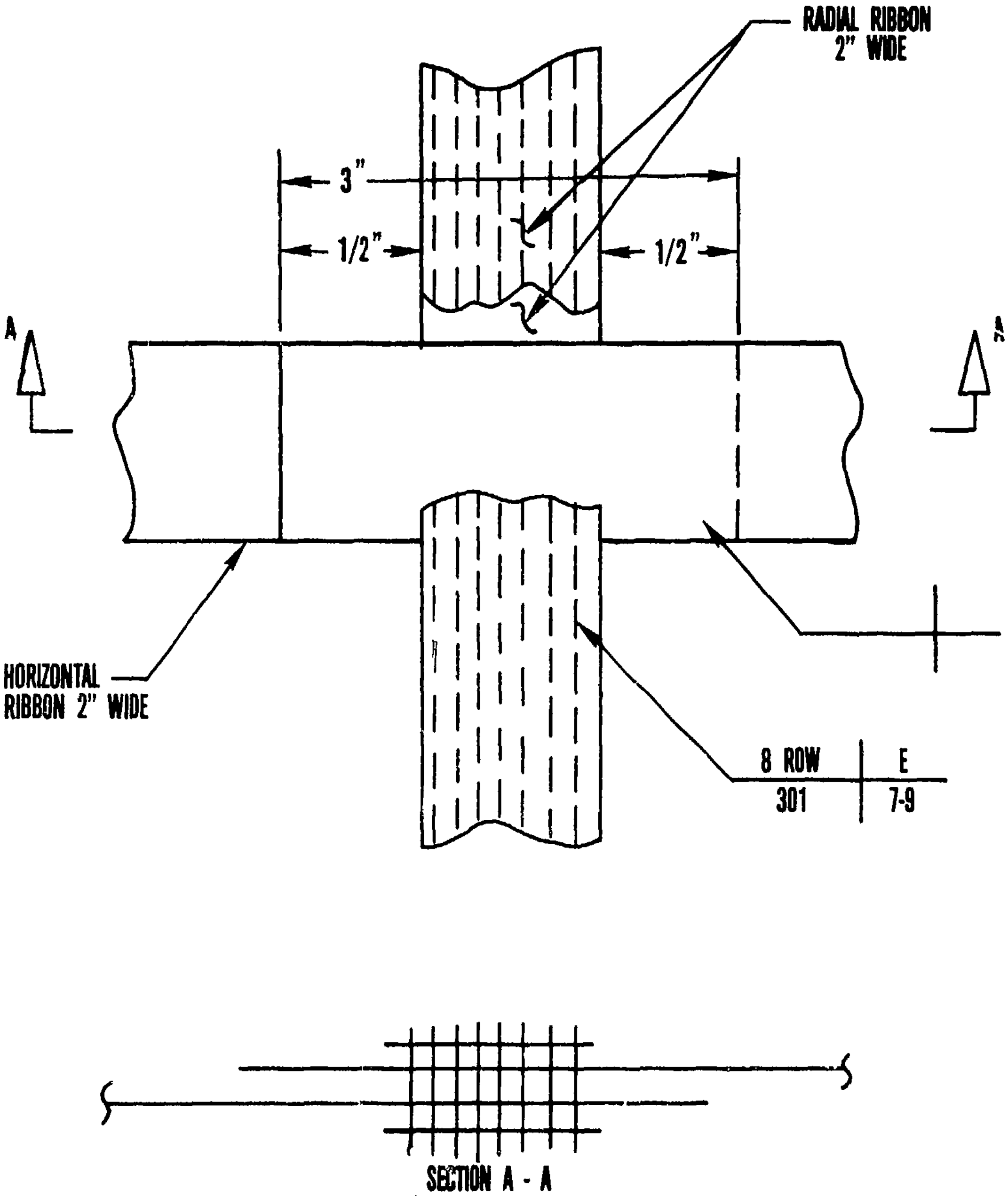


Figure E14 PATTERN NIL

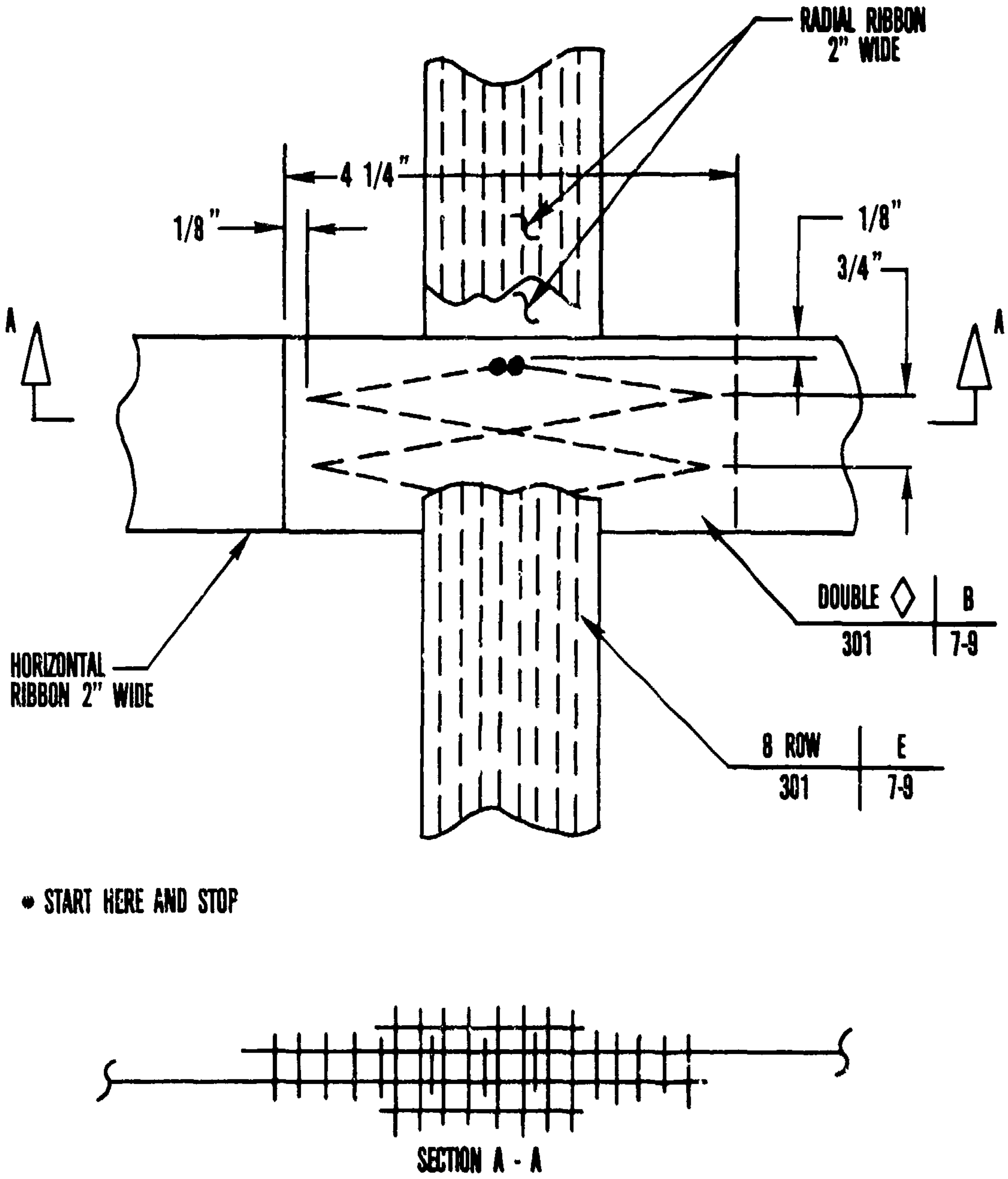


Figure E15 **PATTERN DD1**

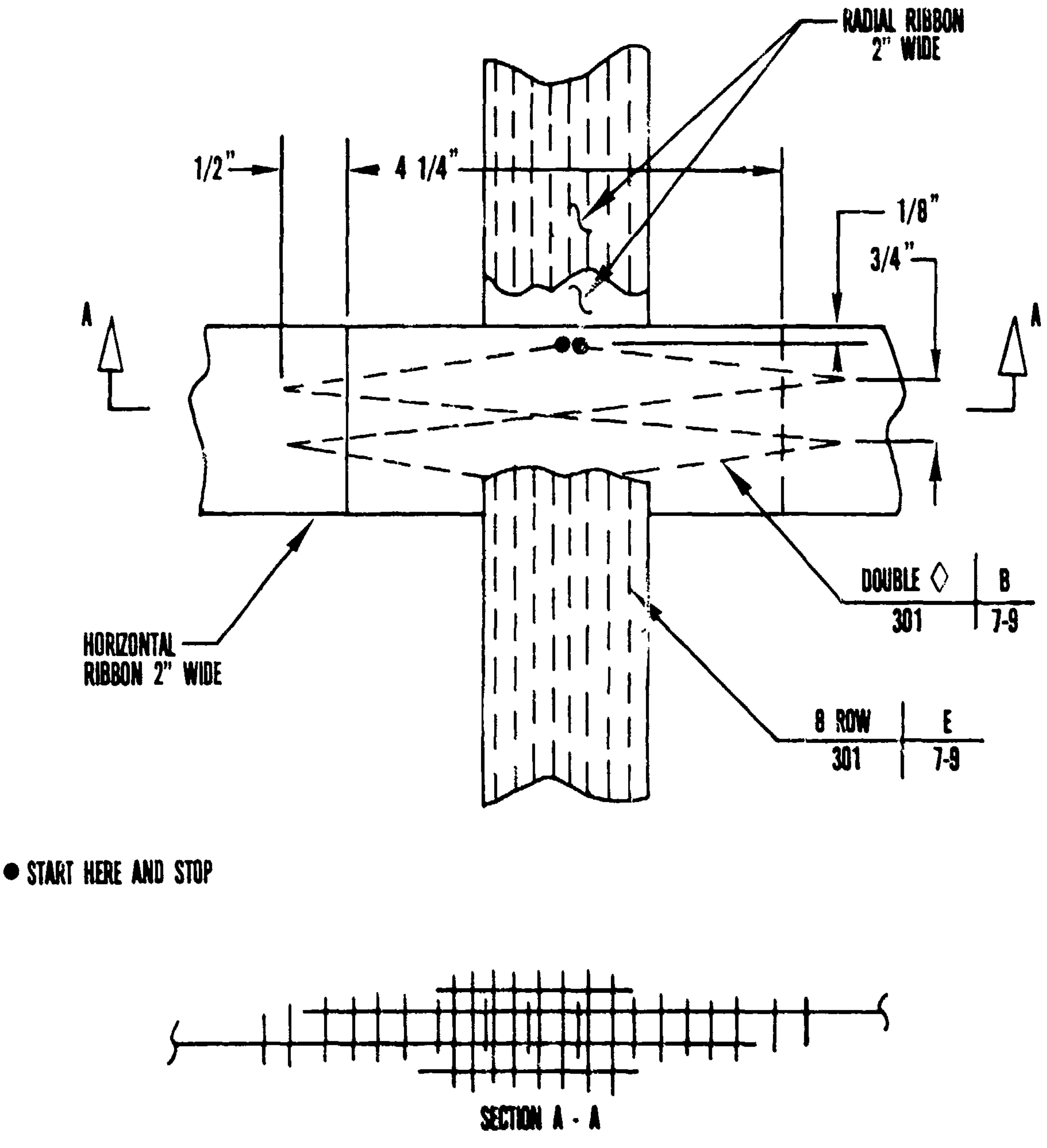
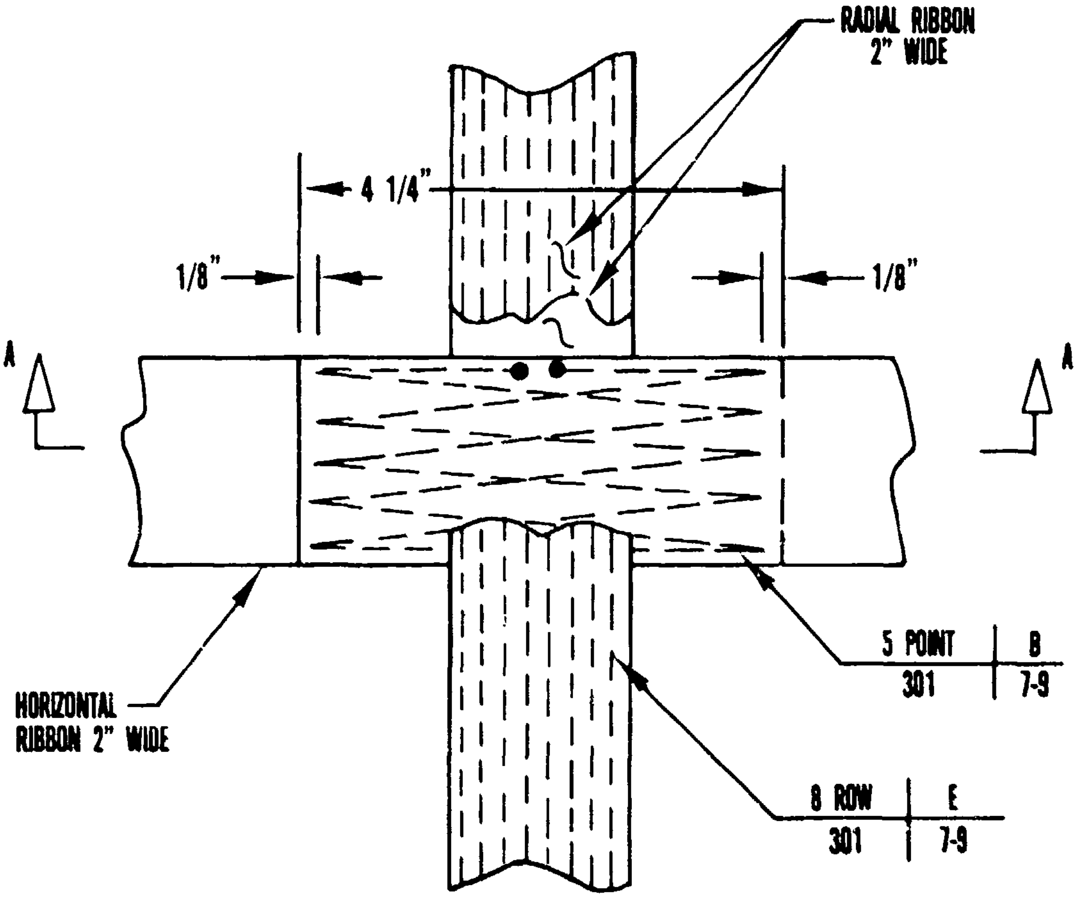


