NASA CR56942

fabric research laboratories inc

FRL®

N70-29942
(ACCESSION NUMBER)
(THRU) 1
76
(PAGES)
(CODE)
CR-66942
(NASA CR OR TMX OR AD NUMBER)
02
(CATEGORY)
FACILITY FORM 602

TESTING AND EVALUATION OF DACRON PARACHUTE ELEMENTS AFTER EXPOSURE TO ETHYLENE OXIDE AND SIMULATED PACKAGE LOADING AND HEAT CYCLE

NASA CR66942

TESTING AND EVALUATION OF DACRON PARACHUTE ELEMENTS AFTER EXPOSURE TO ETHYLENE OXIDE AND SIMULATED PACKAGE LOADING AND HEAT CYCLE

by J. Skelton, R. E. Sebring, and K. D. Cragan

Prepared under Contract No. NAS .-9587 by

FABRIC RESEARCH LABORATORIES, INC.
Dedham, Mass.

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TESTING AND EVALUATION OF DACRON PARACHUTE ELEMENTS AFTER EXPOSURE TO ETHYLENE OXIDE AND SIMULATED PACKAGE LOADING AND HEAT CYCLE

by J. Skelton, R. E. Sebring, and K. D. Cragan

SUMMARY

Dacron parachute components, and assemblies of these components were exposed to the various environments encountered in a sterilization procedure: ethylene oxide; heat cycle and pressure packing; and a sequential combination of these. After exposure the specimens were examined for dimensional stability, and tested for evidence of degradation, or other changes in important mechanical properties. It was shown that components made from heat-set Dacron were completely stable, and showed essentially no loss in strength after exposure to the various conditions, either separately or in combination. As a consequence of the dimensional stability the air permeability of the canopy fabric was not changed significantly. The various environmental exposures had the effect of relaxing stresses in the components and assemblies, with the result that some properties such as seam strength were enhanced. The only component tested that was not made from heat-stable Dacron, namely the riser webbing, showed poor dimensional stability, and marked evidence of degradation after heat cycling.

INTRODUCTION

The development of systems designed to land spacecraft on other planets of the solar system has established the need for suitable deceleration devices. Since all spacecraft destined for landing on extraterrestrial bodies must be sterilized to prevent contamination by earth organisms it is important that the materials used in the spacecraft deceleration system are compatible with the sterilization procedures, and do not suffer degradation which might impair their function. Current sterilization procedures use a combination of exposure to ethylene oxide and dry heat cycling. Previous studies (ref. 1) have shown that Dacron is a suitable candidate material for use in parachute deceleration systems, since it shows only small thermal degradation and has good dimensional stability. The effect of specific mission environment on Dacron fabric intended for the parachute canopy of a Mars landing system has also been described (ref. 2), and it was shown that the mechanical properties of this fabric were relatively insensitive to the various exposure conditions.

In addition to the sterilization procedures, the parachute system is also subjected to pressure packing in order to reduce its bulk, and it is necessary that the components can withstand this treatment without serious degradation. This report discusses the effects on Dacron parachute components of exposure to ethylene oxide, to simulated pressure packing and heat cycle, and to a succession of these environments. In order to permit a full evaluation for design purposes, the study was not limited to canopy fabric, but included also braid, tape and webbing used in parachute manufacture, together with seam samples and radial joint and suspension line assemblies. The materials were examined principally for strength degradation, breaking elongation changes and dimensional stability, but measurements were also made of the air permeability of the canopy fabric under various biaxial loading conditions. The results of the study provide the fundamental data required to determine control parameters for predicting the final size and strength of parachutes after exposure to the prelaunch environment.

TEST SPECIMENS

Test specimens were provided in accordance with drawings supplied by NASA Langley, numbered LC-153,830 through LC-153,840, copies of which are included in the appendix to this report. The specific designations of the drawings for the various test specimens are given below:

LC-153,830 Canopy Panel Strip Tensile Specimen, Fig Ia,Ib
LC-153,831 Canopy Panel Grab Specimen, Fig IIa
LC-153,832 Canopy Panel Grab Specimen, Fig IIb
LC-153,833 Suspension Line Specimen, Fig III
LC-153,834 Reinforcing Line Specimen, Fig IVa, IVb
LC-153,835 Canopy Air Permeability Specimen, Fig Va,Vb
LC-153,836 Canopy French Fell Seam Specimen, Fig VIa,VIb
LC-153,837 Canopy Radial Gore Seam Specimen, Fig VIIa,VIIb
LC-153,838 Canopy Gap-Hem Radial Tape Joint Specimen, Fig VIII
LC-153,839 Suspension Line Radial Tape Joint Specimen, Fig IX
LC-153,840 Riser Specimen, Fig X

The materials used in the fabrication of the test specimens are specified below:

(1) Canopy Fabric. Manufactured by Stern and Stern, and woven from 70 Denier, Type 55 Dacron yarn in a 2.0 oz/sq yd rip-stop pattern, quality 15586, with a minimum thread count of 96x101. The fabric has a minimum strip breaking load of 69.4 lbs in the warp direction and 68.2 lbs in the filling direction. The fabric is natural in color, and is heat-set to maintain dimensional stability within 1.5% after exposure to 350°F for 8 hours.

(2) Radial Tape for Gap Hem Reinforcement. Bally Ribbon Mills, Co. Pattern 1014 woven from 220 denier, type 52 high tenacity Dacron. The tape is plain weave with 232 warp ends and 24 picks per inch and is 3/4 inch wide, 0.027 inch thick and weighs 0.277 oz/yd. It has a minimum tensile strength of 585 lbs and a minimum breaking elongation of 28%. The yarn is heat-set at 350°F and the tape is subsequently heat-set at 315-350°F.

(3) Suspension Lines. Valrayco, Inc., Pattern 9004, braided from 220 denier, 4 turns per inch S twist, type 52 high tenacity Dacron, heat-set and stabilized to provide a residual shrinkage of less than 5% after exposure to 350°F for 30 minutes.

(4) Riser Webbing. Woven from Dacron to conform to MIL-W-25361A natural, Type III, Condition N.

(5) Stitching Thread for Canopy Components. Dacron, conforming to Federal Specification V-T-285b, Type I, Class 3, size F.

(6) Stitching Thread for Riser Components. Conforming to Federal Specification V-T-285b, Type I, Class 3, 6 cord.

(7) Buffer Cotton in Suspension Line Radial Tape Joint. Conforming to MIL-T-5661C, Type III, 3/4 inch wide.

(8) Buffer Cotton in Riser Component. Conforming to MIL-W-5665E, Type VIII, Class 1B.

All materials with the exception of items 7 and 8 were furnished by NASA Langley; items 7 and 8 were purchased by Fabric Research Laboratories from commercial suppliers.

The unsewn canopy fabric specimens, and the suspension line and reinforcing line specimens were prepared by FRL®. All other specimens were prepared by Pioneer Parachute, Company, Inc., Manchester, Connecticut, in conformity with the appropriate NASA Langley drawings and the sewing specifications contained in Exhibit E of the statement of work. Individual test specimens were marked and identified with a legend indicating specimen type and environmental exposure history. Tape and braid specimens were marked with pin tags; all other specimens were marked with ball point pen directly on the fabric. Tensile test specimens were marked at each end in order to maintain identification after specimen rupture. A typical specimen identification is:

VIa-1-B-3

where VIa-1 identifies the type of specimen according to the NASA drawings; B identifies the environmental exposure according to the scheme:

- A Control
- B Ethylene Oxide Exposure
- C Heat Cycle Exposure
- D Ethylene Oxide and Heat Cycle Exposure;

and the final numeral, 3, identifies the third replicate within the group.

All materials were stored in conditioned rooms at 21±1°C and 65±2%RH prior to fabrication and identification. After individual specimens were marked for identification they were placed in separately marked vapor-proof polyethylene envelopes, and thereafter stored in the envelopes in the conditioned room except for removal for environmental exposure or physical testing.

