EFFECT OF BIOLOGICAL STERILIZATION AND VACUUM ON CERTAIN PARACHUTE RETARDATION SYSTEM COMPONENTS

Final Report 4324

AUGUST 1964

COOK ELECTRIC COMPANY TECH-CENTER DIVISION

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FOREWORD

The work presented in this report was performed at the Tech-Center Division of Cook Electric Company, Morton Grove, Illinois. The work was performed for the Jet Propulsion Laboratory, California Institute of Technology, under the authority of Contract No. BE 4-229753. Mr. Robert G. Nagler, Jet Propulsion Laboratory, served as Technical Representative.

This effort was performed under the general direction of Mr. L. E. Benitez, Vice President and General Manager, and Mr. R. C. Edwards, Vice President and Director of Engineering, of Tech-Center Division.

The technical effort was carried out by the Aerospace Technology Section under the direction of Mr. L. J. Lorenz, Section Manager and Dr. R. J. Benjamin, Director of Engineering. Testing was conducted at the Inland Testing Laboratories, Cook Electric Company, under the direction of Mr. T. J. Burns. The program was directed by Mr. Arthur R. Anderson, Program Manager.

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I. INTRODUCTION

With the advent of propulsion systems capable of transporting a payload to other planets has come the need for retardation systems to safely decelerate such a payload within the atmospheres of planets under study. Early experimental payloads may study the possibility of life forms existent on Mars. Thus, it is imperative that the experimental payload, including the retardation system, not carry Earth life forms on board and hence nullify such experiments. This requirement dictates that the retardation system utilize components that can be biologically sterilized without drastically degrading their capability. It is also imperative that the vacuum environment during long periods of interplanetary travel does not impair the proper functioning of the system.

The purpose of this study was to determine the effects of (1) biological sterilization and vacuum on selected control components of a parachute retardation system and (2) the ready availability of these components for Mars entry. The components selected for study included parachute materials and pyrotechnics. Four candidate parachute materials (nylon, nomex, dacron, and silk) woven into fabric, ribbon, and cord forms were investigated. To simulate parachute packaging conditions, the materials were folded and compacted and twisted and compacted as well as laid flat. The folded and twisted configurations were compacted to a density of 30 lb/ft^3. In addition, cords and ribbons of dacron and nomex were subjected to an impact pulling at the end of the vacuum tests (but while still in the vacuum environment) to simulate parachute opening shock loads. After subjection to the specific environmental test, material property tests consisting of weight, permeability, and strength measurements were performed.

The pyrotechnic components investigated were of two types common to retardation systems, pressure generators and reefing cutters. To determine performance variations of these components, special test apparatus were designed and built. Parameters investigated with pressure generators were variations in the time required for peak pressure generation after initiation and the pressure generated; with reefing cutters delay-train time delay and line cutting action were studied.

II. DELINEATION OF AREAS OF INVESTIGATION

In Table I, a list of parachute retardation system components is presented. It is here noted that, from a materials viewpoint, a parachute retardation system consists of polymeric compounds, coated aluminum, steel, epoxy, dielectric insulation materials, and precious metal plating. The ability of metallic or dielectric (such as mica) materials to withstand sterilization and vacuum environments is fairly well-known or is amenable to calculation. The effects of pyrotechnic or polymeric materials to these environments is less known and, due to their composition, less amenable to theoretical calculation.

Thus, it was decided that the polymeric and pyrotechnic materials should be investigated. The practical considerations of utilization dictated the weave forms of the polymeric (parachute) materials to be tested. The parachute consists of fabric, cord, and ribbon, in both sewed and unsewed conditions. After fabrication, the parachute is packed, causing its components to become folded and twisted. Finally, the parachute is pressurized to conserve volume, creating localized stress conditions on the folded and twisted segments. It was believed that all these conditions should be simulated in order to properly evaluate the effects of sterilization and vacuum environments.

Pyrotechnic materials, packaged into pressure generators and reefing cutters, were deemed useful candidates for investigation. Pressure generators were investigated because of their versatility of use in parachute retardation and other systems. Reefing cutters were investigated because of their criticality to proper retardation system performance and to their pyrotechnic and compositional structure. This structure involves a spring-actuated mechanism striking and detonating a primer which in turn ignites time delay material. After burning for a selected period of time, the delay train ignites the main charge which drives a guillotine against the reefing line. Malfunction of any of the above-mentioned components will cause malfunction of the entire unit since all components are series connected with no provision for redundancy.

TABLE I. SUMMARY OF PARACHUTE RETARDATION SYSTEM COMPONENTS

COMPONENTS	MATERIALS	REMARKS
(1) Parachute materials in cord, fabric, and ribbon weave forms.	Long chain polymeric compounds.	Due to organic composition, rather temperature limited. Subject to chain cleavage and cross-linking under elevated temperature and vacuum environment. Should be unattacked by chemical sterilization.
(2) Parachute attachment fittings, swivel, outer shell, etc.	Coated (usually anodized) aluminum.	Stable in thermal and chemical sterilization as well as vacuum environment.
(3) Pyrotechnic materials, usually pressure generators and parachute reefing line cutter.	Steel, coated (usually anodized) aluminum, pyrotechnic materials, epoxy.	Metallic components stable, pyrotechnic materials rather temperature limited if of organic composition, less temperature limited but more difficult to ignite if of inorganic composition. Stable epoxies are available.
(4) Timing mechanism, usually electromechanical design.	Steel, aluminum, gold or platinum plated contacts, insulation materials within relays.	Metallic components stable. Stable insulation materials are available.
(5) Power source, usually chemical battery.	Many types of materials, depending on battery type.	Much test work, primarily by Inland Test Labs, Dayton, Ohio, has indicated battery compatibility with space environment.
(6) Sensing system.	Same as (4).	Same as (4).

III. TEST PROGRAM

A. Materials

1. Parachute

The physical characteristics of the four potential parachute materials investigated, nylon, dacron, Nomex and silk, are given in Table II. All synthetic yarns were manufactured by duPont, their type or merge number and thread denier being noted. Since military specifications exist for nylon weave forms, these forms were so fabricated. Although no military specifications exist for the specific dacron weave forms, the dacron materials were fabricated to the applicable nylon specification. All material strengths of these weave forms were chosen to correspond to initial first stage decelerator requirements for Mars entry except nylon and dacron fabric, which more closely correspond to second stage decelerator requirements. Although these material strengths may be altered in the future, it is believed that the percentages of degradation should remain constant. Attempts were made to keep the strengths constant for any specific weave form. This could be accomplished for the cord and ribbon, but not for the fabric, since Nomex was not manufactured in the lighter weight at the time the fabrics were purchased. A 2 oz/yd Nomex fabric is now available, however.

To remove the variable of surface finish effect on material characteristics, all materials were scoured by the manufacturer. The scouring materials and procedures used were based on recommendations by the various manufacturers. Although neither the fabrics nor the cords were fabricated by one manufacturer, all materials of one specific weave form were scoured by one manufacturer to maintain consistency of operation.

2. Pyrotechnics

The physical characteristics of the pyrotechnics tested are presented in Table III. Other companies, in addition to those noted, were contacted. However, these companies either (1) did not reply, (2) did not have units readily available, or (3) required extensive research and development to fabricate units to perform after environmental subjection. All pressure cartridges were fabricated to the Air Force Missile Test Center ordnance specification, which required that no units ignite when 1 ampere of current, at 1 watt, flow through the unit for 5 minutes. The maximum all-fire current for these units was 4.5 amperes. Pyrotechnic compositions are proprietary information to the respective manufacturers so this could not be included in the table.

Reefing cutters from two manufacturers were investigated. both cutters were initiated by percussion primers, but each manufacturer employed a different technique. The Central Technology unit was fired by

TABLE II. PHYSICAL CHARACTERISTICS AND SCOURING PROCEDURE OF PARACHUTE MATERIALS

Parameter	NYLON			DACRON			NOMEX			SILK
	Fabric	Cord	Ribbon	Fabric	Cord	Ribbon	Fabric	Cord	Ribbon	Fabric
Type (merge number for Nomex)	380 Type 66	300 Type 66	330 Type 66	56	52	51	67008	67008	67008	-
Initial yarn denier	30	210	210	-	1100/250	220	200/100	200/100	200/100	-
Fabricator	(1)	(2)	(3)	(4)	(5)	(3)	(4)	(5)	(3)	(6)
Fabricator Weave Pattern	-	-	7407	15223	8794	9656	HT-3-33	8796	9476	906
Applicable Mil-Spec.	C-7020	C-7515	T-5038	(7)	(7)	(7)	-	(7)	-	-
Weight and/or Break Strength	1.1 oz/yd	750 lb.	3/8"-200 lb.	0.91 oz/yd	750 lb.	3/8"-200 lb.	3.54 oz/yd	750 lb.	3/8"-200 lb.	0.49 oz/yd
Scouring Materials	4 lb. MXP detergent 1 gal. 50% liq. caustic 100 gal. water			4 lb. KYRO A.C. 4 lb. sal soda 100 gal. water			5 lb. Tetrasodium Pyrophosphate 1.5 lb. Triton X-100 100 gal. water			
Scouring Procedure on a dye jig 1. Scour	2 ends - 105°F 2 ends - 150°F Boil 1 hour			2 ends - 105°F 6 ends - 190°F			1 end - 105°F 1 end - 150°F Boil 1 hour			
2. Rinse	1 end - Water at boil 2 ends - 140°F 2 ends - 140°F 1 end - 110°F			1 end - 140°F 2 ends - 130°F 2 ends - 130°F 1 end - 110°F			2 ends - 180°F 2 ends - 140°F 1 end - 110°F			

(1) J. P. Stevens Co., 1416 Broadway, New York, N. Y.
(2) Hope Webbing Co., Box 1495, Providence, R. I.
(3) Bally Ribbon Mills, Bally, Pennsylvania
(4) Stern & Stern Textiles, Inc., Hornell, New York
(5) VALRAYCO, Inc., Box 618, Pawtucket, R. I.
(6) Walter Strassburger & Co., 180 Madison, New York, N. Y.
(7) Woven to same military spec. as for nylon weave form.

TABLE III. PHYSICAL CHARACTERISTICS OF PYROTECHNIC MATERIALS INVESTIGATED

A. PRESSURE CARTRIDGES

Manufacturer	Mfg. P/N	Type of Device	Output	Operating Temp. Range	Type of Sealing	Case Material
Atlantic Research Corporation	209	Press. Cart.	400 psi in a 20 cc bomb	-80°F to +400°F	Glass-to-Metal	Tin-plated Gilding Metal
Central Technology, Inc.	CP 4141	Press. Cart.	2000 psi in a 2.5 in^3 bomb	-60°F to +350°F	Hermetic Seal	Stainless Steel
Hercules Powder Company	S-193-AD	Initiator	Hot Flame	-60°F to +350°F	Diallyl Phthalate	Stainless Steel
Hi-Shear Corp.	PC-10	Press. Cart.	4000 psi in a 10 cc bomb	-65°F to +550°F	Hermetic Seal	Stainless Steel
Unidynamics Corporation	--	Press. Cart.	1000 psi in a 0.2 in^3 bomb	-60°F to +350°F	Hermetic Seal	Stainless Steel

B. REEFING CUTTERS

Manufacturer	Mfg. P/N	Time Delay	Type of Initiation	Case Material	Operating Temp. Range	Line Cutting Capability
Central Technology, Inc.	26-136-1563	4 sec.	Percussion Primer	Stainless Steel	-70°F to +400°F	6000 lb Nylon
Unidynamics Corp.	XUM-4032	10 sec.	Percussion Primer	Anodized Aluminum	-60°F to +400°F	1500 lb Nylon

exerting tension on a lanyard pin-hammer combination which compressed a spring. Upon exerting 15-25 pounds of tension, the pin released from the hammer, the compressed spring then in turn being released to drive the hammer against the primer. The Unidynamics design was such that the spring was compressed in the manufacturing process and held compressed by a firing pin. When this pin was extracted from the reefing cutter body, the compressed spring was released to drive a hammer against the primer. Both cutters used Remington Arms Type G-11 primers. The rest of the pyrotechnic material within the cutters were proprietary to the respective companies.

B. Matrix

The parachute fabrication considerations discussed above led to the generation of a test matrix which considered ribbon, fabric and cord weave forms in flat, folded, and twisted configurations compacted to simulate parachute packing densities. This matrix is presented in Table IV. Five samples of each material, in each configuration, were tested to arrive at a statistical sampling of the material property. Since ribbons and cords are subjected to tensile loads during parachute operation, these weave forms were subjected to this test mode. Possible fabric variables are burst strength and permeability. Since, in application, a parachute fabric is subjected to a multi-directional loading, the fabrics were tested in a ball-burst apparatus for strength variations. This material property test was made after each environmental exposure. Permeability measurements were taken on each test sample prior to the initiation of environmental testing and after each environmental exposure. Samples of each material (from the flat configuration) were also weighed before initiation of environmental testing and immediately after each environmental test to determine weight variation.

One additional practical aspect of the parachute system operation which must be considered is that of deployment at an extreme altitude above Mars. In this instance, the retardation system will be subjected to a sudden shock load which might cause failure if the material has embrittled due to (1) cross-linking, (2) desorption of entrapped fluids, or (3) weakening due to degradation of the organic backbone. Thus, tensile impact load devices were designed and constructed which were activated at the end of the vacuum tests while the materials were still in the vacuum environment. An additional ten samples of each material were subjected to this form of test at the end of each vacuum test period.

A schematic flow diagram of the sequence of tests is presented in Figure 1. This flow diagram was formulated to simulate the actual manner in which the materials would be subjected to the environmental conditions.

TABLE IV. PARACHUTE MATERIAL TEST MATRIX

Weave Form	Material Property Test	CONFIGURATION			Sudden Applied Load in Vacuum
		Flat	Folded/Compacted	Twisted/Compacted	
Ribbon	Tensile	5 Unsewed 5 Sewed	5 Unsewed 5 Sewed	5 Unsewed 5 Sewed	3 Unsewed 3 Sewed
Fabric	Burst Permeability	5 Unsewed 5 Unsewed	5 Unsewed 5 Unsewed	5 Unsewed -	1 Unsewed -
Cord	Tensile	5 Unsewed	5 Unsewed	5 Unsewed	3 Unsewed

NOTE: (1) Numbers refer to quantities of samples tested (Total number of samples per environmental test per material exclusive of Sudden Load in Vacuum -- 70).