Figure E16 **PATTERN D02**



● START AND STOP AT MID-POINT UNDER RADIAL AS SHOWN. NO BACKSTITCH SERGENE LAP STITCHED AREA BEFORE STITCHING ON RADIALS

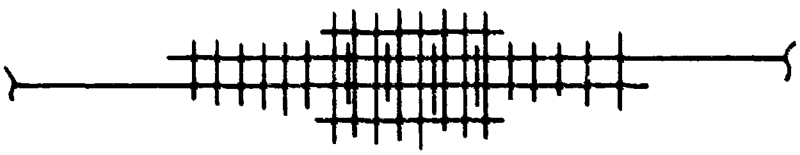


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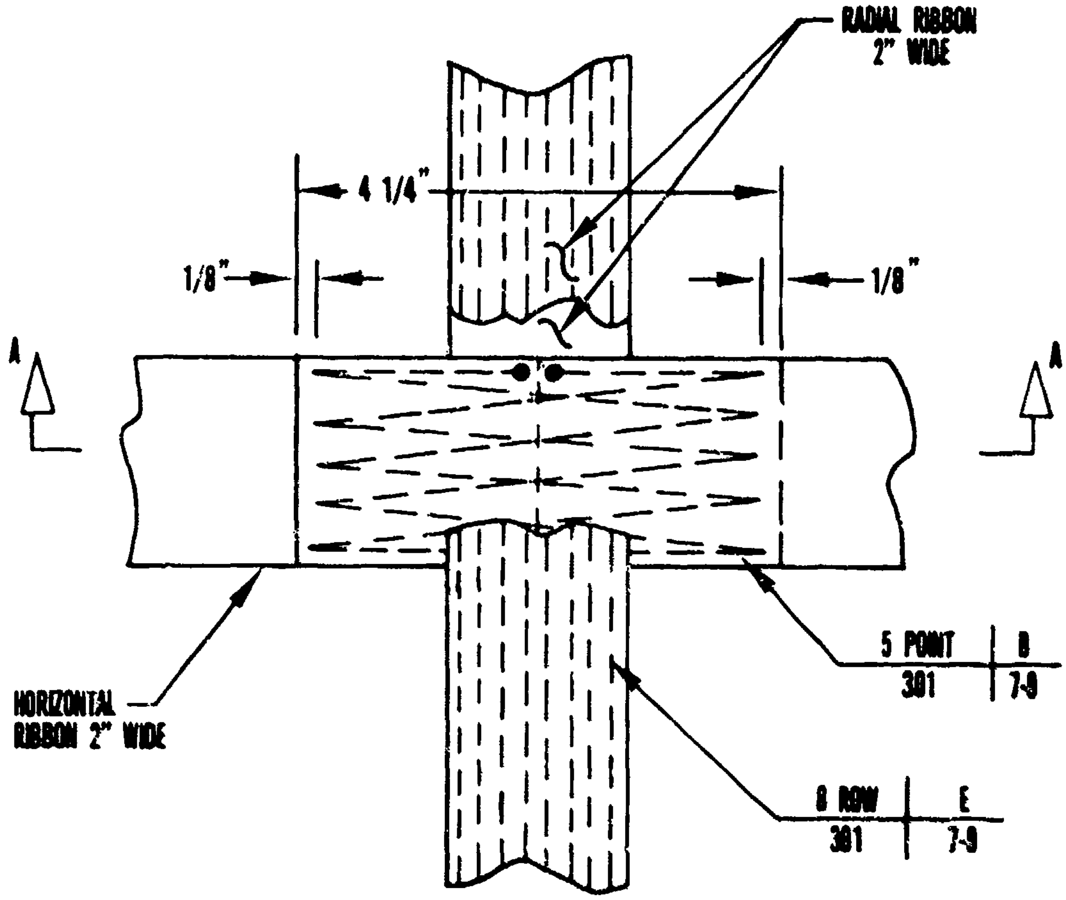
Figure E17 PATTERN SP5



● START AND STOP AT MID-POINT UNDER RADIAL AS SHOWN. NO BACKSTITCH

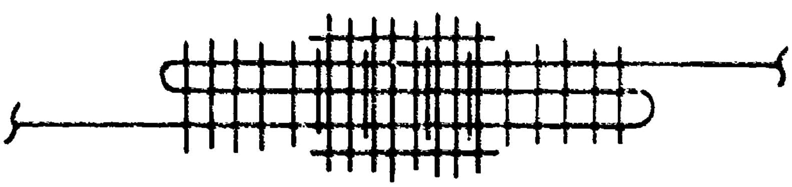

SECTION A - A

Figure E18 PATTERN 5PG

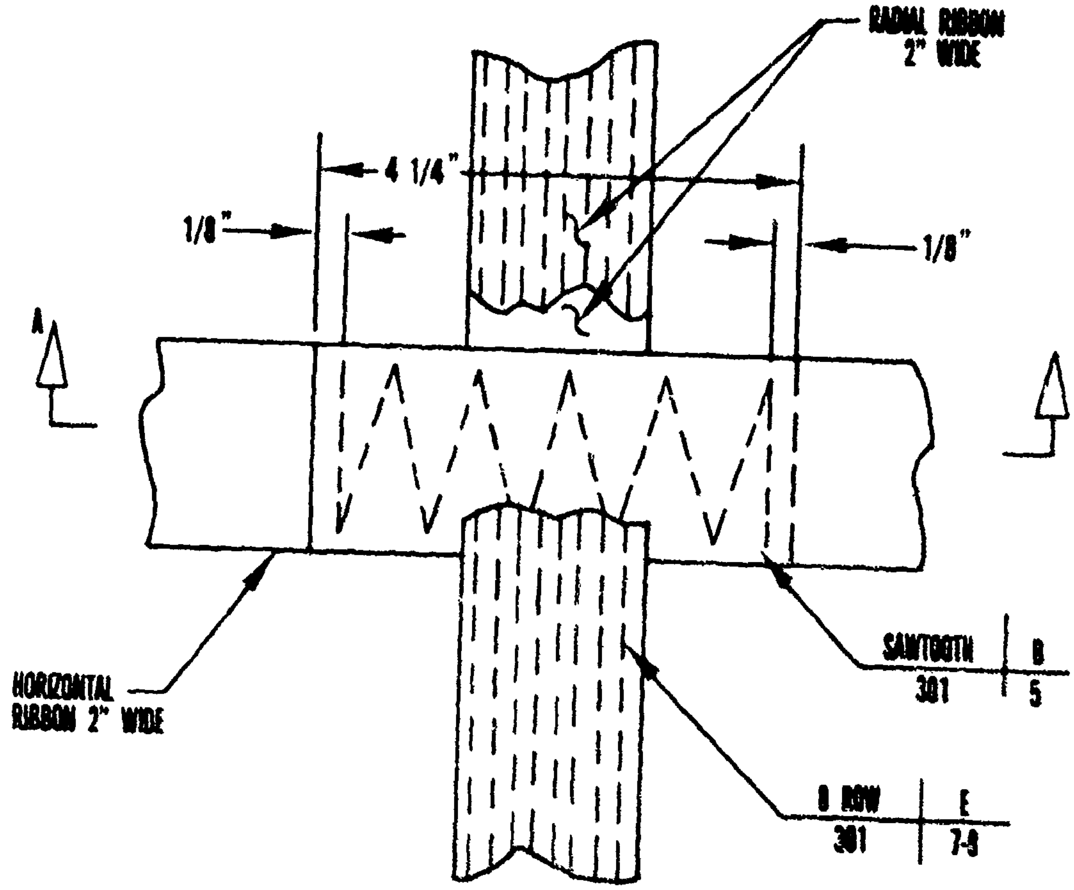


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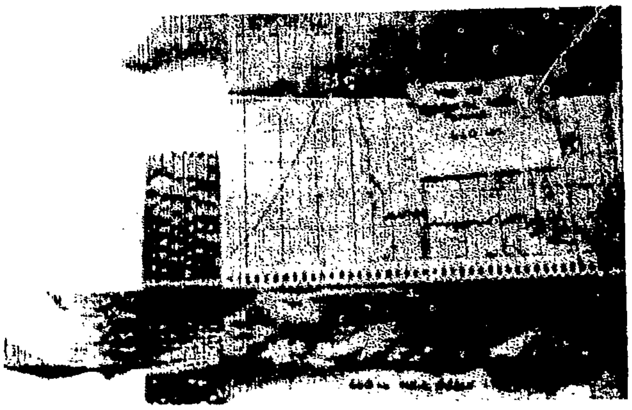
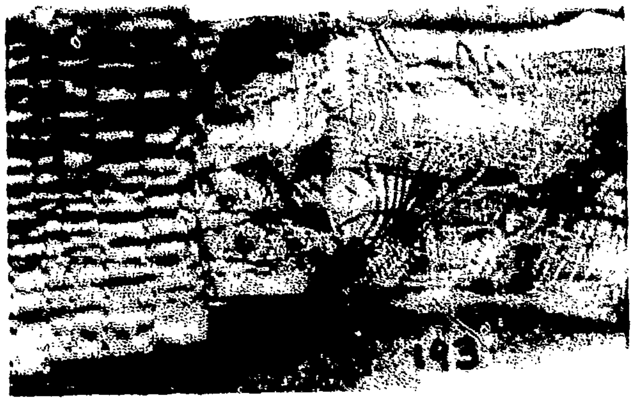
Figure E19 PATTERN ST5