ENVIRONMENTAL EXPOSURE PROCEDURES

Ethylene Oxide Exposure

The experimental arrangement for the ethylene oxide environmental exposure is shown in Figure 1. The heat exchanger was a fifty foot length of 3/8 in. diameter thin-walled aluminum tubing, bent concertina-fashion, and wound with ceramic insulated electric resistance wire. The chamber was an existing stainless steel vacuum chamber adapted for the present use. The outside of the chamber was wound with a plastic-insulated low-temperature heating cable and covered with an insulating blanket. Temperature control within the chamber was achieved with a precision, pre-set mercury-in-glass thermostat operating a solid-state electronic controller. The maximum permissible gas temperature at the output

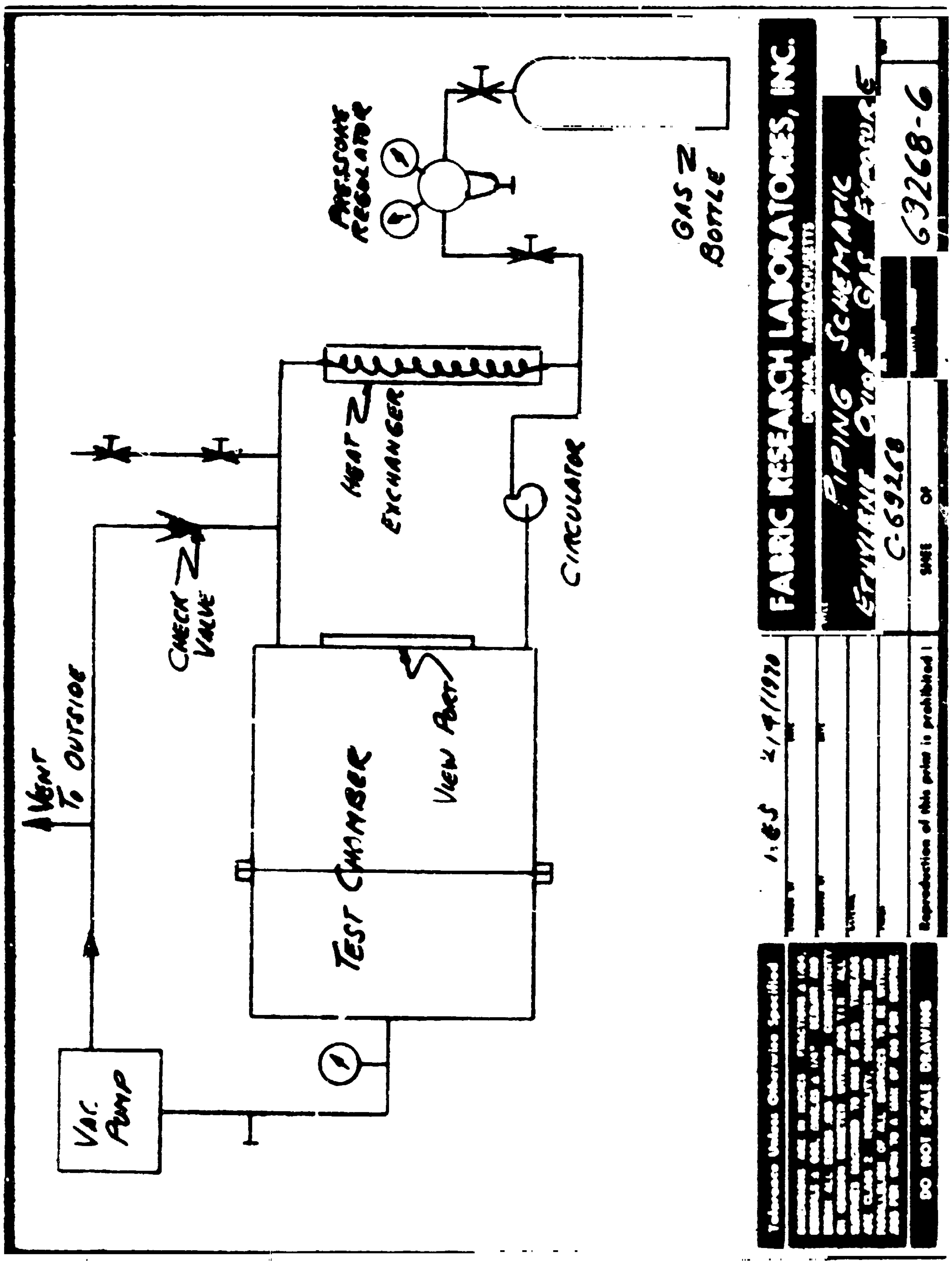


Figure 1 Experimental Arrangement for Ethylene Oxide Exposure

of the heat-exchanger was 55°C, guarded by a second pre-set thermostat, which was connected to the controller in such a way as to override the control action and turn off the heat input if the temperature limit was exceeded. The power supply to the heat exchanger and chamber warming cable was via a Variac, so that the rate of temperature change could be adjusted manually during the warm-up and cooling periods.

All the specimens scheduled for the ethylene oxide exposure were treated at the same time. The exposure procedure is described below:

(1) Specimens were removed from polyethylene protective envelopes, and piled loosely inside the test chamber. The chamber was situated in a conditioned laboratory, and conditions at the start of the exposure were 21±1°C, 65±2%RH.

(2) The chamber was closed, and the circulator and heaters were turned on. The temperature of the circulating air atmosphere inside the system was raised to 40°C in two hours.

(3) When the set point temperature was established, the vacuum pump was started, and the system was evacuated to 27 inches of mercury vacuum.

(4) A precalibrated amount of water was admitted to the system through a double valve airlock. The quantity of water was sufficient to establish a relative humidity of 75% after the chamber pressure was again raised to atmospheric pressure. The circulating pump was continuously operated during this time, circulating the low pressure, moist, warm air atmosphere. This humidity soak continued for one hour.

(5) Ethylene oxide gas mixture was admitted into the system from a bottled gas supply. Certified analysis by the gas supplier was 12.2% ethylene oxide, and the remainder Freon 12. The gas mixture was bled into the evacuated system through a needle valve. The gas was admitted slowly at the inlet side of the heat exchanger, so that the gas was warmed before reaching the chamber, and the chamber temperature was maintained at 40°C. Gas was bled in until the chamber was again at atmospheric pressure. A low pressure relief valve in the system prevented any possible excess pressure build-up by venting outdoors through the vacuum pump discharge line. The 12.2% ethylene oxide gas mixture at atmospheric pressure contains the specified decontaminating agent concentration of 500 ± 50 milligrams per liter.

(6) A constant temperature, constant pressure atmosphere of mixed gas was circulated through the exposure chamber for the scheduled 24 hour exposure time.

(7) At the end of the 24 hour period, the temperature level was reduced to ambient over a two hour time span.

(8) The chamber was evacuated with the vacuum pump, and the atmosphere was replaced with ambient air. This cycle was repeated three times to dispel all the ethylene oxide gas.

(9) The chamber was opened, and the specimens removed and replaced in their polyethylene envelopes for storage prior to testing or further environmental exposure.

Packing Load and Heat Cycle

The experimental arrangement for the packing load and heat cycle exposure is shown in Figure 2; it is based on a Custom Scientific Co. two-compartment environmental chamber, designed for use in conjunction with an Instron testing machine. One compartment is the specimen exposure chamber, which is installed in line with the Instron load cell and cross head. The second compartment contains an electric resistance heating element. A motor driven fan continuously circulates the chamber atmosphere between the two compartments.

In order to simulate pressure packing, test specimens were folded according to the NASA Langley drawings and placed between stainless steel platens; a stack of specimens and loading platens was installed in a compression cage inside the test chamber. The platens were ground to better than a 30 microinch finish, and were washed in ethyl alcohol and covered with a layer of Dacron canopy fabric before assembly of the stack. The compression cage was coupled to the Instron, which was set in the load cycle mode to provide a constant compressive load during the heat cycle. The areas of specimens between the platens and the applied tensile load were calculated to give a uniform compressive stress of 300 psi on the folded specimens. Three separate exposures were required to accommodate all the specimens for the exposure; however, to avoid possible cross-contamination, the specimens that had previously been exposed to ethylene oxide were included in loads. Each of the three packing loads and dry heat cycle exposures was programmed according to the following schedule:

(1) Specimens were removed from polyethylene protective envelopes, and folded in accordance with the drawing requirements.