(2) Notation "Unsewed" refers to materials cut from received form and placed in configurations noted without further working.

(3) Notation "Sewed" refers to materials cut from received form, then sewed in conventional parachute stitching prior to placement in configurations noted.

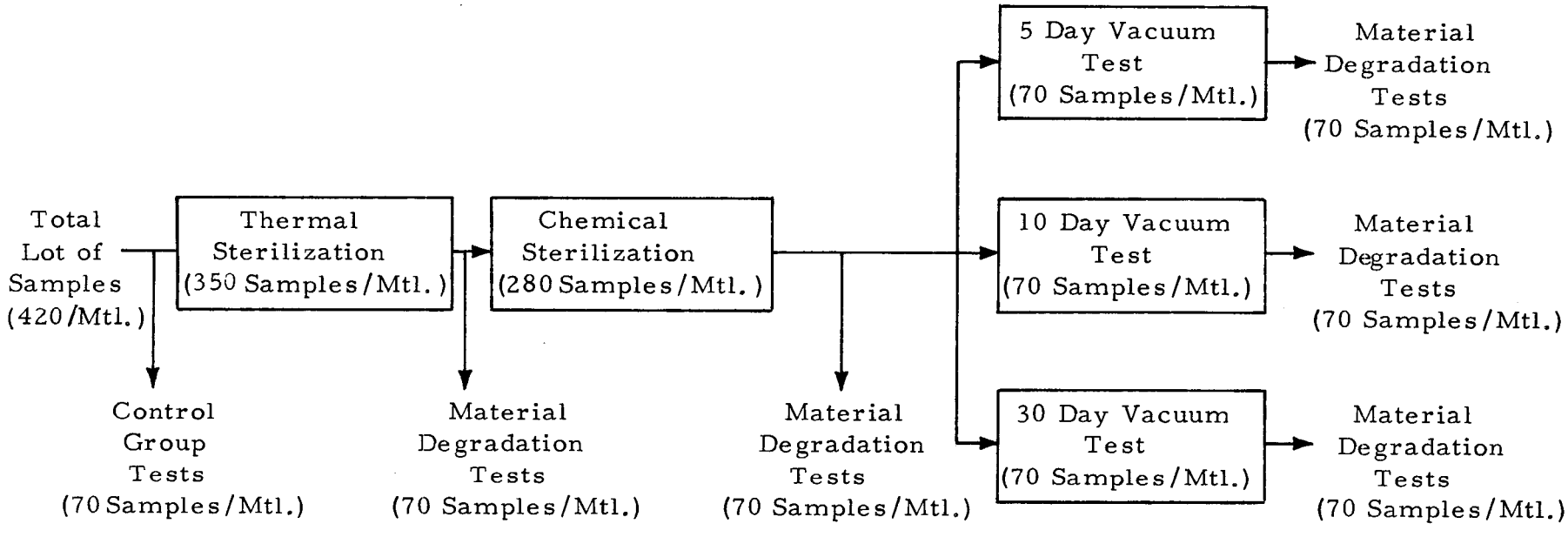


FIGURE 1. SCHEMATIC FLOW DIAGRAM OF ENVIRONMENTAL AND MATERIAL DEGRADATION TEST SEQUENCE

Three separate vacuum tests, of varying time duration, were conducted to determine degradation data as a function of time in vacuum. After each environmental test, seventy samples of each material were withdrawn from the environmental chamber and placed within a dry nitrogen-filled holding chamber until tested. Testing was initiated immediately in a temperature (72°F)-humidity (60%RH) controlled room such that each sample was in the room environment for no more than a few minutes before the specific material property test was concluded.

The test samples were prepared in a clean room, persons wearing the usual protective clothing. Ribbon and cord materials were simply cut by heat or with cleaned shears from the respective rolls. Special precautions were observed for fabrics, however. In reference 1, the effects of permeability of nylon fabric is discussed, wherein it is noted that permeability changes near the selvedge can be quite pronounced. Hence, to avoid this potential problem, fabric samples used in these tests were cut from the center 20 inches of each 36 inch wide roll of material. Further, precautions were taken to avoid leaving any marking dye on any sample as this would vaporize in the environmental tests and cause improper variations in the weight determinations.

After each piece of material was cut to the desired dimensions, it was sequentially separated according to the following plan: First piece-Control Sample; Second piece - Thermal Sterilization Test Sample; Third piece-Chemical Sterilization Test Sample; Fourth piece - 5 day Vacuum Test Sample; Fifth piece - 10 day Vacuum Test Sample; Sixth piece - 30 day Vacuum Test Sample. This sequence was repeated for the 420 samples of each material so that short term variations in fabrication could be averaged out. For example, each control sample of cord was approximately nine lineal feet from the preceding cord control sample.

After cutting, the weave forms designated for one specific environmental and material degradation test were placed on a tray for simplified handling before and after any test. The flat samples designated for weight measurements were first placed in a desiccator for 48 hours prior to weighing determinations. These and other flat samples were then placed on tiered stainless steel plates contained in the tray. The folded-compacted and twisted-compacted samples were so arranged and placed between plates of stainless steel, and then compacted to a simulated 30 lb/cu. in. packing density. Packing was accomplished by placing the samples between channel members which were bolted together. One fold and one twist was applied to each weave form. In this manner, creases were impressed in the material either at 90 degrees (by folding) or at 45 degrees (by twisting) to the axis of the material. All test samples, other than those designated for weighing, were marked with aluminum markers for later identification.

A photograph of a loaded tray of materials is given in Figure 2. This photograph of nylon material after thermal sterilization was selected to additionally show the discoloration of nylon due to the thermal environment. In this photograph can also be seen the sewed and unsewed ribbon samples on the top stainless steel tier. The sewed ribbon samples were stitched with a conventional box stitch, with each end tucked under prior to stitching. These samples were sewn with a machine specially cleaned of oils.

C. Apparatus

1. Environmental

A photograph of the arrangement of trays of materials in the vacuum chamber prior to the thermal sterilization environmental test is shown in Figure 3. The trays were placed on roll pins in a thermal stabilization container within the vacuum chamber. This arrangement was used since preliminary tests indicated a temperature gradient in the vacuum chamber in excess of that allowed by the specification. Twenty-three special grade copper-constantan thermocouples were fabricated, calibrated, and placed in forward, central, and rearward tray planes throughout the chamber. These thermocouples were connected to a pre-calibrated Weston Model 6702, 24-channel null-balance indicator/recorder. A front cover plate over the thermal stabilization container was used, but is not shown in Figure 3.

The chemical sterilization environmental test was conducted in a large steel autoclave (Figure 4) designed to contain both pressure and vacuum. The autoclave was equipped with ports to measure pressure, add moisture via a steam generator, and to take humidity determinations. Pressure (above and below ambient) was measured with a standard Merriam mercury manometer. The moisture content of the sterilizing gas environment was measured with an Alnor Dew-Pointer, Type 7000 U, using appropriate gas constants for this mixture supplied by the Matheson Company, supplier of the gas mixture. Temperature was measured with steel-jacketed copper-constantan thermocouples connected with compression fittings through the wall of the autoclave. Heat was added by means of electrical strip heaters attached to the outer surface of the autoclave. The stainless steel tubing connecting the sterilizing gas bottles was ducted into a stainless steel vat within the autoclave to allow the gas to vaporize and prevent the liquid mixture (as taken from the bottles) from contacting the parachute materials. The trays were placed within the autoclave to allow ready access to the parachute materials by the gas mixture.

The vacuum environmental tests were also conducted in the chamber shown in Figure 3 using the thermal stabilization container. This container was used since it allowed separation of material types (to prevent cross-contamination) and provided a stable platform on which to mount the

Figure 2. Tray Of Nylon Test Samples After Subjection To Thermal Sterilization Environment Compared With Untested Samples

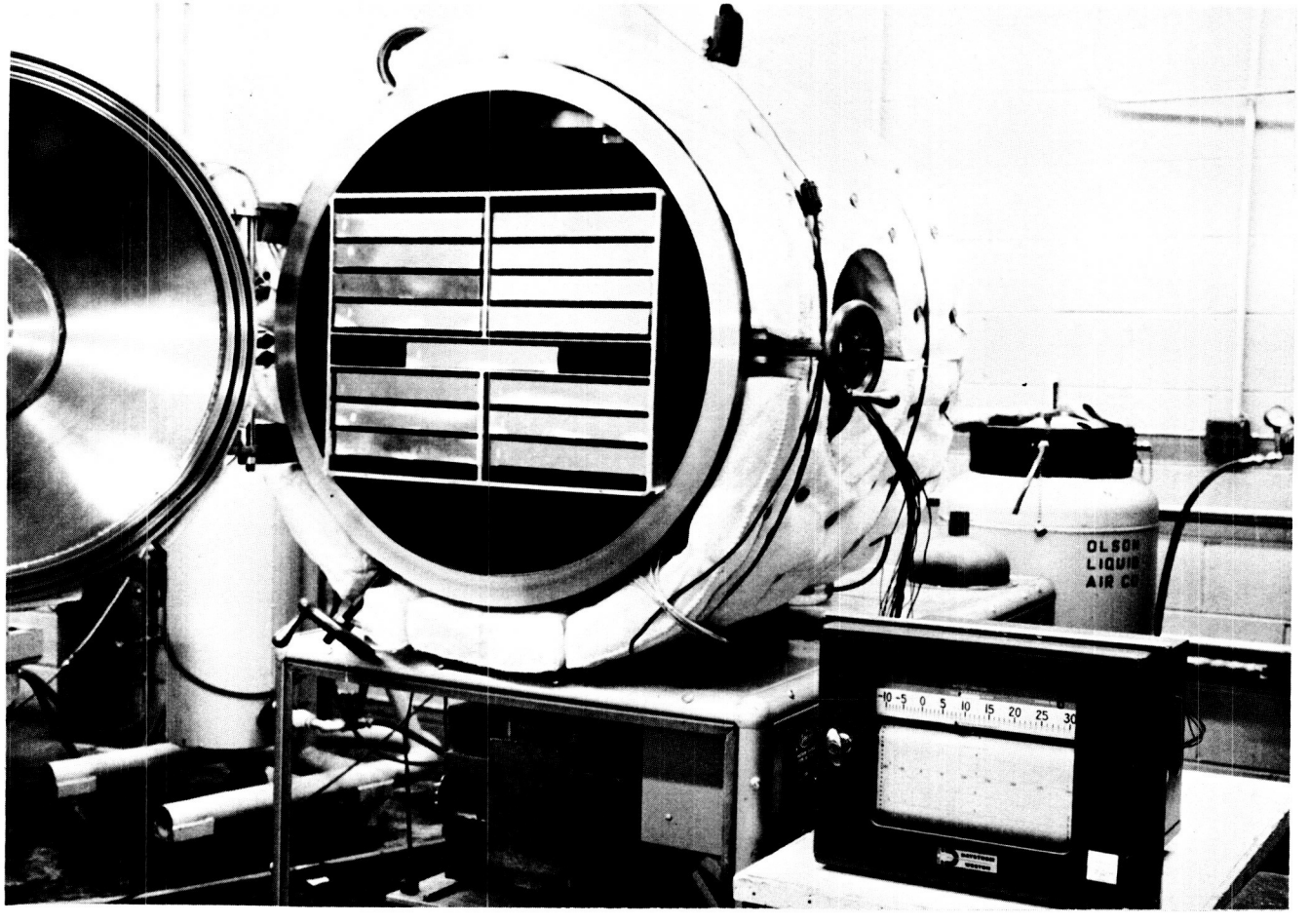


Figure 3. Arrangement of Trays in Vacuum Chamber Prior to Thermal Sterilization Environmental Test

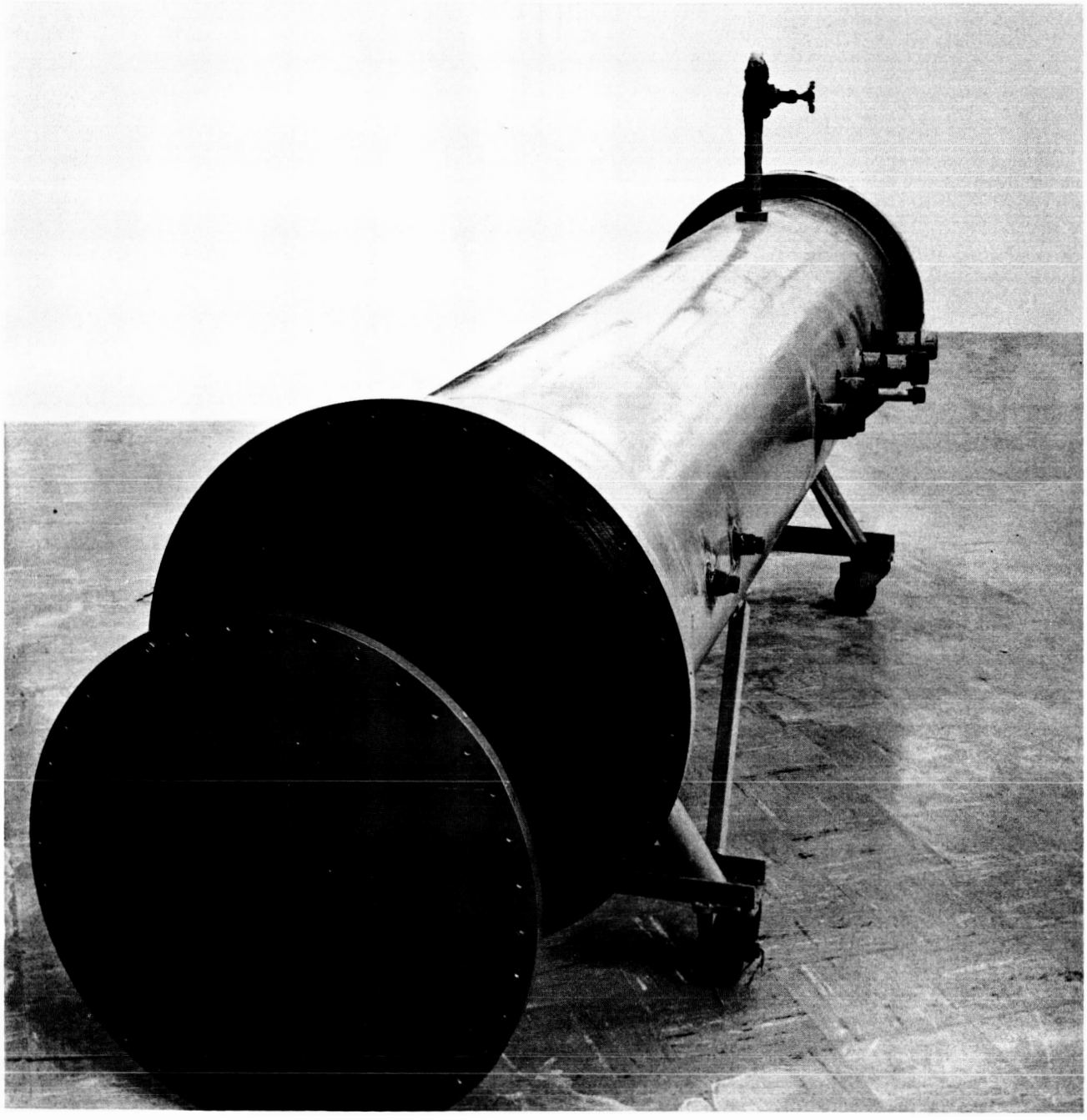


Figure 4. Autoclave Used For Chemical Sterilization Environmental Test

tensile impact load devices. This chamber employs the following pumping system, appropriately linked and valved:

(1) A Kinney Model KC-8 gas ballasted high vacuum pump rated at 8 cfm free air capacity

(2) A Consolidated Vacuum Corporation fractioning oil diffusion pump, Type MCF-61

(3) A Consolidated Vacuum Corporation liquid nitrogen-cooled baffle, Model BC-61

(4) A Varian Associates, Model 911-5020 Vac-Ion pump, rated at 400 liters/sec.