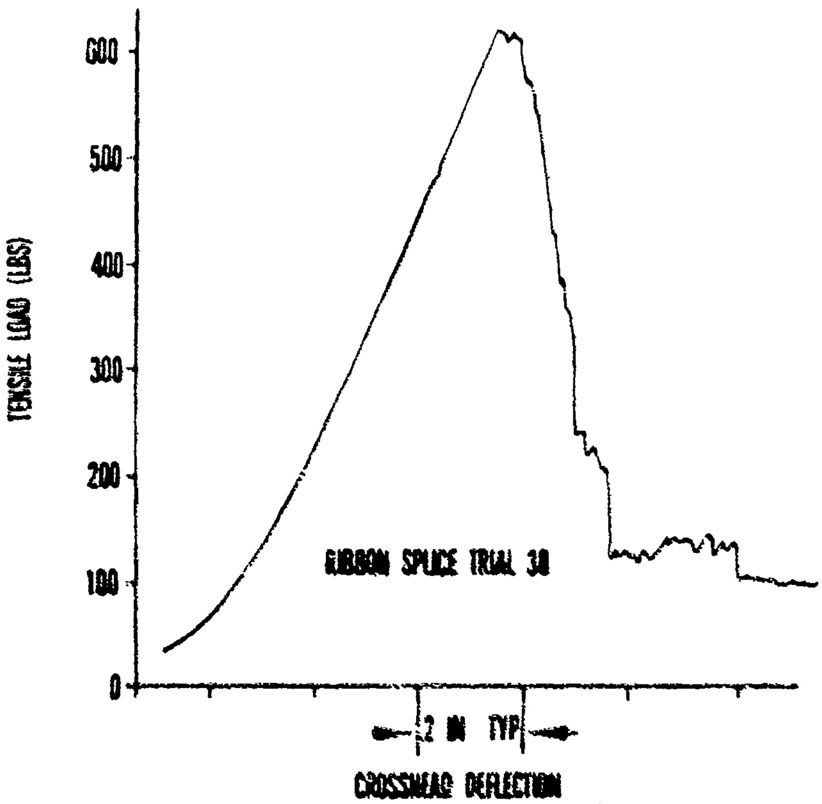
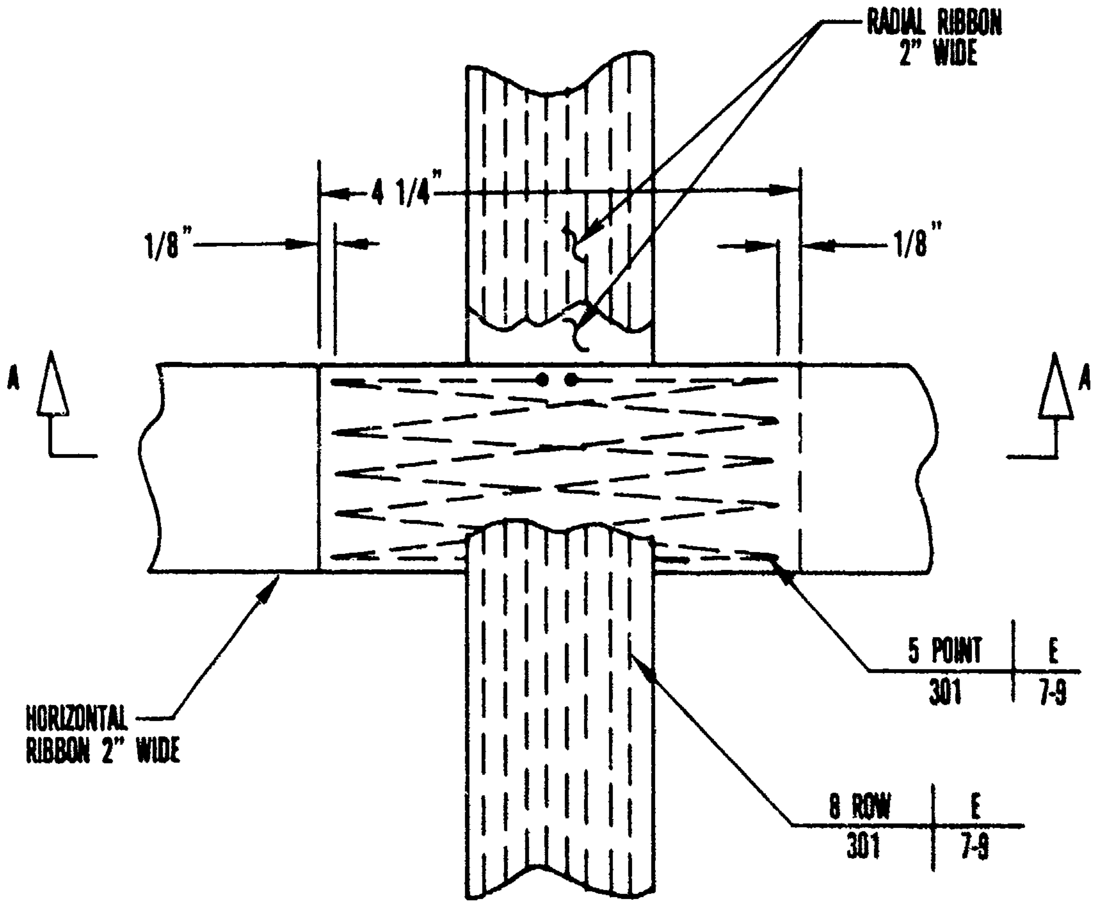


Figure E 20. Horizontal Ribbon Splice Trial 38, Warp Yarn Failure.



- START AND STOP AT MID-POINT UNDER RADIAL AS SHOWN. NO BACKSTITCH

SERGENE 2" WIDE AREA OF COMPLETED SPLICE UNDER RADIAL BEFORE STITCHING RADIAL.
AFTER STITCHING RADIAL, SERGENE BOTH SIDES OF STITCHED RADIAL WHERE IT CROSSES RIBBON.

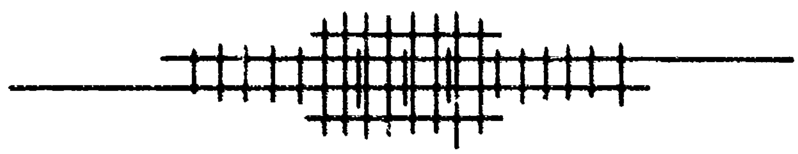


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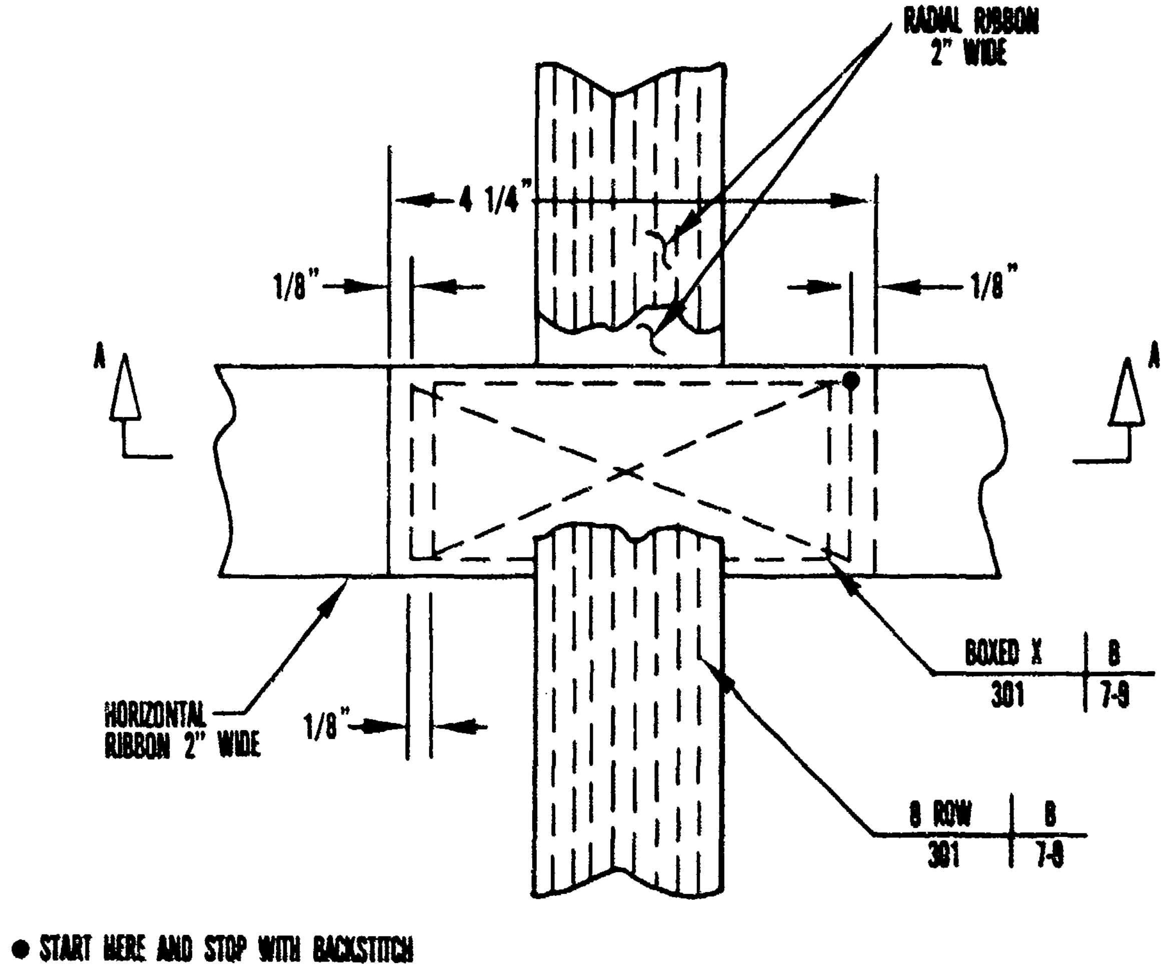
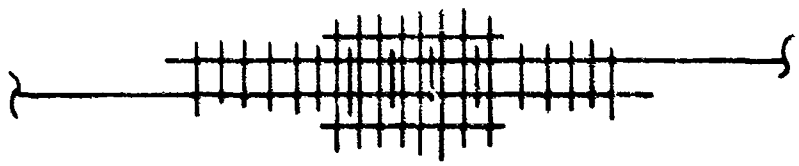
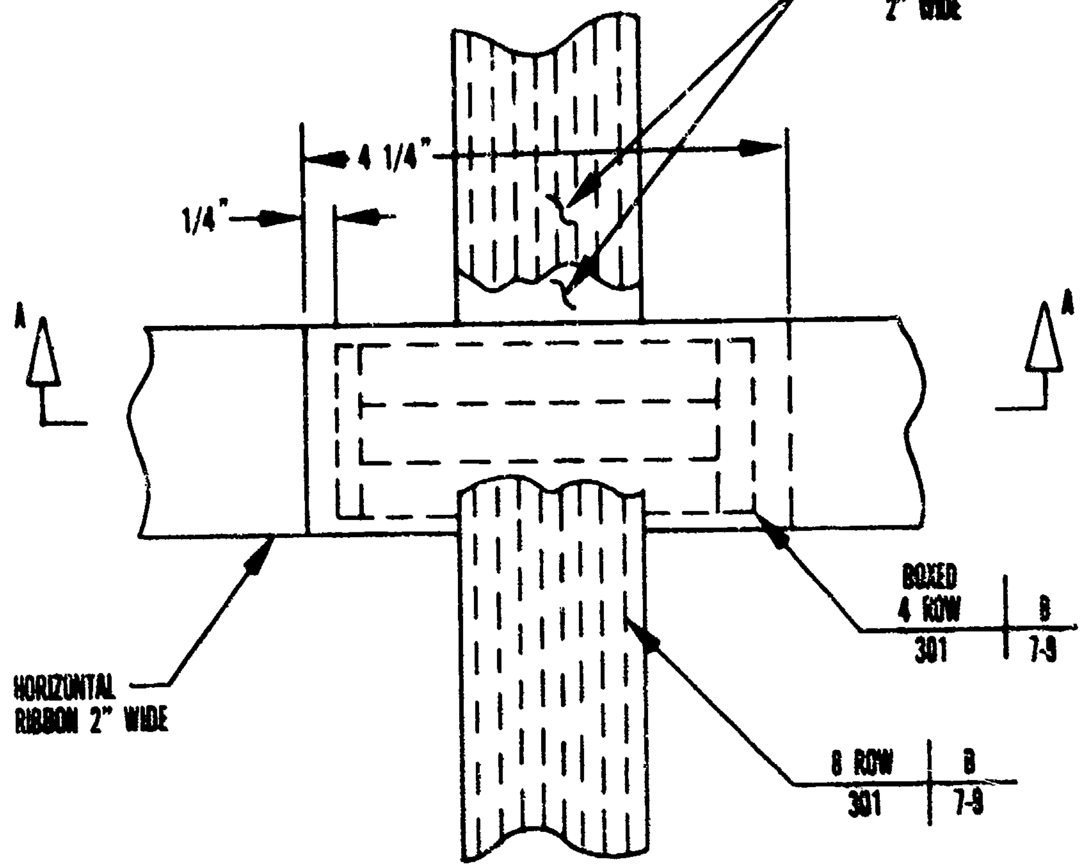
Figure E21 PATTERN 5P7