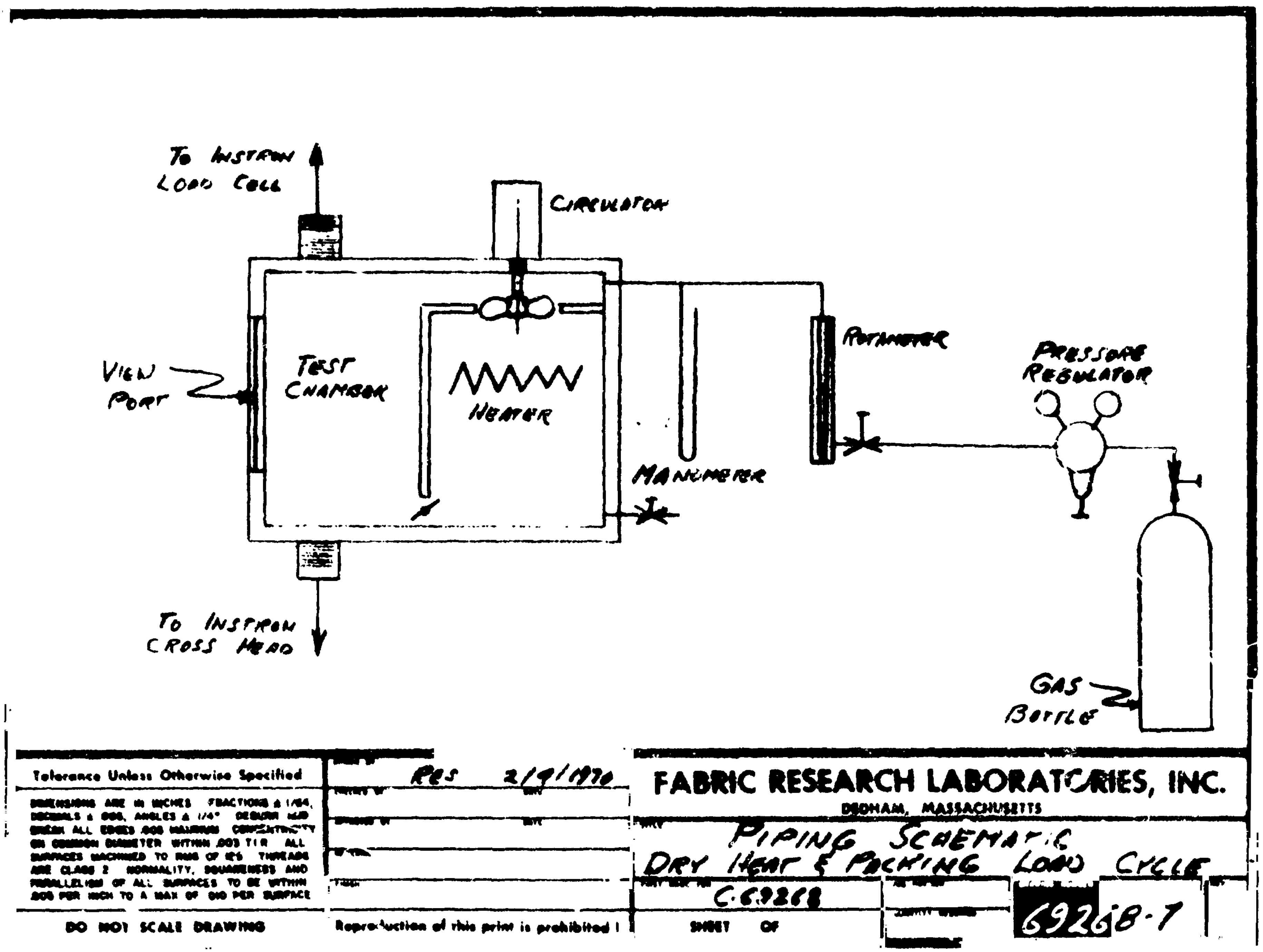


Figure 2 Experimental Arrangement for Heat and Pressure Packing Exposure

(2) The platens and specimens were arranged in a vertical stack in the compression cage inside the test chamber. The compression cage was linked to the load cell and the cross head of the Instron through sliding seals in the test chamber floor and ceiling. Atmosphere in the test chamber at the start of the exposure procedure was 21±1°C, and 65±2%RH.

(3) The chamber was closed, and flushed with several changes of dry nitrogen. A compressive load of 300 psi in the specimens was applied by the Instron, which was set for automatic cycling to maintain a constant pre-set load.

(4) The heating element power supply was set manually to provide a temperature rise rate of approximately 13°C per hour. Slow heating continued until the set point of 125°C was reached in approximately eight hours. During the heating period, the chamber was subjected to additional nitrogen gas flushing, to assure a chamber atmosphere with a minimum contamination of the nitrogen atmosphere from outgassing of heated material inside the chamber. Dimensional changes due to thermal expansion of the metal part of the compression cage and tension linkage which would have resulted in a relaxation of the specimen compression load were offset by the load cycle control of the test machine. When the pre-set temperature level was reached, the load remained essentially constant and required only intermittant control action.

(5) A condition of constant compressive load and constant temperature, with continuous circulation of the heated nitrogen gas, was maintained for 91 hours.

(6) At the conclusion of the constant temperature period, the heater controllers were set manually for a gradual cooling of approximately 13°C per hour. During this time the load application was relaxed to prevent overloading from contraction of the cooling metal parts.

(7) When the chamber temperature approached ambient temperature, the chamber atmosphere was flushed with room air at 21±1°C, 65±2%RH.

(8) The compression cage was removed from the chamber, and the specimens and pressure platens were removed from the cage. Specimens, still folded, were placed in polyethylene bags for storage until they could be examined for evidence of degradation and be subjected to the scheduled physical testing.

TEST PROCEDURES, RESULTS AND DISCUSSIONS

General

All testing was carried out in an atmospheric environment controlled at 21±1°C; 65±2%RH. All tensile testing was carried out using Instron tensile testers, and air permeability measurements were carried out using a Frazier Air Permeometer. All test machines were calibrated before use in accordance with the manufacturers standard procedures. Changes in fabric properties after environmental exposure are calculated as percentages of the control values, and are quoted to the nearest percent throughout.

All specimens were examined visually for damage and degradation after the various environmental exposures. With the exception of a few specimens in which the marking ink had run and caused local discoloration to the fabric and the platen, no evidence of deterioration was found; the specimens with the dispersed ink were not significantly different in their behavior from other specimens.

Tensile Tests and Dimensional Stability of Canopy Fabric

Thirty-two 10 in. x 1 1/4 in. strips with the long dimension parallel to the warp yarns, and eight 10 in. x 1 1/4 in. strips with the long direction parallel to the filling yarns were cut from the canopy fabric; particular care was taken that the same warp and filling yarns were not common to any of the specimens. Measurements under zero load indicated that the thread count of the fabric was approximately 95 ends per inch x 101 picks per inch. Accordingly the warp strips were ravelled down to 100 threads and the filling strips to 104 threads prior to final preparation of the test specimens. The strips were placed under a tensile load of 2.0 ± 0.1 lbs and the end and pick count was measured using a thread counter with a 1/2 in. aperture. The strips were then ravelled down to their final width of 1 inch; all warp specimens contained the same number of warp yarns (96), and all filling specimens the same number of filling yarns (100). All specimens were marked with a 3 in. gauge length under the tensile preload, and were further marked for identification prior to storage or testing.

End and pick counts of the various specimens under the 2 lbs preload are shown in Table I and are summarized in Table II.

TABLE I

END AND PICK COUNT OF CANOPY

FABRIC SPECIMENS UNDER 2 LBS PRELOAD

Specimen Identification	Ends/1/2 Inch	Picks/1/2 Inch
Ia-1-A - 1	48	50
2	48	50
3	48	50
4	48	50
5	48	50
6	48	50
7	48	50
8	48	50
Average	48	50
Ia-1-B - 1	48	50
2	48	51
3	48	50
4	48	50
5	48	50
6	48	50
7	49	50
8	48	50
Average	48	50
IIa-1-C - 1	49	50
2	48	50
3	48	50
4	48	50
5	48	50
6	48	50
7	48	50
8	48	50
Average	48	50
IIa-1-D - 1	48	51
2	48	50
3	48	50
4	48	50
5	48	50
6	48	50
7	48	50
8	48	50
Average	48	50
Ia-2-A - 1	47	52
2	46	51
3	46	51
4	46	52
5	47	51
6	47	51
7	47	51
8	47	51
Average	47	51

TABLE II

SUMMARY - END AND PICK COUNT OF CANOPY

FABRIC UNDER 2 LBS PRELOAD

Specimen Identification	Average Ends/Inch	Average Picks/Inch
Ia-1-A	96	100
Ia-1-B	96	100
IIa-1-C	96	100
IIa-1-D	96	100
Ia-2-A	94	102
Approximate measurement under zero tension	95	101

Under warp-way load the thread count is 96x100 and under filling-way load it is 94x102. Under warp way tension the warp yarns are extended slightly and the pick count falls; the end count is raised slightly since the specimen necks in a little because of crimp interchange. With filling tension these trends are reversed and the end count falls and the pick count rises.

The end and pick count of the B,C and D warp-way samples was measured under a 2.0 lbs preload after exposure to the various environments. Results of these measurements are shown in Table III, where they are compared with the pre-exposure values for the same specimens.

TABLE III

EFFECT OF VARIOUS ENVIRONMENTAL EXPOSURES

ON END AND PICK COUNT OF CANOPY FABRIC

Specimen Identification	Exposure Condition	Thread Count Before Exposure Ends/Inch x Picks/Inch	Thread Count After Exposure Ends/1/2 In. x Picks/1/2 In	Change on Exposure (%)
Ia-1-B-1			49x50	
2			48x49	
3	Ethylene Oxide		48x50	
4			48x50	
5			48x50	
Average		96x100	96x100	
IIa-1-C-1			50x50	
2	Heat and Pressure Packing		50x50	
3			48x50	
6			48x50	
7			48x50	
Average		96x100	97x100	(+1)x(0)
IIa-1-D-1	Ethylene Oxide + Heat and Pressure Packing		48x50	
2			48x51	
3			48x50	
4			48x51	
5			48x51	
Average		96x100	96x101	(0)x(+1)

The dimensional changes in the canopy fabric are very small for all exposure conditions. There is no detectable change in the fabric dimensions on exposure to ethylene oxide, a 1% shrinkage in the filling direction only on exposure to heat and pressure packing and a 1% shrinkage in the warp direction on exposure to ethylene oxide plus heat and pressure packing. Thus, the canopy fabric is stable within 1% for all exposure conditions.

Tensile tests on the various specimens were carried out using an Instron tensile tester in accordance with the requirements of ASTM D-1682-64 for ravel strip specimens. The specimens were held in flat, rubber-lined jaws, and a jaw speed of 2 inches/minute was used. Results are given in Table IV for the breaking load of the variously exposed specimens and in Table V for the breaking elongations of the control specimens.

The control warp specimens have an average breaking load of 69.8 lbs/inch and an average breaking elongation of 33.7%; the filling specimens have an average breaking load of 74.5 lbs/inch and an average breaking elongation of 39.5%. The higher breaking load in the filling direction is partially a result of the greater number of filling threads per inch; the higher breaking elongation in the filling direction is probably caused by the somewhat greater crimp in the filling yarns. This pattern of behavior is typical of fabrics heat-set under predominately warp-way tension.

