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Testing and Environmental Exposure of Parachute Materials for the Solid Rocket Booster Decelerator Subsystem

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TESTING AND ENVIRONMENTAL EXPOSURE OF PARACHUTE MATERIALS FOR THE SOLID ROCKET BOOSTER DECELERATOR SUBSYSTEM

SUMMARY

The materials described in this report were tested specifically for the recovery and reuse of the Solid Rocket Booster Decelerator Subsystem (SRB DSS) under simulated environmental conditions expected during flight. The tests were restricted to static conditions and primarily to nonmetallic materials. Nylon was chosen as the parachute fabric because of its elongation characteristics, durability under "use" conditions, history of successful use in decelerators, and strength.

With the exception of one webbing, all material met the strength tests. All load-bearing webbing met or exceeded the required strength requirements and proved to have a reuse capability of 40 ocean drop-recoveries as limited to UV, seawater withstanding capability, and rinse and dry processes. Worst-case conditions were used or exceeded in inflation load testing. The first recovery rinse, and dry procedure resulted in greater strength degradation than subsequent cycles.

The canopy materials were also exposed to simulated "use" conditions in addition to the tests stipulated in their respective military specifications. Dynamic testing (i.e., flight and drop testing) is still in progress and could result in further changes or modifications to the present parachute's design and material composition.

I. INTRODUCTION

In the basic Space Shuttle configuration, the reusable Orbiter is "piggy-backed" on an expendable External Tank (ET). Two reusable SRB's are strapped to the ET. This report describes the nylon and related materials comprising the parachutes in each SRB DSS. Each DSS consists of a drogue and three main parachutes which open during SRB reentry, slowing the SRB adequately for ocean impact, flotation, and subsequent recovery. Each main parachute is 115 ft in diameter (D_o), has ninety-six 62 ft suspension lined dispersion bridles 70 ft in length, and 40 ft risers. The canopy is a ribbon type with 16 percent geometric porosity. The drogue parachute is 54 ft in diameter and has sixty 100 ft suspension lines (Fig. 1).

These enormous parachutes have the highest strength of any fabricated to date. To our knowledge, the largest load ever dropped by parachute and recovered was in the 50 000 lb range. Each SRB after firing will weigh approximately 170 000 lb. Considering the weight involved, parameters such as design, material selection, material and dynamic testing, and deployment are extremely critical. To keep within budget restraints, recovery and reuse are necessary. All of these factors must be tested in simulated "use" environments.

This project was initiated by performing fabric material studies, testing, and analyses through literature research, and Government and Manufacturer/Vendor contacts. Materials acceptance and identification were performed by tests and analyses. Environmental exposures simulated ascent, ocean drop, recovery, rinsing, drying, and reuse. Laboratory test conditions included heat, artificial seawater soak, and UV light exposure (utilizing a weatherometer), tap water rinse, and oven drying. Tests were then selected to determine the strength, elongation, and durability or degradation resulting from these exposures. It was estimated that the SRB DSS could remain in the ocean for 3 days before recovery. Therefore, one ocean drop-recovery (72 hr) was designated as one cycle. Ten cycles of exposure for canopy materials and up to 40 cycles for other fabrics known as "load bearing" materials (e.g., suspension lines and risers) were completed. Test plans, methods, etc., are presented for each type material. From these tests, the number of parachute drop-recoveries and reuse cycles may be projected.

II. MATERIALS SELECTION AND TEST PREPARATION

A. Materials Selection

1. Parachute Webbing and Tape. Materials screened were those previously evaluated with specified proven properties and a history of successful decelerator experience. Natural fibers were excluded due to their lack of weathering, durability, and strength. Voluminous reports on synthetic fibers

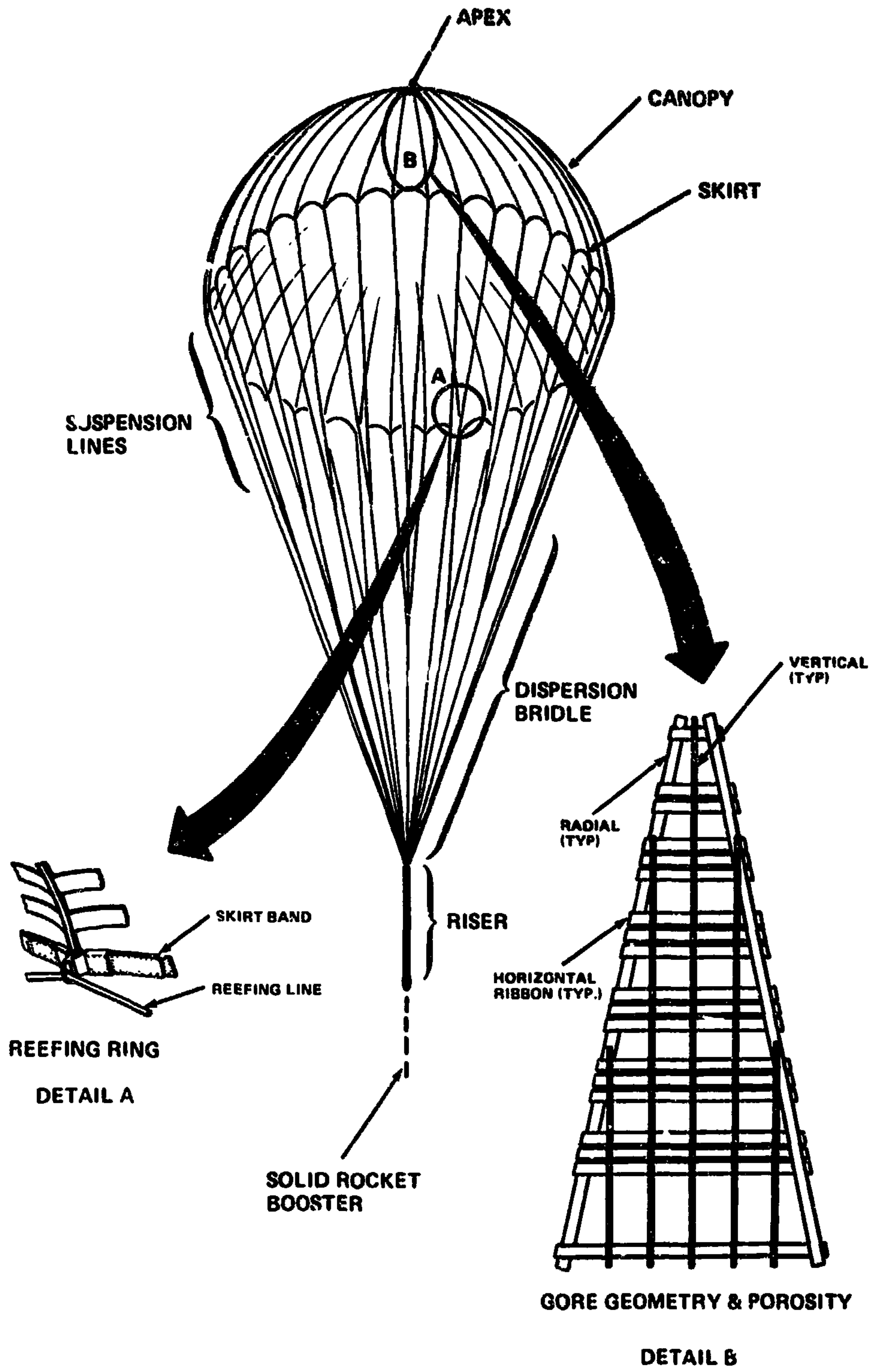

Figure 1. General ribbon type parachute construction canopy with tape/webbing location.

developed by the Air Force, Navy, Army, and several research and manufacturing firms were studied. Aramid materials were considered; however, because of their limited use and their abrasion and elongation characteristics nylon was chosen. Considering all the "use" environments, nylon had the most desirable properties (with no significant heat exposure), and a history of repeated use.

2. Stitching Patterns. It was decided to stitch selected parachute webbing which would carry the brunt of the load due to the lack of proper capstan holders (jaws) for the Instron machine. Stitching simulates as nearly as possible, the parachutes to be fabricated. Stitching usually reduces the strength of the webbing and gives a more realistic tensile strength in use as well as a potential weak-link in the design/materials used.

The stitching and patterns chosen were taken from Wright Air Force Development Center, WADC Technical Report 56-313, Part II, "A Study of Parachute Seam Design Criteria," June 1956.

B. Test Preparation

1. Environmental Exposure Conditions. The weatherometer was utilized to simulate ocean exposure after SRB and parachute drop. All samples were soaked in artificial seawater approximately 1 hr prior to attaching to the test fixture inside the weatherometer. The test fixture rotated around a xenon light at a distance sufficient to emit "one sun" in the UV spectrum. Exposure was continued for 7 hr/day with sample removal and immersion in seawater at least once during this period to keep the nylon wet and to prevent salt crystallization. At the end of 7 hr, the samples were placed in seawater and soaked over night, or weekend, until the next exposure period. Three of these 7 hr exposures (21 hr) are referred to as one cycle, i.e., a 3 day period that parachutes may remain in the ocean before recovery.

Samples of seawater were taken periodically and the percentage of chloride was measured to maintain a 3.5 to 4 percent salts concentration.

2. Rinse and Dry Procedure. Before testing for environmental exposure, it was necessary to determine the number of rinsing operations necessary to reduce the salinity to a level that would not be detrimental to the parachute. With the thicker load-bearing nylon samples, a sample of water was taken from each rinse solution. Salt content was determined by measuring the chloride content and conductivity. Total solid salts were also determined on two samples for a comparison test but were discontinued when they agreed with chloride and

conductivity measurements. Measurements were also taken of the tap water used for rinsing. The results of the rinse tests are given in Table 1 and Figure 2.

The following rinse and dry procedure was established. When removing the nylon samples from the weatherometer for testing, they were immersed in a container of tap water, gently agitated, drained, and refilled with tap water. This was repeated until all salts were removed. Usually five or six rinsing operations were required depending on the quantity of samples. The parachute samples were then placed in an air circulating oven at 140 to 160°F for 4 hr or until dry. Testing was then begun.

TABLE 1. ANALYSIS OF SIX SRB PARACHUTE RINSE WATER SAMPLES AND A TAP WATER SAMPLE

Sample Designation	Chloride (ppm)	Conductivity (millimhos/cm)
Tap Water	11	0.15
1st Rinse Water	1740	4.54
2nd Rinse Water	290	0.88
3rd Rinse Water	107	0.38
4th Rinse Water	56	0.27
5th Rinse Water	62	0.29
6th Rinse Water	42	0.24

III. LOAD-BEARING WEBBING

A. Material Inspection

Webbing identification is given in Table 2. An overall examination was performed on each material received. No uneven dyeing, weaving, or wrong color was noted in the rolls and all were labeled properly. There were no abrasion marks, broken or missing ends, twist or distortion in the webbing weave, nor cuts or tears. All military specification defect criteria were met.

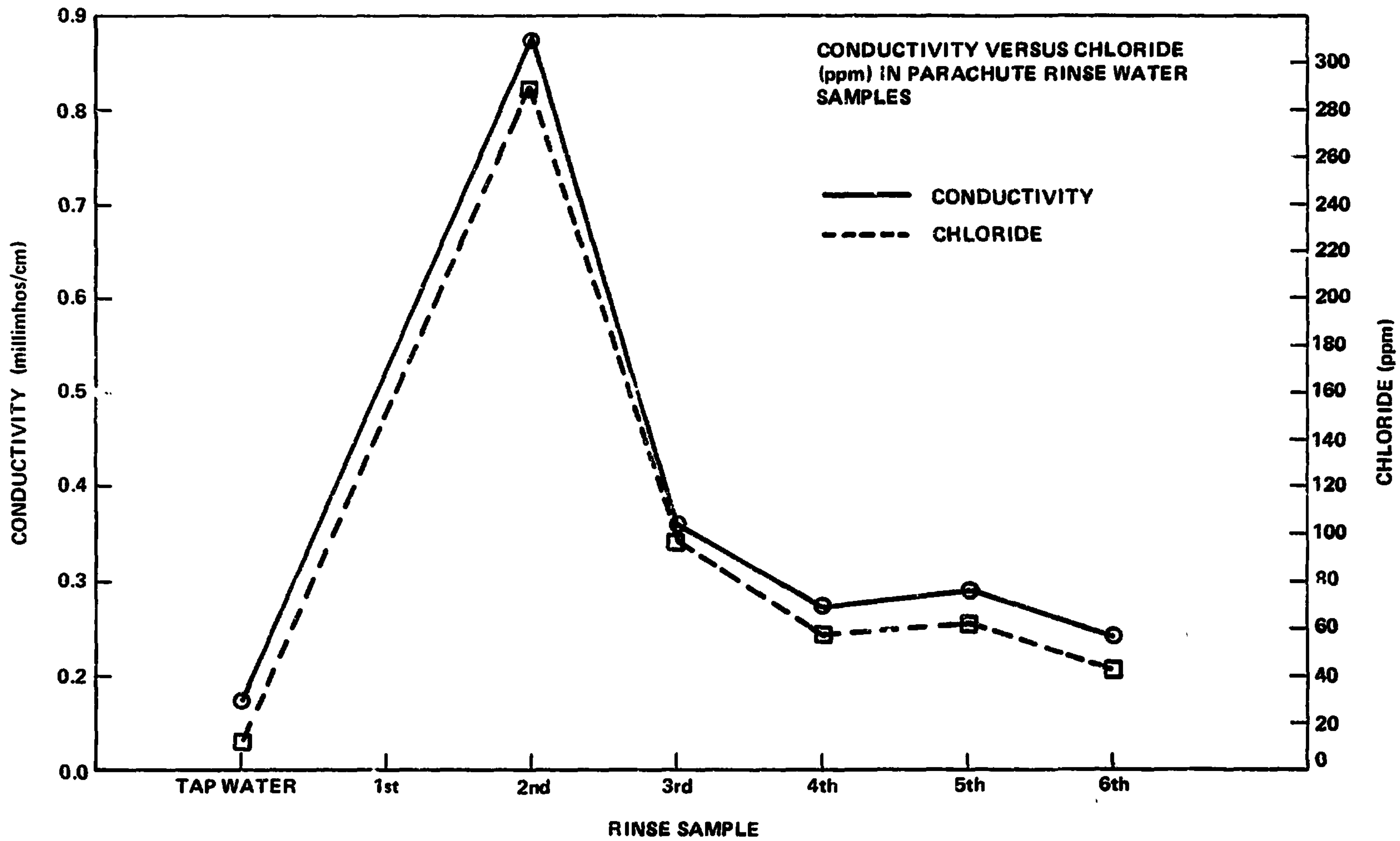

Figure 2. Salinity test chart for parachute rinsing.

TABLE 2. PARACHUTE LOAD-BEARING MATERIALS

Lab No.	Nylon Webbing per MIL-W-27657	Application
EH33 1-A	Type II 1 in. width, 4000 lb breaking strength	Reefing and suspension lines, main
EH33 2-A	Type V, 1 in. width, 9000 lb breaking strength	Reefing and vent lines, main
	Nylon Webbing per MIL-W-4088	
EH33 5-A	Type X, 1 23/32 in. width, 8000 lb breaking strength	Reefing rings, attach band
EH33 8-A	Type XIX, 1 3/4 in. width, 10 000 lb breaking strength	Radial reinforcement, drogue vent and skirt bands, main riser
EH33 3-A	Type VI, 1 23/32 in. width, 2500 lb breaking strength	Pocket band, main
EH33 4-A	Type VII, 1 23/32 in. width, 5500 lb breaking strength	Reefing rings bands, main
EH33 6-A	Type XIII, 1 23/32 in. width, 6500 lb breaking strength	Pocket bands, drogue
EH33 7-A	Type XVI, 1 23/32 in. width, 4500 lb breaking strength	Reinforcement band, main
EH33 9-A	Type XXIII, 1 1/8 in.width, 12 000 lb breaking strength	Suspension line, drogue
EH33 10-A	Type XXVI, 1 3/4 in. width, 15 000 lb breaking strength	Skirt band, drogue

B. Materials Test Procedure and Testing

1. Static Tensile Loading. All tests, unless otherwise stated, were specified in the webbing military specifications and procedures taken from Federal Standard 191. Static tensile tests were conducted on a 10 000 lb capacity Instron or a 60 000 lb capacity Riehle Testing Machine. On the Instron, specimens were mounted in 4 in. diameter capstan jaws with approximately 15 in. between jaw centers. A speed of 2 in./min was used and extension measurements were made with a ruler calibrated in 1/16 in. Extension readings were taken at 1/8 in. intervals. Unless otherwise stated, two samples of each webbing were tested to rupture. Polynomial least squares regression analysis was used for the load-elongation diagrams (Figs. 3-12) for all load-bearing webbing, and values for rupture loads are given in Table 3.

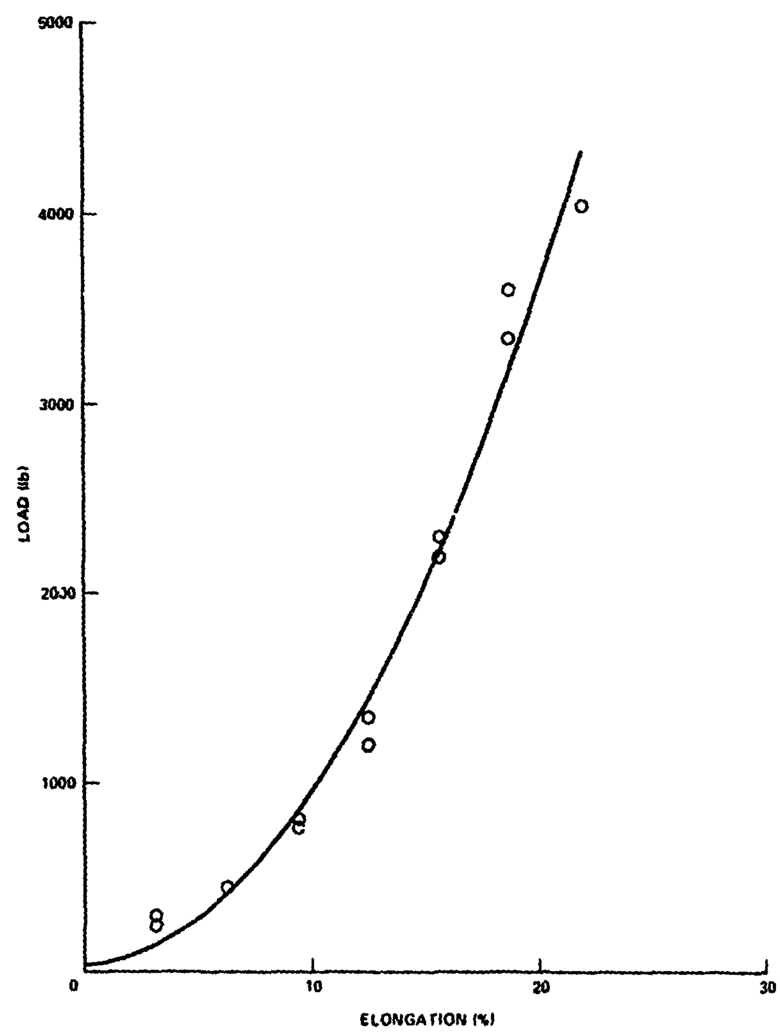

Figure 3. Static load-elongation diagram for unexposed material (nylon webbing, MIL-W-27657, Type II).