(5) A Varian Associates, Model 921-0005 Vac-Ion pump control system

(6) Consolidated Vacuum Corporation valves and a CVC automatic liquid nitrogen filter, Type BC-003.

The prime advantage of this pumping system is that the use of a Vac-Ion pump negates backstreaming, since this pump operates on an electronic getter-ion principle and uses no oil. It is, however, equipped with a liquid nitrogen baffle to prevent backstreaming from the other pumps during initial pumpdown. Electrical resistance heaters are mounted on the periphery of the chamber for achieving operating temperatures over 450°F. A United Electric controller is used in conjunction with the electric heaters to maintain a desired chamber wall temperature. Three pressure sensing methods are utilized: (1) A Veeco thermocouple gauge for initial pumpdown sensing; (2) A Veeco ion gauge for operating pressures (10^{-4} to 10^{-8} Torr); and (3) Vac-Ion pump current (which is directly correlatable to pump pressure). During operating conditions, the second and third methods compare rather closely.

2. Material Property

a. Parachute Material

A tabulation of the physical test equipment used in the material property tests is given in Table V. Both the Scott and Dillon tensile testing machines were calibrated by an outside source (Labquip Corp., Chicago) prior to their use in these tests. The Gurley permeometer is a null-balance type of instrument for which a calibration of orifice opening is supplied by the manufacturer.

A photograph of two of the tensile impact load devices, after being initiated at the end of the 5 day vacuum test, is shown in Figure 5. Each parachute weave was connected to a separate spring which

TABLE V. PHYSICAL TEST EQUIPMENT USED IN PARACHUTE MATERIAL PROPERTY TESTS

TEST	WEAVE	APPARATUS/MANUFACTURER
Tensile	Cord	Dillon Model L., Mfg. by W. C. Dillon & Co., Inc. Van Nuys, California
	Ribbon	Scott Model J-2, Mfg. by Scott Testers, Inc. Providence, R. I.
Burst	Fabric	Scott Model J-2 with Ball-Burst Attachment, Mfg. by Scott Testers, Inc., Providence, R. I.
Permeability	Fabric	Gurley Model 4301, Mfg. by W. and L.E. Gurley Co., Troy, New York
Weight	Cord, Fabric Ribbon	Galileo Sartorius (Milan, Italy), Balance, No Model No.

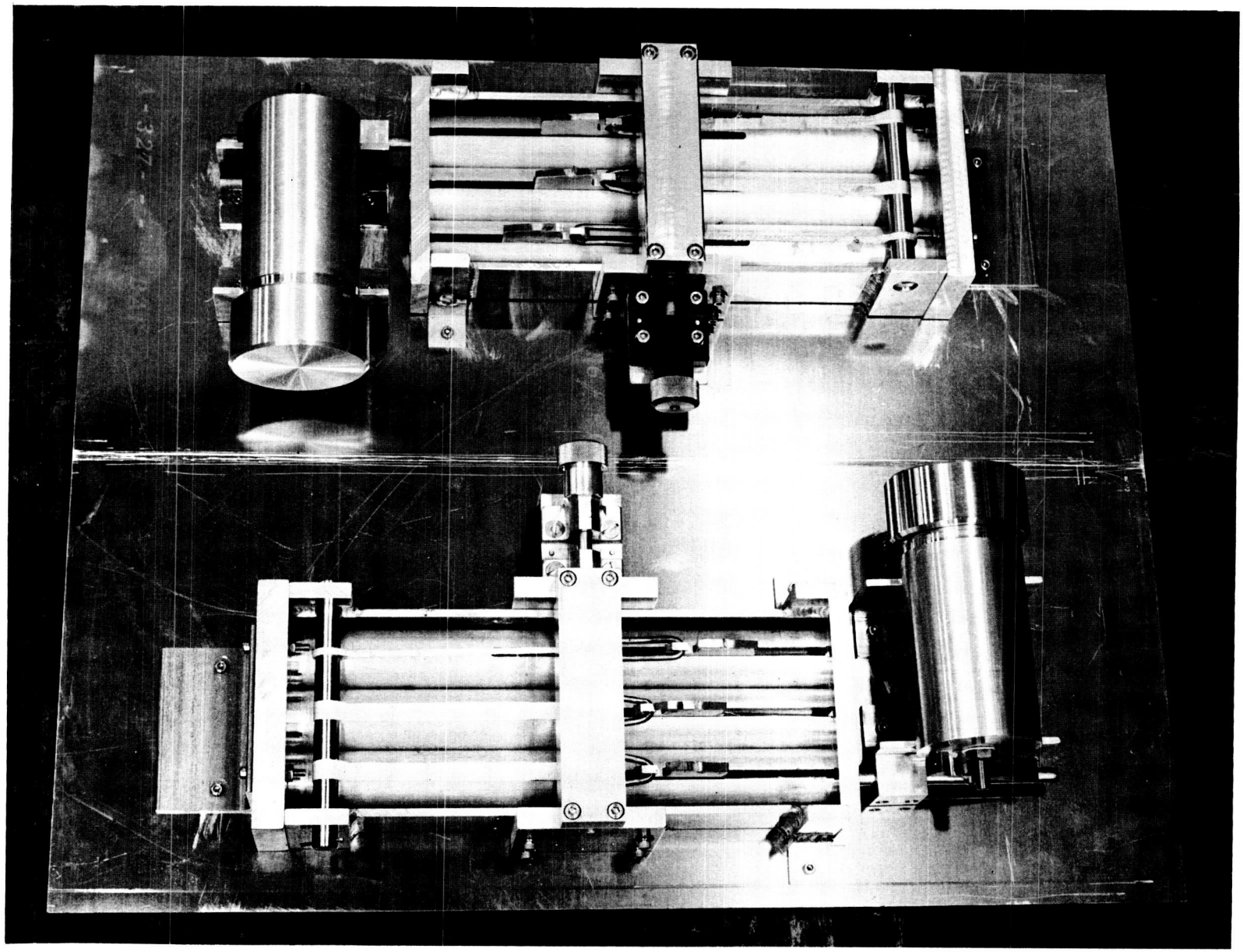


Figure 5. Tensile Impact Load Devices after Initiation in Vacuum Chamber

was placed in compression and held by a retaining pin. When the springs were compressed, the parachute materials were under no stress. The parachute materials were, however, folded over upon itself in the center one inch of each configuration and lightly sewed in that section. The purpose of this was to allow adhesion of the material to take place if this mechanism was operative. One end of the parachute material was connected to a bar on the frame of the device; the other end was connected, via a steel clip, to a plunger pressed against the spring. Release of the springs was accomplished by firing a pressure cartridge in a Cook-designed pin puller. The gas generated by the cartridge moved the retaining pin, which released the plungers to move forward in their tubes under the action of their respective springs. With this design concept, springs of varying compression constants could be employed, and thus parachute materials could be subjected to varying impact load conditions. Spacer blocks were also inserted in the tubes to further permit applied load variability.

The cylindrical members attached to the ends of each of the impact load frames shown in Figure 5 were devices to test parachute fabrics. Within these cylinders were mounted compression springs and a ball-burst apparatus identical in size to that utilized in the Scott attachment (e.g. 1 inch diameter ball pressing against a material held by 1.75 inch I.D. rings.) The ball was drilled and tapped to accept a threaded pin. This pin was inserted into the central core of the spring and protruded from the end of the cylinder, as shown in the foreground device of Figure 5. A spacer block and retaining member was used to hold the spring in a compressed condition. Holes were drilled into the underside of the cylinders to allow the parachute fabrics to be subjected to the vacuum environment. When the pressure cartridge of the pin puller was fired, a rod connected to one of the plungers of the sudden applied load device released the retaining member of the fabric ball-burst apparatus, allowing the compression spring-ball mechanism to function.

To determine the loads applied by these devices, calibrations were performed. A schematic diagram of the calibration apparatus is given in Figure 6. A Cook-designed ring-tensiometer was calibrated and attached to one end of a piece of parachute material by means of a rod of the same diameter as shown in Figure 5. This rod, just long enough to contain one piece of material, was then properly positioned relative to the impact load device. The signal from the tensiometer was connected to a Model 555 dual beam Tektronix oscilloscope by means of the necessary Wheatstone bridge circuitry and power supply. A Polaroid camera was attached to the oscilloscope to obtain a permanent record of the tensile impact load calibration. Two illustrations of records obtained are shown in Figure 7. Two different sweep rates and trace amplitudes were employed in the scope to insure bracketing the variable involved. In the traces shown, sweep rates were 0.2 and 0.1 sec./cm for top and bottom traces, respectively. Amplitudes were 1049 lb/in. and 199 lb/in. for the top and bottom traces, respectively.

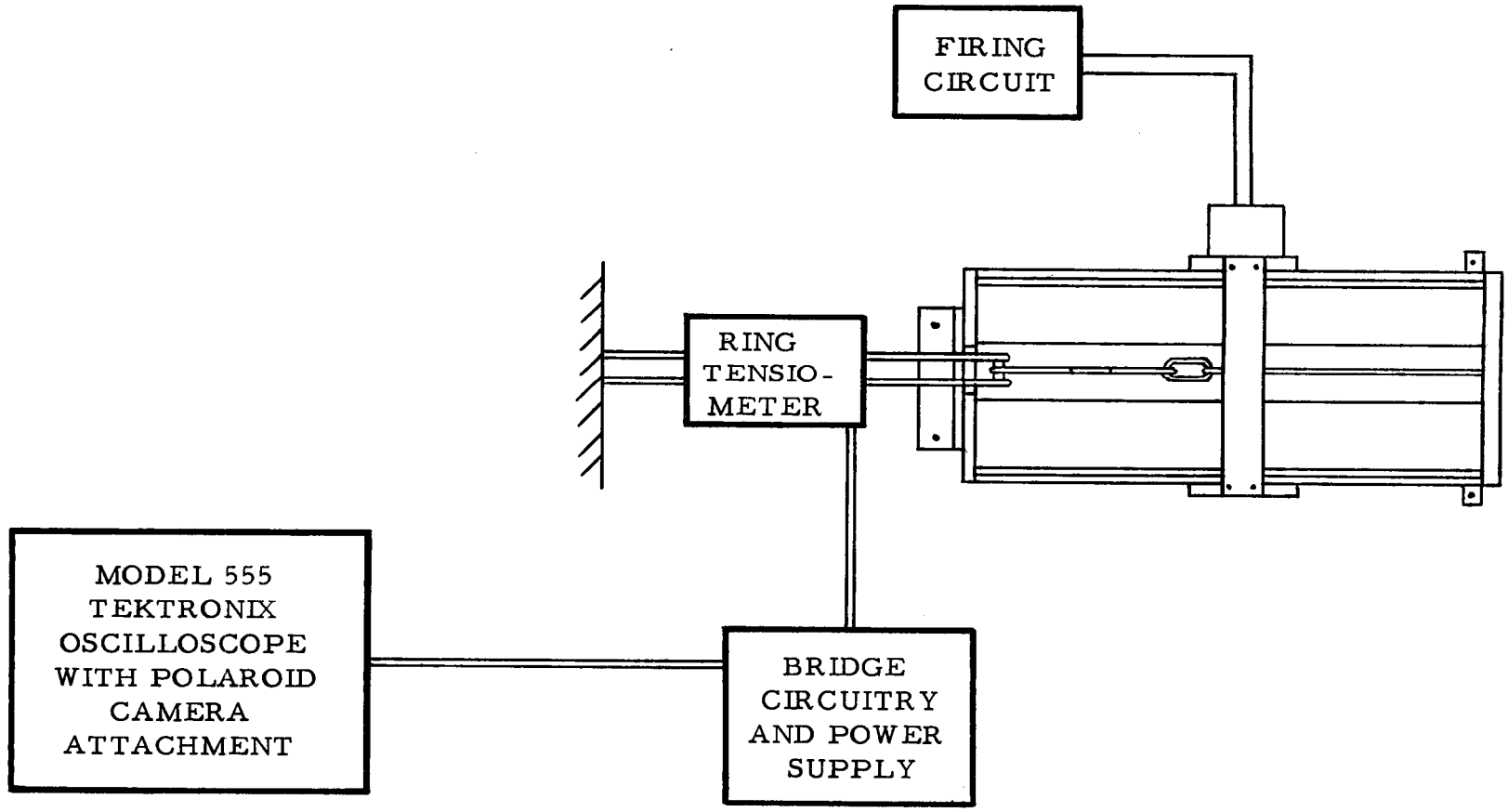
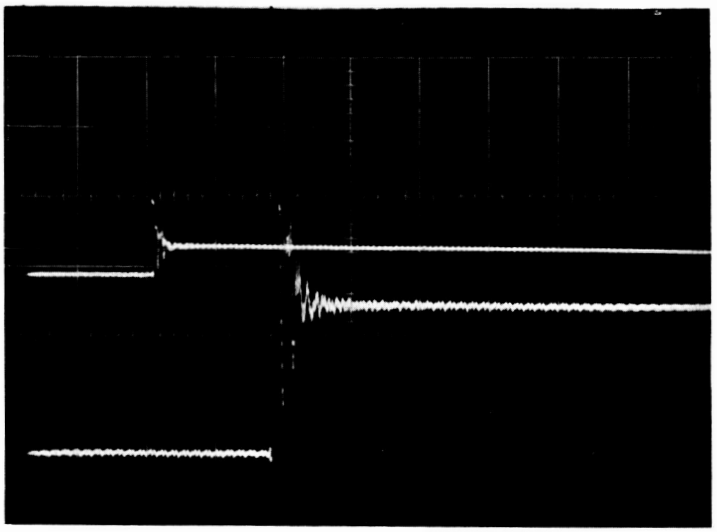
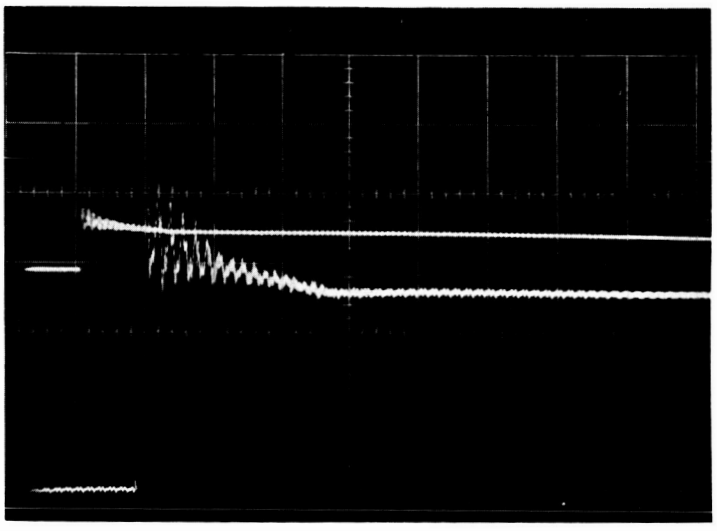