The breaking load of warp specimens exposed to the ethylene oxide and to ethylene oxide heat and pressure packing are essentially the same as the warp control specimens. The average breaking load for the warp specimens exposed to heat and pressure packing alone is 7% less than the average for the control specimens, mainly as a consequence of one test result for specimen IIa-1-C-3 which is significantly less than any other result. Examination of the test specimen showed no obvious reason for this result, and it must be accepted as real. Thus, while the pressure packing usually has little or no effect on the strength of the canopy fabric, it can lead to some degradation under certain indefinite circumstances.

Grab Tests on Canopy Fabric

Grab tests were carried out using an Instron tester on bias specimens of canopy fabric in accordance with the appropriate section of ASTM-D-1682-64. The specimens were held in 2 in. x 1 1/2 in. flat, rubber-lined jaws and a gauge length of 3 inches and a jaw speed of 2 inches/minute were used. The breaking loads of specimens exposed to various environments are shown in Table VI.

TABLE IV

EFFECT OF VARIOUS ENVIRONMENTAL EXPOSURES ON

THE BREAKING LOAD OF CANOPY FABRIC

Specimen Identification	Exposure Condition	Breaking Load lbs/inch	Change On Exposure (%)
Ia-1-A-1		69.0	
2		70.0	
3	Control	69.0	
4		70.8	
5		70.0	
Average		69.8	
Ia-1-B-1		68.5	
2		70.5 JB	
3	Ethylene Oxide	69.2	
4		69.0	
5		70.3	
Average		69.5	0
IIa-1-C-1		64.7	
2		66.0	
3	Heat and Pressure	57.3	
6	Packing	66.0	
7		71.2	
Average		65.0	-7
IIa-1-D-1	Ethylene Oxide +	69.7	
2	Heat and Pressure	69.0	
3	Packing	68.5	
4		69.0	
5		68.9	
Average		69.0	0
Ia-2-A-1		75.0	
2		75.1	
3	Control	76.2	
4		72.4	
5		74.5	
Average		74.5	

JB - Jaw Break

TABLE V

BREAKING ELONGATION OF CONTROL CANOPY FABRIC

Specimen Identification	Breaking Elongation (%)
Ia-1-A-1	33.5
2	33.5
3	34.4
4	33.5
5	33.7
Average	33.7
Ia-2-A-1	39.3
2	43.2
3	41.0
4	36.7
5	37.5
Average	39.5

TABLE VI

EFFECT OF VARIOUS ENVIRONMENTAL EXPOSURES ON THE

GRAB BREAKING LOAD OF BIAS SPECIMENS OF CANOPY FABRIC

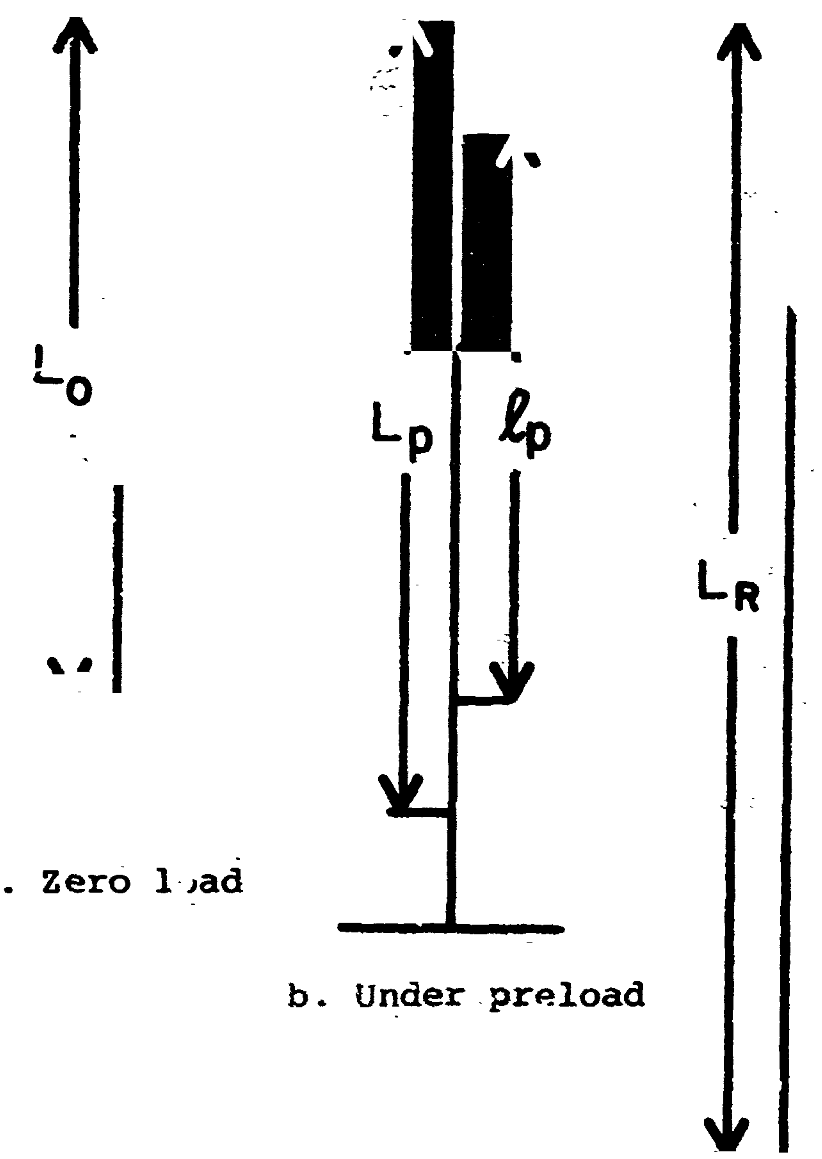
Specimen Identification	Exposure Condition	Breaking Load lbs	Change On Exposure (%)
Ib-A-1		100.0	
2		94.0	
3	Control	101.5	
4		100.0	
5		98.5	
Average		98.7	
Ib-B-1		124.3	
2		129.6	
3	Ethylene Oxide	120.0	
4		121.8	
5		111.4	
Average		121.5	+23
IIb-C-4		126.2	
5		120.0	
6	Heat and Pressure	124.0	
7	Packing	123.8	
8		117.8	
Average		122.4	+24
IIb-D-1	Ethylene Oxide	117.5	
2	+ Heat and Pres-	116.8	
3	sure Packing	122.4	
4		107.2	
5		126.8	
Average		118.1	+20

The grab breaking load is increased over the control for all environmental exposures. The breaking load in a grab test specimen is determined by a combination of yarn strength and the magnitude of the maximum shear deformation that the fabric can sustain. Since the strip strength of the canopy fabric is essentially unchanged by the various exposures, the shear behavior is the controlling influence in this case. The environmental exposures have in common a considerable time at elevated temperature, which usually has the effect of relaxing inter-yarn forces and lowering the shear resistance of fabrics woven from thermoplastic fibers, thus permitting greater deformation under a given shear stress. This allows the yarns to align themselves more nearly with the direction of principal stress in the fabric and thus to bear more load at rupture. The general level of the breaking load in the bias grab test is greater than the strip breaking load since more yarns are intersected by the front edge of the jaw faces in the former case than in the latter.

Tensile Tests and Dimensional Stability of Braid

Tensile tests were carried out on specimens of braid using the Instron tensile tester. The specimens were held in 2 inch diameter capstan jaws with 10 inches between jaw centers, and a jaw speed of 2 inch/minute was used. As directed on the NASA drawing the specimens were wrapped a total of 2 1/2 turns around the capstan grips, in an effort to prevent slippage. The nature of capstan grips are such that relative movement takes place between the specimen and the drum surface, and in the case of 2 1/2 wraps, between one turn of braid and the second turn. This relative movement takes place in an intermittant manner, which superimposes a sawtooth characteristic on the load-elongation curve. This stick-slip behavior was much more pronounced with 2 1/2 turns than with the customarily used 1 1/2 turns, and it is recommended strongly that a stipulation of minimum turns be omitted from future test instructions.

After mounting, a 6.0 inch gauge length was marked in the center of the specimen with the braid just taut, and a photograph was taken of the marked specimen; this gauge length served as the reference for elongation measurements. The specimen was then extended and at a recorded load of 62 lbs the crosshead was stopped and a second gauge length of 2.0 inches was marked as the load decayed to 60 lbs; the second gauge length served as the reference for dimensional stability measurements. A second photograph was taken and the specimens were then tested to rupture (control specimens) or unloaded, removed and stored for subsequent environmental exposure and testing. As the specimens approached rupture, a further sequence of photographs were taken at selected increments of load in order to determine the breaking elongation. Elongation measurements were made on the projected image of the photographic record. The nomenclature used in these measurements is shown in Figure 3.



a. Zero load

b. Under preload

c. Immediately before rupture

Figure 3 Nomenclature for Breaking Elongation and Dimensional Stability Measurements

The 6.0 inch gauge length is denoted by L_o at zero load, and L_r at rupture; the breaking elongation is given by:

$$\text{Breaking Elongation} = [(L_r-L_o)/L_o]\times 100\%.$$

The dimensional stability after environmental exposure was found from direct measurements of the 2.0 inch gauge length under the preload; this length is denoted by ℓ_p.