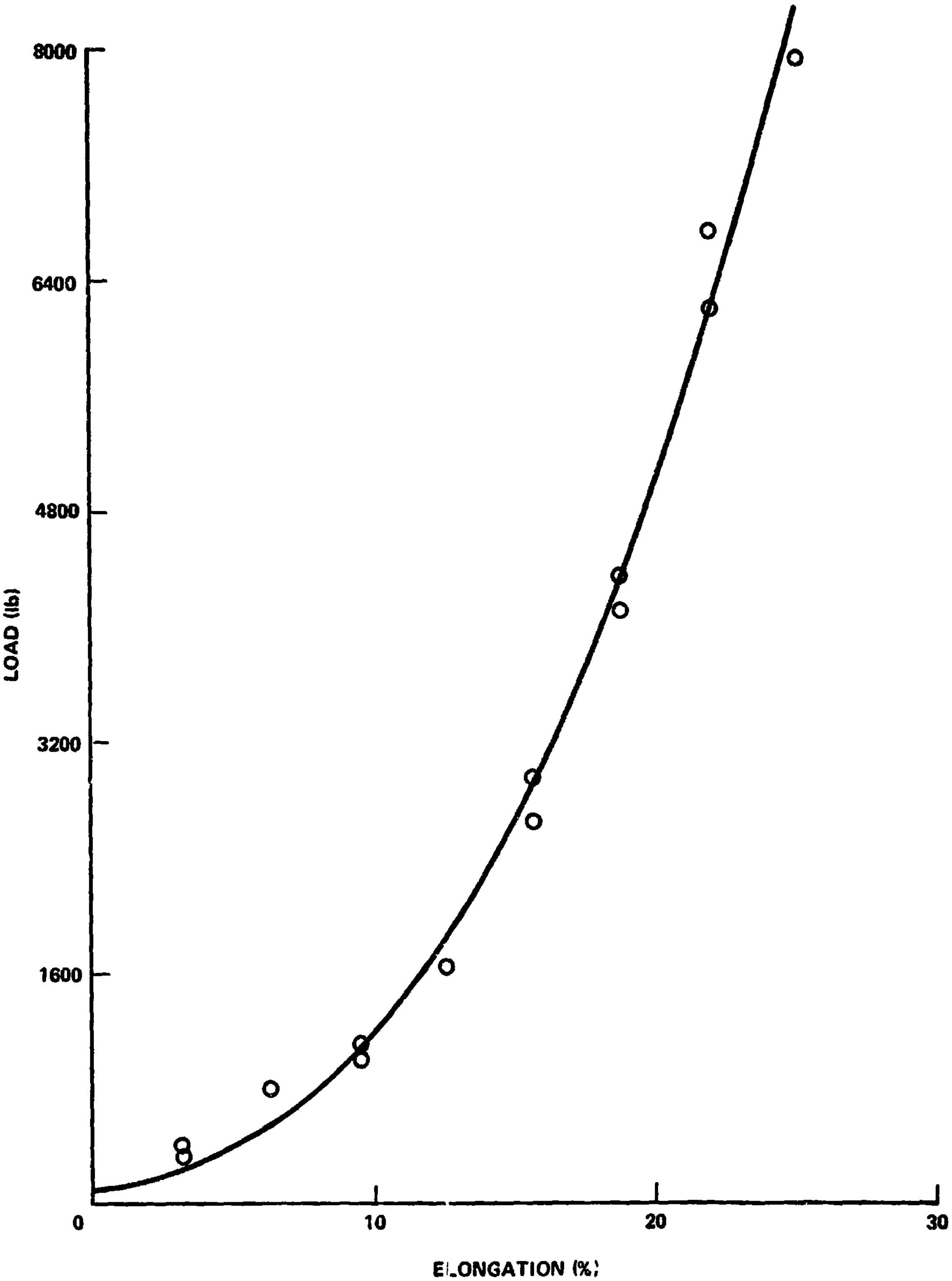

Figure 4. Static load-elongation diagram for unexposed material, stitched (nylon webbing, MIL-W-27657, Type V).

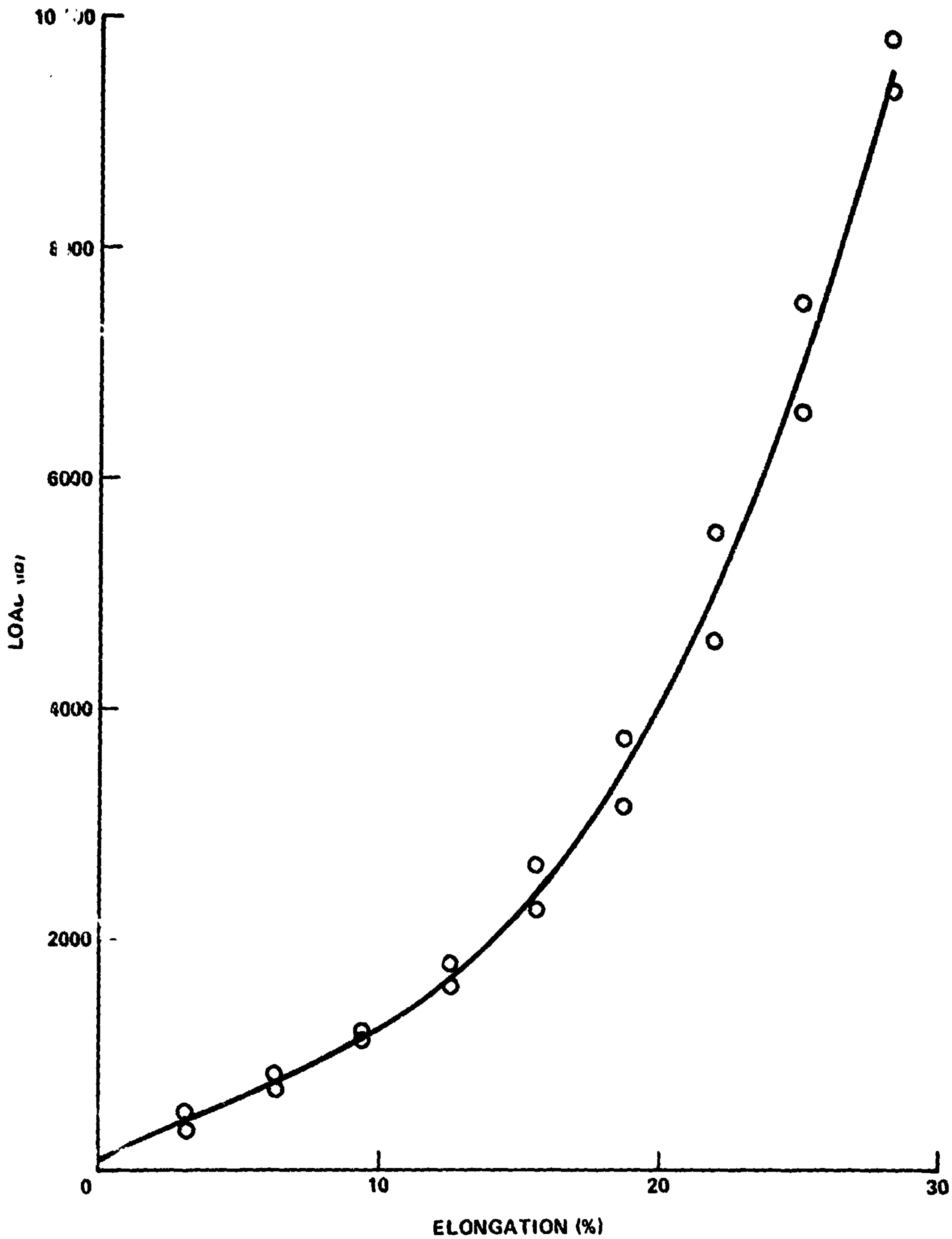

Figure 5. Static load-elongation diagram for unexposed material (nylon webbing, MIL-W-4088, Type X).

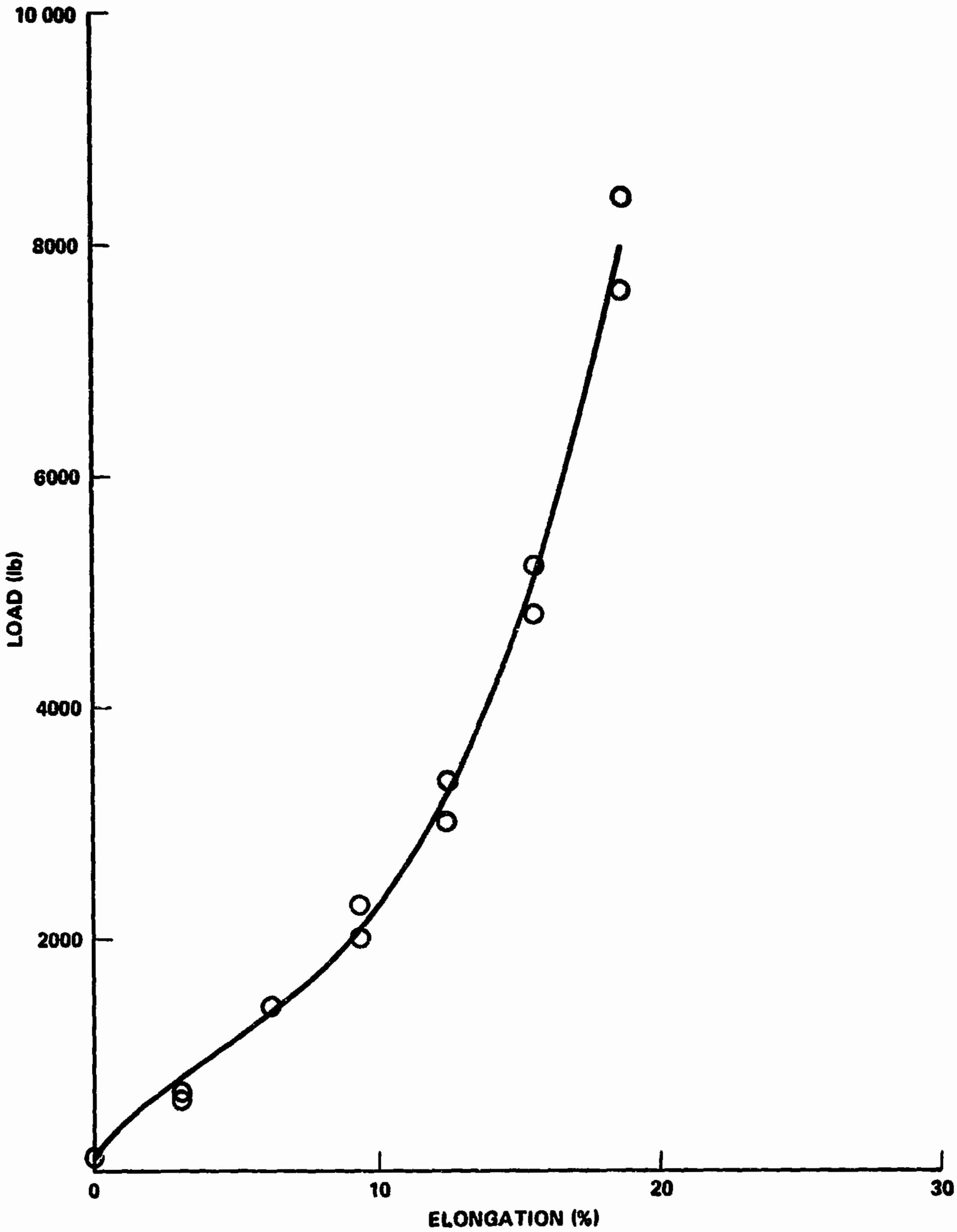

Figure 6. Static load-elongation diagram for unexposed material, stitched (nylon webbing, MIL-W-4088, Type XIX).

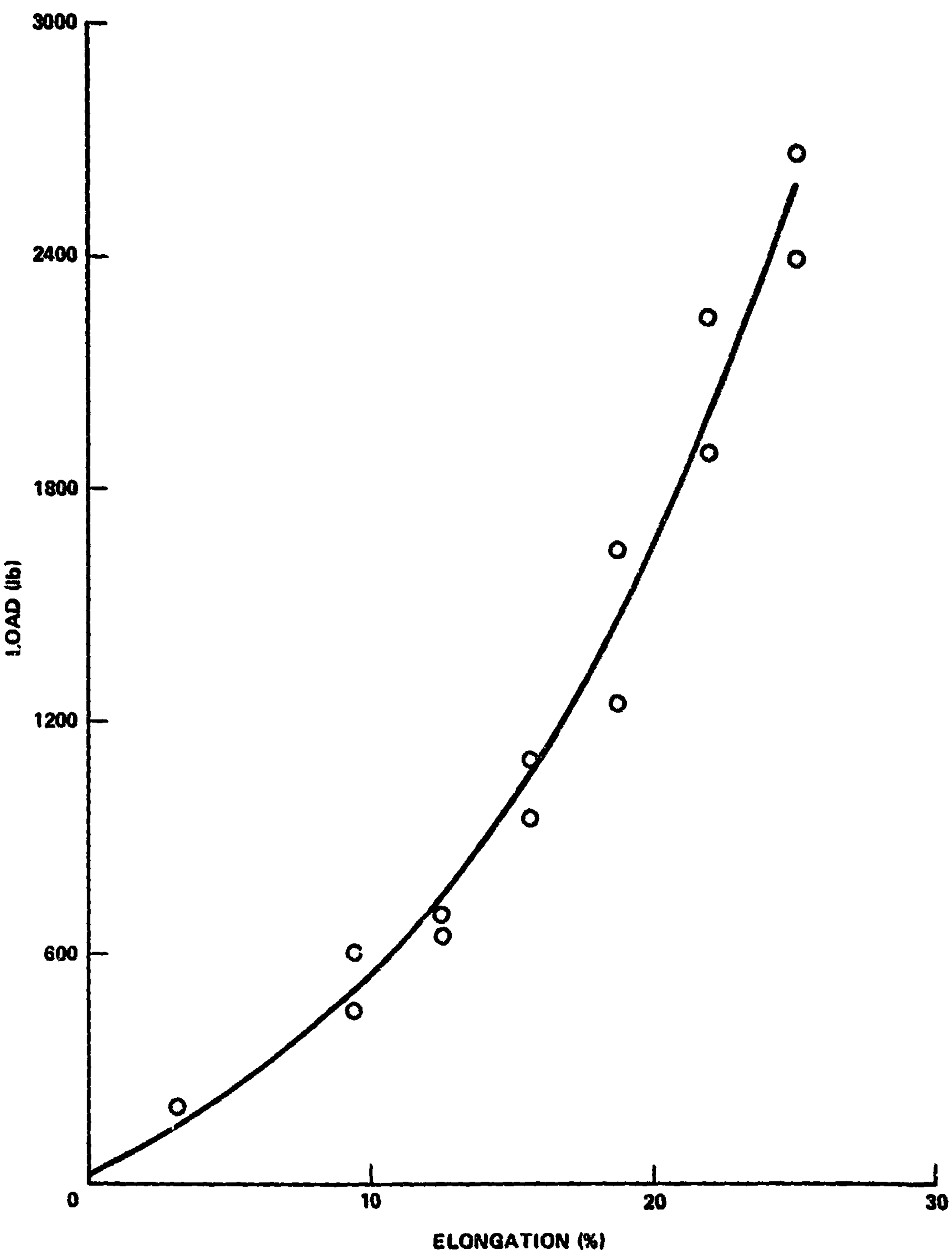

Figure 7. Static-load elongation for unexposed material (nylon webbing, MIL-W-4088, Type VI).

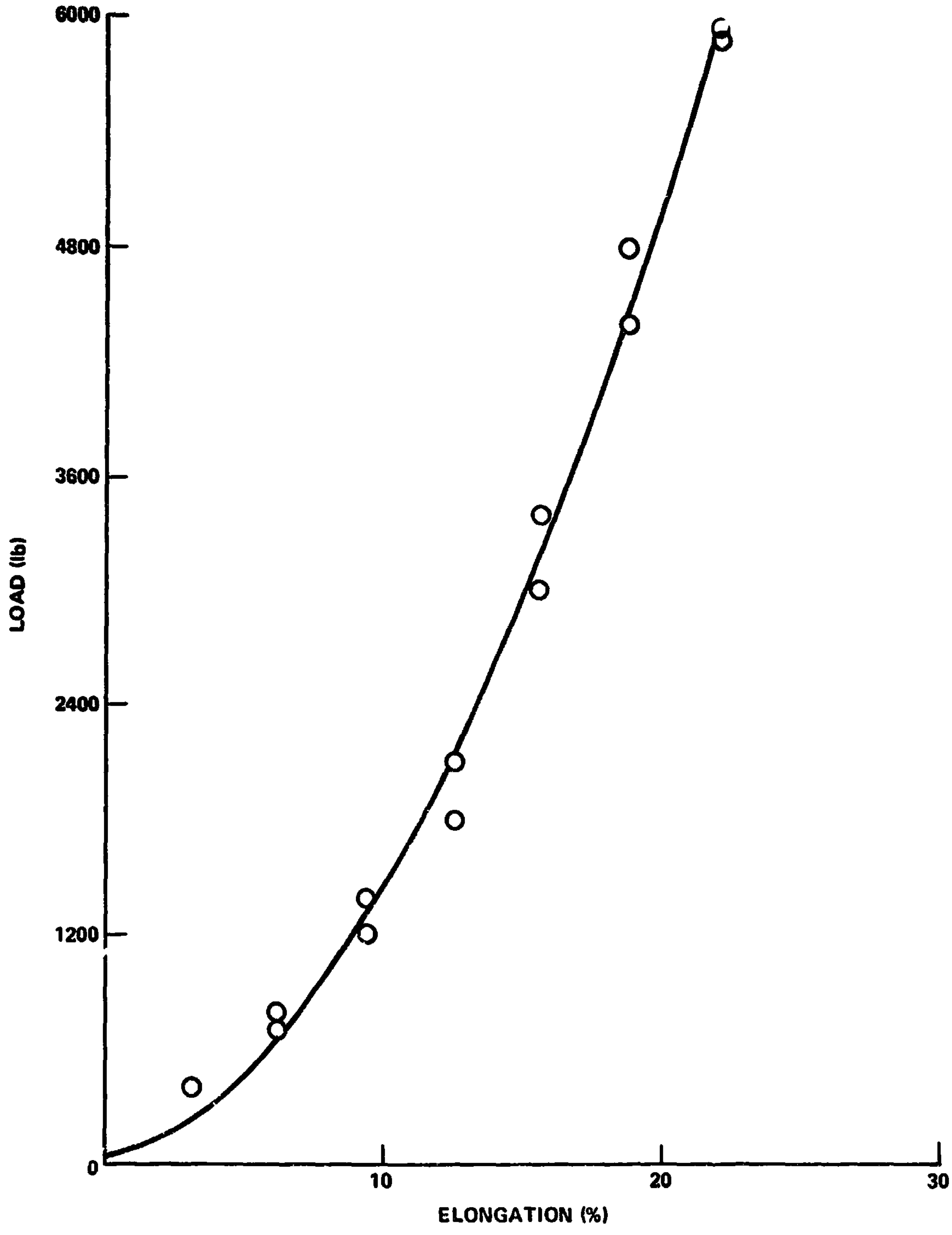

Figure 8. Static load-elongation for unexposed material (nylon webbing, MIL-W-4088, Type VII).

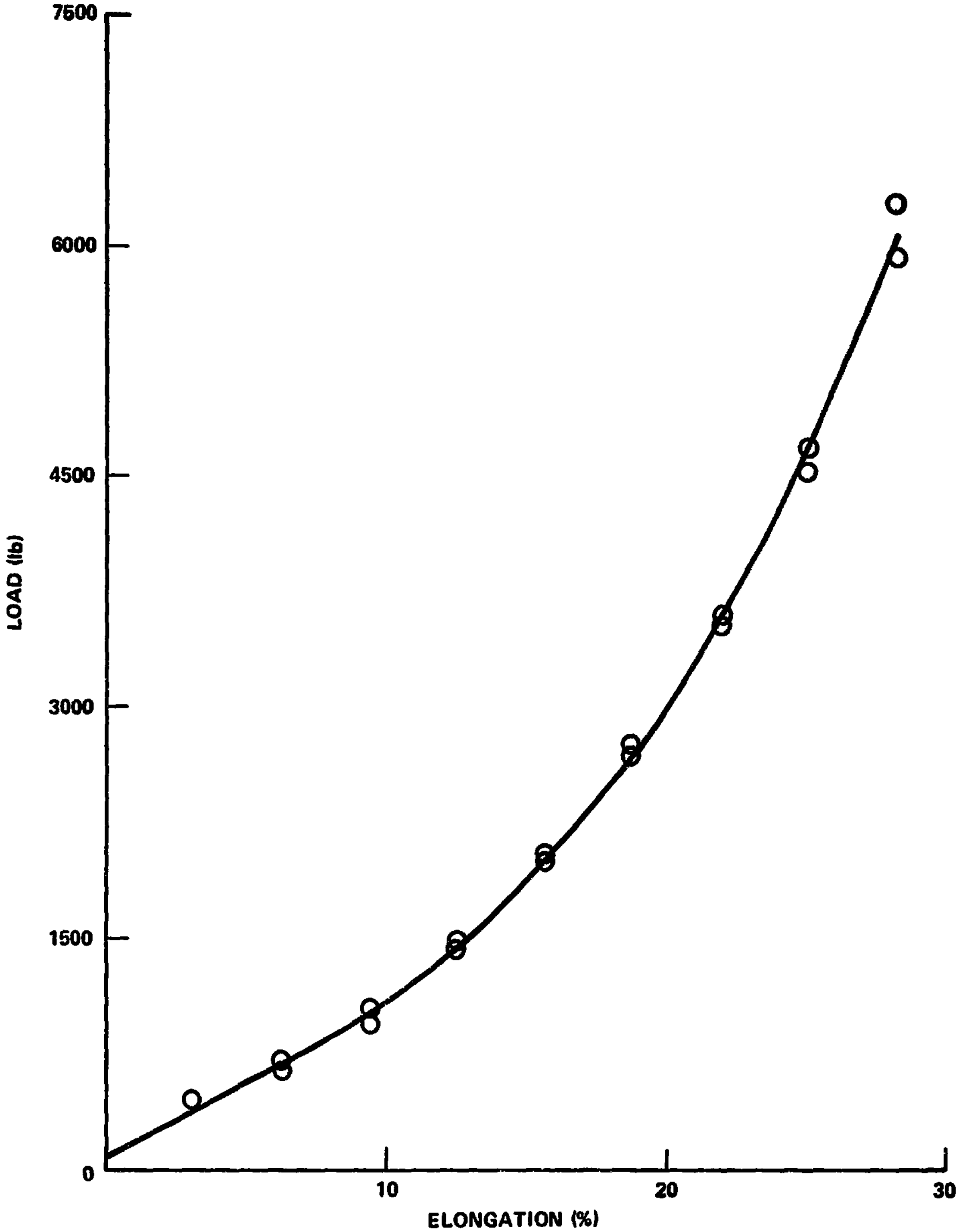

Figure 9. Static load-elongation for unexposed material (nylon webbing, MIL-W-4088, Type XIII).