SECTION A - A

Figure E22 PATTERN BX



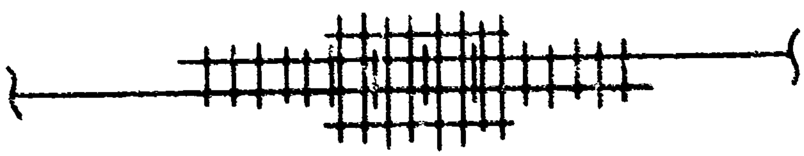


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Figure E?3 PATTERN BAR

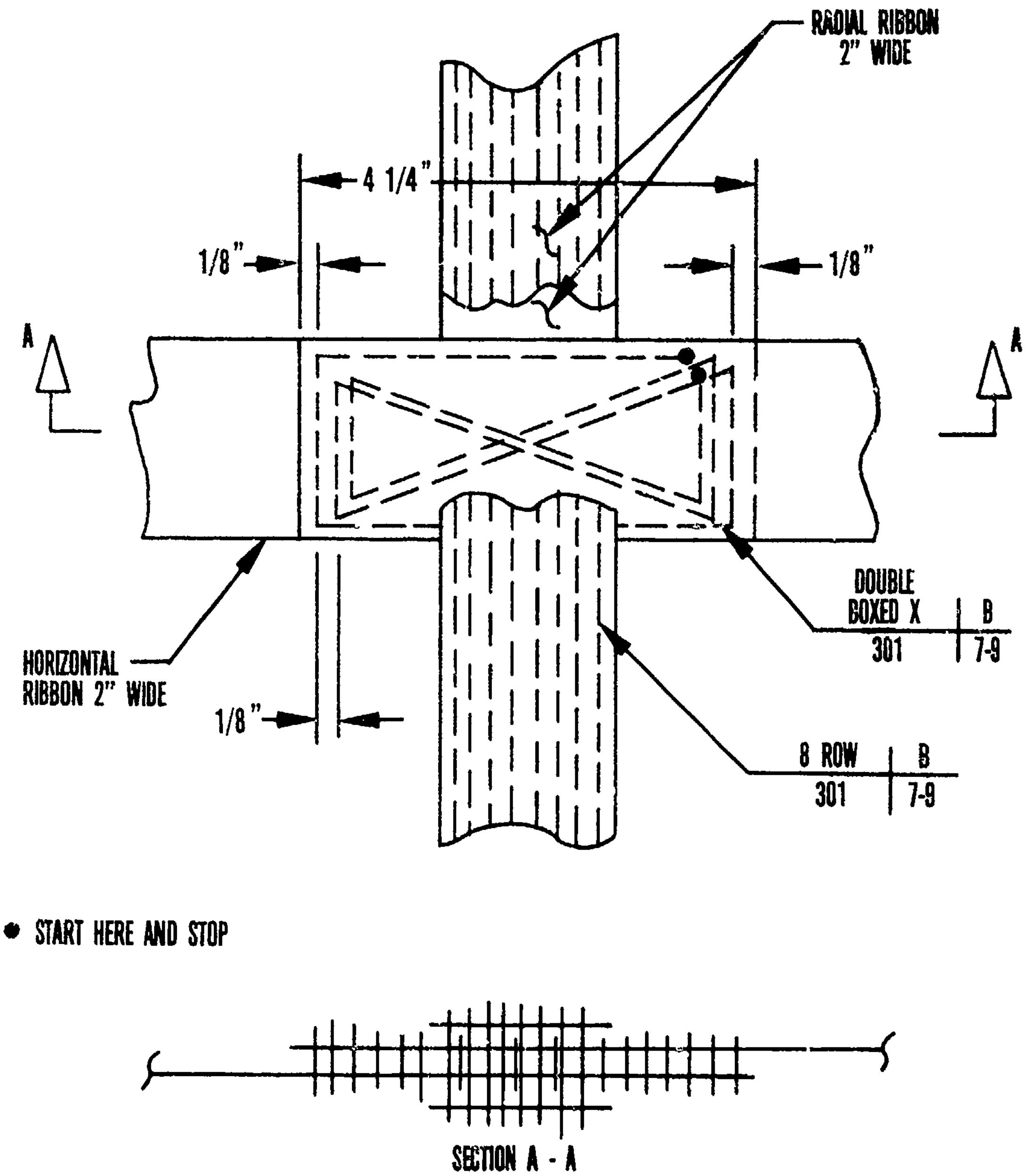


Figure E24 **PATTERN DBX1**