Results for the breaking load for the braids exposed to various environmental conditions are shown in Table VII, for the breaking elongation of certain specimens in Table VIII and for dimensional stability in Table IX.

The breaking load of the braid is very slightly increased as a result of the various environmental exposures and the marked 2.00 inch gauge length also increased slightly on exposure in some specimens. In no case, however, are the dimensions or the mechanical performance characteristics affected significantly.

Tensile Tests and Dimensional Stability of Seam Reinforcing Tape

Tensile tests were carried out on specimens of tape using the Instron tensile tester. The specimens were held on 2 inch diameter capstan jaws with 10 inches between jaw centers and a jaw speed of 2 inches per minute was used. As for the braids, 2 1/2 turns were taken round the capstan grips, in accord with the NASA drawings. The stick-slip behavior reported for the braids was also found, greatly enhanced, in the tape tests. The tapes are more susceptible than the braids since subsequent turns of tape overlay earlier turns rather than lying side by side as in the braid tests, and the problems associated with relative motion are magnified.

TABLE VII

EFFECT OF VARIOUS ENVIRONMENTAL EXPOSURES ON THE BREAKING LOAD OF BRAID

Specimen Identification	Exposure Condition	Breaking Load lbs	Change On Exposure (%)
III-A-1		704	
2		710	
3	Control	710	
4		712	
5		717	
Average		711	
III-B-2		710	
3		730	
4	Ethylene Oxide	723	
5		710	
6		720	
Average		719	+1
III-D-1	Ethylene Oxide	727	
2	+ Heat and Pressure	720	
3	Packing	718	
4		720	
5		721	
Average		721	+1

TABLE VIII

BREAKING ELONGATION OF CONTROL BRAID

Specimen Identification	Exposure Condition	L_o(in)[1]	L_r(in)[1]	Breaking Elongation (%)
II-A-1		4.50	6.00	25.0
2		4.45	5.95	25.2
3	Control	4.45	5.95	25.2
4		4.43	5.93	25.3
5		4.20	5.65	25.7
Average				25.3

1 Measured on film reader

TABLE IX

EFFECT OF VARIOUS ENVIRONMENTAL EXPOSURES ON THE

DIMENSIONAL STABILITY OF BRAID

Specimen Identification	Exposure Condition	ℓ_p*	Change On Exposure (%)
III-A-1		2.00	
2		2.00	
3	Control	2.00	
4		2.00	
5		2.00	
Average		2.00	
III-B-2		2.00	
3		2.00	
4	Ethylene Oxide	2.07	
5		2.05	
6		2.06	
Average		2.04	+2
III-D-1		2.00	
2	Ethylene Oxide	2.00	
3	+ Heat and Pres-	2.03	
4	sure Packing	2.03	
5		2.04	
Average		2.02	+1

* Measured on braid under 60 lbs preload

After mounting, a 6.0 inch gauge length was marked in the center of the specimen with the tape just taut, and a photograph was taken of the marked specimen. The specimen was then extended, and at a recorded load of 57 lbs the crosshead was stopped and the warp count was measured as the load decayed to 55 lbs using a thread counter with a 1/2 inch aperture. The specimen was then extended to rupture (control specimens) or unloaded, removed and stored for subsequent environmental exposure and testing. As the specimens approached rupture, a sequence of photographs was taken to determine the breaking elongation in the same way as was previously described for the braid. Results for the breaking load for the tapes exposed to various environmental conditions are shown in Table X, for the breaking elongation of the control tapes in Table XI and for the dimensional stability in Table XII.

The breaking load is unchanged for the Ethylene Oxide exposure and for the Ethylene Oxide + Heat and Pressure Packing exposure. Several specimens showed no change in the Heat + Pressure Packing exposure but two specimens, Nos. 4 and 5, had significantly lower breaking loads. This behavior is very similar to that found for the breaking load of the canopy fabric, and again it must be concluded that, while pressure packing usually has little or no effect on the strength of the tape it can lead to some degradation under certain indefinite circumstances.

The warp ends per inch decrease slightly after exposure to Ethylene Oxide and considerably after Heat and Pressure Packing. The decrease in the latter case is caused by the increased width of the tape under the compressive load. Presumably the high temperature condition in the ethylene oxide exposure relaxes and stabilizies the structure somewhat and subsequent pressure packing in exposure condition D does not further change the structure. Since these dimensional changes are width-way they do not significantly affect the mechanical performance of the tape, which is a predominately warp yarn structure.

TABLE X

EFFECT OF VARIOUS ENVIRONMENTAL EXPOSURES ON THE

BREAKING LOAD OF TAPE

Specimen Identification	Exposure Condition	Breaking Load (lbs)	Change On Exposure (%)
IVa-A-1		630	
2		627	
3	Control	623	
5		619	
6		630	
Average		626	
IVa-B-1		625	
2		625	
3	Ethylene Oxide	628	
4		624	
5		626	
Average		625	0
IVb-C-1		625	
2	Heat and Pressure Packing	625	
3		625	
4		595	
5		570	
Average		608	-2
IVb-D-1		640	
2	Ethylene Oxide + Heat and Pressure Packing	628	
3		621	
4		630	
5		617	
Average		627	0

TABLE XI

BREAKING ELONGATION OF CONTROL TAPE

Specimen Identification	Exposure Condition	L_o(in)[1]	L_r(in)[1]	Breaking Elongation (%)
IVa-A-1		4.84	6.66	37.6
2		4.75	6.56	38.1
3	Control	4.59	6.25	36.2
5		4.63	6.31	36.3
6		4.63	6.31	36.3
Average				36.9

1 Measured on film reaoer

TABLE XII

EFFECT OF VARIOUS ENVIRONMENTAL EXPOSURES ON THE

DIMENSIONAL STABILITY OF TAPE

Specimen Identification	Exposure Condition	Ends/1/2 In.	Ends/In.	Change On Exposure (%)
IVa-A-1		84		
2		86		
3	Control	82		
5		84		
6		84		
Average		84	168	
IVa-B-1		80		
2		84		
3	Ethylene Oxide	82		
4		80		
5		80		
Average		81	162	-4
IVb-C-1		76		
2		76		
3	Heat and Pressure	78		
4	Packing	78		
5		78		
Average		77	154	-8
IVb-D-1		82		
2	Ethylene Oxide	84		
3	+ Heat and Pres-	78		
4	sure Packing	80		
5		80		
Average		81	162	-4

Air Permeability and Dimensional Stability of Canopy Fabric Under Biaxial Loading

The basic air permeability specimens were 10 inch x 10 inch square, and all the environmental exposures were carried out with the specimens in this form. In order to apply biaxial loads to the specimens, tails of neoprene coated polyester fabric 4 1/2 inches wide and 10 3/4 inches long were sewn to the center of each side of the square, to form a composite cruciform specimen. The biaxial loading was carried out using an available loading device in which the free ends of the tails are gripped in small capstan-type jaws attached to pistons actuated by four identical pneumatic cylinders. The entire piston assembly is designed to fit on the Frazier Air Permeometer and when pressure is applied to the cylinders an area of uniform biaxial stress is set up in the center of the original square fabric specimen. This area is about 3 inches square and sufficient to cover the orifice of the Permeometer. A photograph of the biaxial stress assembly is shown in Figure 4 and a close up of a fabric specimen under biaxial stress is shown in Figure 5.

Following mounting, the ends and picks per inch in the center of the specimen were measured using a pick counter with a 1 inch aperture, with the specimen under zero biaxial load. Pressure was then applied to the cylinders to give successively tensile loads of 5, 15 and 25 lbs/inch in each direction of the fabric, and the end and pick count was remeasured, and the air permeability was found at each load level; the air permeability was measured in accordance with the requirements of ASTM-D-737-67. Results for the end and pick counts are given in Table XIII and for the air permeability in Table XIV.

The information contained in Table XIII is summarized in Figure 6. All the specimens exposed to the various environments clearly follow the same trend of decreasing threads per inch under increasing biaxial load. The control specimens shows slightly different behaviors at low load levels, having rather more extension in the warp direction than in the filling direction. While the detailed explanation for this difference is not known, it seems probable that it is another manifestation of slight fabric relaxation during the long dwell time at elevated temperature common to all the exposure conditions.

The air permeability measurements are summarized in Figure 7. All materials show an increase in air permeability as the biaxial load increases, since the extension of the fabric increases the size of the inter-yarn interstices. All test results, except those for the fabric in the D condition at maximum load, form a self-consistent set, with air permeability increasing in order D,C,A,B; the difference between the various fabrics is very small, however, as might be expected from the fact that only insignificant dimensional changes are found in the fabrics.