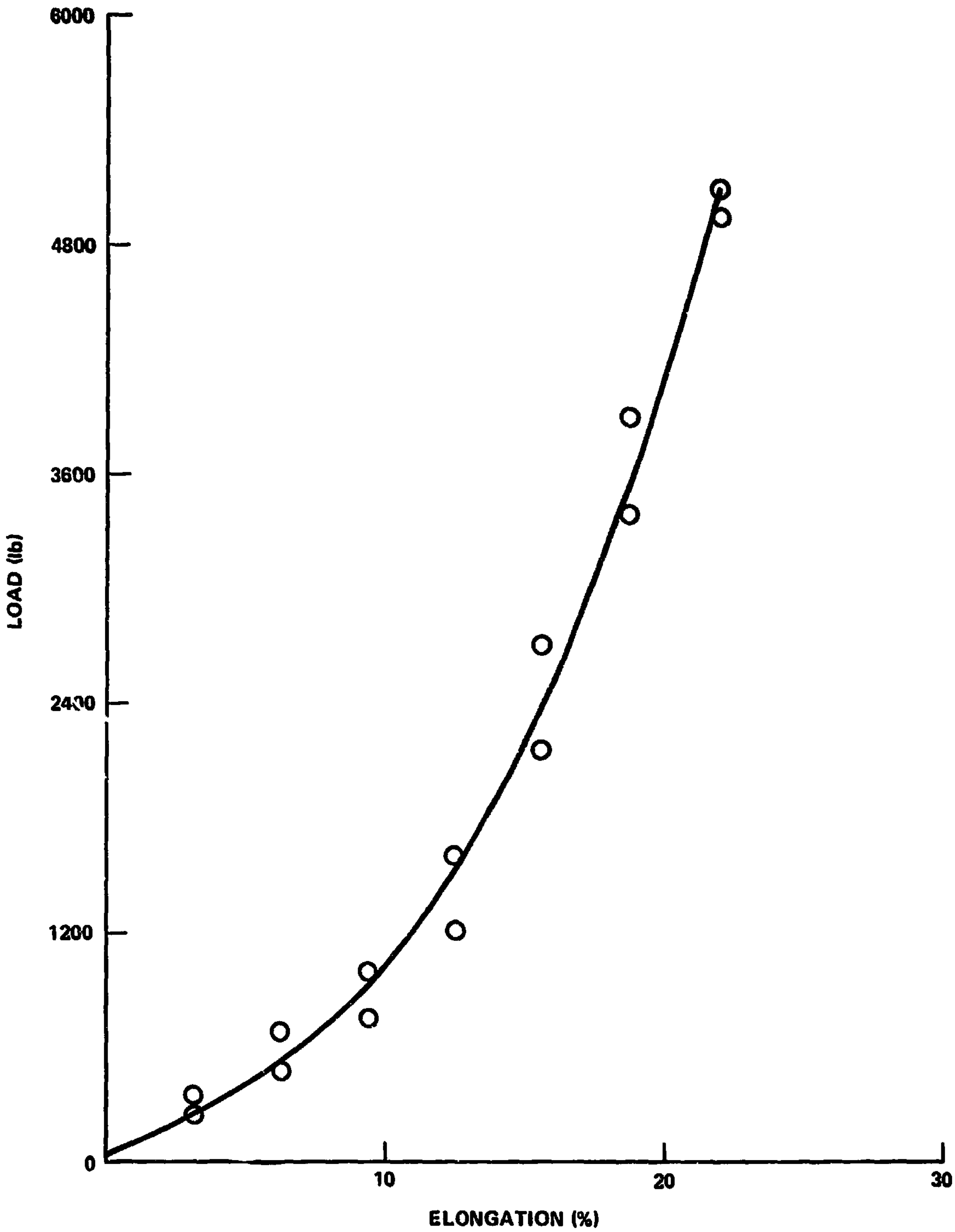

Figure 10. Static load-elongation for unexposed material (nylon webbing, MIL-W-4088, Type XVI).

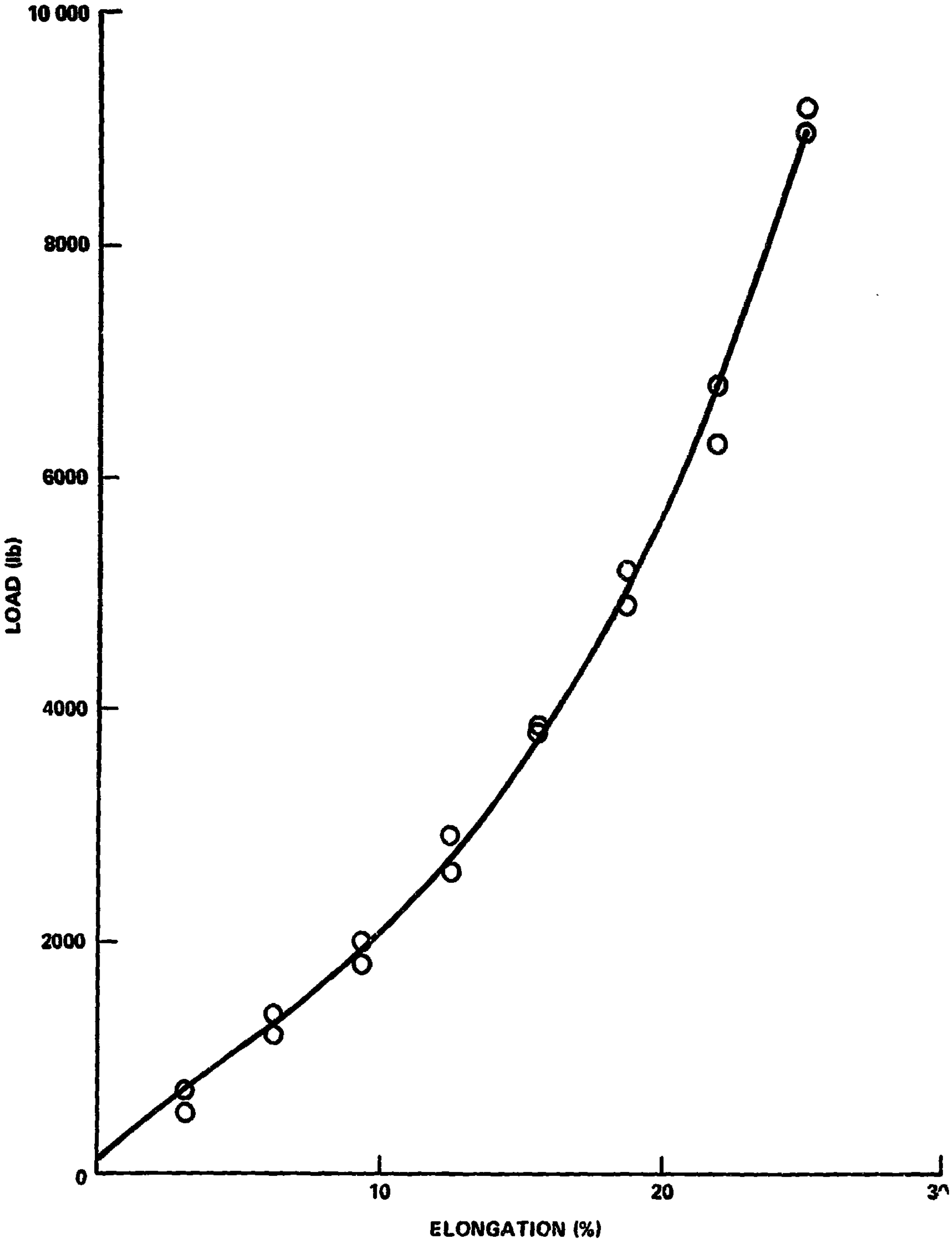

Figure 11. Static load-elongation for unexposed material, stitched (nylon webbing, MIL-W-4088, Type XXIII).

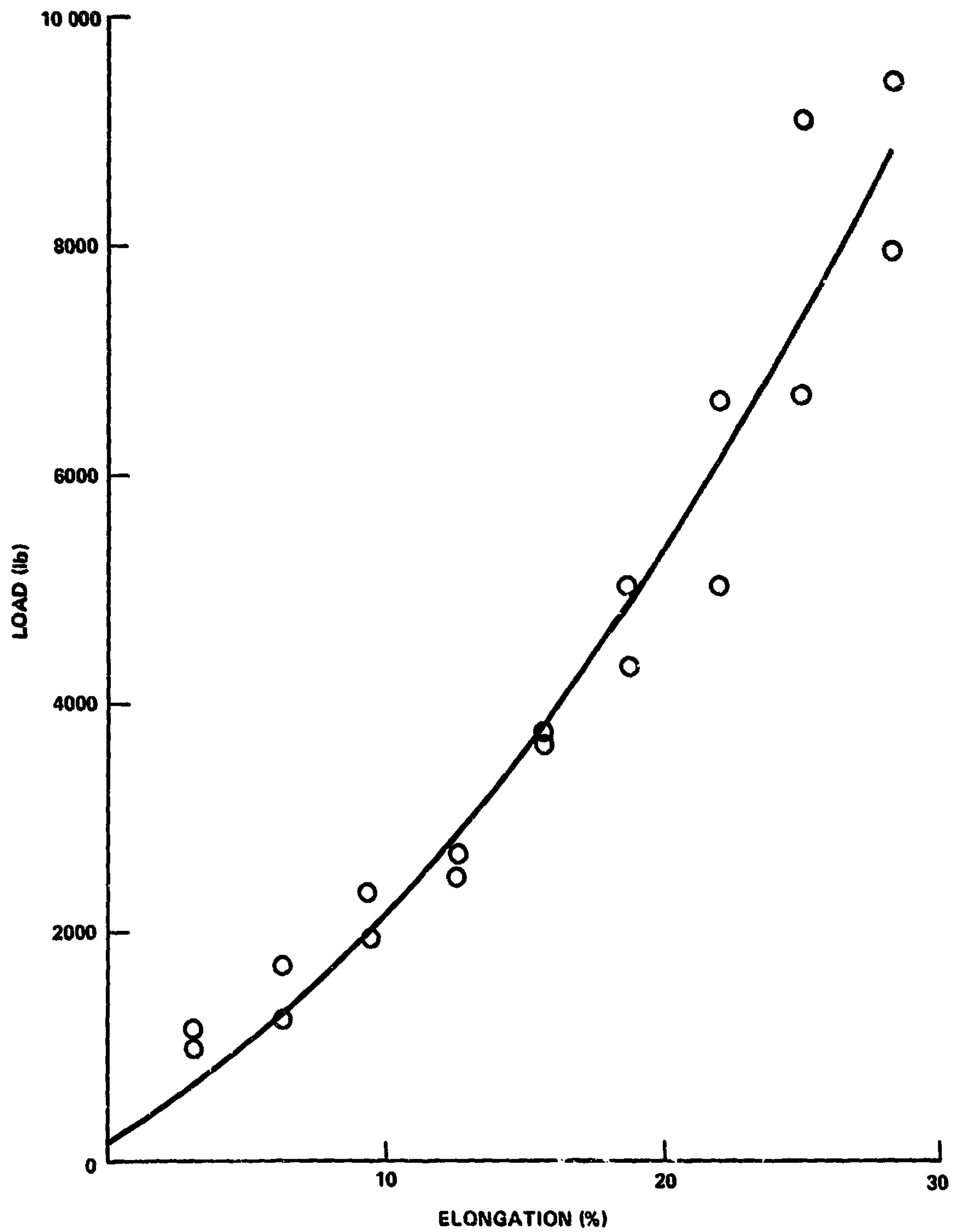

Figure 12. Static load-elongation for unexposed material, stitched (nylon webbing, MIL-W-4088, Type XXVI).

TABLE 3. STATIC BREAKING STRENGTH OF CONTROL (UNEXPOSED) PARACHUTE LOAD-BEARING WEBBING

Sample Identification	Rated Strength (lb)	Breaking Force (lb)
MIL-W-27657, Type II		
1A		4 100
1A		4 050
Average	4 000	4 075
MIL-W-27657, Type V[a]		
2A		7 940
2A		7 960
Average	9 000	7 950
MIL-W-4088, Type VI		
3A		2 625
3A		2 675
Average	2 500	2 650
MIL-W-4088, Type VII		
4A		5 950
4A		5 950
Average	5 500	5 950
MIL-W-4088, Type X		
5A		9 450
5A		9 850
Average	8 700	9 650
MIL-W-4088, Type XIII		
6A		8 125
6A		8 000
Average	6 500	8 062
MIL-W-4088, Type XVI		
7A		5 150
7A		5 100
Average	4 500	5 125
MIL-W-4088, Type XIX[a]		
8A		9 640
8A		10 160
Average	10 000	9 900
MIL-W-4088, Type XXIII[a]		
9A		9 960
9A		10 180
Average	12 000	10 070
MIL-W-4088, Type XXVI[a]		
10A		14 100
10A		13 900
Average	15 000	14 000

a. Webbing stitched with a 1 in. loop at both ends. A bolt was passed through loops, placed in Instron, and tested. Samples ruptured in stitched area.

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Four of the primary high strength webbings (i.e., main reefing line, main riser, drogue suspension line, and drogue skirt band), all with a breaking strength in excess of 10 000 lb, were loop stitched and reinforced at both ends. A 1 in. diameter rod was placed in the loop, and load-elongation measurements were made on the Riehle Testing Machine. The same technique was used as the Instron measurements. As expected, the stitched-reinforced samples ruptured in the stitched area. The load-to-rupture was lower in these samples than in their equivalent webbing without stitching but more closely simulated actual parachute "use" conditions. The stitching is dense at the termination of sewing, forming a "V" pattern which cuts several fibers in the webbing; thus, a weak strength area is created (Fig. 13). In a subsequent test, all of the vital load-bearing webbing were stitched to simulate the true design limit load.

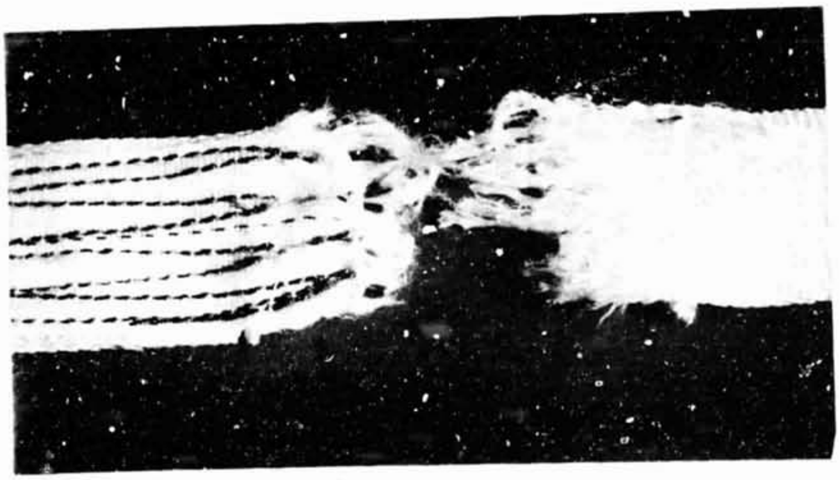

Figure 13. "V" pattern stitching used in webbing.

2. Inflation Load Testing. The principal load-bearing locations on these parachutes are the main suspension lines, the main risers, and the drogue suspension lines which are connected directly to or carry the full load of the SRB. It was decided to subject the webbings at these locations to the worst-case load conditions in testing (i.e., inflation loads until complete disreefing occurs) (Figs. 14 and 15).

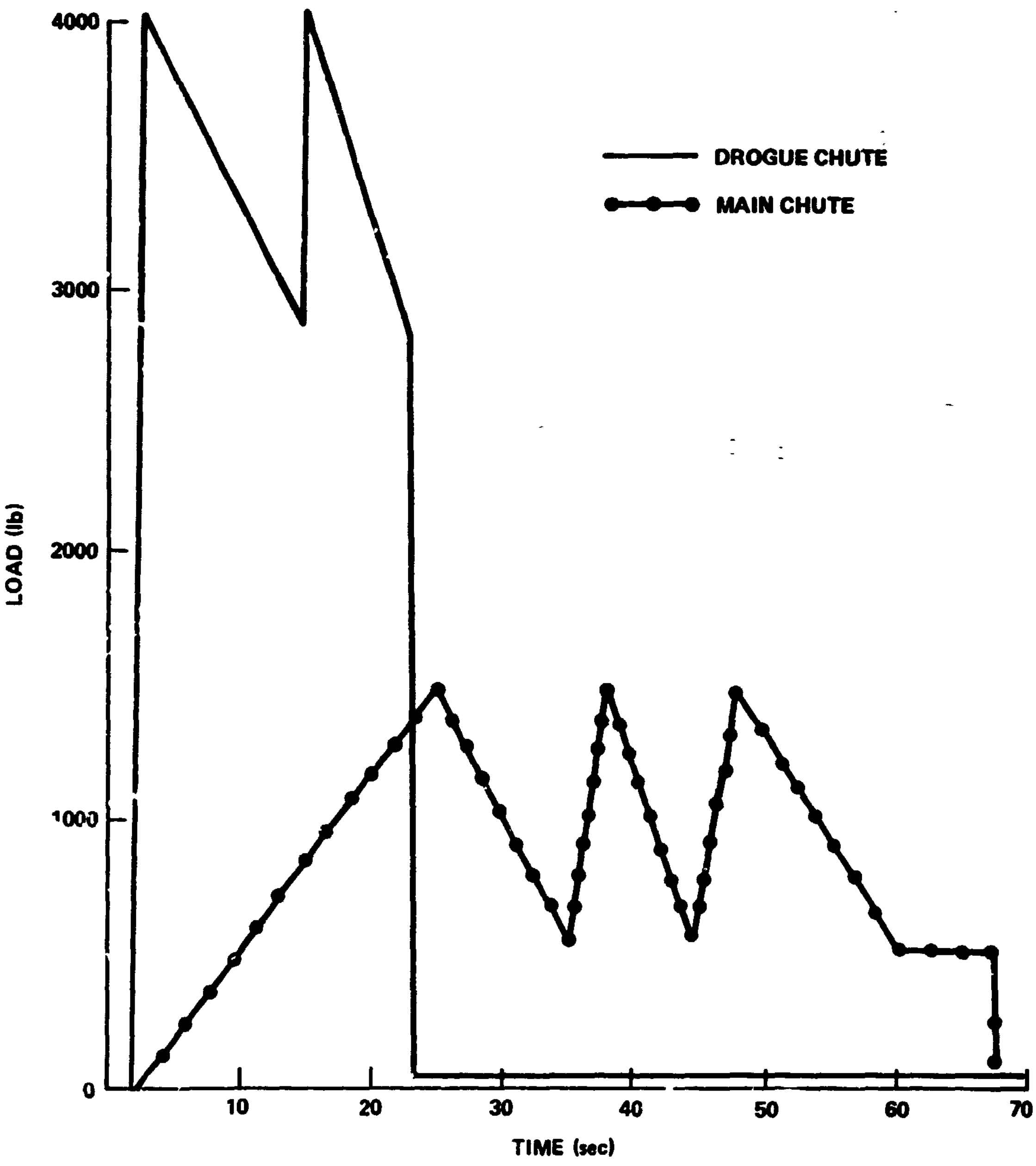

Figure 14. Suspension line load inflation and disreefing peaks.