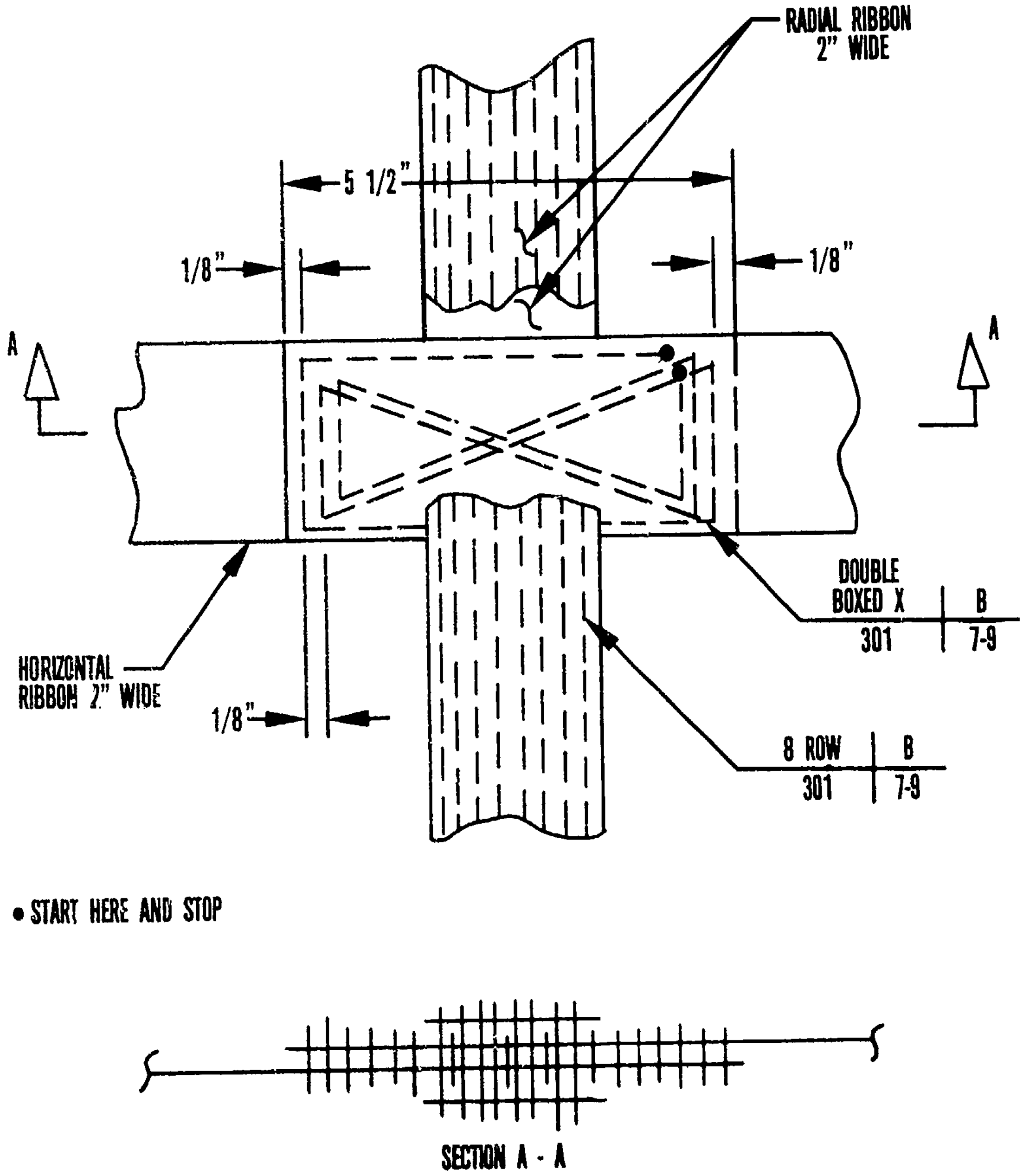


Figure E25 PATTERN DBX2

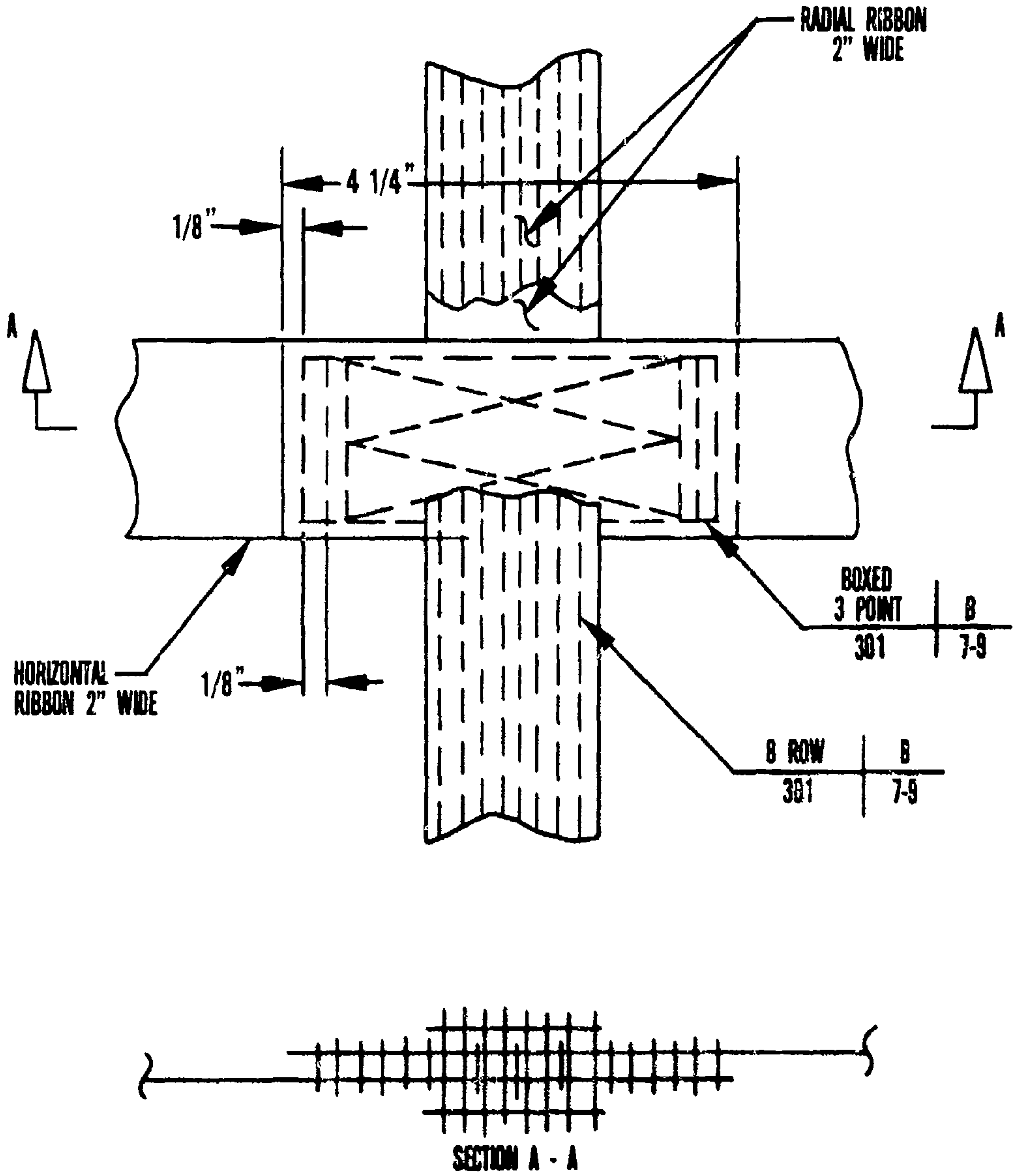


Figure E26 PATTERN B3P

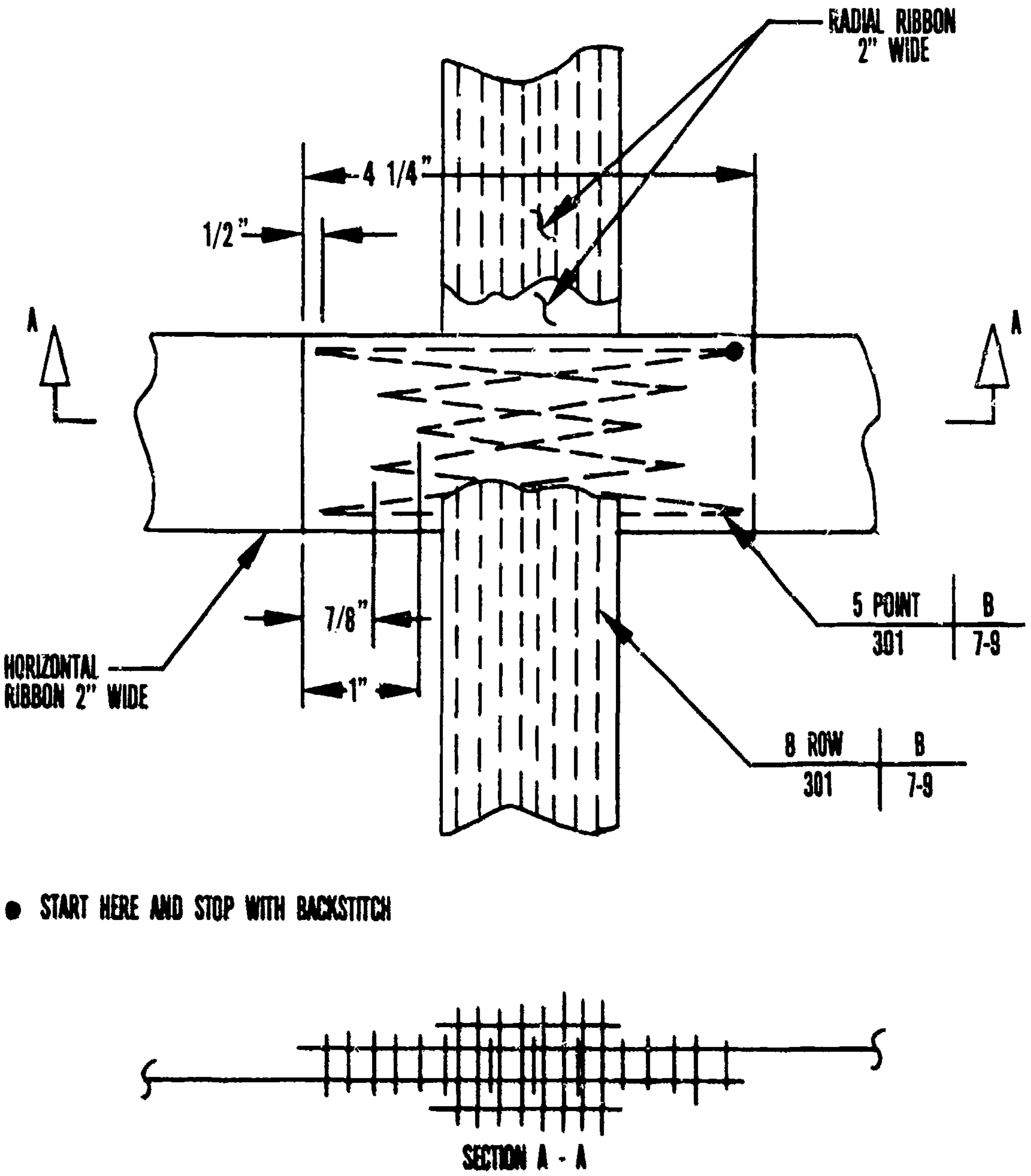
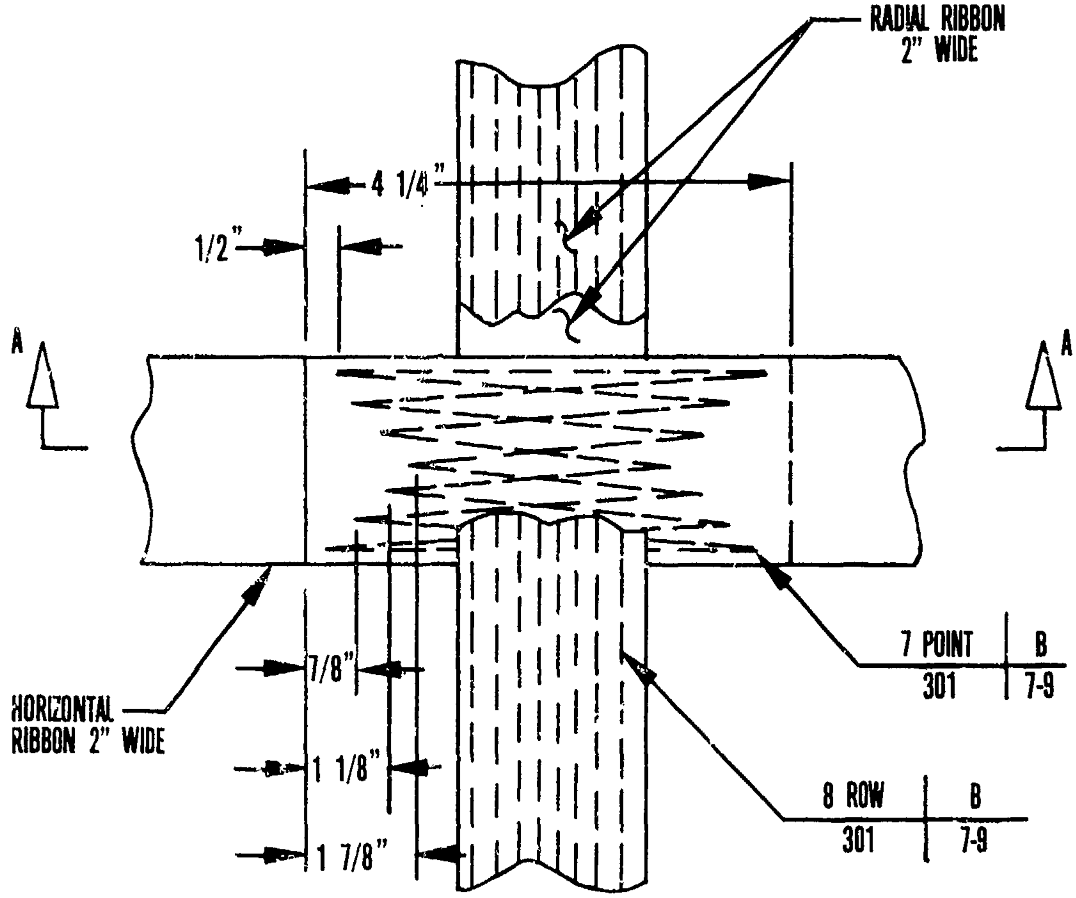