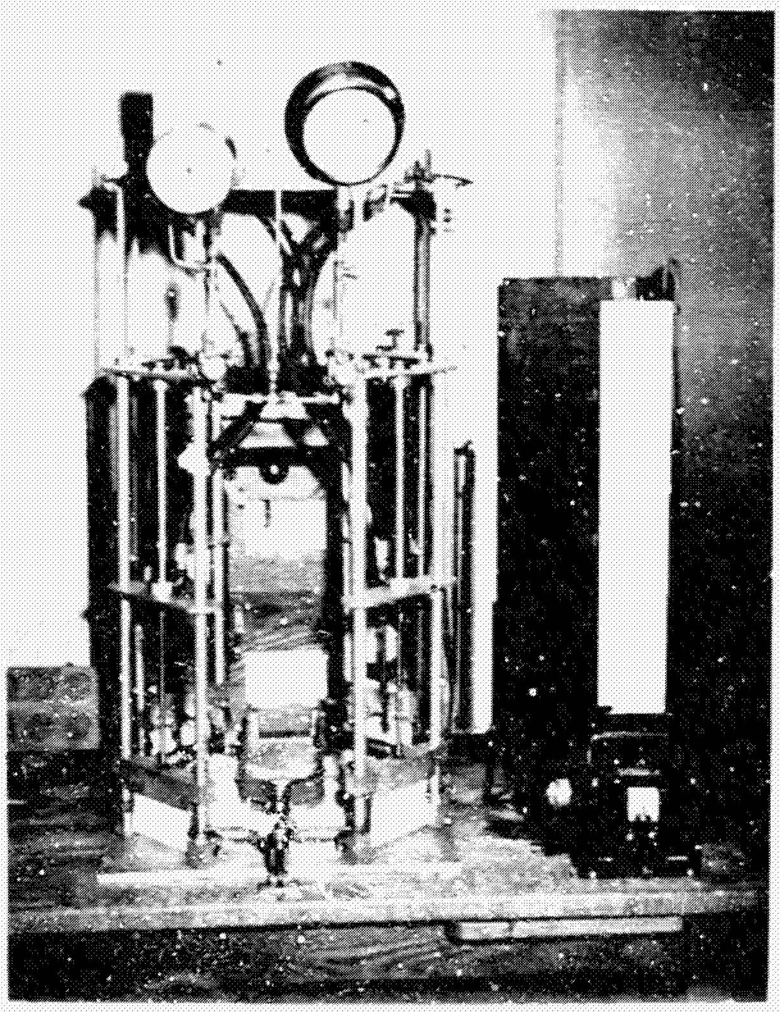


Figure 4. Overall View of Biaxial Loading Device

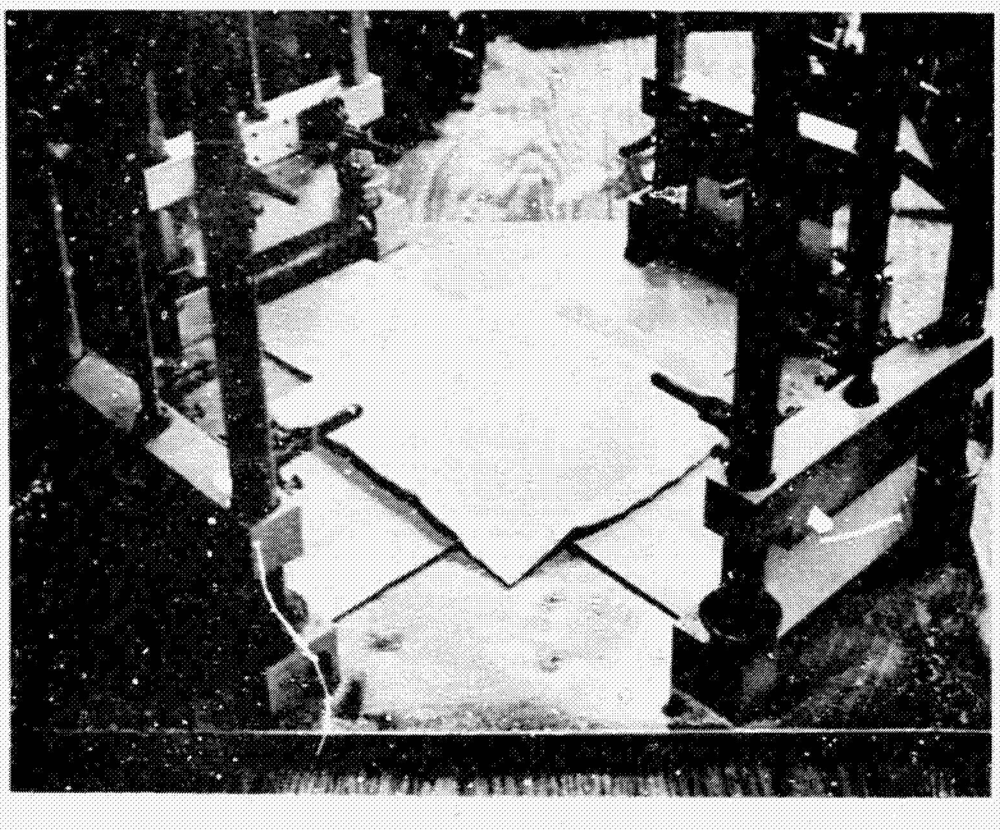


Figure 5. Close Up of Specimen Mounted on Biaxial Loading Device

TABLE XIII

EFFECT OF VARIOUS ENVIRONMENTAL EXPOSURES ON THE

DIMENSIONAL STABILITY OF CANOPY FABRIC

UNDER BIAXIAL LOAD

Exposure Condition	Biaxial Load (lbs/inch)	Specimen Identification	Ends/Inch x Picks/Inch	Change On Exposure (%)
Control	0	Va-A-1	93 x 100	
		3	95 x 100	
		4	94 x 100	
		5	93 x 101	
		6	94 x 100	
		Average	94 x 100	
	5	Va-A-1	93 x 94	
		3	95 x 95	
		4	94 x 94	
		5	96 x 98	
		6	92 x 100	
		Average	94 x 96	
	15	Va-A-1	93 x 90	
		3	93 x 95	
		4	94 x 94	
		5	96 x 96	
		6	92 x 100	
		Average	94 x 95	
	25	Va-A-1	93 x 85	
		3	83 x 95	
		4	87 x 91	
		5	93 x 88	
		6	87 x 94	
		Average	89 x 91	
Ethylene Oxide	0	Va-B-1	95 x 100	
		3	96 x 100	
		4	95 x 100	
		5	96 x 100	
		6	95 x 101	
		Average	95 x 100	(+1)x(0)
	5	Va-B-1	92 x 97	
		3	91 x 100	
		4	90 x 100	
		5	93 x 100	
		6	95 x 100	
		Average	92 x 99	(-2)x(-3)

TABLE XII. (Cont)

EFFECT OF VARIOUS ENVIRONMENTAL EXPOSURES ON THE
DIMENSIONAL STABILITY OF CANOPY FABRIC
UNDER BIAXIAL LOAD

Exposure Condition	Biaxial Load (lbs/inch)	Specimen Identification	Ends/Inch x Picks/Inch	Change On Exposure (%)
	15	Va-B-1	88 x 94	
		3	91 x 97	
		4	90 x 97	
		5	91 x 94	
		6	92 x 98	
		Average	90 x 96	(-4)x(+1)
	25	Va-B-1	85 x 92	
		3	84 x 92	
		4	85 x 94	
		5	88 x 94	
		6	88 x 93	
		Average	86 x 93	(-3)x(-2)
Heat and Pressure Packing	0	Vb-C-1	96 x 102	
		2	96 x 102	
		3	96 x 102	
		4	96 x 102	
		5	96 x 100	
		Average	96 x 102	(+2)x(+2)
	5	Vb-C-1	93 x 96	
		2	96 x 102	
		3	93 x 102	
		4	96 x 99	
		5	96 x 97	
		Average	95 x 99	(+1)x(+3)
	15	Vb-C-1	91 x 96	
		2	91 x 99	
		3	91 x 96	
		4	93 x 96	
		5	91 x 94	
		Average	91 x 96	(-3)x(+1)
	25	Vb-C-1	89 x 93	
		2	89 x 96	
		3	86 x 96	
		4	86 x 96	
		5	89 x 94	
		Average	88 x 95	(-1)x(+4)

TABLE XIII (Cont)

EFFECT OF VARIOUS ENVIRONMENTAL EXPOSURES ON THE

DIMENSIONAL STABILITY OF CANOPY FABRIC

UNDER BIAXIAL LOAD

Exposure Condition	Biaxial Load (lbs/inch)	Specimen Identification		Ends/Inch x Picks/Inch	Change On Exposure (%)
Ethylene Oxide + Heat and Pressure Packing	0	Vb-D-1		96 x 103	
		2		94 x 103	
		3		96 x 103	
		4		95 x 101	
		5		96 x 102	
			Average	96 x 102	(+2) x (+2)
	5	Vb-D-1		93 x 103	
		2		92 x 100	
		3		91 x 99	
		4		96 x 98	
		5		93 x 99	
			Average	93 x 100	(-1) x (+4)
	15	Vb-D-1		93 x 97	
		2		89 x 100	
		3		88 x 99	
		4		94 x 98	
		5		91 x 96	
			Average	91 x 98	(-3) x (+3)
	25	Vb-D-1		91 x 94	
		2		87 x 97	
		3		86 x 96	
		4		91 x 93	
		5		86 x 94	
			Average	88 x 95	(-1) x (+4)