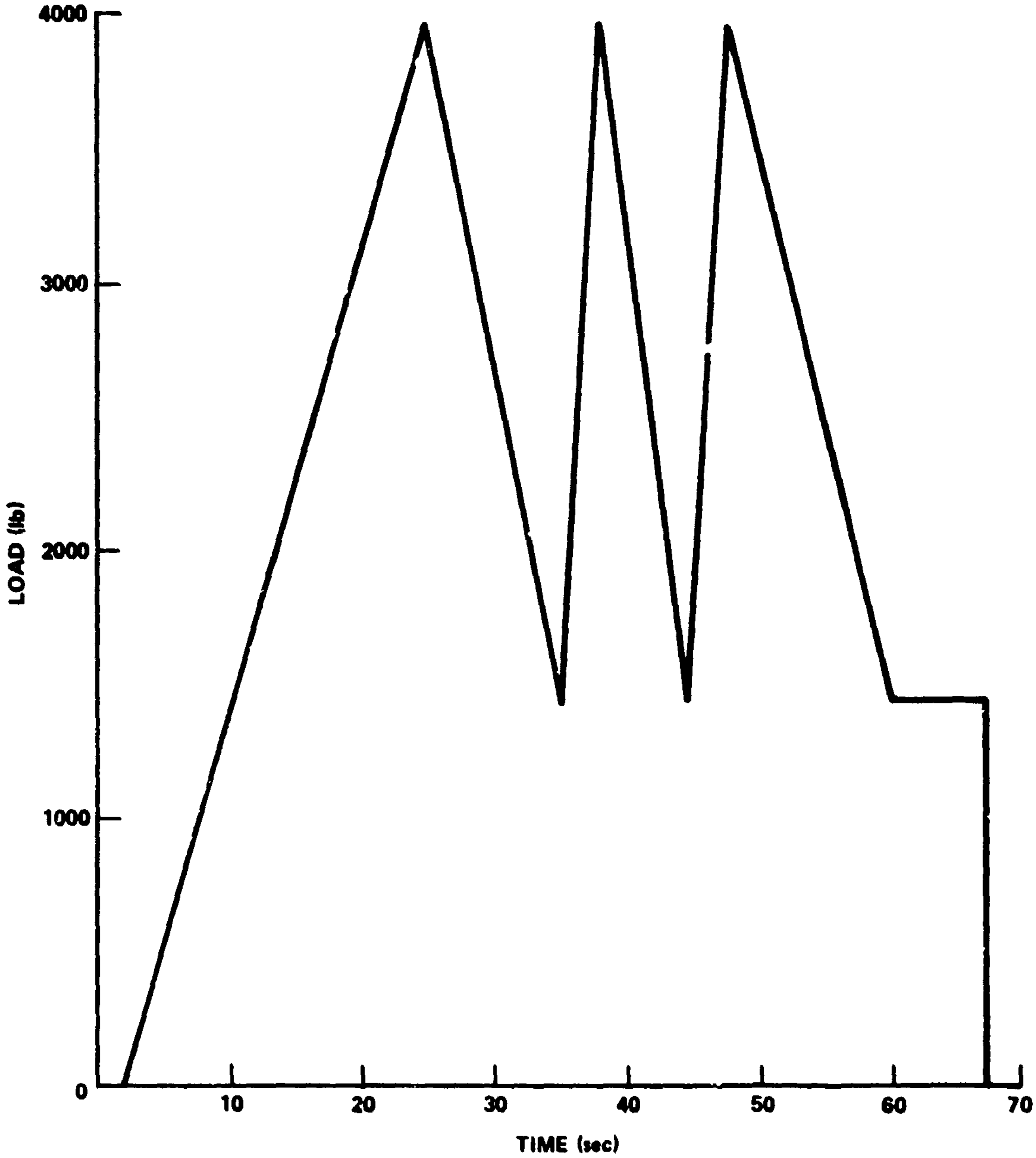

Figure 15. Main riser line load inflation and disreefing peaks.

An extended life test in simulated "use" environments was performed on the materials at the design limit load of 40 percent of the material's rated strength, which includes a safety factor. The other inflation loads range from an under-design limit load to several overload conditions. This gives some idea of what may be expected if an anomaly occurs during deployment (e.g., non-simultaneous opening of the parachute cluster, premature disreefing, failure of a main parachute to open, etc.). The webbing was subjected to seawater soak and UV light according to the procedure given in Table 4 and Figure 16.

TABLE 4. TEST PROCEDURE STEPS

1. Preload sample to 1 percent of its rated strength; measure reference length of sample
2. Load sample to inflation load; measure elongation
3. Hold inflation load for required time[a]
4. Relax to secondary load position; hold for required time[a]
5. Relax to preload 1 percent position; measure elongation
6. Remove sample, continue environmental exposure cycling, and subject to rinse and dry procedures established.
7. Cycle each material for a minimum of ten 21 hr exposure cycles, repeating test procedure steps 1 through 6 before the first cycle (control) and after cycles 1, 4, 7, and 10. Continue to 40 cycles for extended life test, repeating inflation loads after 20, 30, and 40 cycles
8. Load to failure

a. Hold inflation load constant for time period from top of first to top of final peak. Hold secondary load as depicted on graph from end of disreefing to deflation. Consider drogue chute secondary load time interval from peak of dereefing point to deflation. This is due to the slow rise time (2 in./min.) of the testing apparatus.

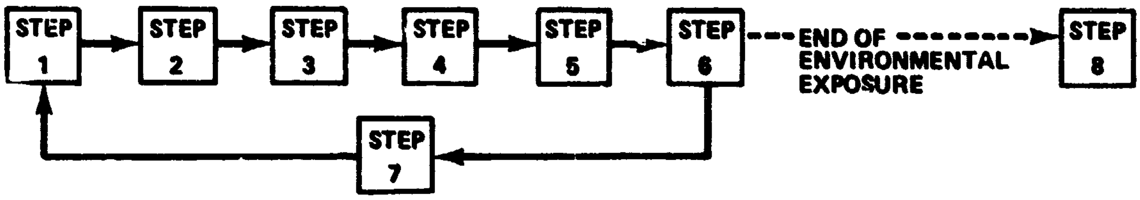

Figure 16. Test cycle.

The number of exposure cycles was dependent on the materials and their capability to withstand additional exposure-loading. Test loads applied are specified in Table 5. The inflation tests call for dynamic testing. Since the test machines used in this laboratory are not capable of the rapid rise (load) time, the regular 2 in./min was used to reach the first inflation (reefed) peak and the load was held for the time period required for final disreefing. A secondary load was then held for the time required for complete deflation, representing full main parachute inflation and descent to touchdown. These static loads represent a much more severe condition than the dynamic load test. This was obvious during cycling and testing while holding the specified time interval at peak loads. Webbing fibers could be heard snapping, and several webbings ruptured toward the end of the hold time period. Tables 6, 7, and 8 give results of these tests.

TABLE 5. RISER INFLATION LOADS AND BREAKING STRENGTH PROCEDURE FOR SUSPENSION LINES ON MAIN AND DROGUE PARACHUTES

Test Number	Sample Identification		
1. Reference, load to failure	1A-1	8A-1	9A-1
2. 25 percent of rated load, lb	1A-2/1000	8A-2/2500	9A-2/3000
3. 40 percent of rated load, lb, extended life test	1A-3/1600	8A-3/4000	9A-3/4800
4. 60 percent of rated load, lb	1A-4/2400	8A-4/6000	9A-4/7200
5. 75 percent of rated load, lb	1A-5/3000	8A-5/7500	9A-5/9000
6. 85 percent of rated load, lb	1A-6/3400	8A-6/8500	9A-6/10 200
Hold time at inflation peak, load values listed above	ALL 1A 23 sec	ALL 8A 23 sec	ALL 9A 13 sec
Secondary peak and hold time	525 lb 7 sec	1450 lb 7 sec	2800 lb 8 sec

Rated Strength: Main — MIL-W-27657, Type II (1A) 4000 lb; Riser — MIL-W-4088, Type XIX (8A) 10 000 lb; Drogue — MIL-W-4088, Type XXIII (9A) 12 000 lb

TABLE 6. TEST RESULTS OF INFLATION LOADS ON MAIN SUSPENSION LINE (STITCHED 1A, MIL-W-27567, TYPE II; RATED STRENGTH — 4000 lb)

Table 5 Test No.	Environmental Cycles	Preload Length (in.)	Elongation at Load (%)	Final Preload Length (in.)
(25 percent of Rated Strength — 1000 lb)				
1	0	Ultimate Elong.	21	Load to Failure — 3637 lb
2	0	10 1/4	16	11
2	1	9 3/4	19	10 1/4
2	4	9 3/4	15	10 1/2
2	7	9 1/2	21	10 1/2
2	10	10	16	10 5/8
1	10	Load to Failure --------- 2900 lb		
(40 percent of Rated Strength — 1600 lb)				
3	0	10 1/4	20	11 1/8
3	1	9 3/4	20	10 9/16
3	4	9 5/8	20	10 3/4
3	7	9 3/4	22	10 3/4
3	10	10	20	10 7/8
3	20	—	30	—
3	30	Passed — No Failure		
3	40	—	24	—
1	40	Load to Failure --------- 1818 lb		

Note: No length measurements taken after 10 cycles.

TABLE 6. (Concluded)

Table 5 Test No.	Environmental Cycles	Preload Length (in.)	Elongation at Load (%)	Final Preload Length (in.)
(60 percent of Rated Strength — 2400 lb)				
4	0	10 1/4	21	11 1/16
4	1	9 5/8	22	10 9/16
4	4	9 1/2	21	11
4	7	9 7/8	23	11
4	10	10 1/8	22	11.
4	20	Failed at Inflation Load — 2400 lb		
(75 percent of Rated Strength — 3000 lb)				
5	0	10 1/4	19	11 1/16
5	1	10 5/8	Failed While Holding at Inflation Peak — 3000 lb	
(85 percent of Rated Strength — 3400 lb)				
6	0	10 3/8	21	11 1/8
6	1	9 11/16	Failed at 3063 lb	

TABLE 7. TEST RESULTS OF INFLATION LOADS ON MAIN RISER HARNESS (STITCHED 8A, MIL-W-4088, TYPE XIX; RATED STRENGTH — 10 000 lb)

Table 5 Test No.	Environmental Cycles	Preload Length (in.)	Elongation at Load (%)	Final Preload Length (in.)
(25 percent of Rated Strength — 2500 lb)				
1	0	—	23	Load to Failure — 9900 lb
2	0	10 1/2	10	11
2	1	9 3/4	12	10 1/4
2	4	9 7/8	11	10 3/8
2	7	9 7/8	14	10 1/2
2	10	10	13	10 1/2
1	10	Load to Failure — 7515 lb		
(40 percent of Rated Strength — 4000 lb)				
3	0	10 3/8	12	10 3/4
3	1	9 7/8	14	10 3/8
3	4	9 3/4	14	10 1/2
3	7	9 3/4	16	10 9/16
3	10	9 7/8	16	10 1/2
3	20	—	22	—
3	30	Passed — No Failure		
3	40	—	16	—
1	40	Load to Failure — 5493 lb		

Note: No length measurements taken after 10 cycles.

TABLE 7. (Concluded)

Table 5 Test No.	Environmental Cycles	Preload Length (in.)	Elongation at Load (%)	Final Preload Length (in.)
(60 percent of Rated Strength — 6000 lb)				
4	0	10 5/16	15	11
4	1	9 3/4	16	10 1/4
4	4	9 3/4	17	10 1/2
4	7	9 3/4	20	10 5/8
4	10	9 7/8	18	10 1/2
4	20	—	26	—
1	20	Load to Failure — 6050 lb		
(75 percent of Rated Strength — 7500 lb)				
5	0	10 1/4	19	11
5	1	9 13/16	17	10 1/2
5	4	9 7/8	17	10 3/4
5	7	9 7/8	Failed at 6850 lb	
(85 percent of Rated Strength — 8500 lb)				
6	0	10 1/2	23	11 1/4
6	1	9 3/4	Failed While Holding at Inflation Peak — 8500 lb	

TABLE 8. TEST RESULTS OF INFLATION LOADS ON DROGUE SUSPENSION LINE (STITCHED 9A, MIL-W-4088, TYPE XXIII; RATED STRENGTH — 12 000 lb)

Table 5 Test No.	Environmental Cycles	Preload Length (in.)	Elongation at Load (%)	Final Preload Length (in.)
(25 percent of Rated Strength — 3000 lb)				
1	0	10 1/8	Ultimate Elong. 20%	Load to Failure 11.150
2	0	11 7/8	15	12 1/2
2	1	10 1/4	14	10 1/2
2	4	10	12	10 9/16
2	7	10	13	10 5/8
2	10	10 1/8	12	10 5/8
1	10	10	Load to Failure — 10 395 lb	
(40 percent of Rated Strength — 4800 lb)				
3	0	11 7/8	20	12 5/8
3	1	10 1/4	14	10 9/16
3	4	10 1/8	14	10 3/8
3	7	10 1/16	17	11
3	10	10 1/8	17	10 7/8
3	20	—	22	—
3	30		Passed — No Failure	
3	40	—	20	—
1	40	Load to Failure — 6300 lb		

Note: No length measurements taken after 10 cycles.

TABLE 8. (Concluded)

Table 5 Test No.	Environmental Cycles	Preload Length (in.)	Elongation at Load (%)	Final Preload Length (in.)
(60 percent of Rated Strength — 7200 lb)				
4	0	11 7/8	21	13 3/8
4	1	10 3/16	16	10 3/4
4	4	10 1/8	16	11
4	7	10 1/4	17	11 1/16
4	10	10 1/8	20	10 7/8
1	20	Load to Failure — 8480 lb		
(75 percent of Rated Strength — 9000 lb)				
5	0	10 1/8	21	10 13/16
5	1	10 1/8	18	10 11/16
5	4	10 1/8	—	11 1/8
5	7	10 1/4	22	11 1/18
5	10	Failed While Holding at Inflation Peak — 9000 lb		
(85 percent of Rated Strength — 10 200 lb)				
6	0	10 1/8	20	11 1/8
6	1	Failed While Holding at Inflation Peak — 10 200 lb		

C. Other Tests

1. Abrasion Tests. The drogue suspension lines (a smooth weave webbing) and the main riser lines (a rough weaving finish) were chosen for these tests. Abrasion testing per MIL-W-4088 D was conducted and both materials proved to be extremely susceptible to abrasion (Table 9 and Figs. 17 and 18). Both samples were new, unexposed, unstitched webbing.

TABLE 9. ABRASION TEST

Sample	Rated Rupture Strength (lb)	Rupture Strength After Abrasion (lb)
Main Riser (MIL-W-4088, Type XIX)		
EH33 8A		4400
EH33 8A		3750
Average	10 000	4085
Drogue Suspension Line (MIL-W-4088, Type XXIII)		
EH33 9A		5120
EH33 9A		5530
Average	12 000	5325

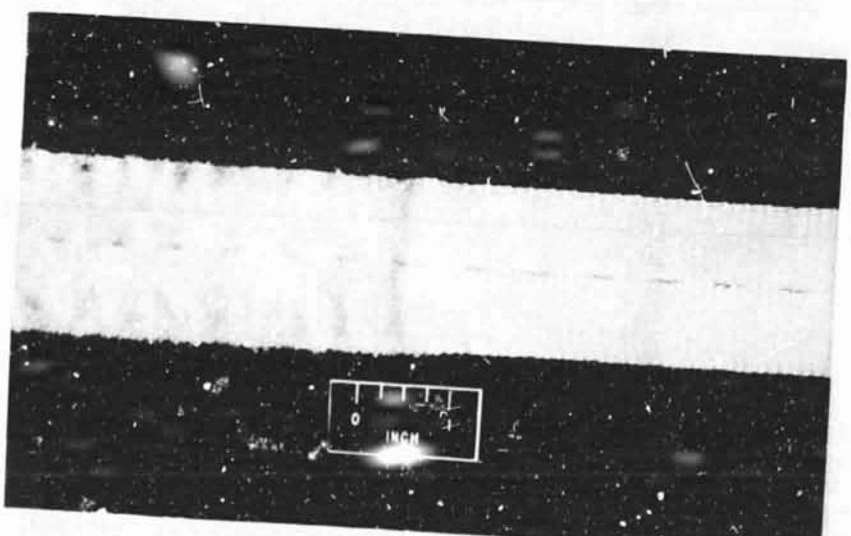

Figure 17. Abraided area in webbing.

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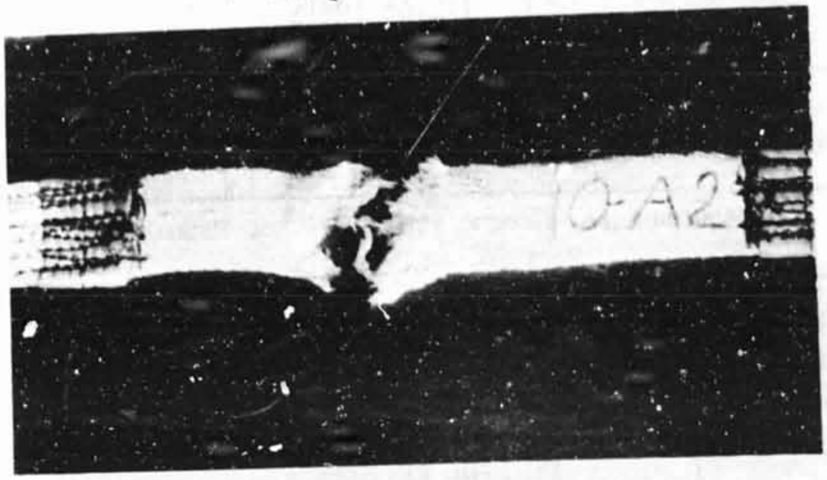

Figure 18. Rupture on load test in abraided area (not in the normal stitch area).

2. Metallic Suspension Link Strength Test. The metallic separable parachute link assemblies are an in-line integral part of the suspension lines in both the main and drogue parachutes. They are fastened to the suspension lines by interlink screw bolts and designed to be removed during the recovery-cleaning and refurbishment operations. The location of these links makes their strength as important as the webbing. A load was applied and the links tested on the Instron machine. They were connected as shown in Figure 19. Table 10 gives the results of the metallic suspension link strength test.

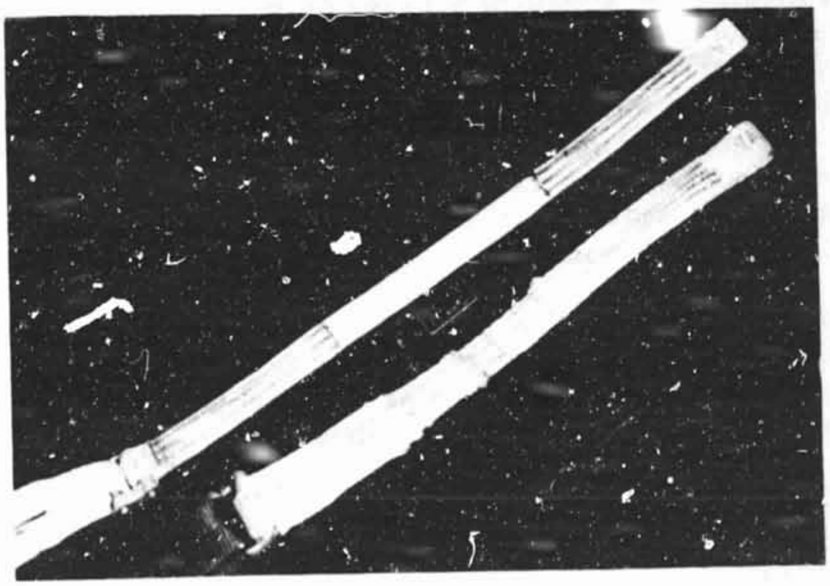

Figure 19. Metallic link test configuration.

TABLE 10. RESULTS OF METALLIC SUSPENSION LINK STRENGTH TEST

Sample	Link Bent (lb)	Rupture (lb)
Suspension Line, Drogue (MIL-W-4088, Type XXIII) Part No. 52 B 6660-1		
EH33 9A Average	6000	8550
Suspension Line, Main (MIL-W-27657) Part No. MS 22021-1		
EH33 1A Average	3517	7250

Note: These values exceed the design limit load.

IV. CANOPY TAPE AND WEBBING

Requirements were not as demanding on the canopy materials listed in Table 11 as on the load-bearing webbing. Therefore, no permanent deformation test nor worst-case "use" conditions were determined during these analyses. The environmental conditions were severe as in previous webbings with one cycle consisting of three 7 hr exposures to UV light in the weatherometer while keeping samples wetted with the artificial seawater and an overnight seawater soak (21 hr UV light exposure). Rupture loads were measured on the Instron machine in determining the effects of heat exposure, seawater soak and rinse, environmental cycles, and environmental cycles plus abrasion (Fig. 20). A summary of results is given in Table 12.

In collaboration with the previously chosen parachute manufacturer, The Pioneer Parachute Co., it was found that the shrinkage regained its normal length when subjected to a load. This keeps the parachute to within approximately 95 percent of its initial fabrication measurements.