Figure E27 **PATTERN S5P**



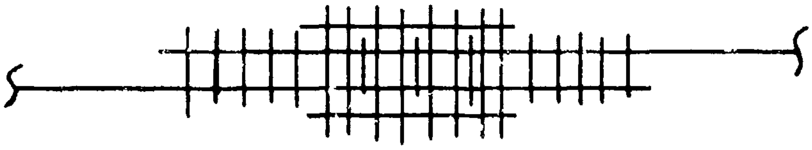


Figure E28 **PATTERN S7P**

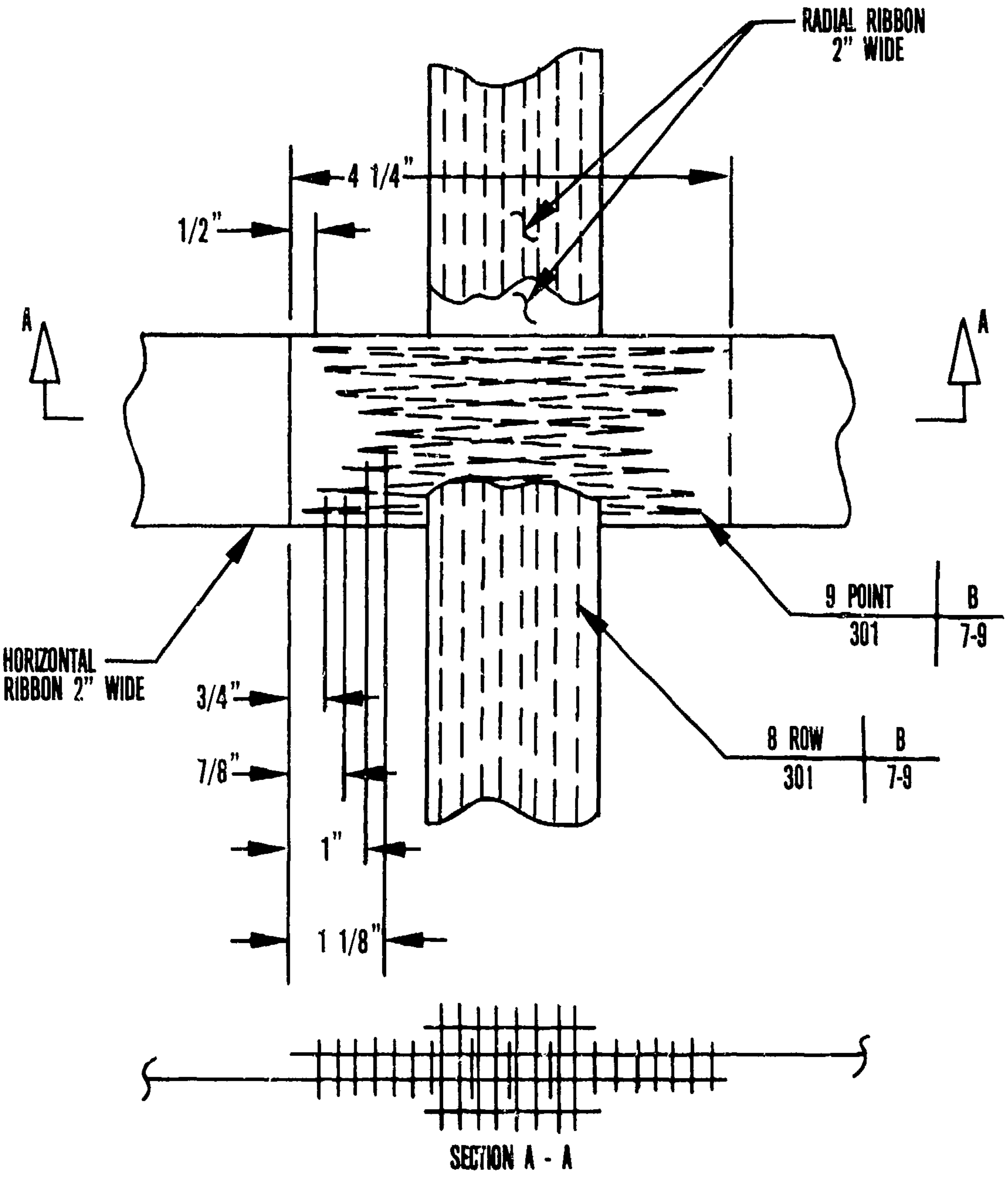


Figure E29 PATTERN S9P

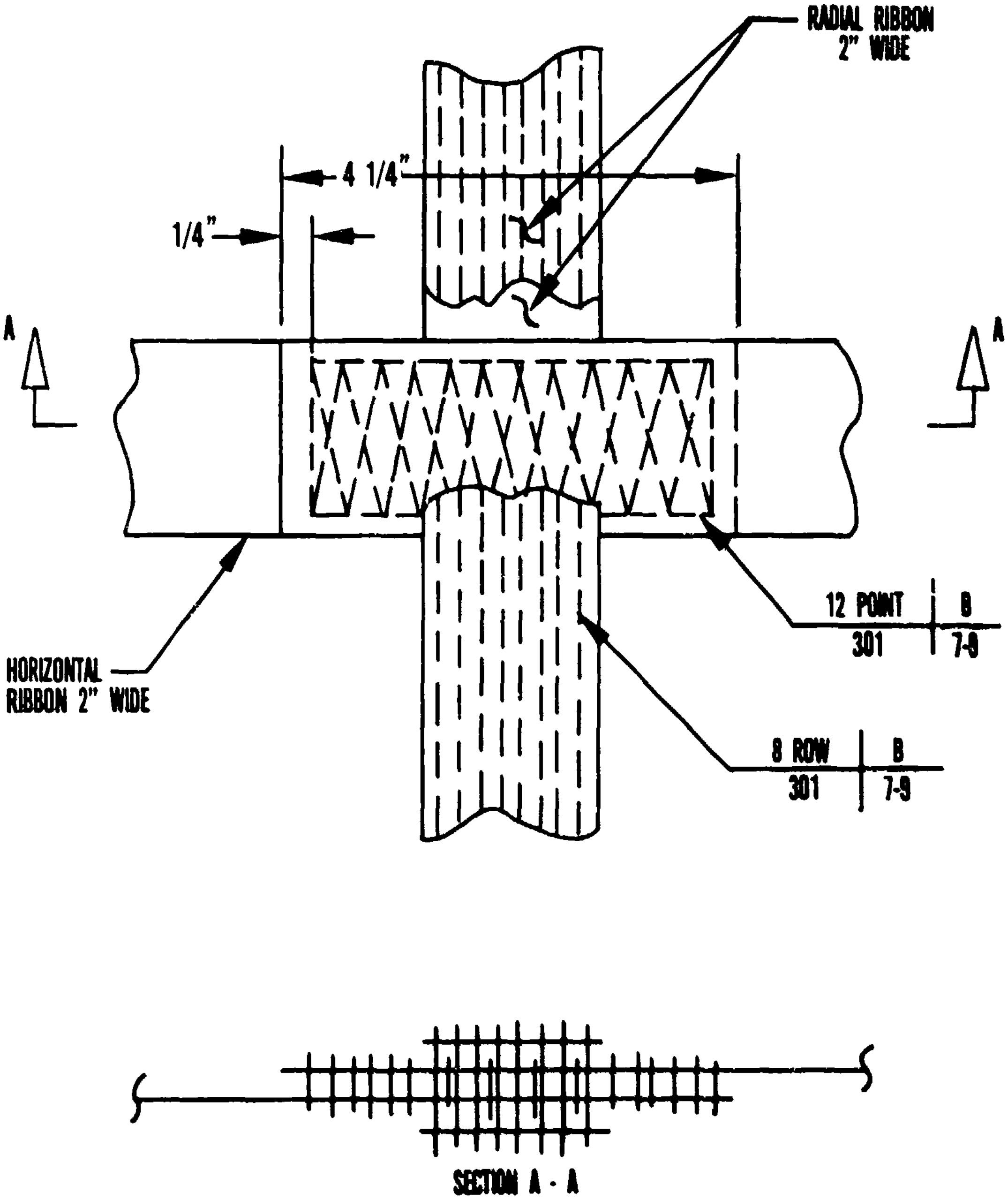


Figure E30 PATTERN C12P

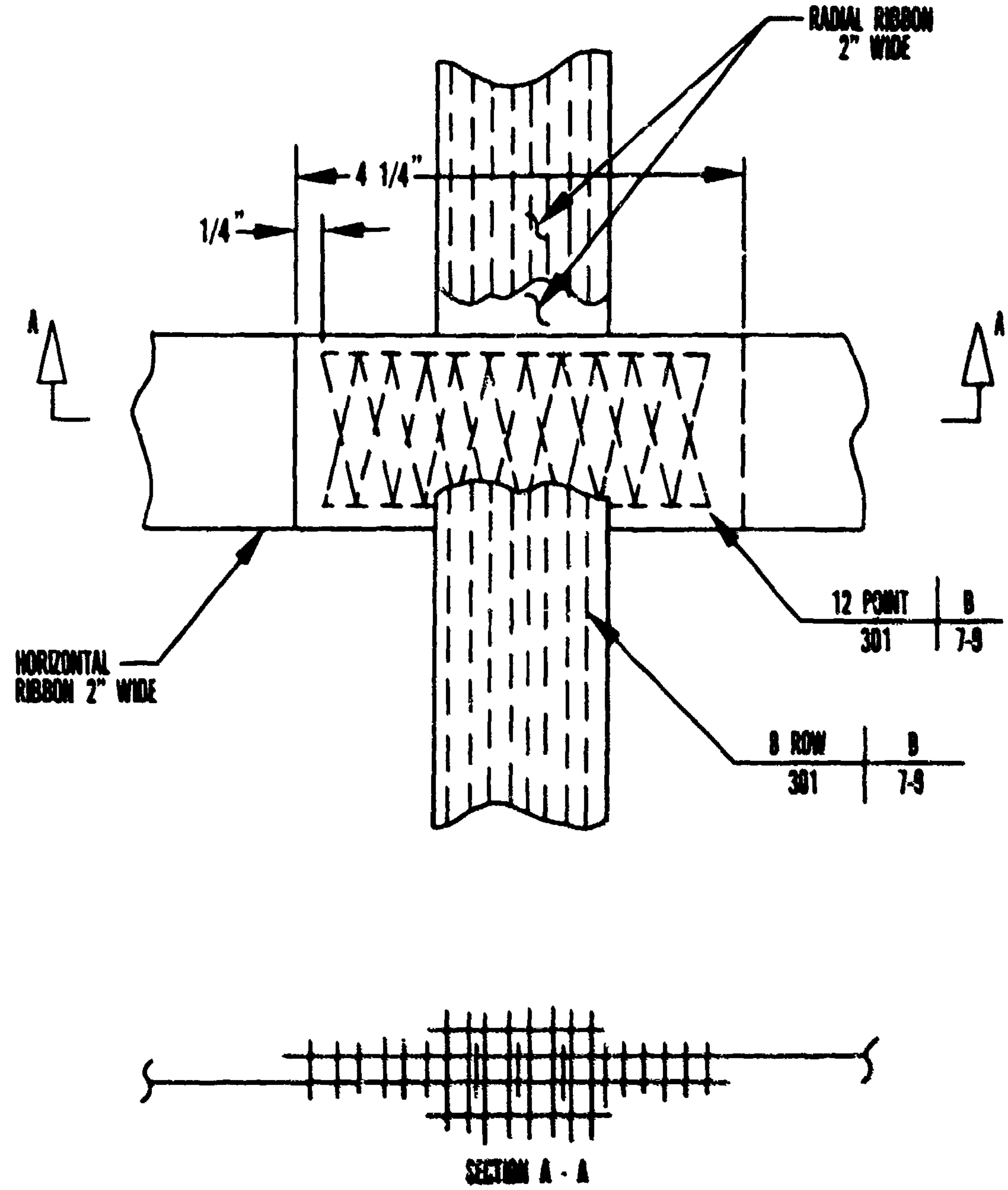


Figure E31 PATTERN 812P

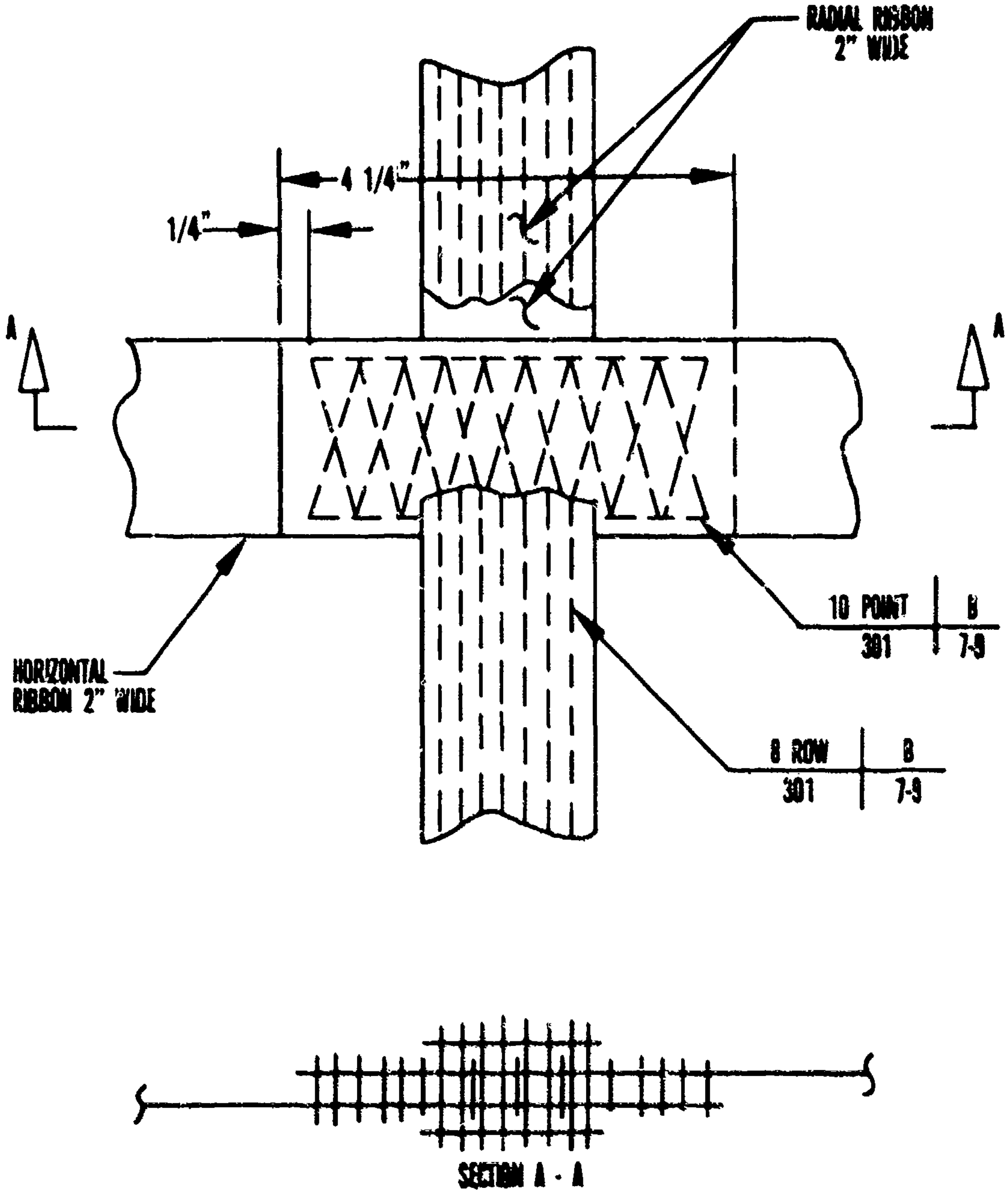


Figure E32 PATTERN 010P

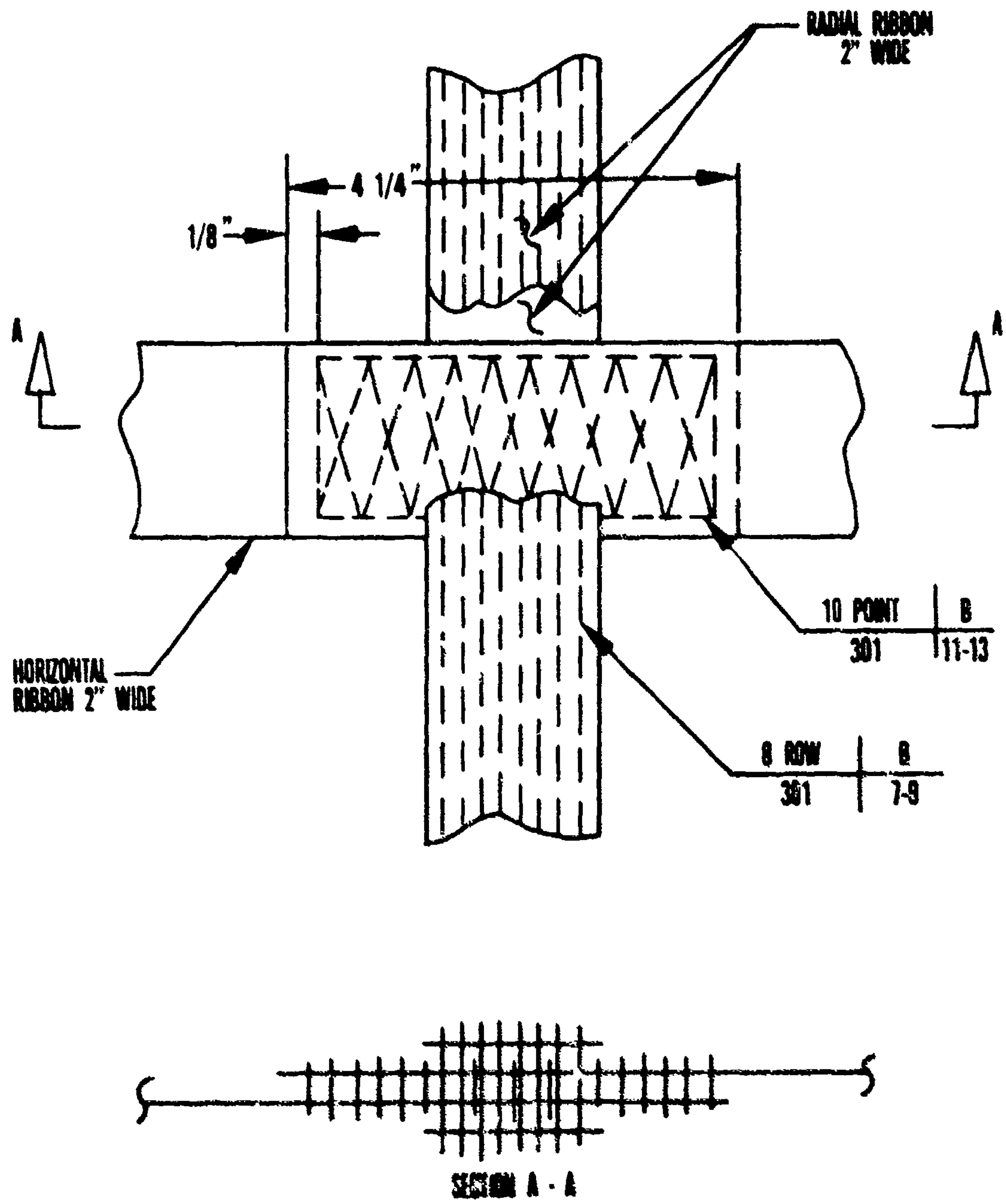


Figure E33 PATTERN C19P

APPENDIX F

COMMENTS AND OBSERVATIONS RELATIVE TO SPECIFIC DESIGN CRITERIA

TEST ITEM 1

TEST NO. 141175 D

CONFIGURATION: 32 Gores
1 15/16" Ribbons Spaced .665 in.
No Reefing Cutter Pockets
Nylon Vent Lines 1 inch shorter than finished vent diameter.
Weight 14.6 lbs including riser swivel.

TEST ABNORMALITIES: One gore disreefed at second stage inflation by failure of reefing cutter attachment.

DAMAGE: One reefing cutter attachment failed.

TEST ITEM 1M

TEST NO. 171275 D

CONFIGURATION: Add reefing cutter pockets.
Weight 14.7 lb including riser swivel.

TEST ABNORMALITIES: Deployment hang-up, pilot chute riser failed.

DAMAGE: None

TEST ITEM 1M

TEST NO. 310877S

CONFIGURATION: Replaced 2300 lb nylon vent lines with Kevlar lines of same three-fourth inch width but 3000 lb strength. New cutter brackets and pockets. Replace riser with one of similar geometry but without swivel.
Weight 13.6 lbs.