TABLE XIV

EFFECT OF VARIOUS ENVIRONMENTAL EXPOSURES ON THE

AIR PERMEABILITY OF CANOPY FABRIC

(UNDER BIAXIAL LOAD)

Exposure Condition	Biaxial Load (lbs/inch)	Specimen Identification	Air Permeability (cu ft/min/sq ft)	Change On Exposure (%)
Control	5	Va-A-1	192	
		3	186	
		4	193	
		5	200	
		6	224	
		Average	199	
	15	Va-A-1	232	
		3	230	
		4	236	
		5	238	
		6	263	
		Average	240	
	25	Va-A-1	304	
		3	297	
		4	315	
		5	311	
		6	335	
		Average	312	
Ethylene Oxide	5	Va-B-1	207	
		3	196	
		4	213	
		5	201	
		6	227	
		Average	209	+5
	15	Va-B-1	258	
		3	243	
		4	254	
		5	244	
		6	268	
		Average	253	+5
	25	Va-B-1	323	
		3	320	
		4	327	
		5	315	
		6	335	
		Average	324	+4

TABLE XIV (Cont)

EFFECT OF VARIOUS ENVIRONMENTAL EXPOSURES ON THE

AIR PERMEABILITY OF CANOPY FABRIC

UNDER BIAXIAL LOAD

Exposure Condition	Biaxial Load (lbs/inch	Specimen Identification	Air Permeability (cu ft/min/sq ft)	Change On Exposure (%)
Heat and Pressure Packing	5	Vb-C-1	209	
		2	188	
		3	171	
		4	188	
		5	190	
		Average	190	-5
	15	Vb-C-1	248	
		2	244	
		3	213	
		4	236	
		5	232	
		Average	235	-2
	25	Vb-C-1	321	
		2	314	
		3	278	
		4	310	
		5	298	
		Average	305	-2
Ethylene Oxide + Heat and Pressure Packing	5	Vb-D-1	216	
		2	188	
		3	211	
		4	179	
		5	173	
		Average	194	-2
	15	Vb-D-1	268	
		2	225	
		3	241	
		4	221	
		5	230	
		Average	238	0
	25	Vb-D-1	332	
		2	293	
		3	310	
		4	292	
		5	285	
		Average	302	-3