TABLE 11. PARACHUTE CANOPY MATERIAL

Lab No.	Nylon Tape per MIL-T-5608	Application
EH33-4	Type V, Class C, 2 in. width, 300 lb breaking strength	Radial, main
EH33-5	Type II, Class D, 2 in. width, 400 lb breaking strength	Horizontal, main
EH33-6	Type II, Class E, 2 in. width, 1000 lb breaking strength	Radial, main
EH33-7	Type IV, Class E, 2 in. width, 2000 lb breaking strength	Radial, main
	Nylon Tape per MIL-T-5038	
EH33-8	Type V, 9/16 in. width, 500 lb breaking strength	Vertical, drogue, main
	Nylon Webbing per MIL-W-83144	
EH33-1	Type I, 2 in. width, 1000 lb breaking strength	Horizontal, drogue
EH33-3	Type V, 2 in. width, 1500 lb breaking strength	Horizontal, drogue, main
EH33-2	Type II, 2 in. width, 2200 lb breaking strength	Horizontal, drogue, main

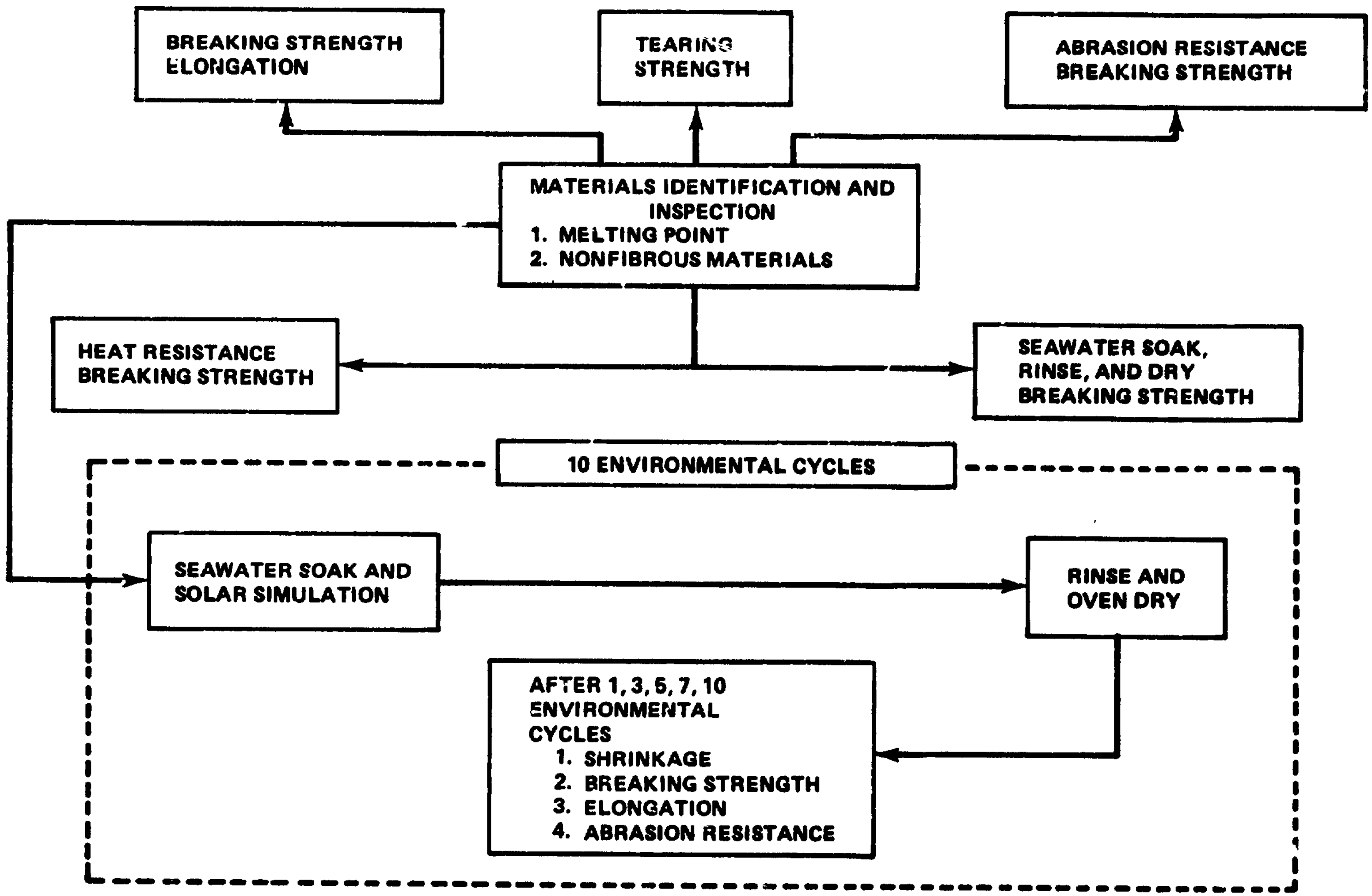

Figure 20. Canopy parachute materials test plan.

TABLE 12. PARACHUTE CANOPY MATERIALS TEST SUMMARY

	MIL-W-83144 Type I	MIL-W-83144 Type II	MIL-W-83144 Type V	MIL-T-5608 Type V, Cl C	MIL-T-5608 Type II, Cl D	MIL-T-5608 Type II, Cl E	MIL-T-5608 Type IV, Cl E	MIL-T-5038 Type V
Nonfibrous Materials (%)	1.47	1.82	150	1.41	1.28	1.55	1.44	1.44
Chloroform Soluble (%)	0.99	1.17	0.81	0.64	0.65	0.84	0.81	0.79
Water Soluble (%)	0.44	0.65	0.69	0.77	0.62	0.71	0.63	0.65
Melting Point (°C)	260	260	260	257	260	259	258	260
Tearing Strength (lb)	54	62	47	7	50	58	47	N/A
Specified Breaking Strength (lb),(Elongation (%))	1000	2200	1500	300,(22)	460,(18)	1000,(18)	2000,(24)	500,(18)
Breaking Strength (lb), (Elongation (%))	1185,(18)	2005,(22)	1755,(22)	385,(22)	540,(18)	1160,(18)	2357,(22)	642,(19)
After Abrasion	1178	1563	1690	392	545	1125	2287	440
After Heat Exposure	1223	2163	1803	391	584	1183	2193	634
After Seawater Soak and Rinse	1122	1910	1652	375	530	1090	2140	620
Environmental Cycles								
After 1 Cycle	1015	1990	1400	270	452	1065		
After 3 Cycles	1050	1807	1432	287	447	1040		
After 5 Cycles	995	1885	1417	302	412	990		
After 7 Cycles	900	1640	1365	250	375	872		
After 10 Cycles	975	1865	1365	235	410	912		
After Abrasion								
1 Cycle	1012	1315	1413	396	408	1085		
3 Cycles	1000	1180	1405	247	375	975		
5 Cycles	1055	1280	1480	268	445	990		
7 Cycles	1015	1300	1250	245	455	1032		
10 Cycles	980	1415	1290	290	343	973		
Shrinkage After								
1 Cycle (%)	3.44	2.40	2.88	1.12	4.44	4.90		
3 Cycles (%)	2.62	3.24	3.12	0.50	4.62	5.24		
5 Cycles (%)	2.38	3.24	3.36	0.24	4.74	5.12		
7 Cycles (%)	3.12	3.36	3.50	0.18	4.54	5.54		
10 Cycles (%)	2.74	3.76	3.74	0.12	4.48	5.06		

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No load-elongation curves were plotted for abraded samples since abrasions resulted in very little damage to samples abraded after the environmental and the load-environmental cycles. Figures 21 through 28 give the comparative environmental effects on static load-elongation curves.

A description of the parachute canopy material test method is given in Appendix B.

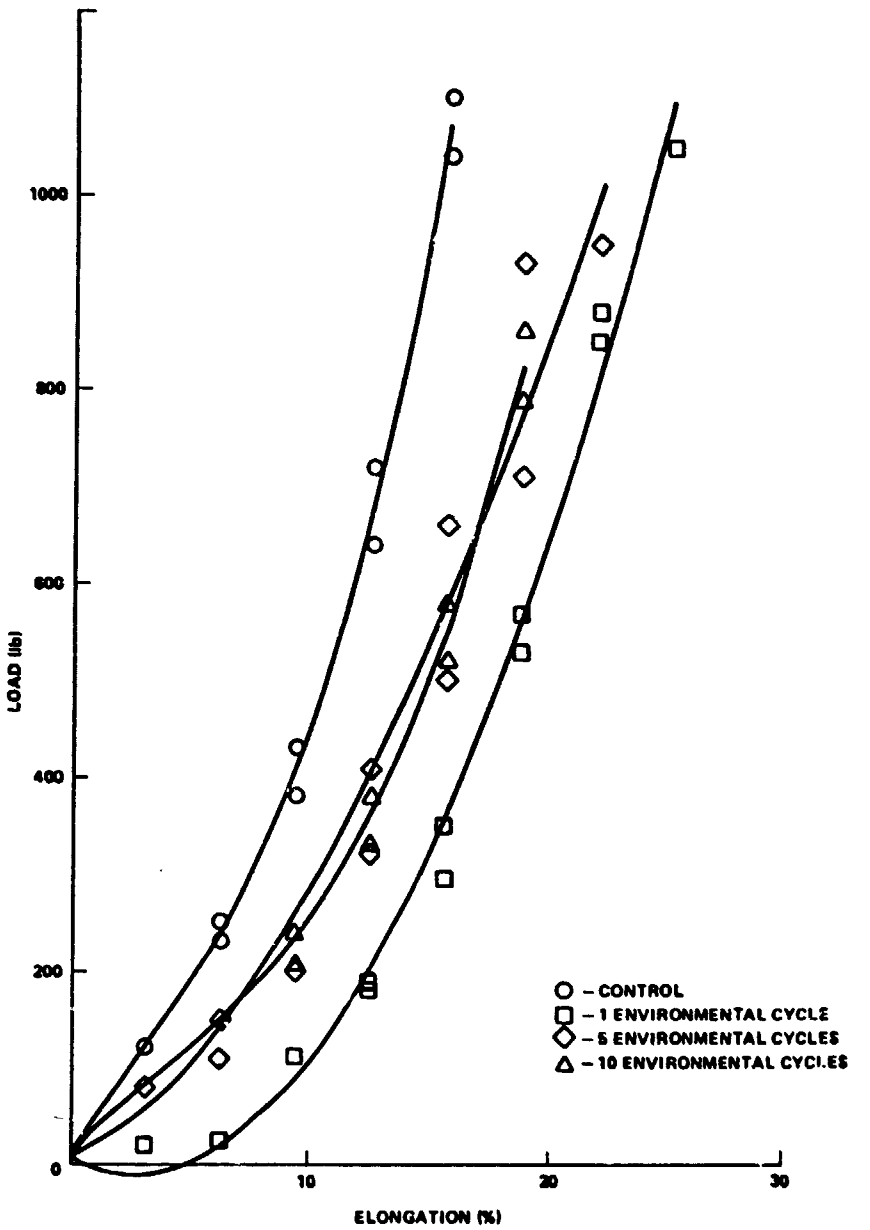

Figure 21. Comparative environmental effects on static load-elongation (nylon webbing, MIL-W-83144, Type I).

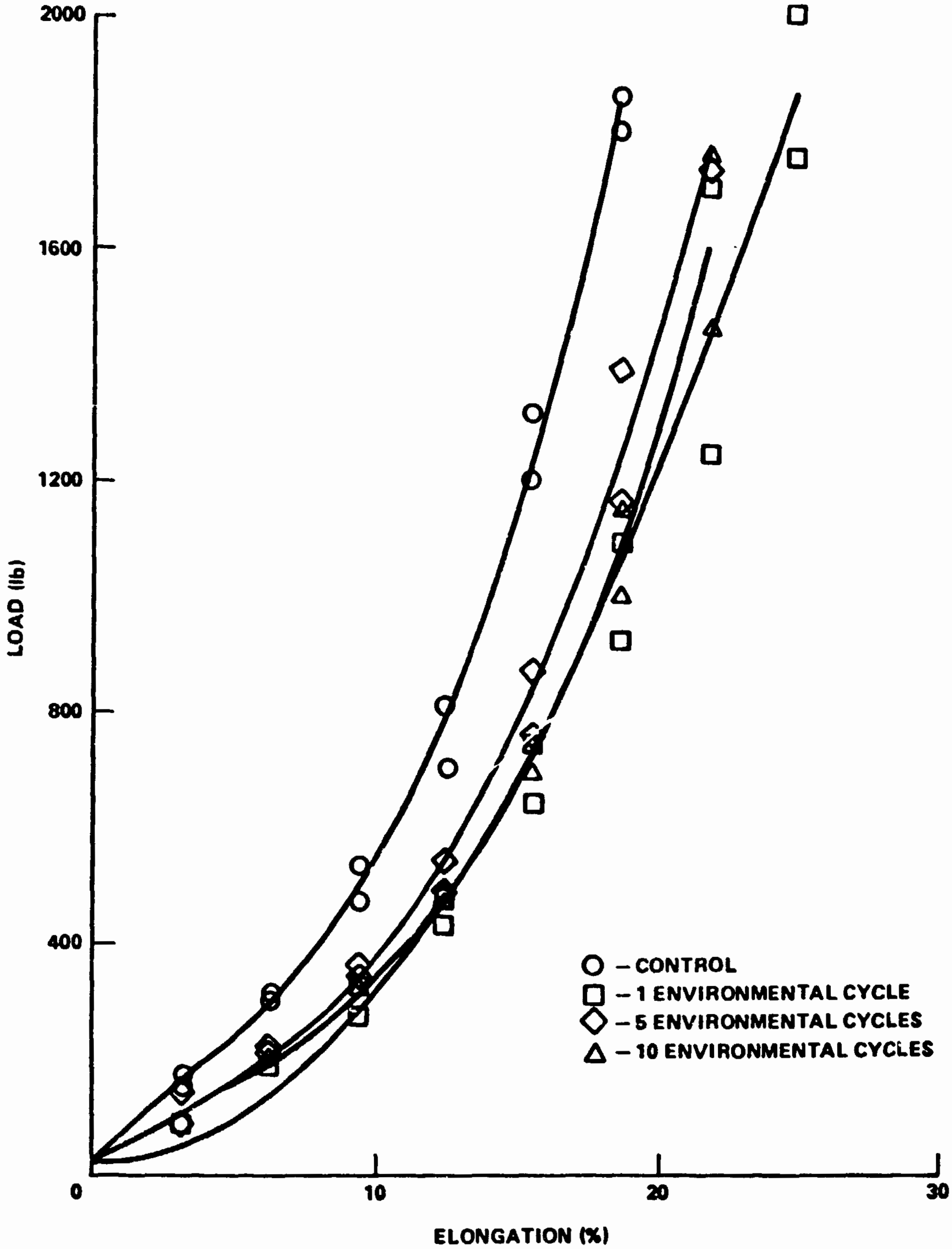

Figure 22. Comparative environmental effects on static load-elongation (nylon webbing, MIL-W-83144, Type II).

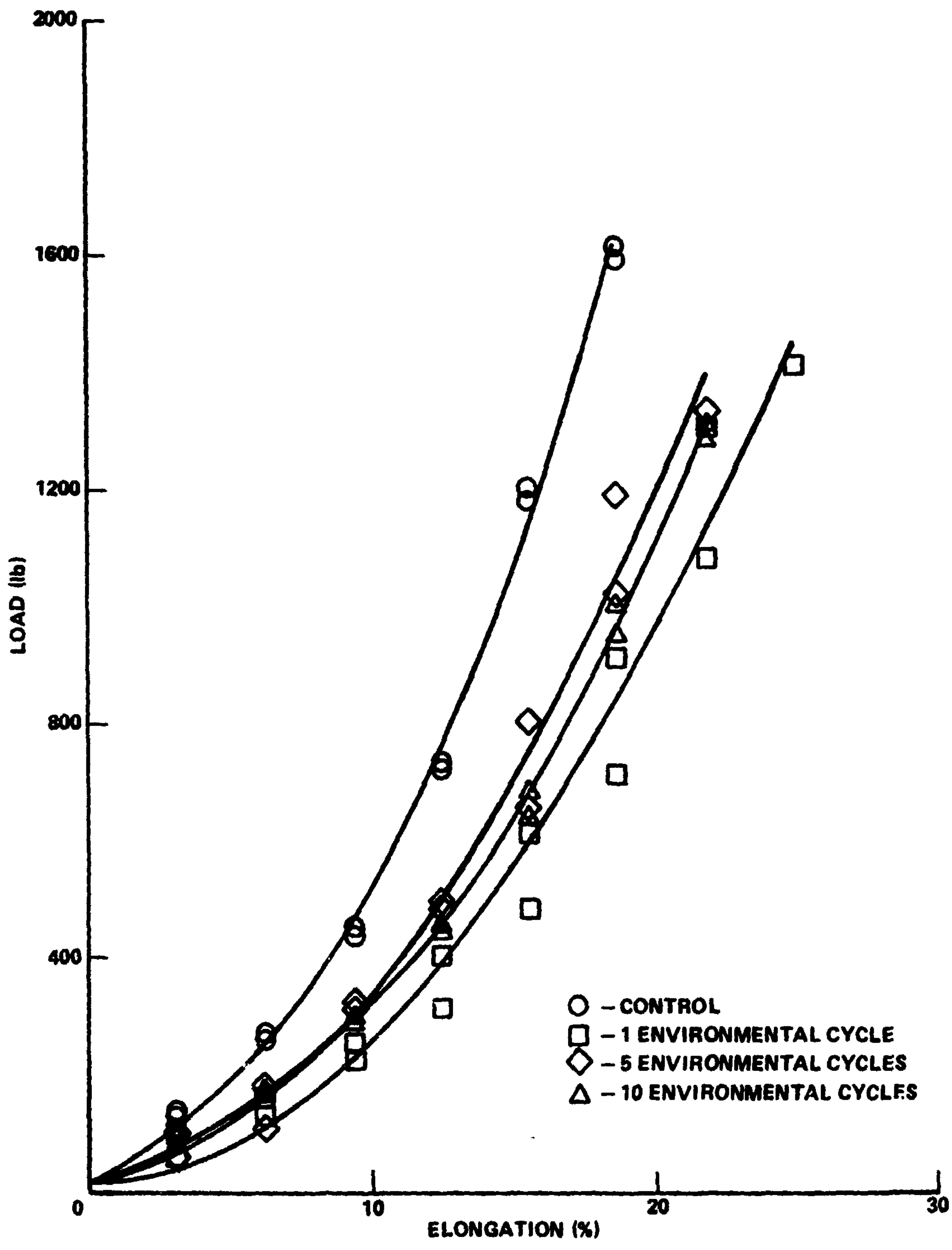

Figure 23. Comparative environmental effects on static load-elongation (nylon webbing, MIL-W-83144, Type V).

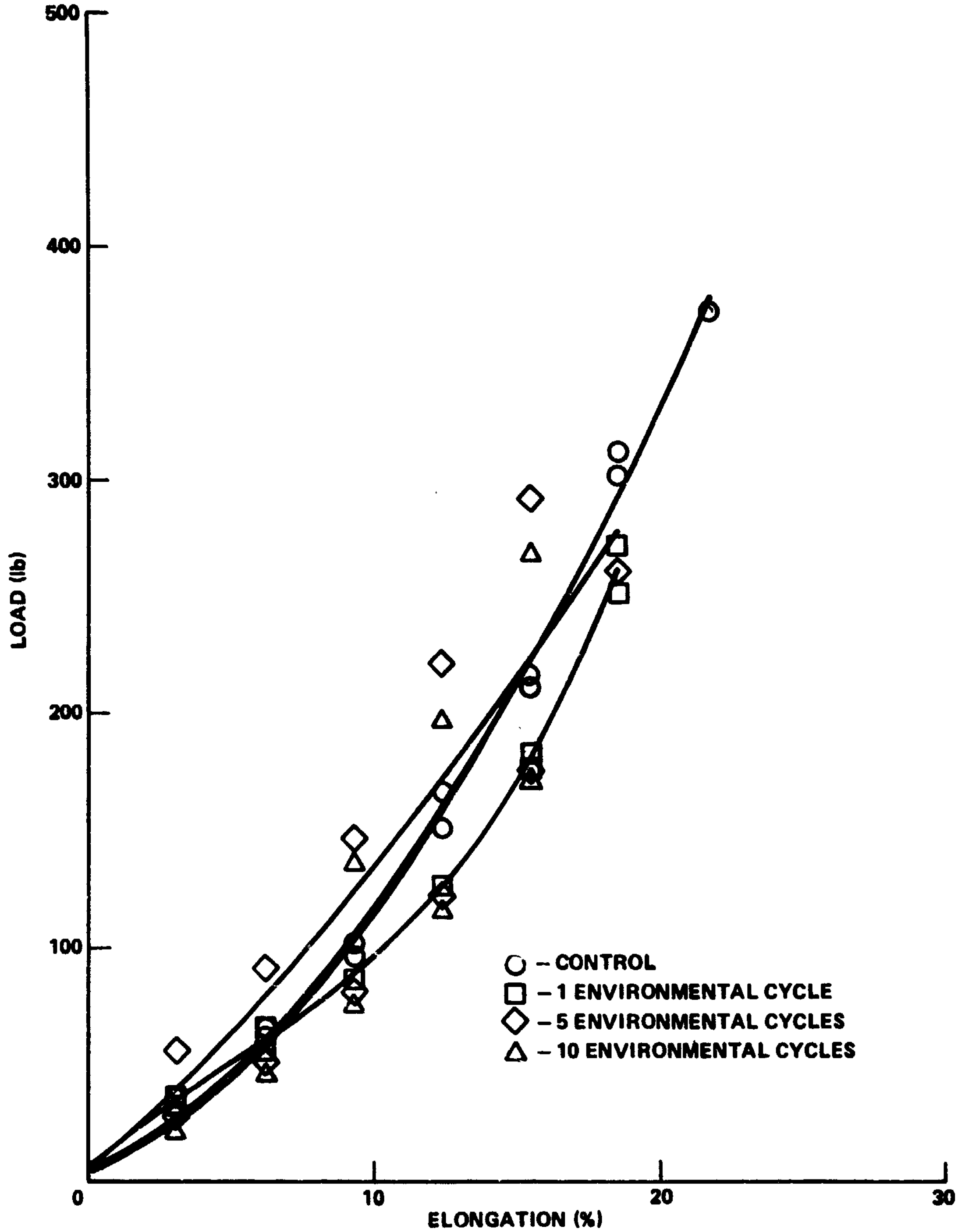

Figure 24. Comparative environmental effects on static load–elongation (nylon tape, MIL-T-4608, Type V, Class C).