Figure 6. Schematic Diagram of the Tensile Impact Load Calibration Apparatus



a. Dacron



b. Nomex

Figure 7. Calibration Records of Parachute Cords

Hence, peak and steady state loads for the cords tested here were: dacron, 419 and 157 lbs; nomex, 565 and 209 lbs. These data will be discussed further in Section V.

b. Pyrotechnic

Pressure cartridges were tested in a Cook-designed device, the function of which was to drive a piston against a strain-gage instrumented beam upon gas generation. The signal from the strain gages was connected to a Model 555 Tektronix dual beam oscilloscope synchronized to operate with the firing circuit of the pressure cartridge. A Polaroid camera attached to the oscilloscope recorded the resulting traces as discussed for the impact load devices. The strain gage circuitry was connected to both channels of the oscilloscope, each channel operating at a different sweep rate. One channel operated at a fast sweep to record the initial time delay and rise transient, the other channel operated at a slow sweep to record the entire action. A typical trace is shown in Figure 8 of a low pressure Atlantic Research pressure cartridge after subjection to thermal sterilization. Other sweep rates employed were 10 and 2 ms/cm for the top and bottom traces, respectively. These data will be discussed further in Section V.

Since time delay is of prime concern in reefing cutter performance, this parameter was measured by utilizing small diameter wire circuits broken as a sequence was initiated or terminated. One wire circuit was connected to the firing pin sequence such that the circuit would be broken when the hammer struck the primer. The other wire circuit was placed between the reefing cutter guillotine and the taut parachute cord and would be broken when the guillotine sheared the cord. These circuits were also connected to a Model 555 dual beam Tektronix oscilloscope, with the signal variations being recorded on Polaroid film. A typical trace is shown in Figure 9 of a Central Technology reefing cutter exposed to both the thermal sterilization environment and a 10 day vacuum test. Again, the signals from the wires were displayed on two traces, each traveling at a different sweep rate, in this case, 2 and 1 sec./cm for the top and bottom traces, respectively.

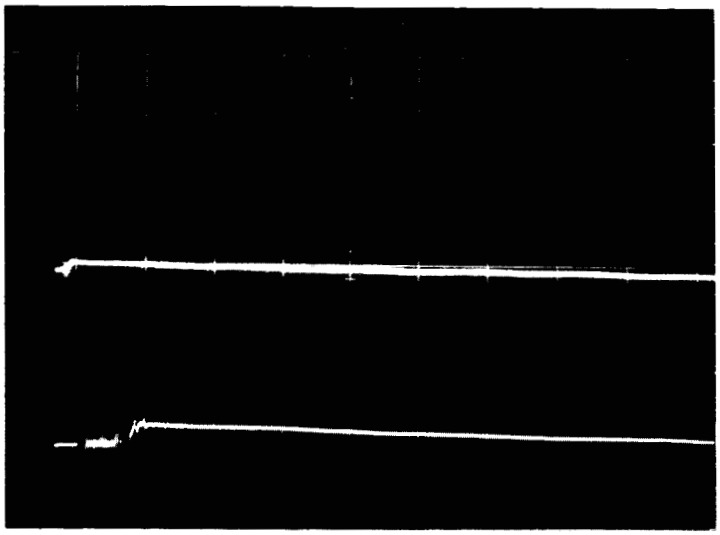


Figure 8. Typical Record of Pressure Cartridge Initiation and Gas Generation

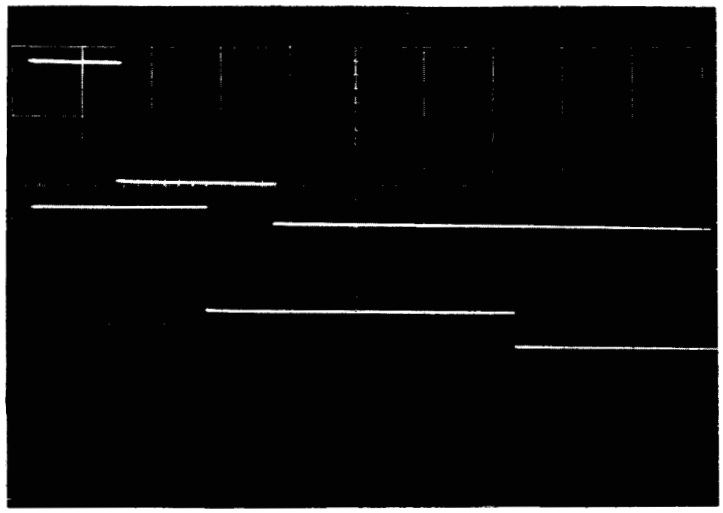


Figure 9. Typical Record of Reefing Cutter Time Delay

IV. ENVIRONMENTAL TEST CONDITIONS

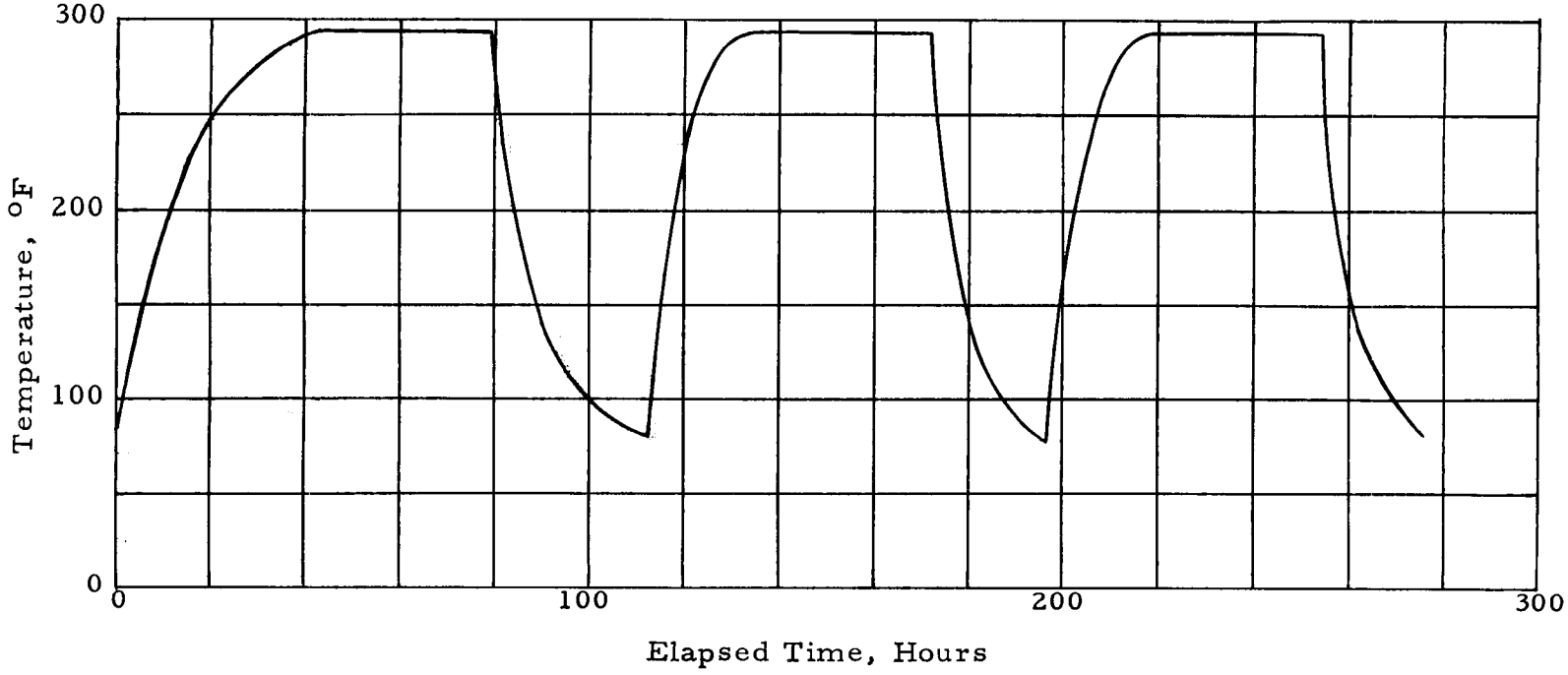
The desired and attained environmental test conditions are given in Table VI. Prior to the thermal sterilization test, a preliminary test was conducted of the thermal stabilization container-tray arrangement (loaded with plates and channels but without parachute materials) as shown in Figure 3. The purpose of this preliminary test was to determine the temperature uniformity and stability of the apparatus. The results of this test showed that a temperature uniformity throughout the entire container was $\pm 2^{\circ}F$, well within the allowed $\pm 3.6^{\circ}F$. Temperature stability, both short and long-term, was very good. The procedure followed for the thermal sterilization environmental test on the parachute and pyrotechnic materials was to evacuate the chamber to a low pressure (12 microns) after which the vacuum chamber was back-filled to ambient pressure with dry nitrogen. The externally mounted electrical heaters were then activated, heating the materials to the required temperature and maintaining this temperature for 36 hours. The heaters were then de-activated, large floor fans used to hasten cooling of the chamber to ambient temperature. This thermal cycle was then repeated two additional times. The vacuum pumpdown-nitrogen backfilling procedure was not repeated prior to the last two cycles. The thermal cycle-time history is plotted in Figure 10.

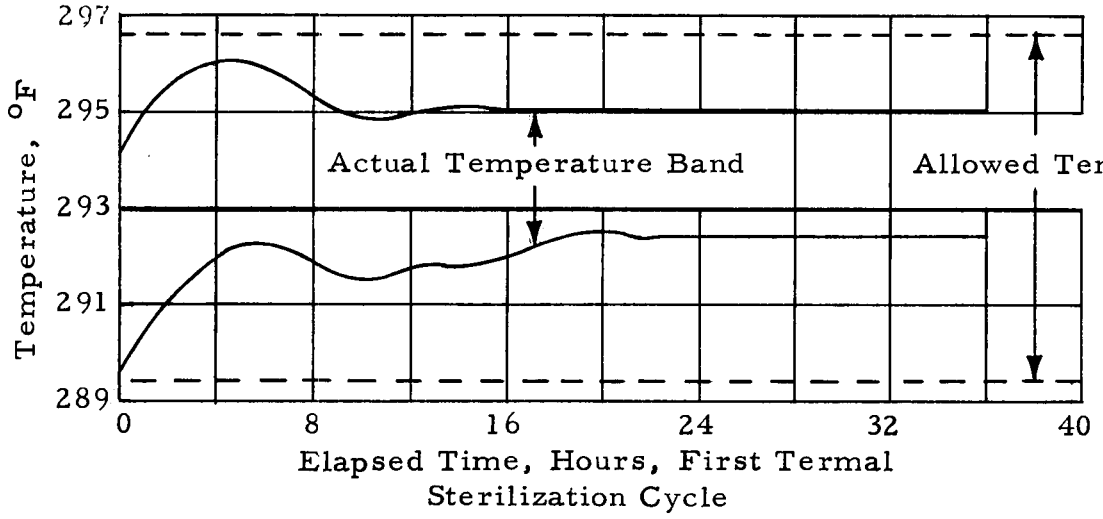
For the chemical sterilization environmental test, the ethylene oxide concentration specification of 550 ±50 mg/ℓ required a sterilizing gas pressure of 17.1 psia at $75^{\circ}F$ and 18.1 psia at $104^{\circ}F$ (Ref. 2). Since this gas mixture is toxic, it was deemed safer to conduct the test at the lowest practicable pressure. Thus, the procedure employed was to evacuate the autoclave of air, then admit the sterilizing gas mixture until the desired pressure was attained. Preliminary tests, using pressurized air, were conducted to prove the pressure-holding ability of the autoclave at both temperature conditions for the time durations involved. For the environmental test, the autoclave was evacuated to 1.5 psia. Steam was then added to the autoclave until the pressure increase as read on a manometer after a humidity dwell of 0.5 hours, indicated a relative humidity of approximately 45%, assuming 550 mg/ℓ sterilizing gas content. Sterilizing gas mixture was then added slowly until the manometer indicated a pressure equivalent to 550 mg/ℓ. Humidity readings with the Alnor Dew-Pointer confirmed a 45% relative humidity. Additional steam and sterilizing gas mixture was added to the autoclave to meet the conditions of test No. 2, although the same test procedure was followed. On test completion, the autoclave was evacuated of sterilizing gas mixture using a vacuum pump, the output of which was forced through water (since ethylene oxide is completely soluble in water) prior to venting to the outside atmosphere. When the pressure was 1.7 psia, the autoclave was back-filled with dry nitrogen to ambient pressure.