TEST ABNORMALITIES: After achieving first stage inflated shape (peak force 24,117 lbs), three gores disreef to second stage due to failure of reefing rings, ring attachments or cutter attachments. First disreef results in second stage reefed shape for very short time. (.08 sec. peak force

23,620 lbs) then remaining reefing fails by pulling away from skirt sequentially by gore. Canopy fills to full open and fails (peak force 29,156 lb) as skirt breaks away from canopy.

DAMAGE: No evidence of horizontal ribbon failure before break up. All radial ribbons fail near skirt, general failure of reefing ring and cutter attachments. Elongated rings. Vent intact, no vent line failure

TEST ITEM 2

TEST NO. 231275D

CONFIGURATION: 32 gores, Kevlar vent lines
1 15/16 inch ribbon spaced .665 inch cutter pockets
vent lines 1 inch shorter than finished vent dia.

TEST ABNORMALITIES: None

TEST NO. 080377S

CONFIGURATION: Same as test 231275D

TEST ABNORMALITIES: None

DAMAGE: None

TEST ITEM 2

TEST NO. 270777S

CONFIGURATION: As previous two tests (original).

TEST ABNORMALITIES: Swivel in riser failed just after first stage inflation.

DAMAGE: Minor

TEST ITEM 2M

TEST NO. 270977SM

CONFIGURATION: Riser with no swivel
New reefing system with two rows stitching (instead of one) in ring attach tapes.
High strength heat treated reefing rings.

TEST ABNORMALITIES: Holes in two gores in crown. Canopy remains inflated.