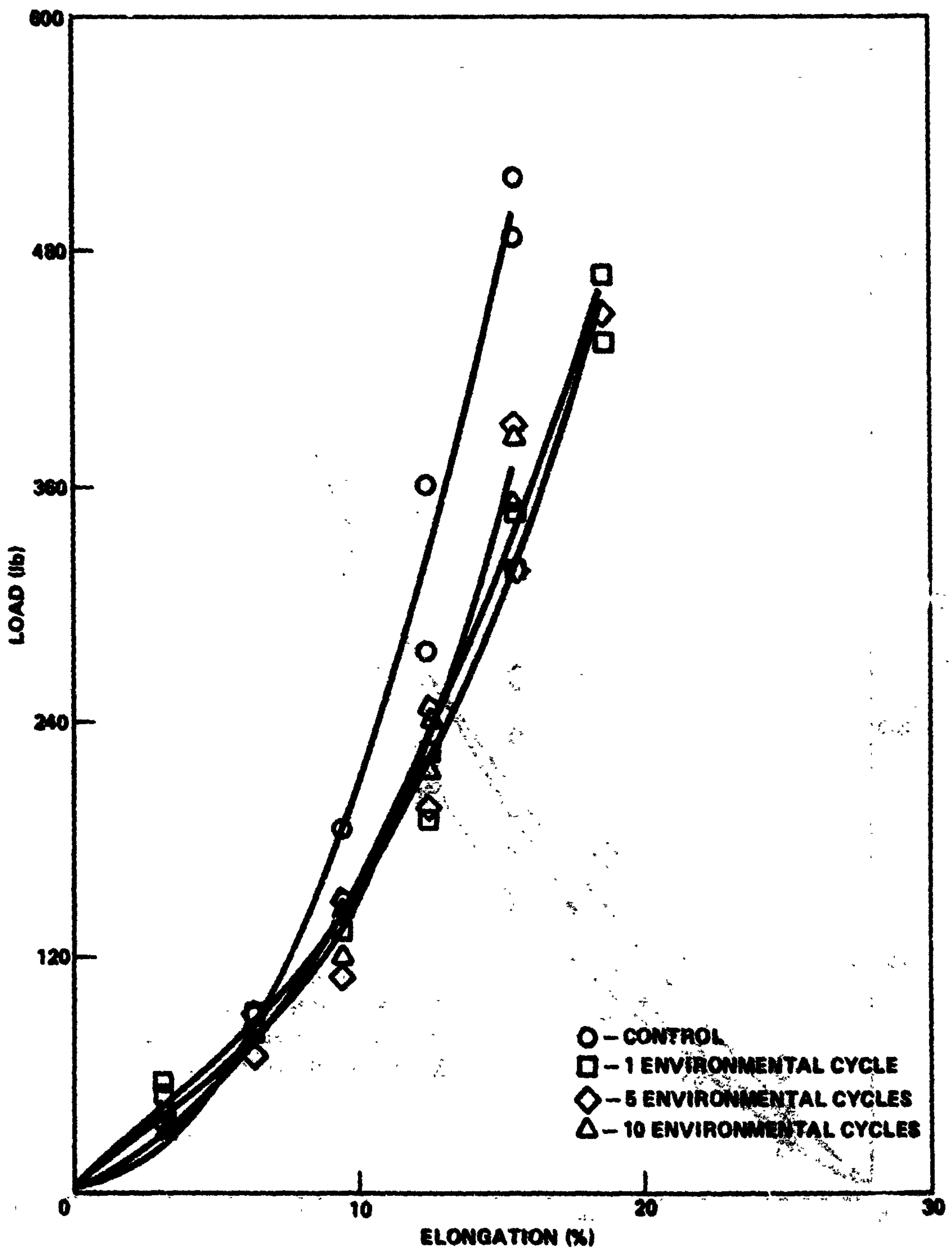

Figure 25. Comparative environmental effects on static load-elongation (nylon tape, MIL-T-5608, Type II, Class D).

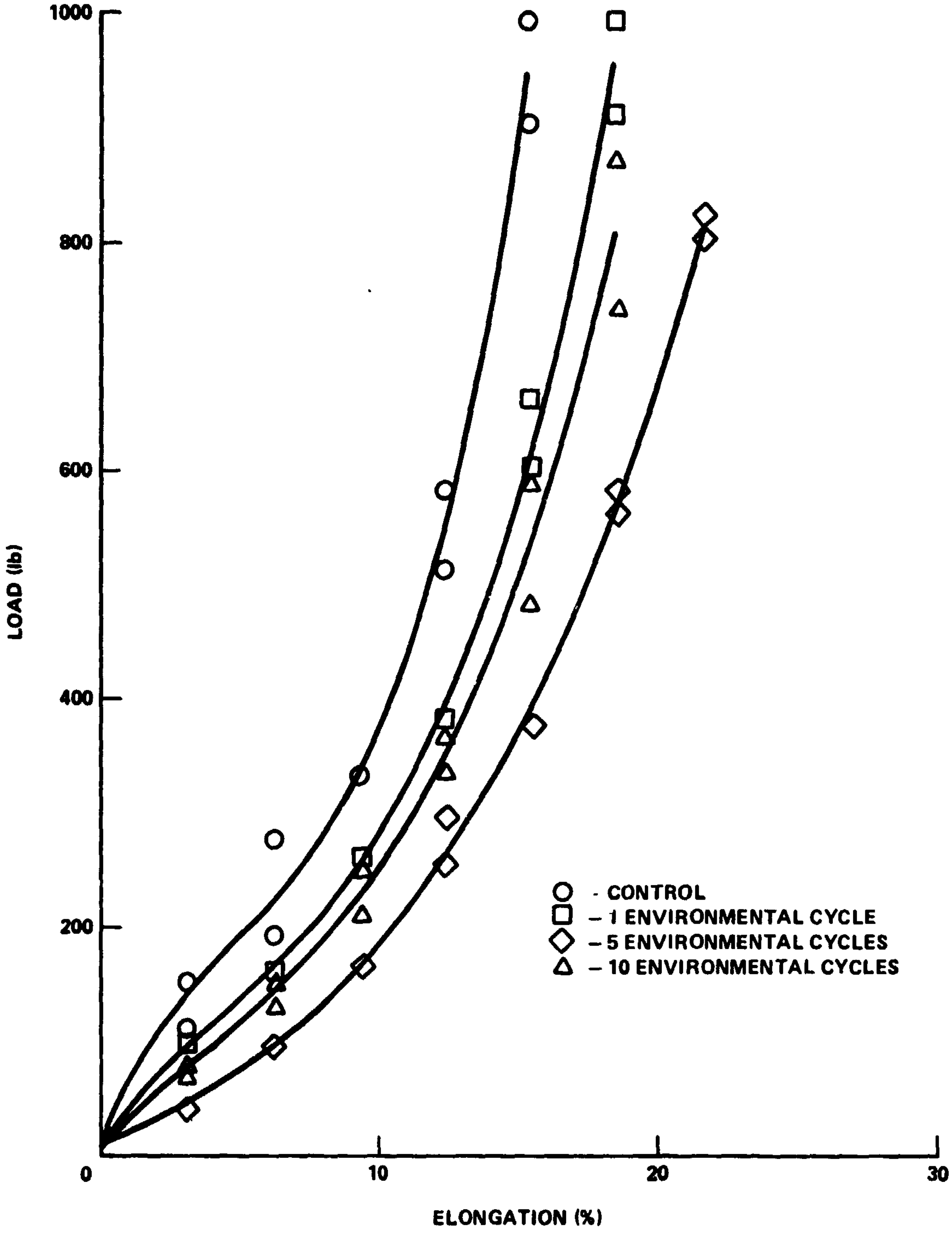

Figure 26. Comparative environmental effects on static load-elongation (nylon tape, MIL-T-5608, Type II, Class E).

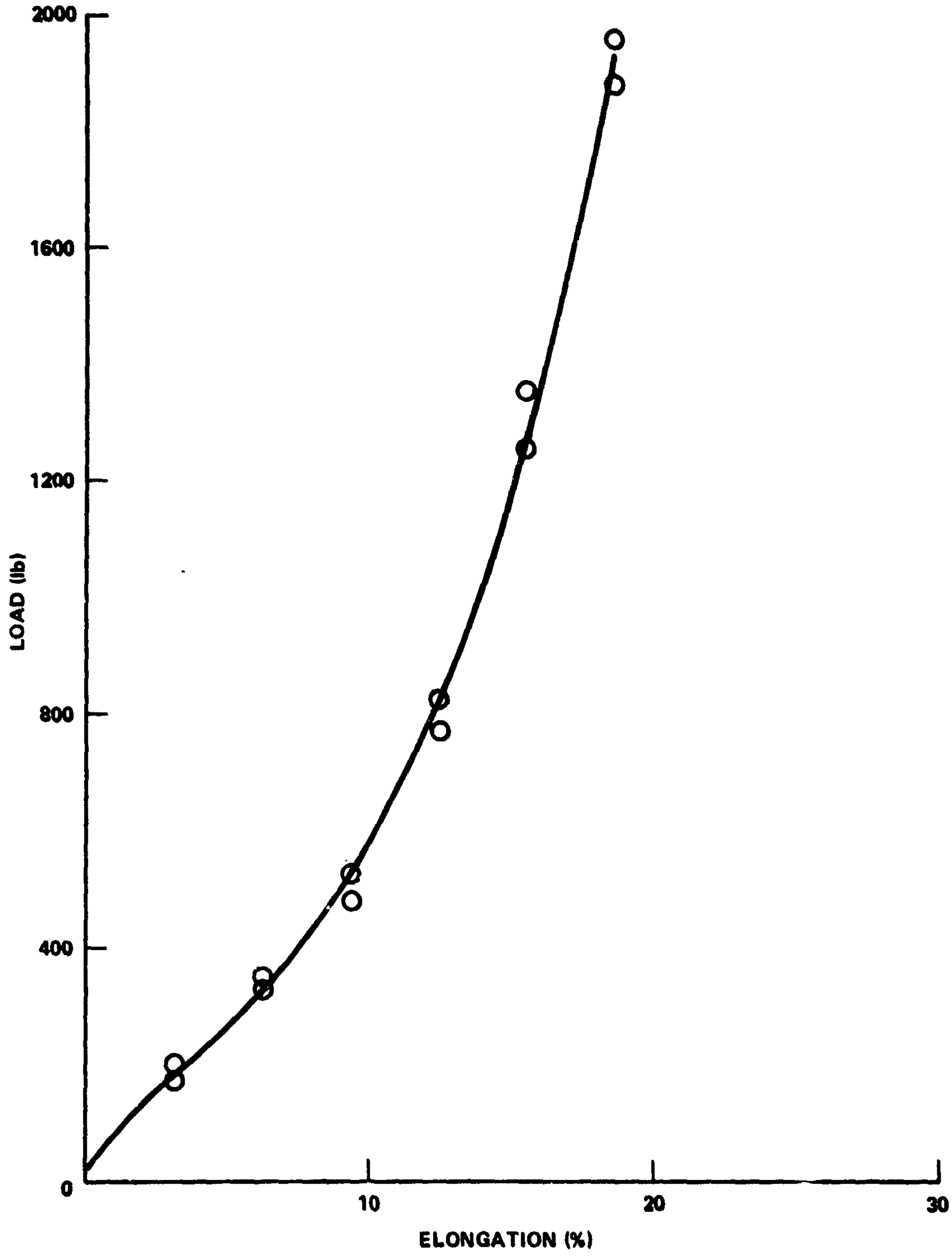

Figure 27. Static load-elongation for unexposed material (nylon tape, MIL-T-5608, Type IV, Class E).

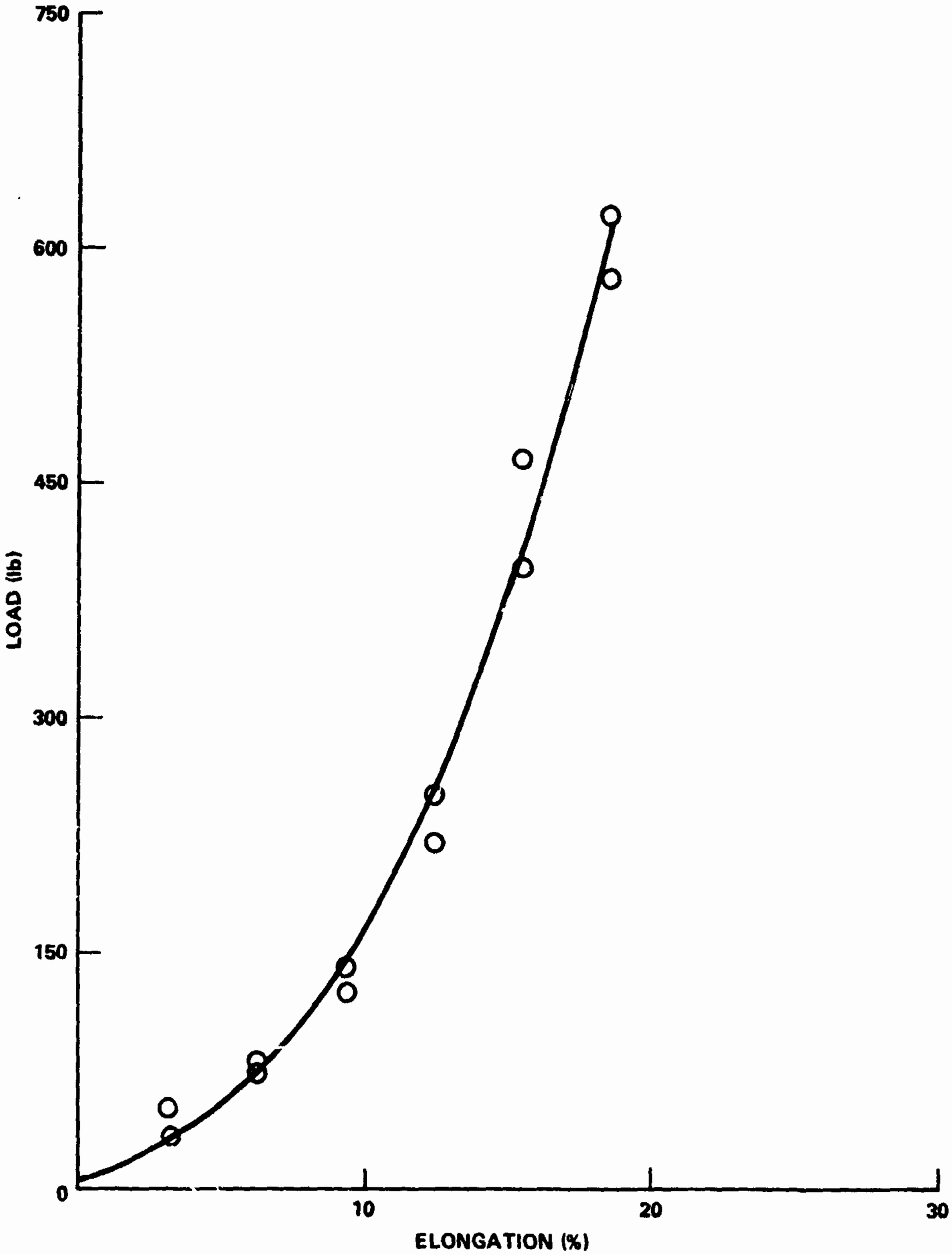

Figure 28. Static load-elongation for unexposed material (nylon tape, MIL-T-5038, Type V).

V. OCEAN WATER SUBMERSION AT KENNEDY SPACE CENTER (KSC)

A. Materials Study of Marine Organism Effects

A study was planned to determine the effect of seawater bioorganisms on the nylon parachute material after some concern was expressed as to:

1) What types of growths are likely to be encountered?

2) Do any of the organisms mechanically or chemically degrade the material?

3) How effectively is the marine life removed by the planned rinsing operations?

Eight materials were selected for exposure. Parameters for selection were (1) importance of function in SRB recovery, (2) military specification requirements (minimum of one material per specification), (3) strength of material, and (4) weave pattern.

The samples were mounted on a rack and placed 35 ft deep in the ocean approximately 700 yards offshore from KSC. Some degree of abrasion was expected due to the close proximity of samples and the action of the sea while submerged. The samples were recovered after 7 days, placed in a container of the seawater, and returned to the MSFC Materials and Processes Laboratory.

B. Materials Testing

An outline of marine organism studies and distribution of the eight samples selected are given in the following listing:

1) Unexposed nylon samples

2) After 7 days KSC ocean submersion

3) After approved rinsing procedure.

Unexposed samples were received by biological personnel of the University of Maryland Microbiology Department [1], and the MSFC Materials and Processes Laboratory for control analysis.

After 7 days of ocean submersion and after the approved rinsing procedure, both sets of samples were sent to MSFC biological personnel and to the University of Maryland for microscopic quantitative analysis for a colony count of marine orgnisms and scanning electron microscopic (SEM) examination for identification. Samples from Groups 2 and 3 were also retained by the Materials and Processes Laboratory for load-elongation and ultimate breaking strength analysis. Additional SEM analyses with energy dispersion of X-ray (EDAX) attachments were processed by the Materials and Processes Laboratory for debris and inorganic contaminants.

Biodegradation tests are presently underway at the University of Maryland to determine if there are actually any detrimental effects on nylon by marine organisms or fungi.

Figure 29 shows the KSC submersion rack being removed to the ship after a 7 day submersion test. Figure 30 shows the degree of abrasion on some of the samples.

C. Test Results

Results indicate the specimens examined in the "as received" condition with SEM micrographs of 50X, 100X, 200X, 500X, and 1000X magnifications had no significant contamination. After exposure to seawater for 7 days, specimens of the same material were examined by SEM to determine if any damage was detectable to the material and what, if any, types of growth were present. There was no noticeable growth on the specimens examined at the Materials and Processes Laboratory (Figs. 31, 32, and 33). EDAX analyses were also made of the eight exposed specimens and the following elements were detected: Na, Mg, Si, Cl, K, Ca, and P. From Table 13 it can be seen that after rinsing a clean surface is present with only minute amounts of debris. Therefore, no potential problem is predicted using the standard rinsing procedure.

Figure 29. KSC submersion rack after 7 day submersion test.

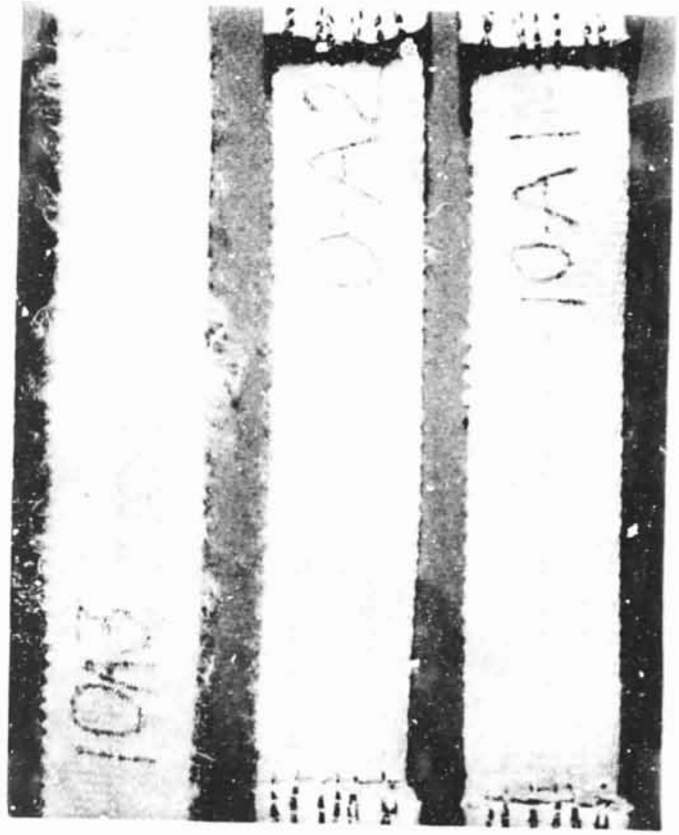

Figure 30. Degree of abrasion to parachute material resulting from 7 day submersion test.