TABLE VI. ENVIRONMENTAL TEST CONDITIONS

Environmental Test	Applicable JPL Specification	Desired Test Condition	Actual Test Condition
Thermal Sterilization	X50-30275-TST-A	-Dry Nitrogen Environment -3 Temperature Cycles -Temperature: 145 ±2°C (293 ±3.6°F) -Time at Temperature: 36 hrs/cycle -Stabilization to Room Conditions between Heating Cycles	-Dry Nitrogen Environment -3 Temperature Cycles -Cycle 1 - 293 ±2°F -Cycle 2 - 294 ±2°F -Cycle 3 - 294 ±2°F -Time at Temperature: 36 hrs/cycle -Cycle 1 - 79 -81°F -Cycle 2 - 76 - 82°F -Cycle 3 - 76 - 81°F
Chemical Sterilization	Correspondence from JPL dated 26 July 1963	-Gas Mixture: 12% Ethylene Oxide, 88% Freon 12 -Ethylene Oxide Conc.: 550 ±50 mg/ℓ -Temperature: Test 1 - 24 ±3°C (75.2 ±5.4°F) Test 2 - 40 ±3°C (104 ±5.4°F) -Relative Humidity: 40-50% -Exposure Time: 24 hrs/test	-Gas Mixture: 12% Ethylene Oxide, 88% Freon 12 (from Matheson Co.) -Ethylene Oxide Conc.: Test 1 - 560 mg/ℓ Test 2 - 590 mg/ℓ -Temperature: Test 1 - 75, +4, -3°F Test 2 - 104, +2, -5°F -Relative Humidity: Test 1 - 45% Test 2 - 49% -Exposure Time: 24 hrs(both tests)
5 Day Vacuum	---	-Pressure: 10^{-6} Torr Region -Temperature: 160°F	-Pressure: 3.9 to 1.0 x 10^{-6} Torr -Temperature: 158-160°F
10 Day Vacuum*	---	-Pressure: 10^{-6} Torr Region -Temperature: 160°F	-Pressure 4.0 to 0.8 x 10^{-6} Torr -Temperature: 156-160°F (overshoot cycle to 169°F for 19 hrs)
30 Day Vacuum	---	-Pressure: 10^{-6} Torr Region -Temperature: 160°F	-Pressure:4.0 to 0.5 x 10^{-6} Torr -Temperature: 158-161°F (overshoot cycle to 163°F for 14 hrs.)

*Test interrupted after 7.5 days due to equipment malfunction.





NOTE: Thermal Sterilization Cycles 2 and 3 followed a similar trend.

FIG. 10 TIME-TEMPERATURE HISTORY OF THE THERMAL STERILIZATION TEST

The vacuum tests were performed utilizing the same thermal stabilization container as shown in Figure 3. However, only one tray of parachute materials per type was subjected to each vacuum test. The remainder of the thermal stabilization container was used as a platform for the tensile impact load devices. The procedure for evacuating the vacuum chamber was to: (1) use the Kinney mechanical roughing pump until the chamber pressure was approximately 10 microns; then (2) activate the CVC oil diffusion pump (with appropriate CVC liquid nitrogen-cooled baffle) until the pumping action of the Vac-Ion pump was sufficient to maintain or decrease the chamber pressure without assistance of the diffusion pump. When this condition occurred, the diffusion pump was valved out of the system, completely negating any oil backstreaming. The roughing pump was in service at all times, since it maintained the vacuum between the double-seals on all openings in the chamber. The Vac-Ion pump began pumping at a pressure of approximately 2×10^{-5} Torr for each vacuum test. When the chamber internal pressure was decreased to approximately 1×10^{-6} Torr, the electrical heaters on the outside of the vacuum chamber were activated. Outgassing of the chamber walls and retardation system materials increased due to the heating such that when the internal chamber temperature stabilized near the desired condition, the chamber pressure was approximately 4.0×10^{-6} Torr. The start of each vacuum test was considered, then, as the time at which the temperature stabilized near the desired conditions.

The five day test proceeded to conclusion in a normal manner. However, after 7.5 days of operation of the 10 day test, a phenomena occurred in the Vac-Ion pump system so as to trip a protective alarm and shut off the pump. The usual causes of this are main power interruption or excessive pump current. The former cause is readily determinable. The latter cause could be due to sudden excessive outgassing of some material from the chamber or to shorting between the cathode and anode plates of the pump due to flaking of the titanium compounds from the anode surfaces. Since this phenomena occurred at the start of a holiday weekend, cognizant personnel could not be immediately located. By the time personnel could be reached, the chamber pressure had increased to such a point that a new start was necessitated. Since this is roughly an 18 hour procedure, dry nitrogen was introduced into the chamber to return the pressure to ambient for the remainder of the holiday weekend. The normal starting procedure outlined above was initiated again at the start of the work week, completing the remaining 2.5 days of the test.

After the end of the 10 day test, a step-wise procedure was initiated to determine the cause of the malfunction. None was found, except that in disassembly of the Vac-Ion pump, it appeared that the plates were coated excessively and that some flaking could have occurred. If flaking would have

occurred, this would allow a shorter conductive path during its period of fall, possibly causing excessive pump current for a short period of time. The plates were cleaned and re-assembled. One malfunction also occurred during the 30 day test, but this was a main power interruption during a thunderstorm. Since this occurred during work hours, the Vac-Ion pump was immediately started again.

V. RESULTS AND DISCUSSION

A. Preliminary Thermal Sterilization and Vacuum Tests

Preliminary tests were conducted on four candidate parachute materials to determine catastrophic failure of any candidate material. Tests were conducted on nylon and nomex ribbon, cord, and fabric weave forms, and on dacron and silk fabrics. These samples were taken from our supplies and hence were cut from as-received, unscoured spools and rolls. Samples were both laid flat and pressure-packed. The procedures outlined in Section IV were followed. Materials were weighed and fabric permeabilities measured. The samples were then subjected to thermal sterilization for 41 hours after which one-half of the samples were removed and placed in a nitrogen-filled holding chamber prior to test. The remaining samples were subjected to 2.5 hours of vacuum environment (pressure less than 10^{-6} Torr) at ambient temperature.

The test results indicated catastrophic degradation of silk. Thus, it was concluded that silk should be eliminated from further consideration as a candidate parachute material for Mars entry. These preliminary results also showed nylon to be somewhat questionable as to usage in the Mars entry application. A discrepancy was observed in the comparative magnitude of tensile strength loss in fabrics and ribbons. This had been noted previously (Ref. 3). Some adhesion of the nylon samples was noted, both the material itself, when folded, and slightly to the stainless steel members compacting the nylon.

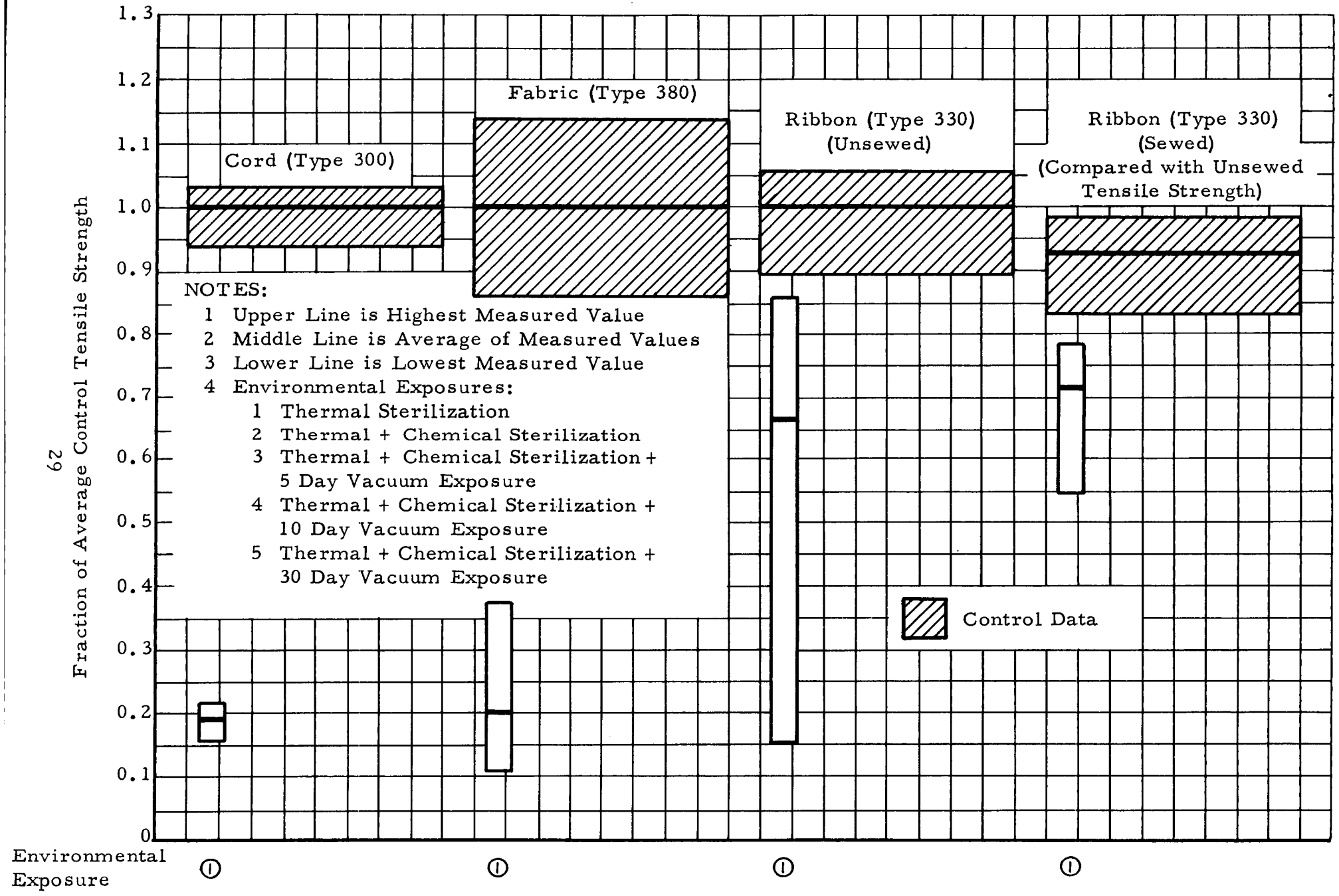
The dacron and nomex test results showed them to be promising as candidate materials. Nylon, dacron, and nomex were then subjected to the more extensive environmental tests.

B. Environmental Tests

1. Parachute Materials

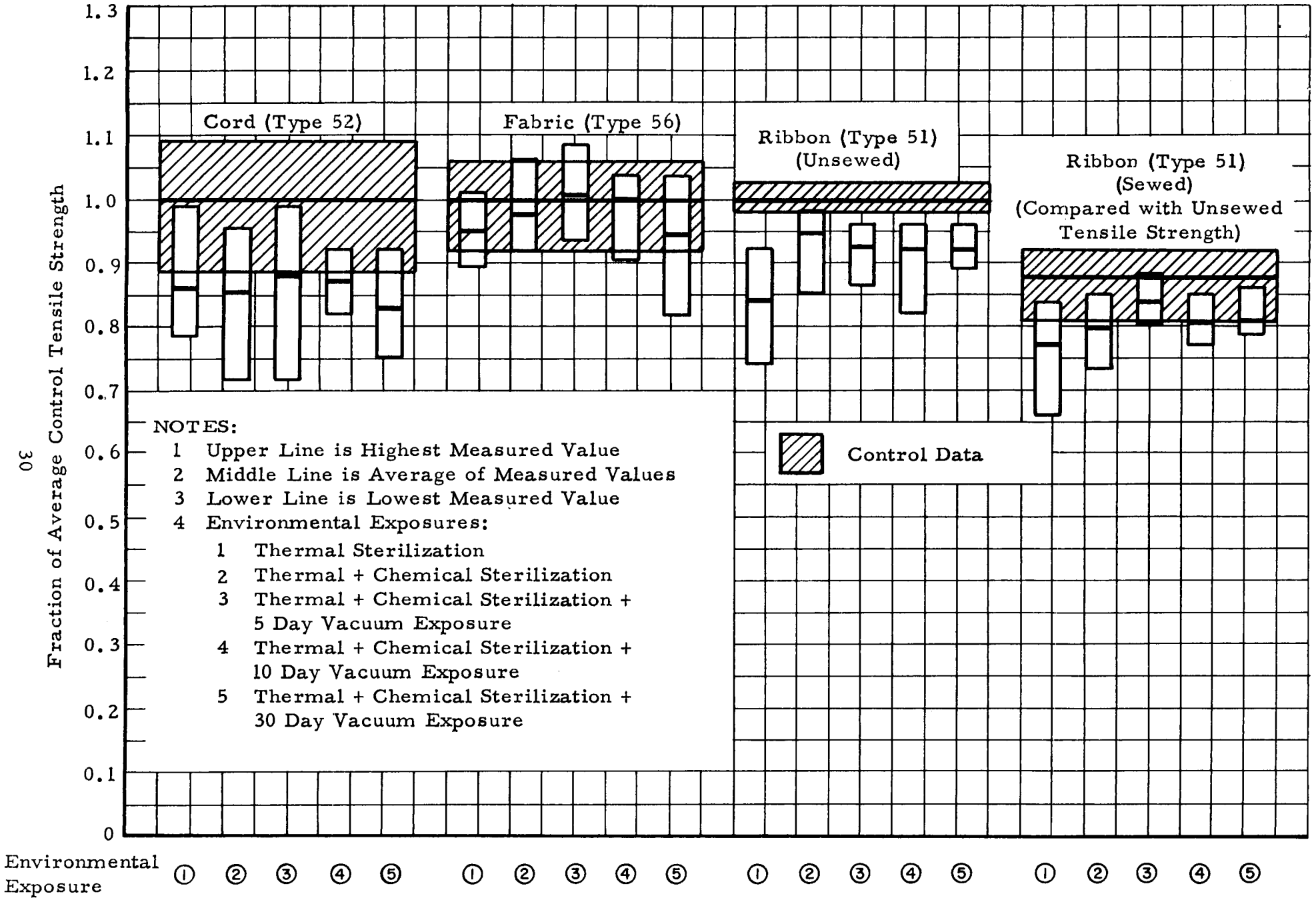
a. General

The variations in material properties for the three remaining candidate materials are presented in bar chart form in Figures 11 and 12. In these data, all variations are presented as fractions of the average tensile strength of the control samples. In each bar, the upper line represents the highest measured value in any set of data; the lowest line represents the lowest measured value; and the middle line represents the average of all measured values of any one set of data. The control data is so presented to connote its constancy for any set of environmental