DAMAGE: Twelve horizontal ribbon failures as follows:

GORE	RIBBON
16	1
18	3
19	1
26	1, 2, 3, 4, and 6
27	3, 4, 5, and 6

Several partial ribbon breaks all within top six ribbons.
No breaks in ribbon splices.
Ventband pulled off gores 14 through 19 not broken. Gore holes did not increase in subsequent stage inflations.

TEST ITEM 3

TEST NO. 270476D

CONFIGURATION: Twenty-four gores with pocket bands; 1 13/32 inch ribbon width; vent lines, 1 inch shorter than finished vent diameter. Diameter 1500 lb reefing line. Weight with swivel 12.4 lbs.

TEST ABNORMALITIES: Malfunction of reefing system both lines cut (or broken) simultaneously.

DAMAGE: Suspension lines failed simultaneously as riser legs at overload beyond instrumentation capability.
No canopy damage (based on film - parachute not recovered).

TEST ITEM 4

TEST NO. 160876D

CONFIGURATION: Identical to Test Item 3 but with 2000 lb reefing lines.

TEST ABNORMALITIES: Test prematurely aborted by disconnect of test item before first disreef.

DAMAGE: Minor - 2 ribbon breaks near vent (15,097 lbs peak load)

TEST ITEM 4R

TEST NO. 151076DR

CONFIGURATION: As test 160876 D. Repaired broken ribbons.

TEST ABNORMALITIES: Test prematurely aborted by early disconnect before first stage inflation.

DAMAGE: None

TEST ITEM 4M

TEST NO. 091276D

CONFIGURATION: Modifications including no swivel in riser; replaced top 5 ribbons with 1000 lb tensile strength. Spliced piece into one suspension line (repair) Weight 11.75 lbs, no swivel.

TEST ABNORMALITIES: None

DAMAGE: Minor - no ribbon breaks. Scattered incidence of strains in radials which caused edge breaks but not failures.

TEST ITEM 5

TEST NO. 171176D

CONFIGURATION: MARS SM 28 gores. Weight 12.0 lbs with swivel. Vent lines 1 inch shorter than finished vent diameter.

TEST ABNORMALITIES: None

DAMAGE: None

TEST ITEM MARS 6M

TEST NO. 250577DM

CONFIGURATION: Twenty-eight gores two-inch ribbons.
Top 10 ribbons 1000 lbs nominal strength.
Bottom 23 ribbons 800 lbs nominal strength.
1500 lb cord vent lines.
No reinforcement band. 11.92 lbs with swivel.

TEST ABNORMALITIES: None

DAMAGE: Ribbon 11 had 7 partial breaks where vertical tapes intersect radials (lower edge ribbon 11)

TEST ITEM MARS 6

TEST NO. 021277D

CONFIGURATION: MARS 6; 2 inch ribbons.
Replaced ribbon 11 with the material.
Add three-fourth inch 3000 lb reinforcement band at bottom edge of ribbon 11.
Top 10 ribbons 1000 lb.
Bottom 23 ribbons 800 lb.
This is now "MARS" configuration.

TEST ABNORMALITIES: Forces derived from acceleration data.

DAMAGE: Two ribbon breaks - #12 and #16 one place each, several scattered partial ribbon breaks.
No damage to ribbon 11.

TEST ITEM MARS 7

TEST NO. 080378D

CONFIGURATION: MARS

TEST ABNORMALITIES: No force or acceleration data.

DAMAGE: Minor - no broken ribbons. Partial broken ribbons and loosened vertical tape stitching in bottom third of gores.

TEST ITEM MARS 8

TEST NO. 030578D

CONFIGURATION: MARS

TEST ABNORMALITIES: Test Item Lost. No detailed post test inspection.

DAMAGE: No damage evident from films.

TEST ITEM MARS 9

TEST NO. 041278D

CONFIGURATION: MARS

TEST ABNORMALITIES: None. Some inflation instability in first stage, but canopy is always inflated.

DAMAGE: None

TEST ITEM MARS 10

TEST NO. 260578D

CONFIGURATION: MARS

TEST ABNORMALITIES: None

DAMAGE: None

TEST ITEM MARS 10

TEST NO. 180878

CONFIGURATION: MARS

TEST ABNORMALITIES: No tracking data, no onboard film, some inflation instability in first stage.

DAMAGE: None

TEST ITEM IH-1

TEST NO. 080377D

CONFIGURATION: Twenty-eight gores; two-inch ribbons; permanently reefed.
Overstrength radials, under strength horizontal ribbons with "sleazy" weaving.
Top 16 ribbons 540 lbs.
Ribbons 17 thru 33, 420 lbs.

TEST ABNORMALITIES: None

DAMAGE: Yarn slippage in all lower ribbons. Scattered partial but no complete ribbon tensile failures.

TEST ITEM IH-2

TEST NO. 150377D

CONFIGURATION: Twenty-eight gores permanent-fourteen reefed.
All ribbons 420 lbs understrength.
Overstrength radials. Two-inch ribbons.

TEST ABNORMALITIES: None

DAMAGE: Weave distortions.
No tensile failures.
Scattered incidence of partially broken ribbons.

TEST ITEM IH-3

TEST NO. 270178D

CONFIGURATION: Twenty-seven gores; two-inch ribbons; two stage reefing. High strength reefing rings.
Under strength bottom ribbon.
Top 16 ribbons - 600 lb; Ribbons 17 thru 33 - 420 lb.

TEST ABNORMALITIES: None

DAMAGE: No tensile breaks in ribbons. All ribbons 18 through 33 partially broken with weave distortion.

TEST ITEM IH-5

TEST NO. 161177S

CONFIGURATION: Two-inch 1000 lb ribbons throughout; no swivel in riser. Two reinforcement bands on ribbons 11 and 12 (bottom edges). Vent lines one-inch shorter than finished vent diameter.
Deployment hangup late pilot space chute. Very little time between full open and test item cutoff.

DAMAGE: None

TEST NO. 100278S

CONFIGURATION: Same as test 161177S

TEST ABNORMALITIES: None

DAMAGE: Ribbon 3 broken at splice. Ribbon 4 broken same gore.
Scattered partial breaks mostly in ribbons near skirt.

TEST NO. 040878SM

CONFIGURATION: IH-5M
Repaired and replaced ribbons.
Replace suspension lines with 3500 lb cord.
Weight 17.7 lbs, no swivel.

TEST ABNORMALITIES: None

DAMAGE: One radial failure.
Several broken ribbons mostly in lower part of canopy.
Some loose vertical tapes in lower part of canopy.

TEST ITEM IH-6

TEST NO. 300378S

CONFIGURATION: Same as test item IH-5.

TEST ABNORMALITIES: None

DAMAGE: No complete tensile breaks.
Many partial breaks, mostly in lower 12 ribbons.
Some vertical tapes torn loose.

TEST NO. 230678

CONFIGURATION: IH-6R repaired by replacing damaged lower ribbons, some vertical tape segments.

TEST ABNORMALITIES: Suspension lines all fail at riser legs.
Some failures in crown ribbons observed before lines fail.

TEST ITEM IH-7

TEST NO. 120978D

CONFIGURATION: Fifty percent Genton coated two-inch 400 lb ribbons throughout - Reinforcement bands on ribbons 11 and 12.

TEST ABNORMALITIES: None

DAMAGE: Yarn slippage throughout entire canopy. No tensile breaks, some partial breaks in crown and near skirt.

TEST ITEM IH-8

TEST NO. 290878S

CONFIGURATION: Same as IH-7, 50 percent Genton coating.

TEST ABNORMALITIES: None

DAMAGE: Three ribbon splices broken in crown ribbons (8, 7 & 6), ribbon 5 also broken. Severe yarn slippage all over canopy.

TEST ITEM IH-9

TEST NO. 190978S

CONFIGURATION: Same as IH-7 and IH-8 but with 100 percent Genton coating.

TEST ABNORMALITIES: None

DAMAGE: No tensile breaks, some partial breaks in crown extensive yarn slippage throughout canopy.

TEST ITEM WP-1

TEST NO. 140679S

CONFIGURATION: Geometry as per IH-6 with stronger lines and radials but same ribbons. Vent lines same length as finished vent diameter.

TEST ABNORMALITIES: None

DAMAGE: Failure of top ribbon followed by vent band failure at one gore which ripped to reinforcement band, broken ribbons in adjacent gores.

TEST ITEM WP-2

TEST NO. 190779S

CONFIGURATION: Same as WP-1 with more stitching in vent band, vent lines one-inch shorter than finished vent diameter.

TEST ABNORMALITIES: Pilot chute riser failed - little time lost in deployment.

DAMAGE: No. 4 ribbon fails just before vent band broken. This gore has top 4 ribbons broken. Ribbons 3 thru 6 broken in another gore, other crown ribbons broken.

TEST ITEM WP-3

TEST NO. 170879S

CONFIGURATION: Twenty-eight gores. Angles between verticals and horizontal ribbons controlled. Tucks in vent and crown ribbons vent line length equal to finished vent diameter.

TEST ABNORMALITIES: Deployment as much higher dynamic pressure than planned (790 instead of 690 psf). Canopy catastrophically failed before first disreef.

DAMAGE: Vent band failed before inflation to first stage gore ripped to reinforcement bands.
Vent lines failed sequentially after some time in first stage inflated state.
Nearly all ribbons partially broken. Vent line failure proceeded crown ribbon failure.

TEST ITEM WP-4

TEST NO. 060979S

CONFIGURATION: Same as WP-3 with vent lines one-inch shorter than finished vent diameter.

TEST ABNORMALITIES: Reefing system failed during first stage.

DAMAGE: Three crown ribbon breaks in top 4 ribbons. Reefing rings pulled off allowing early disreef and overload.
All suspension lines fail at load in excess of 25933 lbs.

TEST ITEM WP-5

TEST NO. 270979S

CONFIGURATION: Geometrically like WP-1, 2, 3, and 4 with stronger reefing attachments. Vent lines one-half inch shorter than finished vent diameter.

TEST ABNORMALITIES: None

DAMAGE: Ribbons of one gore failed down to reinforcement band. Vent band failed after ribbons in this gore, just after reaching first state inflated shape. Several vent lines fail but canopy remained inflated.

TEST ITEM WP-6

TEST NO. 181079S

CONFIGURATION: Same as WP-5 with vent lines the same length as finished vent diameter.

TEST ABNORMALITIES: None

DAMAGE: Vent band and top 10 ribbons in 2 gores broken prior to first reefed open. No breaks at ribbon splices. No vent line breaks.

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2. Reynolds, D. T., Mullins, W. M., Stress Analysis of Ribbon Parachutes, AIAA Paper No. 75-1372, presented at AIAA, Aerodynamic Deceleration Systems Conference, Albuquerque, NM, (A76-13168), November 1975.

3. McEwan, A. J., et al., Descriptions of Computer Programs for the Analysis of Apollo Parachutes, Northrop Ventura Report NVR-6428, June 1969.

4. Pinnell, W. R., Design Criteria for and Development of Kevlar Ribbon Parachutes, AIAA Paper No. 79-0430 included in "A Collection of Technical Papers - AIAA 6th Aerodynamic Decelerator and Balloon Technology Conference, Houston Texas, March 5-7, 1979," published by AIAA.

5. Abbott, N. J., et al., Some Mechanical Properties of Kevlar and Other Heat Resistant, Nonflammable Fibers, Yarns and Fabrics, Air Force Materials Laboratory Report AFML-TR-74-65, Part III, March 1975. (AD B006949L)

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