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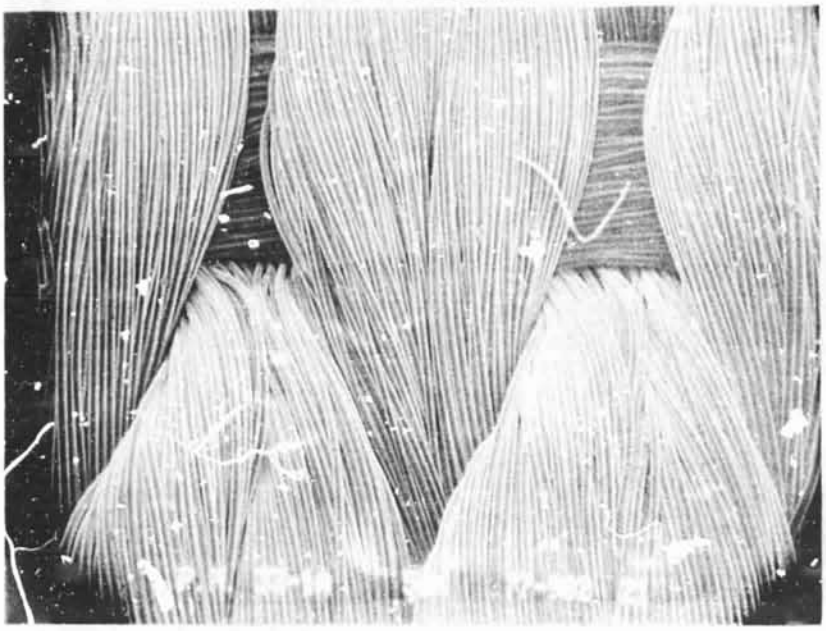

Figure 31. Main suspension line unexposed (SEM).

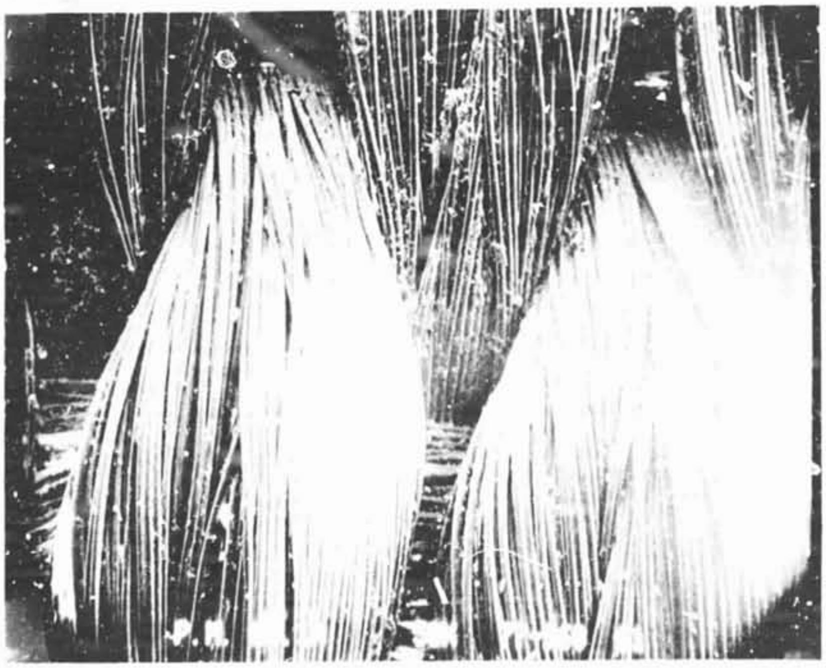

Figure 32. Main suspension line after submersion for 7 days at KSC (SEM).

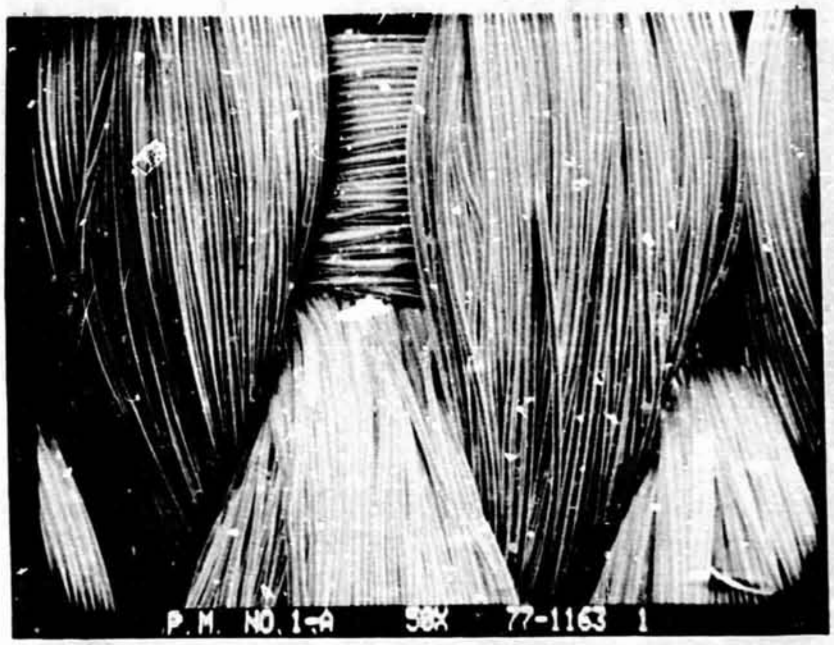

Figure 33. Main suspension line after approved rinsing (SEM).

TABLE 13. PARACHUTE MATERIAL AFTER RINSING

MIL-W-27657, Type II	MIL-W-83144, Type V
(1) Clean	(1) Clean
(2) Clean	(2) Clean
(3) Clean, No EDAX	(3) Clean
(4) Clean	(4) Some Debris, No EDAX
(5) Clean	(5) Some Debris
MIL-T-5608, Type V	**MIL-T-5608, Type II**
(1) Clean	(1) Clean
(2) Some Debris	(2) Clean
(3) Some Debris, No EDAX	(3) Clean
(4) Some Debris	(4) Some Debris, No EDAX
(5) Some Debris	(5) Some Debris
MIL-T-5038, Type V	**MIL-W-4088, Type X**
(1) Clean	(1) Clean
(2) Clean	(2) Clean
(3) Clean	(3) Clean
(4) Clean	(4) Clean
(5) Clean	(5) Clean
MIL-W-4088, Type XXIII	**MIL-W-4088, Type XXVI**
(1) Clean	(1) Clean
(2) Clean	(2) Some Debris
(3) Clean	(3) Some Debris
(4) Clean	(4) Some Debris, No EDAX
(5) Some Spots, No EDAX	(5) Some Debris

Note: Where No EDAX appears, EDAX was determined but no reading obtained.

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Comparative breaking strength and static load-elongation effects are given in Table 14 and Figures 34 through 40, respectively. The weatherometer results, where available, were exposures to artificial seawater for the equivalent time (7 days) under laboratory conditions. Other comparative values shown were control (unexposed) samples. Two of three samples show a significantly larger loss in breaking strength and a trend toward greater elongation.

TABLE 14. COMPARATIVE BREAKING STRENGTH OF PARACHUTE WEBBING AND TAPE AFTER 7 DAY KSC SEAWATER SOAK AND THREE WEATHEROMETER CYCLES

Sample Identification	KSC Seawater Sample (lb)	Weatherometer Sample (lb)	Control Unexposed Sample (lb)
MIL-W-83144, Type V	1390		
	1660	1435	1 720
	1200	1430	1 790
Average	1417	1432	1 755
MIL-T-5608, Type V, Class C	250		
	155	310	380
	177	265	390
Average	193	287	385
MIL-T-5608, Type II, Class E	1000		
	750	1030	1 180
	760	1050	1 140
Average	837	1040	1 160
MIL-T-5038, Type V	580		
	565		645
	615	—	640
Average	587		64[illegible]
MIL-W-27657, Type II	3875		
	3700		4 100
	3900	—	4 050
Average	3825		4 075
MIL-W-4088, Type XIX	8720		
	82[illegible]0		9 640
	9060	—	10 160
Average	8660		9 900
MIL-W-4088, Type XXIII	9550		
	9000[a]		9 960
	9700[a]	—	10 180
Average	9417		10 070
MIL-W-4088, Type XXVI	11 675[b]		
			14 100
			13 900
Average			14 000

a. Stitches broke.

b. Severely abraided; anchor tie-down broke loose on rack at sea on two samples and abrasion is visible on third sample with recorded value.

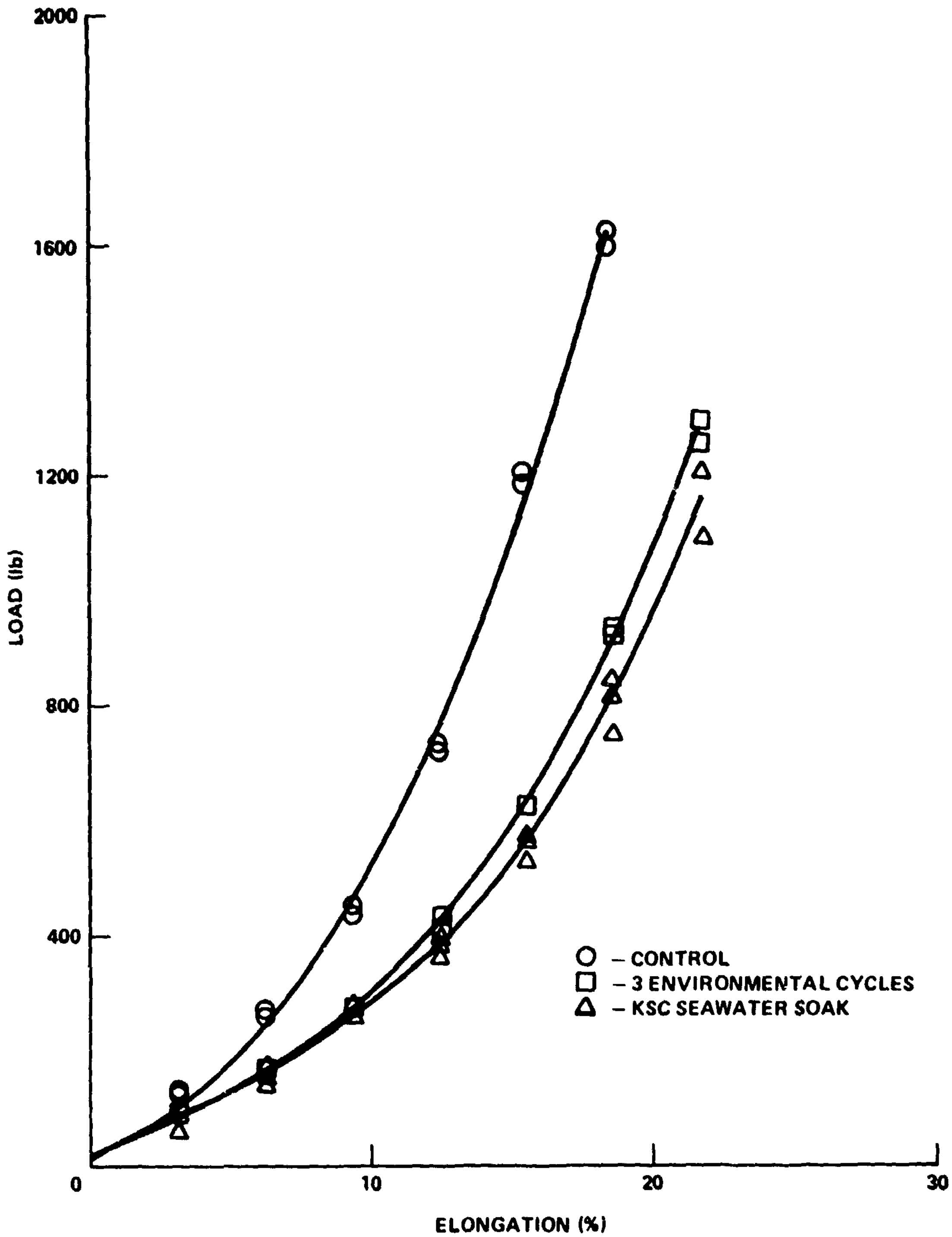

Figure 34. Comparative static load-elongation effect of 7 day KSC seawater soak and equivalent weatherometer exposure (nylon webbing, MIL-W-83144, Type V).

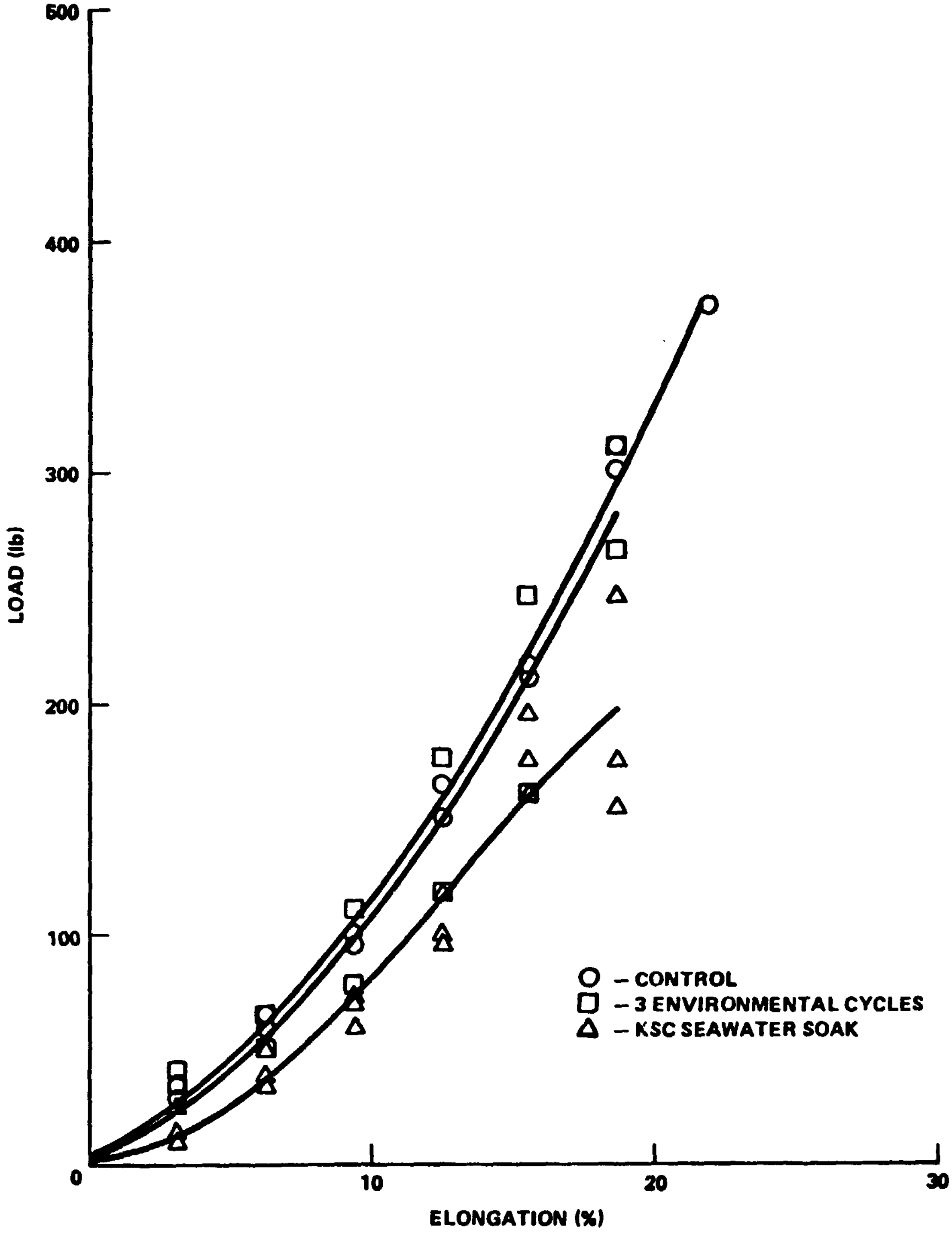

Figure 35. Comparative static load-elongation effect of 7 day KSC seawater soak and equivalent weatherometer exposure (nylon tape, MIL-T-5608, Tvpe V, Class C).

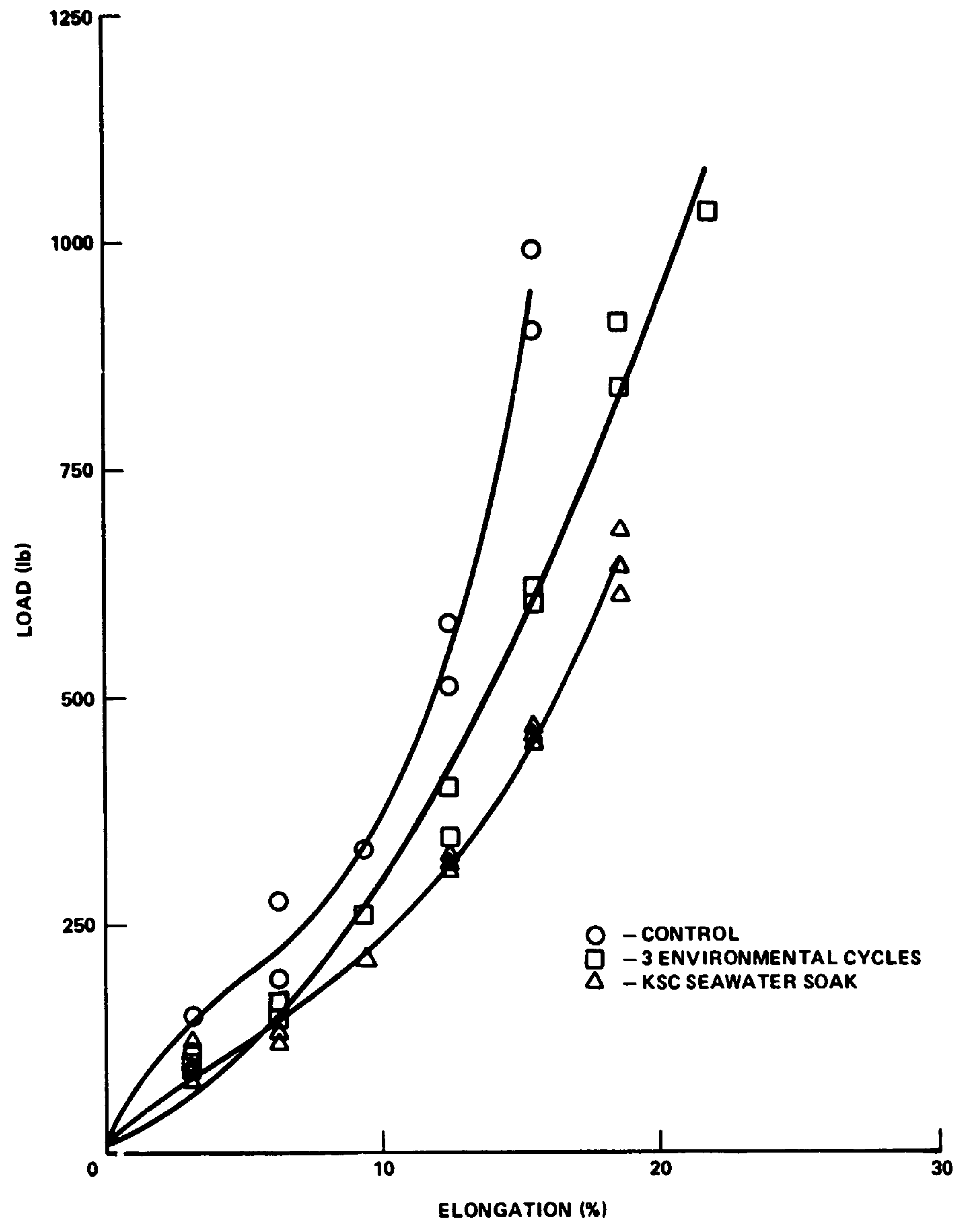

Figure 36. Comparative static load-elongation effect of 7 day KSC seawater soak and equivalent weatherometer exposure (nylon tape, MIL-T-5608, Type II, Class E).