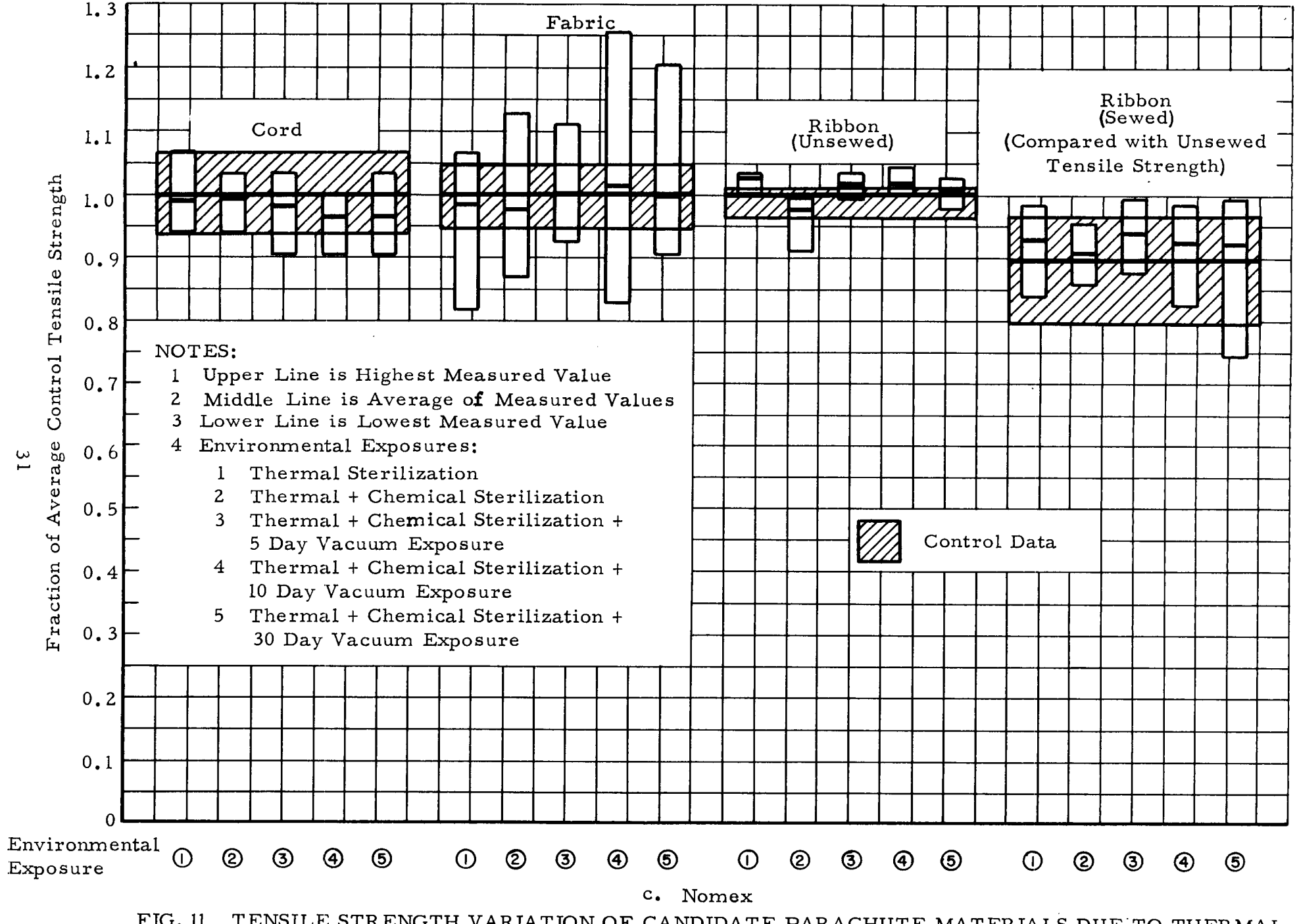
a. Nylon

FIG. 11 TENSILE STRENGTH VARIATION OF CANDIDATE PARACHUTE MATERIALS DUE TO THERMAL AND CHEMICAL STERILIZATION AND VACUUM EXPOSURE



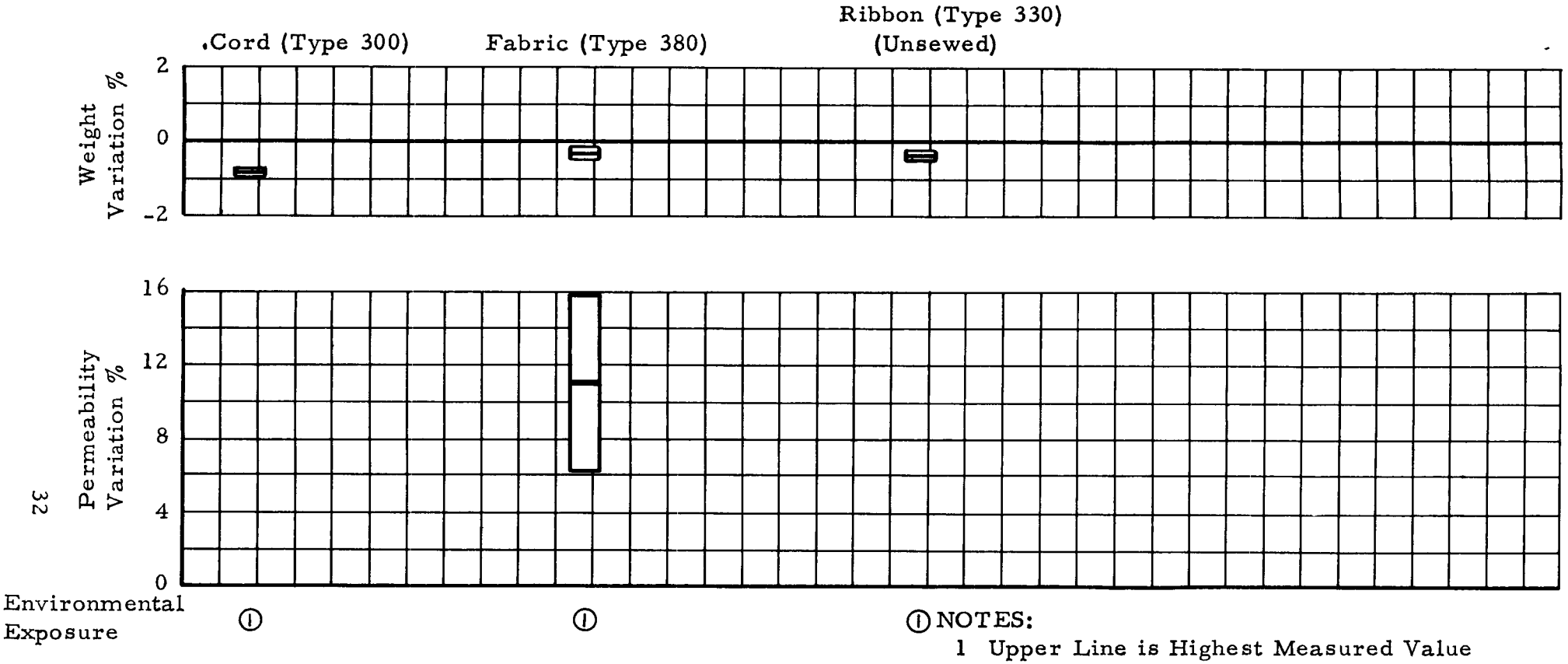
b. Dacron

FIG. 11 TENSILE STRENGTH VARIATION OF CANDIDATE PARACHUTE MATERIALS DUE TO THERMAL AND CHEMICAL STERILIZATION AND VACUUM EXPOSURE



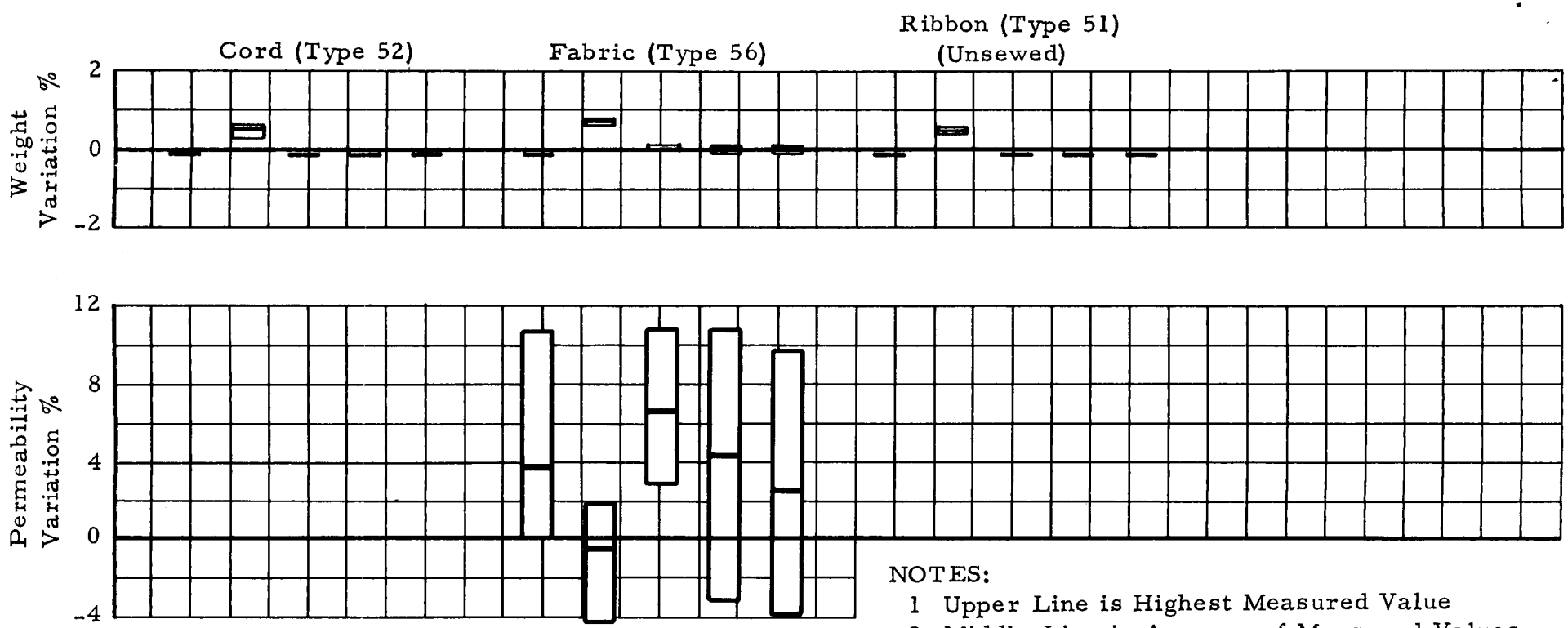
c. Nomex

FIG. 11 TENSILE STRENGTH VARIATION OF CANDIDATE PARACHUTE MATERIALS DUE TO THERMAL AND CHEMICAL STERILIZATION AND VACUUM EXPOSURE



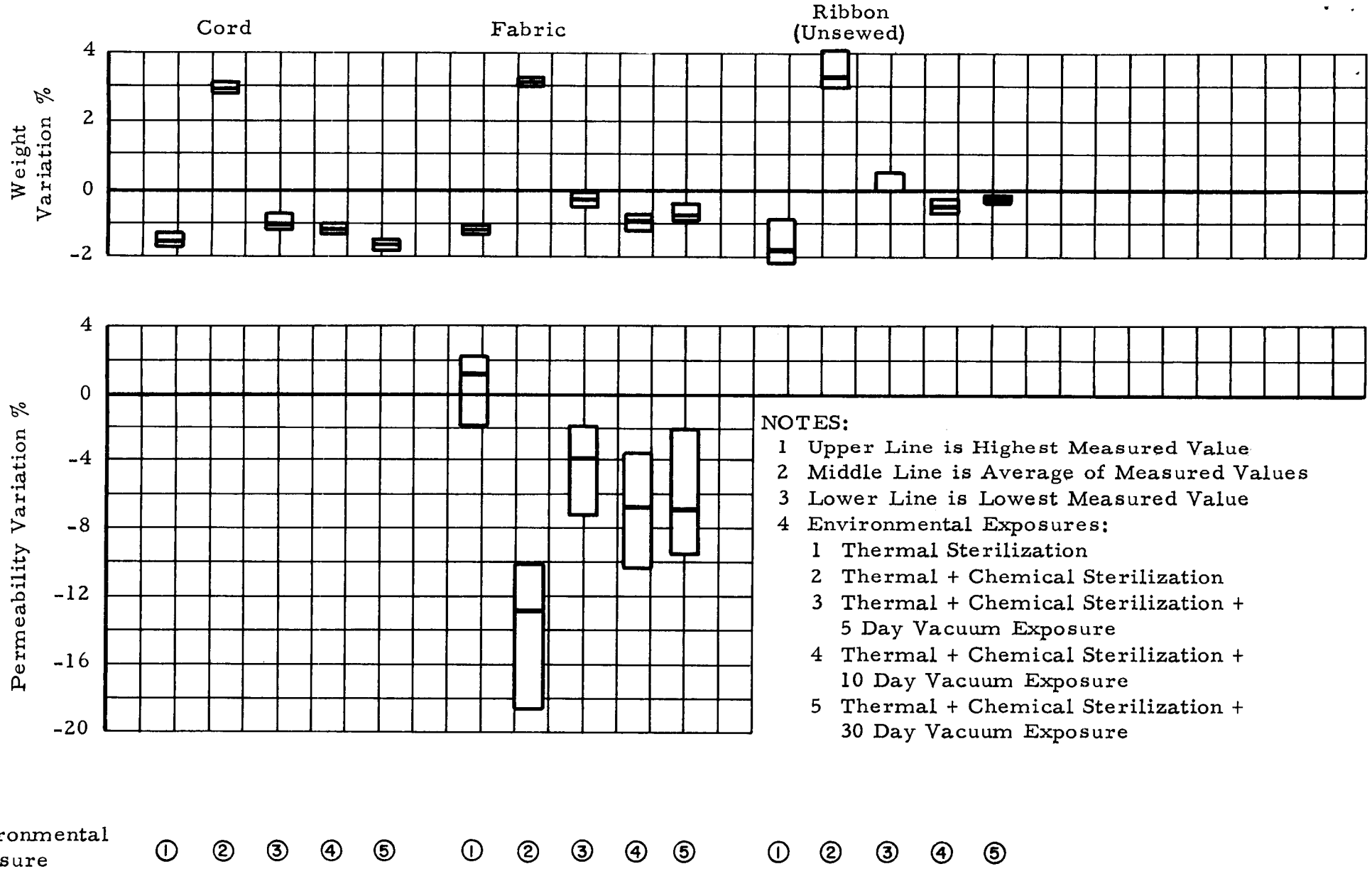
a. Nylon

FIG. 12 WEIGHT AND PERMEABILITY VARIATIONS OF CANDIDATE PARACHUTE MATERIALS DUE TO THERMAL AND CHEMICAL STERILIZATION AND VACUUM EXPOSURE



b. Dacron

FIG. 12 WEIGHT AND PERMEABILITY VARIATIONS OF CANDIDATE PARACHUTE MATERIALS DUE TO THERMAL AND CHEMICAL STERILIZATION AND VACUUM EXPOSURE



c. Nomex

FIG. 12 WEIGHT AND PERMEABILITY VARIATIONS OF CANDIDATE PARACHUTE MATERIALS DUE TO THERMAL AND CHEMICAL STERILIZATION AND VACUUM EXPOSURE

exposures of one weave form. Test materials were subjected to a maximum of five environmental exposures; the narrower bars present the material property data resulting from each exposure.