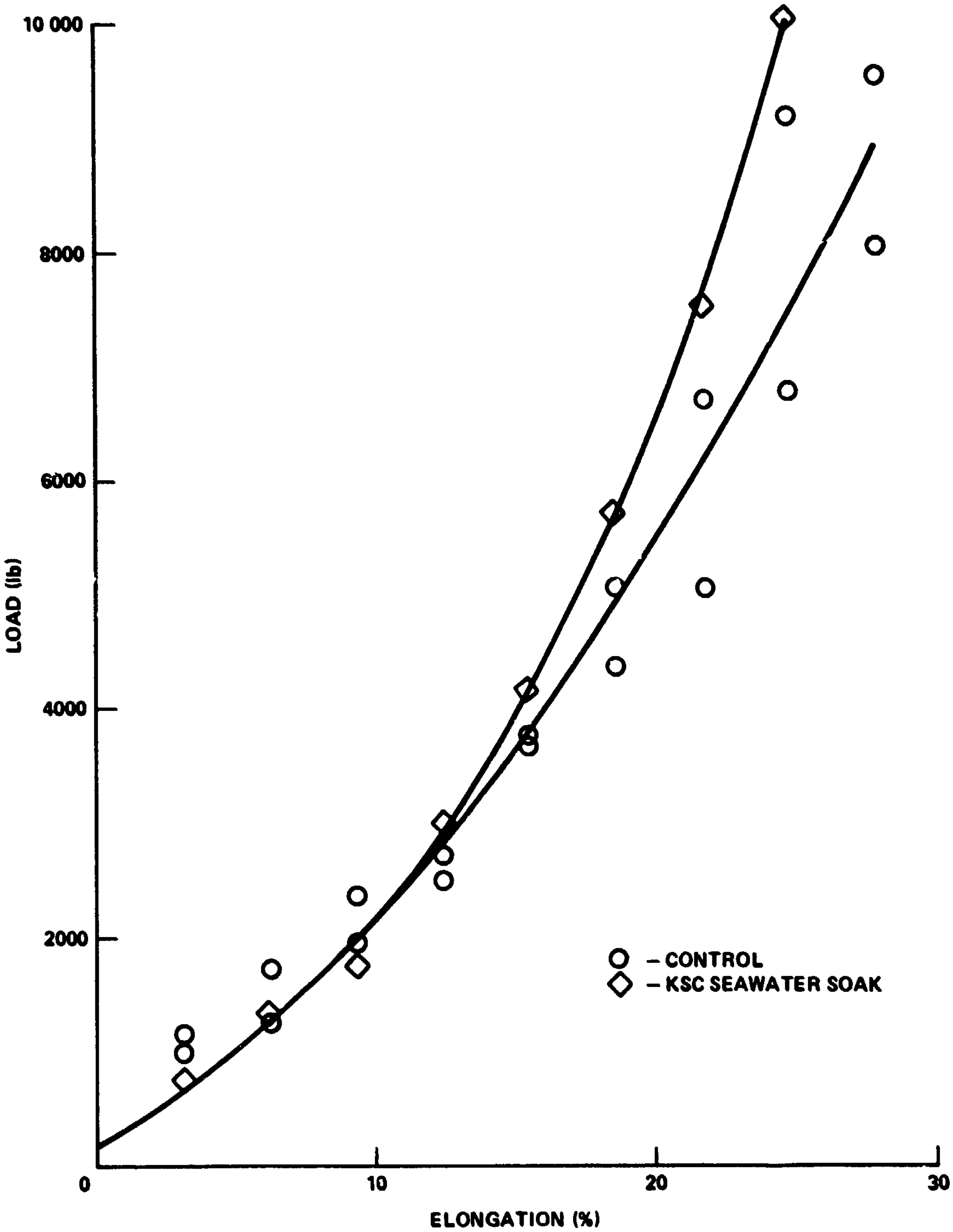

Figure 37. Static load-elongation effect of 7 day KSC seawater soak (nylon webbing, MIL-W-4088, Type XXVI).

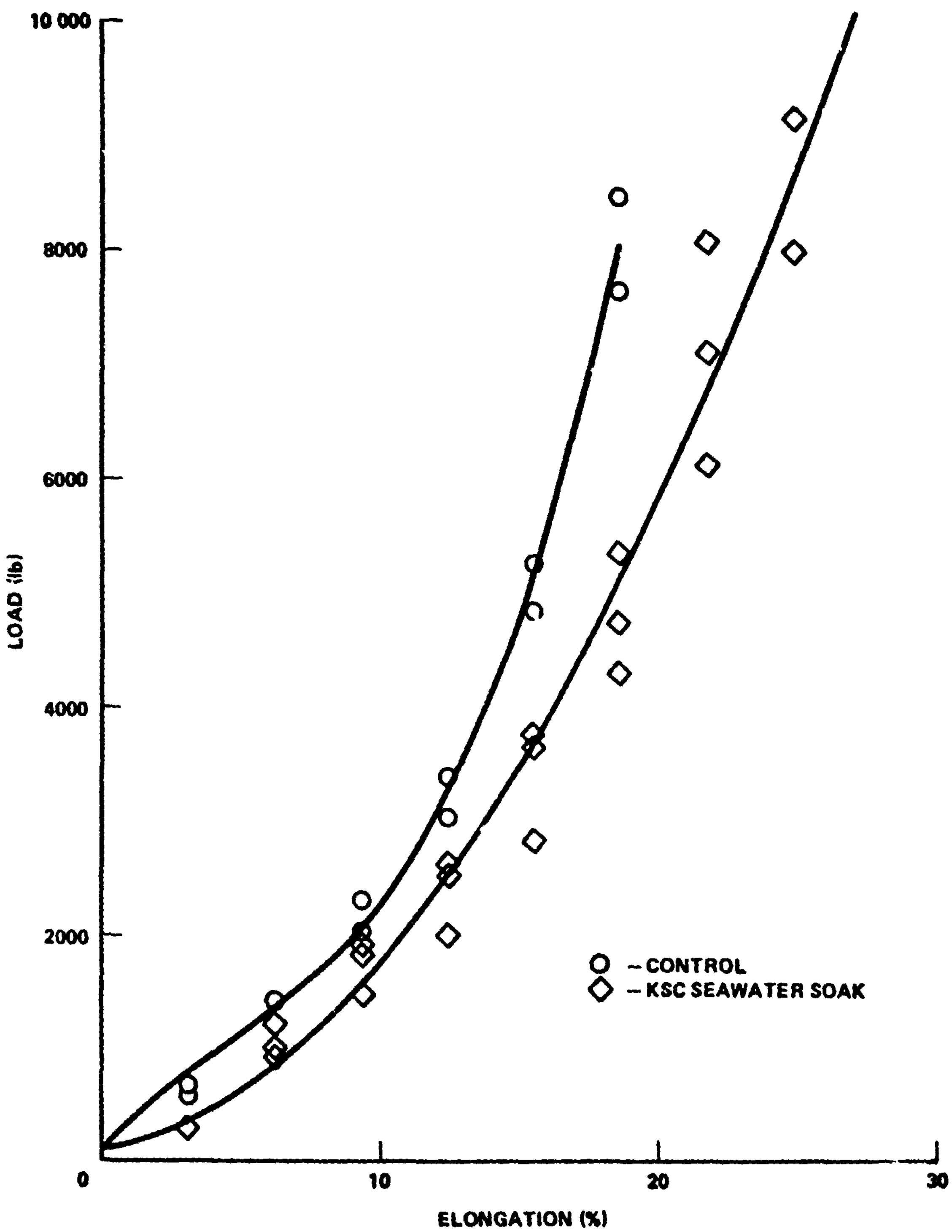

Figure 38. Static load-elongation effect of 7 day KSC seawater soak (nylon webbing, MIL-W-4088, Type XIX).

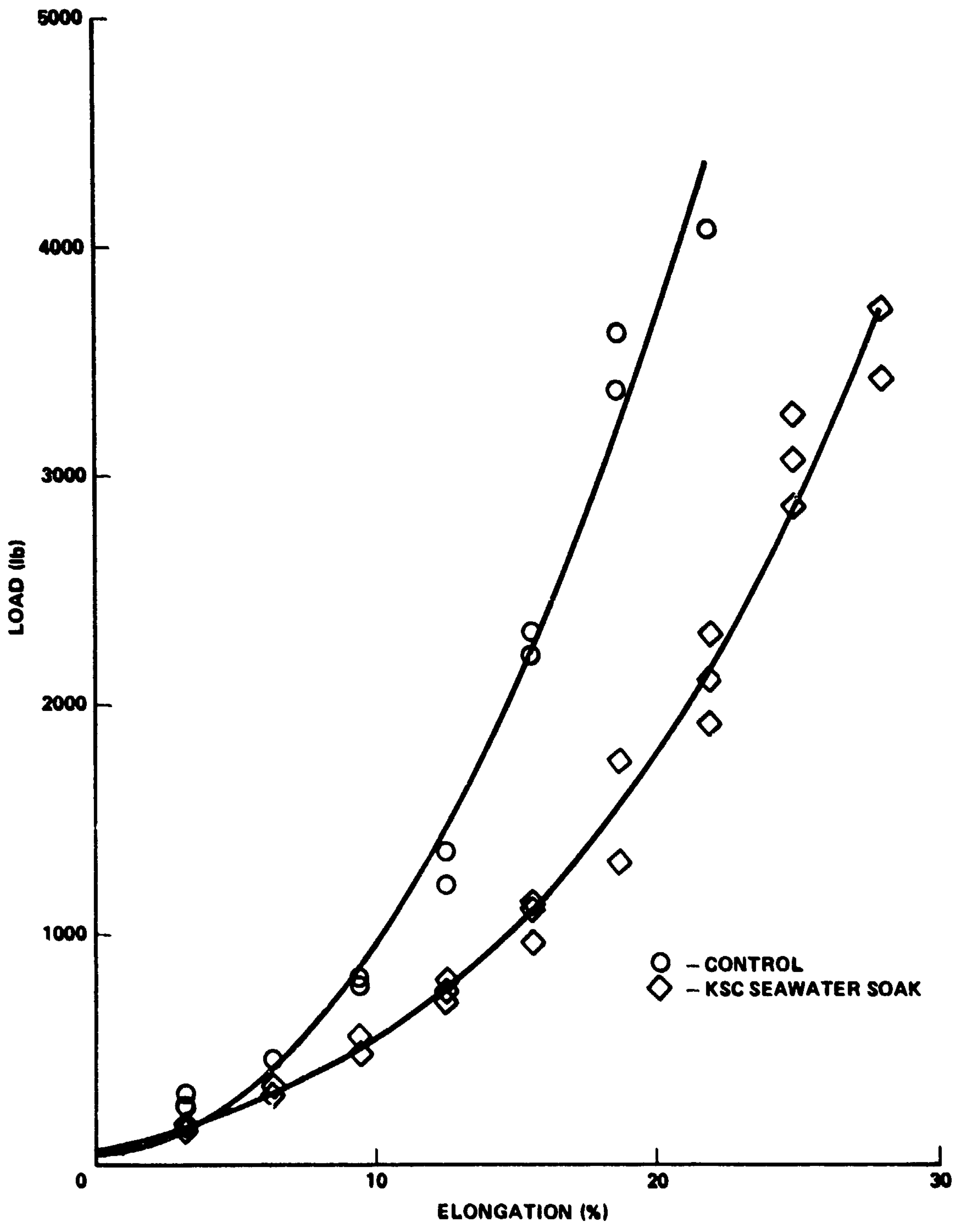

Figure 39. Static load-elongation effect of 7 day KSC seawater soak (nylon webbing, MIL-W-27657, Type II).

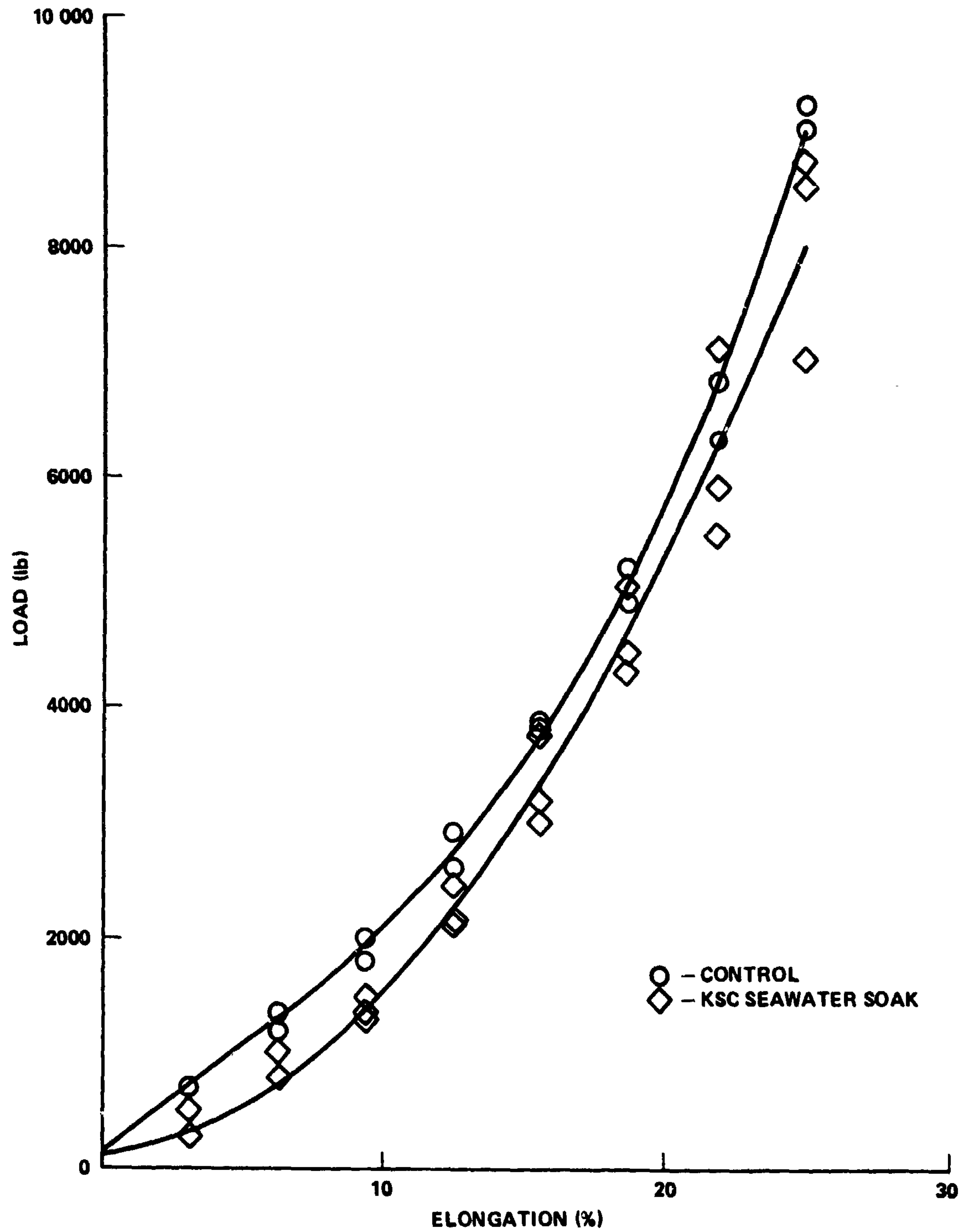

Figure 40. Static load-elongation effect of 7 day KSC seawater soak (nylon webbing, MIL-W-4088, Type XXIII).

On the basis of further technical literature research and, especially, work done under the supervision of Dr. H. P. Vind of the Naval Facilities Engineering Command [2] with nylon and other plastics, it is projected that the marine environment will present no problems insofar as microorganisms are concerned. Dr. Vind found no significant degradation in nylon sheet samples or nylon rope samples following submersion in aerobic and anaerobic environments for 2.5 years. The difference in strength indicated by the MSFC study was probably caused by the manner in which the samples were mounted, causing two samples to break loose at one end resulting in an abrasive action. A degree of abrasion occurred to other samples due to the action of ocean currents, tides, etc., flowing through and around them.

VI. CONCLUSIONS

A. Load-Bearing Webbing

1. Stitching Patterns. Stitching the nylon webbing is extremely important since it may reduce the rated strength of the material up to approximately 17 percent. A "V" pattern is used in sewing with three to eight points. The width and strength of the webbing governs the size cord and number of points. Large cord with more points severs nylon fibers in the webbing and creates a weakened material. Too small a cord or insufficient points will break the cord and also weaken the webbing, making the optimum selections critical. The control samples listed in this report all broke at the stitched point area near the rated strength of webbing which indicates near optimum conditions.

2. Abrasion Resistance. The load-bearing materials, especially risers and suspension lines, are very susceptable to abrasion. When under a load in the sea, damage which would require a change-out or refurbishment may occur. The parachute should be recovered as soon as possible, especially in rough seas.

B. Canopy Tape and Webbing

Canopy webbing to MIL-W-83144, Type II is slightly out of specification tolerence in strength. It should be rejected or new webbing ordered and retested.

C. Material Selection and Tests Preparation, Rinsing and Drying

The recommended conductivity of the final rinse solution after recovery of the parachutes is 0.125 millimhos/cm (approximately 52 ppm chloride content) above that of the incoming water. The rinse water should be potable water at ambient temperature. Due to the size and number of parachutes, this saline level may have to be less restrictive. To limit seawater salt crystallization and, more importantly, hygroscopicity, controls should be established to insure the minimum level (e.g., weighing the parachute after drying, etc.). It is further recommended that the oven drying temperature be 140°F ± 10° until completely dried.

D. General

Generally, the parachute materials met all requirements within design limitations. Worst-case conditions were used during static and environmental testing. The results have been coordinated with design personnel.

An overall evaluation that covers individual tape and webbing tests is not possible since the nylon materials cover strength rating from 300 to 15 000 lb, all types of weave patterns, shrinkage factors, abrasion characteristics, etc. Each material must be evaluated for its particular use under its real or simulated environmental exposure.

E. Omission Considerations

The parachutes are in the initial phase of fabrication and air drop testing. Each failure or anomaly has and will continue to add modifications, changes in design, and possibly new materials or fabrication techniques. Changes have been made in parachute canopy widths, a second reefing line has been added to the drogue parachute, and the webbing has been reinforced around reefing rings. Other minor changes are anticipated.

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APPENDIX A

LOAD VERSUS ELONGATION CALCULATION EXAMPLE

A forced intercept polynomial least squares regression analysis (Fig. A-1) was used to plot the load versus elongation curves in this technical memorandum. Usually polynomial coefficients of Degree 2 or 3 was used to produce the curve. Higher degrees, though giving correlation coefficients closer to unity, were not used because the small amount of data caused the curves to interweave between data points.

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POLYNOMIAL LEAST SQUARES REGRESSION ANALYSIS

NYLON WEBBING PER MIL-W-27657,TYPE II;SAMPLES 1-A.

FORCED INTERCEPT?                 YS
     X0= 0              Y0= 40
ABS. X SCALE FACTOR:               1
BEGINING POLYNOMIAL DEGREE:        2
DEGREE INCREMENT:                  1
FINAL POLYNOMIAL DEGREE:           5

   #           X                  Y
   1      0.000000E+00       4.000000E+01
   2      0.000000E+00       4.000000E+01
   3      3.120000E+00       3.000000E+02
   4      3.120000E+00       2.500000E+02
   5      6.250000E+00       4.500000E+02
   6      9.380000E+00       8.000000E+02
   7      9.380000E+00       7.750000E+02
   8      1.250000E+01       1.200000E+03
   9      1.250000E+01       1.350000E+03
  10      1.560000E+01       2.200000E+03
  11      1.560000E+01       2.300000E+03
  12      1.870000E+01       3.350000E+03
  13      1.870000E+01       3.600000E+03
  14      2.190000E+01       4.050000E+03

MEANS OF INDIVIDUAL DATA POINTS:
      X BAR= 1.048214E+01       Y BAR= 1.478929E+03

STD DEV OF THE DATA POINTS ABOUT THEIR MEAN:
      SIGMA X= 6.940850E+00      SIGMA Y= 1.335106E+03
```

Figure A-1. Polynomial least squares regression analysis.

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POLYNOMIAL COEFFICIENTS FOR DEGREE 2 FOLLOW
      A( 0)= 4.000000000E+01
      A( 1)= 3.081383622E+00
      A( 2)= 8.838565183E+00

STANDARD DEVIATION= 2.043E+02

CORRELATION COEFFICIENT= 0.989910145

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POLYNOMIAL COEFFICIENTS FOR DEGREE 3 FOLLOW:
      A( 0)= 4.000000000E+01
      A( 1)=-1.319477190E+01
      A( 2)= 1.117592253E+01
      A( 3)=-7.670387768E-02

STANDARD DEVIATION= 2.138E+02

CORRELATION COEFFICIENT= 0.989877303

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POLYNOMIAL COEFFICIENTS FOR DEGREE 4 FOLLOW:
      A( 0)  [illegible]500E+01
      A( 1)= 1.879917392E+02
      A( 2)=-4.148335949E+01
      A( 3)= 3.967835127E+00
      A( 4)=-9.495066225E-02

STANDARD DEVIATION= 1.177E+02

CORRELATION COEFFICIENT= 0.997222092

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POLYNOMIAL COEFFICIENTS FOR DEGREE 5 FOLLOW:
      A( 0)= 4.000000000E+01
      A( 1)= 2.889093690E+01
      A( 2)= 2.595072894E+01
      A( 3)=-5.064576412E+00
      A( 4)= 3.863072214E-01
      A( 5)=-8.879651695E-03

STANDARD DEVIATION= 9.776E+01

CORRELATION COEFFICIENT= 0.998610367
```

Figure A-1. (Concluded)