The sewed ribbon data was compared to the average control data of the unsewed ribbons so that variations due to this parameter could also be meaningfully presented in Figure 11.

Each narrow bar includes all of the flat, folded and compacted, and twisted and compacted data, since the variations (average, maximum, and minimum) between each configuration were small.

Since weight and permeability data were taken before and after each environmental exposure, these data are presented relative to their weight or permeability prior to any environmental exposure noted in Figure 1.

In these figures, a certain amount of variability in material property data can be seen, even though careful procedures of material selection and test were observed. This variability can be attributed to many factors. First, at the molecular level, strength variations of a resultant weave are dependent upon the chains in the network - such factors as their length and orientation, their flexibility and degree of entanglement with other chains, and their degree of polymerization and homogeneity. Secondly, at the fabrication level, strength variations of a resultant weave are dependent upon such factors as the degree of twist and filament stress in the yarn, and machine variables of yarn tension and placement resulting in weave non-uniformity. Finally, at the testing level, strength variations of the resultant weave are dependent upon such factors as machine testing uniformity, and frictional and varying extensibility effects between greater or lesser number of filaments grabbed by the machine (which can be prominent in this work due to moisture desorption).

b. Thermal Sterilization

The effect of temperature on textile materials has been studied rather extensively (Ref. 3-7), but not under the time-temperature-atmosphere conditions required for the thermal sterilization cycle noted in Table VI.

Tensile strength degradation of nylon is presented in Figure 11a. The effect of thermal sterilization in producing catastrophic degradation of cord (Type 300) and fabric (Type 380) is readily apparent. The average degradation of ribbon (Type 330) is less, but the tensile strength variations are much more marked. The explanation of this variability of

tensile strength among different types of nylon can be seen in Figure 13, in which the strength variation with temperature of types 300 and 330 nylon is shown. Although both types 300 and 330 nylon are bright, high tenacity filament yarns, type 330 is modified to give improved heat and light resistance. This modification would normally incorporate changes in the processing variables to increase the molecular weight and chain linearity, but does not necessarily mean improvement in the organic backbone. Hence, this modification extends the strength characteristic to somewhat higher temperatures, but above some critical temperature, the slope of the strength degradation curve is the same as the type 300. The thermal sterilization temperature is such that it intersects the nylon strength curve on the high slope (e.g. large strength degradation/^{o}F) portion of the curve. Hence, the average degradation of type 300 was approximately 80 percent of the average control sample strength, whereas Type 330 ribbon, of improved heat resistance, incurred an average degradation of only approximately 30 percent.

The following visible factors were observed: (1) the nylon materials were markedly stiffer and less flexible; (2) no adhesion of the nylon to itself or to the stainless steel plates was observed (in contrast to the preliminary tests where adhesion of unscoured materials was observed); and (3) the materials, especially cords and fabrics, were very discolored. Discoloration is evident in Figure 2, which compares nylon materials which had been subjected to the thermal sterilization environment (in the tray) to unheated samples (foreground). In this figure, some discoloration of the materials due to the numbering markers can be seen, but the markers were placed in a section of the material which would not be subjected to property testing.

From the above data and observations, it can be seen that even the more heat resistant types of nylon are extremely marginal for use in this application. Hence, it was concluded that nylon be eliminated from further consideration as a candidate parachute material for a sterilizible retardation system.

The effect of thermal sterilization on dacron is much less pronounced than with nylon. Variations in strength degradation were also noted with different types of dacron, the least affected being Type 56 (fabric weave). The degradation of different types of dacron probably follow a pattern similar to that of Figure 13 for nylon, but due to the increased temperature properties of dacron, the high rate of strength degradation with temperature portion of the curve does not occur in the thermal sterilization temperature range. Hence, less degradation due to thermal sterilization would be expected with dacron weaves than with nylon. It should be noted that the manufacture of Type 51 yarn has been discontinued.

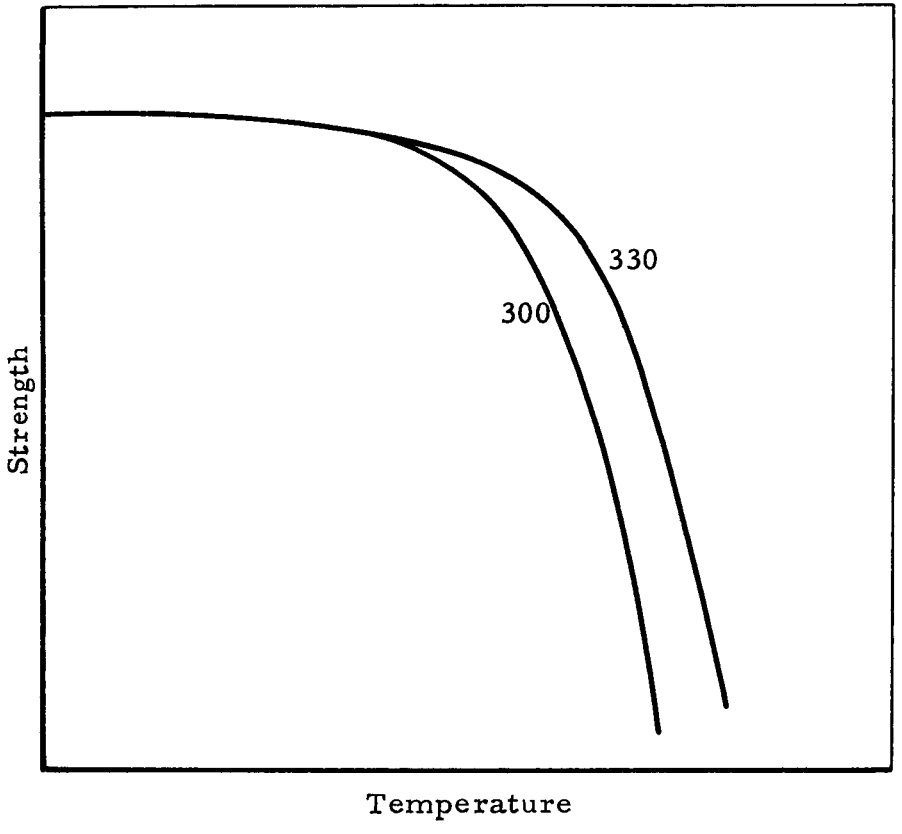


FIG. 13 STRENGTH VARIATION OF NYLON TYPES WITH TEMPERATURE

On an average basis, there is a negligible effect of thermal sterilization on nomex. However, rather large variations in the break strength of fabric were noted. This variation is evidently due to the weave itself, since all nomex weave forms were fabricated from the same merge number yarns. Slightly higher break strengths of ribbons over the control sample data were also noted. This small increase (2-3%) is probably due to the variations in break strength of the small sample quantities used rather than due to some physical phenomena.

c. Chemical Sterilization

Whereas water was desorbed from the organic structure in the thermal sterilization process, it was returned to the structure in the chemical sterilization process. This is graphically indicated in the weight variation charts of dacron and nomex (Figure 12 b and c). It is known (Ref. 8) that water desorption or absorption has an effect on the resultant strength and extensibility of the filament; consequently, increases in strength of textile materials due to chemical sterilization could be anticipated. This strength increase occurred in all dacron fabric and ribbon; dacron cord (Type 52) remained relatively unchanged. Variations in break strength of any one weave form remained approximately the same due to either thermal or chemical sterilization.

The structure of nomex seems to be less affected by moisture variations. Neither the cord nor the fabric weaves appeared affected. A slight decrease in strength of the ribbon was noted, but this was probably due to the atypical results obtained after thermal sterilization (e.g. small sample results) rather than any physical phenomena.

No visible changes in either dacron or nomex were observed.

d. Vacuum

The effect of vacuum is again to cause desorption of water from the organic structure, as well as to promote molecular changes. These changes can occur with little apparent weight change (Ref. 9), but most detrimental strength changes are accompanied with sizeable weight changes (10% or so).

Some strength variations occurred in dacron due to vacuum exposure, but these did not appear to be catastrophic. After five days of vacuum, the cord and fabric weave forms exhibited some increase in strength, but with slightly increased maximum and minimum strength variations of each weave form over the previous environmental exposure. Due

to the large increase of material strength after chemical sterilization, the unsewed ribbon strength after five days of vacuum can be considered either to increase or decrease. Based on the other dacron weave forms, the unsewed ribbon after chemical sterilization appears abnormally high due, perhaps, to the small statistical sample. If this were the case, it can then be stated categorically that the effect of five days vacuum is to increase the material strength of all dacron weave forms. This strength increase may be due to cross-linking, but no marked increase in material stiffness was noted. Material strength appears to decrease somewhat with increased time of vacuum exposure. Cord (Type 52) and fabric (Type 56) weave forms decreased approximately 5 percentage counts from 5 to 30 days of vacuum exposure. The ribbon (Type 51) appeared to remain more stable with time in vacuum. No adhesion of the material to itself or to the stainless steel was noted.

It is significant to note that the average strength of the Type 56 fabric remained within the control band of data throughout the series of environmental exposures.

On an over-all average basis, nomex is negligibly affected by vacuum exposure. The average data of all weave forms deviated approximately ±4 percent from the control sample average data. Sizeable variations from the average were noted, however, especially in the fabric weave, where strength reductions as great as 17 percent below average control were exhibited by some samples. Slight additional degradation with increased periods in vacuum exposure was noted. This appears to be asymptotic with time. No marked increase in material stiffness was noted, nor was any adhesion of the material to itself or to the stainless steel apparent.

e. Tensile Impact Loads in Vacuum

As stated earlier, the purpose of applying sudden impact loads to the parachute materials was to simulate opening loads on a parachute retardation system. A criteria chosen for design purposes was to load each material to approximately one-half its design break strength, although it was realized that variations from these values should be obtained as well. Thus, for the five day vacuum tests, the following peak force loads were applied to the dacron and nomex parachute materials: cords, 304, 348, and 371 pounds; ribbons (sewed and unsewed), 62, 100, 113 pounds; fabrics, 68 pounds (dacron) and 190 pounds (nomex). At the end of the five day vacuum test, the pyrotechnics were initiated, releasing the springs. All devices functioned properly, and no materials were ruptured as a result of this type of loading. A photograph of two of the activated shock devices after this test is shown in Figure 4. The dacron samples are pictured in the foreground, nomex samples in the background.

The same arrangement of test samples for the ten day vacuum test was employed as above, except that the compression springs providing a peak load of 304 pounds on the cords were replaced by springs creating peak loads of 414 pounds. At the end of the ten day vacuum test, the pyrotechnics were again initiated. All devices functioned properly, and no materials were ruptured.

The same arrangement was employed for the thirty day vacuum test also, except that only two nomex cords, loaded with springs to give peak loads of 371 and 414 pounds, were utilized. In the place of one nomex cord, nylon cord was inserted, using a compression spring to provide a peak load of 304 pounds. At the end of the thirty day vacuum test, the pyrotechnics were initiated, and all devices again functioned properly. The nylon cord was broken by the peak load, whereas no dacron or nomex samples were ruptured.

Thus, although the material property tests indicate a slight reduction of the strength of dacron with time in a vacuum environment, impact loadings to 55 percent of the design break strength of the material were made with no apparent deleterious effect.

After the thirty day test had been started, some heavier duty compression springs, ordered earlier but which were out of stock, were received. After completion of the thirty day test, one dacron and one nomex cord were tested using this type of compression spring. The results are presented in Figure 6, which shows typical calibration records as well as sudden impact loading on these samples. The peak and steady state loads imposed on the cords were: dacron, 419 and 157 pounds; nomex, 565 and 209 pounds. These samples had been stored in the dry nitrogen-filled holding chamber until tested, although to conduct these tests, the sample had been in room ambient conditions for approximately 20 minutes. The peak loads attained correspond to 67 percent for dacron and 75 percent for nomex of the respective break strength of the cords after the 30 day vacuum test. However, it must be realized that some strength increase would occur on moisture regain. Thus, although this would have to be verified in vacuum, it appears that the design factor of 2 commonly employed in parachute design may be reduced considerably, which would result in significant weight savings for the sterilizable retardation system.

f. Configurational Effects

Two configurational effects were investigated: (1) the effect of folds and twists on the material samples; and (2) the effect of ribbon stitching. Little variation between the average flat, folded and compacted, and twisted and compacted data was observed. Further, when

maximum and minimum values of each set of data were analyzed, the variations due to configurational effects were indistinguishable. Thus, it can be concluded that the effect of packaging is negligible. This is in agreement with the results of References 3 and 4.

The effect of strength loss of ribbons due to sewing is presented in Figure 11. To obtain an initial comparison, the control data of the sewed ribbon was compared to the average control data for the unsewed ribbon. This data indicates that an average strength degradation of 10 percent occurs due to sewing. This same variation appears to be approximately maintained for ribbons subjected to sterilization and vacuum environments as well.

g. Weight and Permeability

Variations in weight and permeability are given in Figure 12. The effect of thermal sterilization was to cause a weight-loss in all materials tested. This was probably due to a loss of absorbed water in addition to that which was lost in the desiccator prior to the weight measurements and the environmental exposure. Due to the moisture involved with chemical sterilization, the weight of each material increased markedly as expected. With subsequent exposure to hard vacuum, the absorbed water was again given off resulting in weight losses approaching that which occurred due to thermal sterilization.

It has been shown (Ref. 10 and 11) that the permeability of a fabric, at a constant pressure differential, is a function of its open area (per the principles of fluid mechanics). This open area is also a function of the fabric and yarn geometry, i.e., yarn twist and ellipticity. Another parameter affecting permeability appears to be that of moisture content within the organic structure when subjected to extreme environments. Nylon fabric lost approximately one-half of one percent weight during thermal sterilization. One of the consequences of this loss (perhaps due to yarn twist tightening with concomitant increase in open area) was an increase in permeability averaging 11 percent.

Dacron lost only a trace of its weight during thermal sterilization but it gained an average of 4 percent in permeability, the variation in permeability being quite large. This may indicate greater sensitivity of moisture variation of dacron with permeability. With the weight gain due to moisture absorption during chemical sterilization, permeability decreased. The loss of moisture during vacuum exposure again occurred and the permeability accordingly increased to the levels attained after thermal sterilization.

Nomex lost 1 to 2 percent of its weight during thermal sterilization but the permeability varied only 2 percent. This could perhaps indicate only a small increase of yarn twisting with moisture loss. However, nomex gained this weight back plus 3 percent due to moisture absorption during chemical sterilization. This may have caused extreme twist relaxation since permeability decreased as much as 19 percent. The moisture was again lost during vacuum exposure, but only one-half the permeability was regained during vacuum exposure.

In the above-cited work on permeability, one factor which was not considered (and which was beyond the scope of the intended work) was that of boundary layer and the resultant effect of air flow blockage due to the effective boundary layer displacement thickness. If the yarn twist is great and the open area is large, this effect will be negligible. However, if the filaments are caused to relax by some means and in relaxing, tend to "spread out" closing the larger open areas, the effect of boundary layer can become more pronounced. Thus, the degree to which the spreading out of the filaments occurs in large measure can affect the permeability and the variations of permeability of one set of samples after exposure to the same environmental conditions. It is known that many organic filaments tighten or stretch depending upon their moisture content. This mechanism may be operative here.

2. Pyrotechnics

a. Pressure Cartridges

The purpose of investigating pressure generators was to determine the efficacy of utilizing this form of energy generation after subjection to sterilization and vacuum environments, and was not intended to assess the relative merits of the product of one company over another. If such an assessment were intended, sufficient quantities of cartridges would have to be obtained to allow statistical analyses to be performed. A maximum of eight units from any one company was subjected to a specific set of environmental conditions permitting indication of trends only to be reached.

The effects of thermal sterilization and vacuum on the pressure generators tested is presented in Table VII. All data was obtained in the test fixture discussed in Section III C, except the Unidynamics Corporation data. Due to the fact that the Cook fixture had an internal volume in excess of one cubic inch compared to the 0.2 cubic inch output specification of the Unidynamic cartridges, these cartridges were shipped to and tested by the Unidynamic Corporation after environmental exposure. Further, the pressures generated by the other cartridges vary from the output specifications of Table III due to the difference in internal volume of the test fixture.

TABLE VII. EFFECT OF THERMAL STERILIZATION AND VACUUM ON PRESSURE GENERATOR PERFORMANCE

Environmental Exposure \ Company		Atlantic Research	Central Technology	Hercules Powder	Hi-Shear	Unidynamics*
1.	Control					
	a. No. of Units	5	1	3	-	1
	b. Average time to peak pressure	1.7 ms	9.0 ms	1.0 ms	-	5.7 ms
	c. Range of time to peak pressure	1.0 - 3.0 ms	-	0.8 - 1.2 ms	-	-
	d. Average peak pressure generated	270 psig	1175 psig	160 psig	-	1000 psig
	e. Range of peak pressure generated	245 - 375 psig	-	90 - 205 psig	-	-
2.	Thermal Sterilization					
	a. No. of Units	8	1	6	-	2
	b. Average time to peak pressure	1.5 ms	8.9 ms	0.8 ms	-	11.8 ms
	c. Range of time to peak pressure	1.0 - 2.5 ms	-	0.6 - 0.9 ms	-	10.0 - 13.5 ms
	d. Average peak pressure generated	380 psig	1450 psig	230 psig	-	920 psig
	e. Range of peak pressure generated	310 - 515 psig	-	150 - 315 psig	-	685 - 1150 psig
3.	Thermal Sterilization Plus 5 Days Vacuum					
	a. No. of Units	-	1	-	1	3
	b. Average time to peak pressure	-	12.5 ms	-	2.0 ms	20.5 ms
	c. Range of time to peak pressure	-	-	-	-	13.3 - 27.2 ms
	d. Average peak pressure generated	-	1725 psig	-	2520 psig	915 psig
	e. Range of peak pressure generated	-	-	-	-	770-1110 psig

*Units tested at the Unidynamics Corporation in a 0.2 in^3 bomb by Unidynamics personnel.

The time to reach peak pressure was measured from the oscilloscope records as the time lapse from the initiation of the pressure pulse to the peak of the pressure pulse. This separates variations in ignition time.

In general, the cartridges from all companies functioned well, proving the efficacy of using this form of energy generation after exposure to sterilization and vacuum.

The effect of thermal sterilization on pressure generators appears to cause an increase in the pressure generated at the expense of a decrease in the time to reach peak pressure after initiation of pressure rise. Sufficient quantities of Atlantic Research and Hercules Powder cartridges were tested to indicate this trend which indicates a peak pressure increase approaching 45 percent and a time decrease approaching 20 percent. This trend also appears to be indicated by the Central Technology cartridges but no further conclusions can be drawn from only one sample tested. This trend is not maintained by the data of Unidynamics cartridges, but the data of one control unit is not sufficient upon which to draw conclusions. Of the total of 17 pressure generators fired after receiving thermal sterilization, no mis-fire occurred.

Insufficient quantities of pressure cartridges were subjected to the combined environments of thermal sterilization and vacuum to allow any conclusions to be drawn as to pressure or time variations. One important consideration, though, is to note that hermetic sealing can be very important to proper functioning of the cartridge after vacuum exposure. Two pressure cartridges which had been hermetically sealed in manufacture were punctured intentionally prior to test. After being subjected to vacuum, one unit did not fire. Any hermetic seal is subject to some amount, however small, of leaking in vacuum. When exposed to vacuum for the eight to nine months duration of flight to Mars, a small amount of leakage could be deleterious.

It is of interest to note that pressure cartridges were used in initiating the sudden applied load devices in vacuum. Of all the cartridges initiated, there were no mis-fires, although these units had not been subjected to thermal stabilization prior to the vacuum.

b. Reefing Cutters

The same comments made above concerning assessment of manufacturer's pressure generator products apply to reefing cutters. The efficacy of reefing cutters, when subjected to sterilization and vacuum, is even more questionable than pressure generators due to the series-type sequence of events which must all occur prior to firing the main charge. Further, hermetic sealing of a reefing cutter is more difficult.

The effects of thermal sterilization and vacuum on the reefing cutters tested is presented in Table VIII. A total of six

TABLE VIII. EFFECT OF THERMAL STERILIZATION AND VACUUM ON REEFING CUTTER PERFORMANCE

Environmental Exposure \ Company	Central Technology	Unidynamics*
1. Control		
a. No. of Units	2	3
b. Average force required to actuate	19.5 lb.	**
c. Range of force required to actuate	18 - 21 lb.	**
d. Average delay train time delay	4.47 sec.	10.0 sec.
e. Range of delay train time delay	4.39 - 4.55 sec.	9.6 - 10.7 sec.
f. Amount of line cut	9000 lb.	1500 lb.
2. Thermal Sterilization		
a. No. of Units	2	4
b. Average force required to actuate	20.0 lb.	**
c. Range of force required to actuate	16 - 25 lb.	**
d. Average delay train time delay	4.43 sec.	10.2 sec.
e. Range of delay train time delay	4.36 - 4.55 sec.	9.4 - 12.7 sec.
f. Amount of line cut	9000 lb.	1500 lb.
3. Thermal Sterilization Plus 10 Days Vacuum		
a. No. of Units	2	-
b. Average force required to actuate	20.0 lb.	-
c. Range of force required to actuate	15 - 24 lb.	-
d. Average delay train time delay	4.62 sec.	-
e. Range of delay train time delay	4.54 - 4.66 sec.	-
f. Amount of line cut	9000 lb.	-

* Data observed after modifying the method of primer initiation.
** Data not recorded.

reefing cutters were subjected to thermal sterilization. On test, the two Central Technology units fired normally, the same amount of lanyard tension being required to initiate the hammer as was required with the control units. All time delays functioned within 0.2 second of the control units. The lines were cut cleanly. None of four Unidynamics reefing cutters fired, using the pre-compressed method of primer initiation. As stated above, the Unidynamics units were modified to accept the higher temperature G-11 primer; however, these primers require a larger firing force to activate them. When the Unidynamics cutters were further modified to accept the Central Technology primer activation method, the four units fired normally. Time delays functioned within 0.6 second of the control units. This is a larger time delay variation, but the time delay is much longer. Again the lines were cut cleanly. Thus, it appears that the method of using an external force to cock and fire a hammer against the primer is preferable, considering the greater force required to activate the high-temperature primers.

Two additional Central Technology cutters were subjected to both thermal sterilization and a ten day vacuum test. One cutter was of stainless steel and the other of aluminum construction. On test, the stainless steel cutter functioned normally, again cutting the line cleanly within the tension and time delay values noted above. However, the aluminum cutter mis-fired due to the hammer hanging up on the anodized aluminum firing housing. When this unit was modified to accept a stainless steel head and refired, the cutter functioned normally in all respects. Although this is only a one-unit sample, the use of an all stainless steel head and firing pin may be necessary, although the body of the reefing cutter can probably be made of aluminum for weight reduction. One result of vacuum exposure is to effectively remove the thin layer of grease present on all components, and unless the sliding friction of the respective surfaces is low, hanging up as occurred here can easily result.

Thus, the efficacy of using reefing cutters for sterilizable parachute retardation systems appears to be established.

V. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are reached as a result of the above-described tests and analyses:

(1) Silk was completely degraded in preliminary test and eliminated from further consideration.

(2) The effect of thermal sterilization on nylon is to seriously degrade this material and cause it to become markedly stiffer. Although Type 330 nylon exhibited less average degradation, break strength variations among the samples tested precluded further consideration of this type. Thus, it was concluded that nylon should be eliminated as a candidate material for the Mars entry parachute retardation system.

(3) Dacron is a promising candidate material for a sterilizable retardation system. Average strength losses of all material configurations resulting from both sterilization and vacuum exposures did not exceed 20 percent. Type 56 dacron appeared to be least affected by thermal sterilization (approximately 5 percent); Types 51 and 52 were equally affected (approximately 15 percent). Slight moisture desorption occurred due to thermal sterilization; additional moisture was added in chemical sterilization tending to increase the material strength properties. The effect of vacuum appears to indicate an initial increase in strength followed by a decrease with time in vacuum. This increase could be due to polymeric cross-linking with strength degradation following, but the result was not sufficiently severe to break any materials when subjected to sudden impact loads in vacuum. A correlation of weight variations with permeability also appears evident. No visible effects were observed (discoloration, stiffness, etc.) as a result of either sterilization or vacuum exposure.

(4) Nomex is also a promising candidate material for the Mars entry retardation system. Average strength losses of all material configurations resulting from both sterilization and vacuum exposures did not exceed 5 percent. However, rather large variations in break strength of the fabric occurred. This was evidently due to the weave as all weave forms were fabricated from the same merge number yarns. No visible effects due to environmental exposure were observed, and no weave forms were broken as a result of sudden impact loading in vacuum. Much larger weight variations occurred, however, in comparison to dacron; these variations appeared to correlate with permeability variations.

(5) Negligible effects due to folding and compacting, or twisting and compacting, were observed. However, an average strength degradation of approximately 10 percent occurred due to sewing.

(6) The force-time curve of pressure cartridges appears to be modified by thermal sterilization toward a decrease in the time to peak pressure and an increase in the pressure generated. Further, there appears to be no effect of vacuum on hermetically sealed pressure cartridges. The hermetic seals of two cartridges were intentionally punctured prior to vacuum, and after vacuum environment, one unit did not fire. Thus, the effect of a good hermetic seal is evident.

(7) Reefing cutters appear to be available which can withstand the sterilization and vacuum environments. The most reliable method of primer activation appears to be that of using a lanyard to cock and release the hammer rather than utilizing pre-compressed springs. Further, since the vacuum environment will cause vaporization of thin protective layers of grease, sliding members should be chosen that will not gall and cause possible mis-fire.

As a result of the foregoing work, the following recommendations are offered:

(1) An additional vacuum test or tests should be conducted for approximately 60 days duration to determine the strength degradation of dacron over a longer period of time.

(2) Dacron and nomex materials should be subjected to larger sudden applied loads in vacuum to determine the break point of the materials. This information can result in reduced parachute system weight.

(3) Dacron and nomex materials should be subjected to strength test measurements in vacuum to determine the maximum realizable strength in that environment.

(4) A complete parachute system of dacron and nomex should be fabricated and subjected to sterilization and at least 30 days of vacuum. The system should then be deployed, while still in the vacuum environment, on a rocket test vehicle. This will provide a proof test of the entire system, and will negate any material strength increase due to moisture re-absorption.

(5) Pressure generators and reefing cutters of the size required for the Mars entry retardation system should be designed and fabricated. A statistically significant quantity of these pyrotechnic devices should then be subjected to sterilization, simulated lift-off conditions, and vacuum to determine the reliability of operation.

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