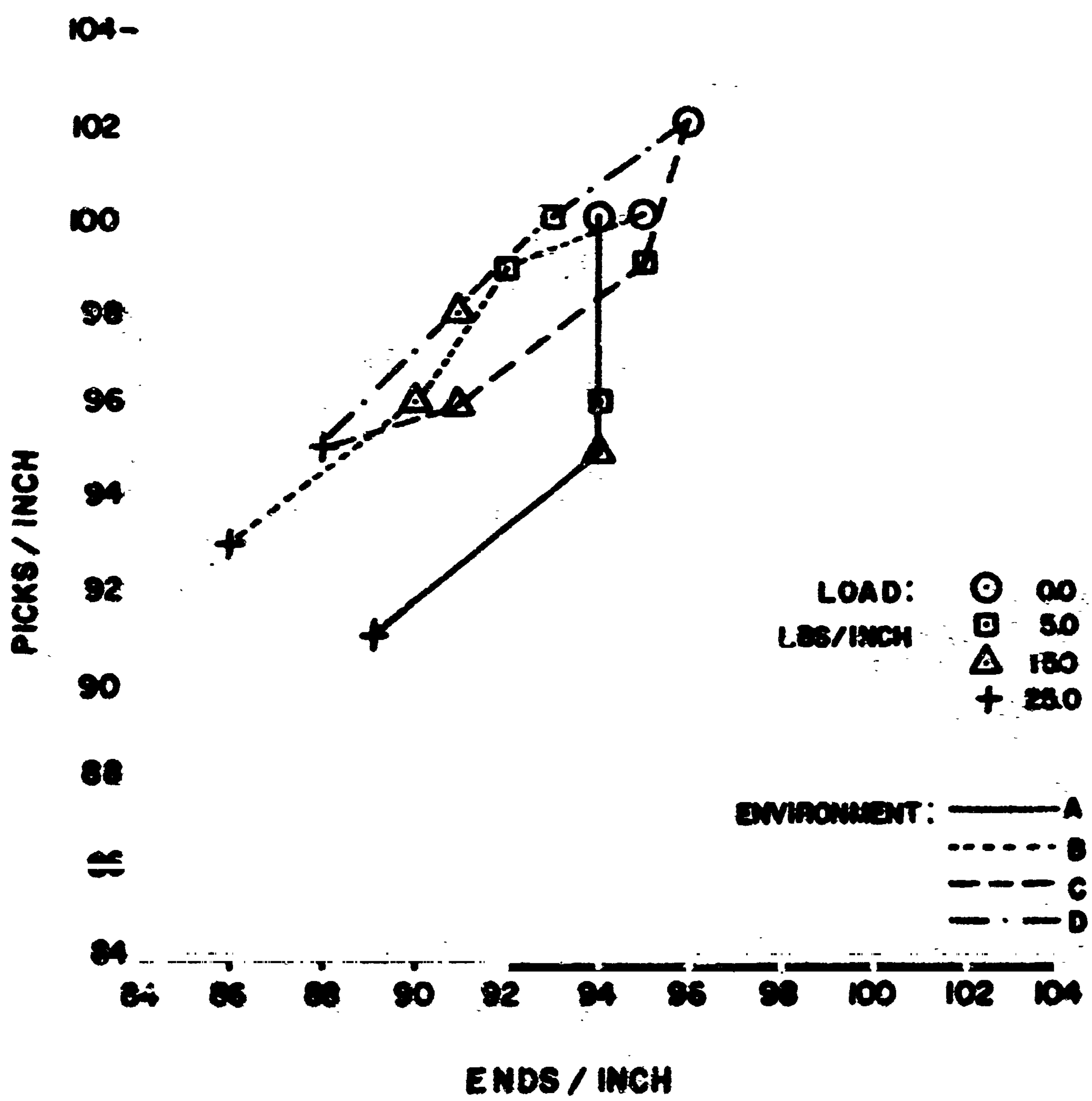


Figure 6. Variation of Canopy Fabric Construction with Biaxial Load

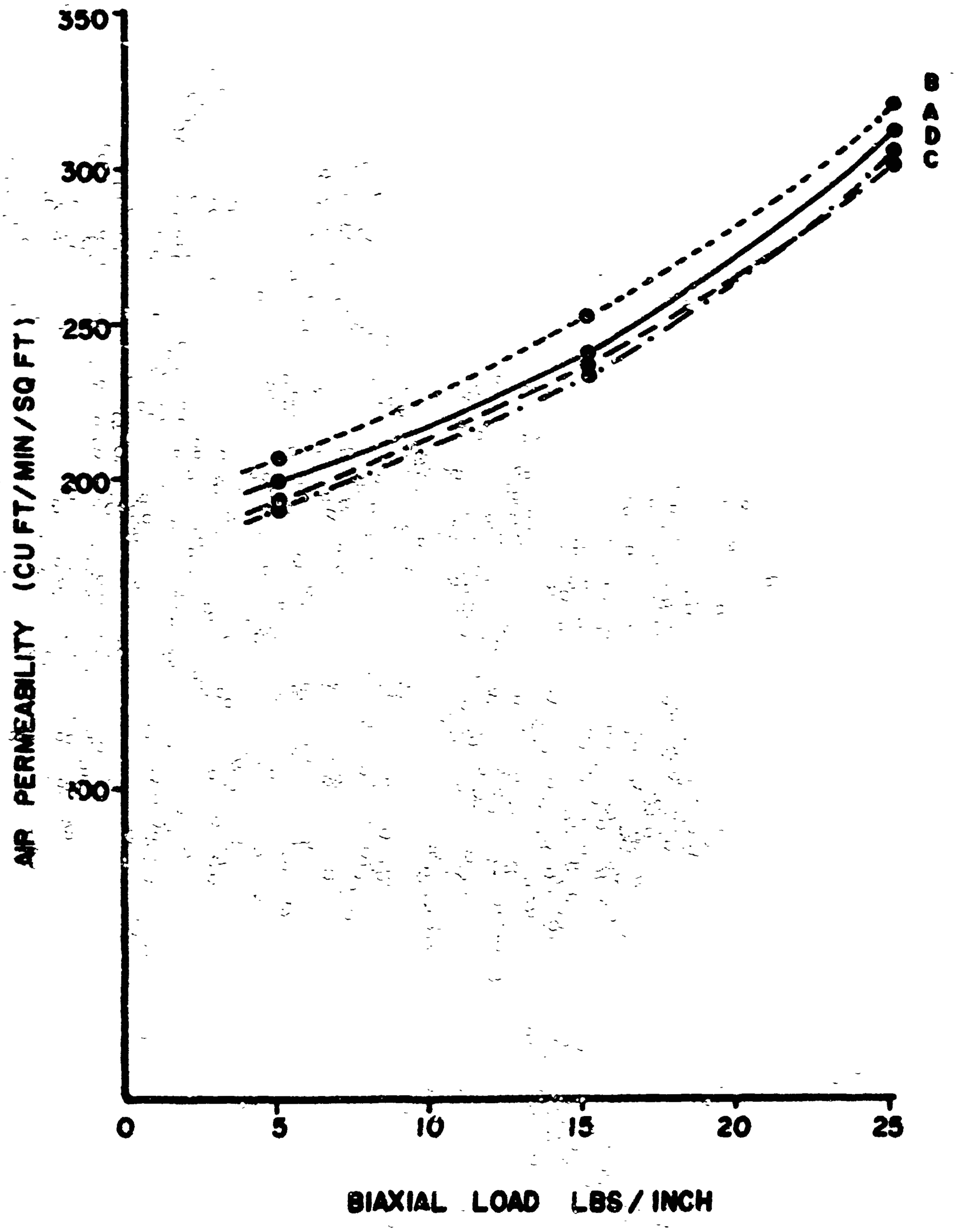


Figure 7. Variation of Air Permeability of Canopy Fabric with Biaxial Load

Seam Strength and Dimensional Stability of Canopy French Fell Seams

Prior to environmental exposure, the seams of all specimens were marked with a 2.00 inch gauge length under a 5.0 $\pm$ 0.10 lbs preload. The preload was applied by deadweight loading, with one end of the seam clamped in the Instron upper jaw and the weight of the freely suspended lower jaw increased to 5.0 lbs. After environmental exposure the gauge length was remeasured under the same load conditions. Seam strength tests were carried out on an Instron tensile tester. The specimens were gripped in 2 in. x 2 in. flat, rubber lined jaws, with a three inch separation between the jaws, the overall elongation of the seam specimens at rupture was obtained directly from the jaw position at rupture. Results for the seam strength of the specimens exposed to various environmental conditions are shown in Table XV, for the breaking elongation of the control seam specimens in Table XVI and for the dimensional stability of the seams in Table XVII.

The strength of the seam perpendicular to the warp yarns is not affected by the ethylene oxide alone but the heat and pressure packing, either alone or in conjunction with the ethylene oxide treatment, increases the seam strength considerably. For seams in the bias direction the trend is different; an increase of 2.7% is found after ethylene oxide exposure, but for treatments involving heat and pressure packing the increase is much less; the mechanism of these changes is not clear.

The seams shrink a little on exposure to ethylene oxide, and extend slightly on exposures involving pressure packing; the increase is probably caused by the comressive load on the specimen under these conditions.

The overall seam efficiency for specimens with seams perpendicular to the warp yarns can be calculated from these results and those for the ravel strip specimens. An average strip strength is 70 lbs, and for the perpendicular seam specimens 54 lbs. This gives a seam efficiency of approximately 77% for the specimens. The complexity of the geometrical arrangements in the various tests preclude a similar calculation for the bias seams; however, as a consequence of the greater number of yarns crossing a unit length of seam the bias seam strength per inch is higher than that of the perpendicular seams.

TABLE XV

EFFECT OF VARIOUS ENVIRONMENTAL EXPOSURES ON THE

STRENGTH OF CANOPY FRENCH FELL SEAMS

Seam Perpendicular to Warp Yarns

Specimen Identification	Exposure Condition	Seam Strength (lbs/inch)	Change On Exposure (%)
VIa-1-A-1		50.0	
2		55.4	
3	Control	53.0	
4		53.[illegible]	
5		51.[illegible]	
Average		52.7	
VIa-1-B-1		55.8	
2		50.0	
3	Ethylene Oxide	56.7	
4		49.0	
5		52.3	
Average		52.8	0
VIb-1-C-1		53.7	
2	Heat and Pressure Packing	53.7	
3		57.2	
4		56.0	
5		55.0	
Average		55.1	+5
VIb-1-D-1		59.8	
2	Ethylene Oxide + Heat and Pressure Packing	57.5	
3		55.2	
4		53.0	
5		51.7	
Average		55.4	+5

TABLE XV (Cont)

EFFECT OF VARIOUS ENVIRONMENTAL EXPOSURES ON THE

STRENGTH OF CANOPY FRENCH FELL SEAMS

Bias Seams

Specimen Identification	Exposure Condition	Seam Strength (lbs/inch)	Change On Exposure (%)
VIa-2-A-1		64.3	
2		65.0	
3	Control	61.8	
4		59.6	
5		69.0	
Average		63.9	
VIa-2-B-1		65.6	
2		65.5	
3	Ethylene Oxide	67.0	
4		65.8	
5		64.0	
Average		65.6	+3
VIb-2-C-1		68.2	
2	Heat and Pressure	65.0	
3	Packing	68.0	
4		62.0	
5		59.3	
Average		64.5	+1
VIb-2-D-1		60.8	
2	Ethylene Oxide +	58.0	
3	Heat and Pressure	64.0	
4	Packing	70.4	
5		68.5	
Average		64.3	+1

TABLE XVI

BREAKING ELONGATION OF CONTROL SPECIMENS OF

CANOPY FRENCH FELL SEAMS

Specimen Identification	Seam Direction	Specimen Elongation (%)
VIa-1-A-1		25.8
2	Perpendicular	34.7
3	to	32.7
4	Warp Yarns	29.9
5		32.0
Average		31.0
VIa-2-A-1		58.0
2		63.2
3	Bias	60.1
4		58.3
5		60.1
Average		61.1

TABLE XVII

EFFECT OF VARIOUS ENVIRONMENTAL EXPOSURES ON THE DIMENSIONAL STABILITY OF CANOPY FRENCH FELL SEAMS

Seams Perpendicular to Warp Yarns

Specimen Identification	Exposure Condition	Gauge Length Under 5.0 lbs Preload (Inches)	Change On Exposure (%)
VIa-1-A-1		2.00	
2		2.00	
3	Control	2.00	
4		2.00	
5		2.00	
Average		2.00	
VIa-1-B-1		2.00	
2		1.96	
3	Ethylene Oxide	2.00	
4		2.00	
5		1.97	
Average		1.99	-1
VIb-1-C-1		2.00	
2	Heat and Pressure Packing	2.00	
3		2.02	
4		2.03	
5		2.02	
Average		2.01	+1
VIb-1-D-1		2.02	
2	Ethylene Oxide + Heat and Pressure Packing	2.04	
3		2.01	
4		2.02	
5		2.03	
Average		2.02	+1

TABLE XVII (Cont)

EFFECT OF VARIOUS ENVIRONMENTAL EXPOSURES ON THE

DIMENSIONAL STABILITY OF CANOPY

FRENCH FELL SEAMS

Bias Seams

Specimen Identification	Exposure Condition	Gauge Length Under 5.0 lbs Preload (Inches)	Change On Exposure (%)
VIa-2-A-1		2.00	
2		2.00	
3	Control	2.00	
4		2.00	
5		2.00	
Average		2.00	
VIa-2-B-1		1.92	
2		1.95	
3	Ethylene Oxide	1.96	
4		1.95	
5		2.00	
Average		1.96	-2
VIb-2-C-1		2.00	
2	Heat and Pressure	2.02	
3	Packing	2.03	
4		1.98	
5		2.00	
Average		2.00	0
VIb-2-D-1		2.00	
2	Ethylene Oxide +	2.00	
3	Heat and Pressure	2.00	
4	Packing	2.00	
5		2.00	
Average		2.00	0

Seam Strength and Dimensional Stability of Reinforced Canopy Radial Gore Seams

These specimens were geometrically identical with those prepared for the French fell seam studies, and differed only in that the seams were reinforced with the tape previously described. All experimental arrangements were identical with those used for the French fell seams, with the exception that the dimensional stability was determined from measures of the end and pick count of the reinforcing tape, measured with a pick counter with a 1/2 inch aperture. Results for the seam strength of the specimens exposed to various environmental conditions are shown in Table XVIII, for the breaking elongation of the control seam specimens in Table XIX, and for the dimensional stability in Table XX.

The seam strength of all specimens is essentially unchanged by all exposure conditions. The increase found for the perpendicular seamed specimens exposed to heat and pressure packing is caused by the high value found for specimen under VIIb-1-C-4, which is probably a result of specimen-to-specimen variation. There is no significant change in the dimensions of the seams perpendicular to the warp yarns, or in the bias seams in the direction of the seam. The measured ends per inch in the tape shows an increase for all exposure conditions, indicating a contraction in the width of the seam tape. The fabric in the seam gives more support to the tape when the seam is perpendicular to the warp yarns than when the seam runs in the bias direction, and prevents the contraction in tape width. This difference is also manifested in the result for breaking extension; the perpendicular seam specimens have an overall breaking elongation of 30.3% while that of the bias specimens is 56.6%, as a result of the greater deformation potential of the fabric in the bias direction.

The strength of the seams perpendicular to the warp yarns is not changed by the addition of the reinforcing tape. However, in the bias direction the addition of the tape increases the breaking load of the seam from approximately 64 lbs/inch to approximately 73 lbs/inch, an increase of 14%, though the increase is at the expense of greater weight per unit length of seam.

TABLE XVIII

EFFECT OF VARIOUS ENVIRONMENTAL EXPOSURES ON THE STRENGTH OF REINFORCED CANOPY RADIAL GORE SEAMS

Seam Perpendicular to Warp Yarns

Specimen Identification	Exposure Condition	Seam Strength (lbs/inch)	Change On Exposure (%)
VIIa-1-A-1		53.0	
2		51.5	
3	Control	52.2	
4		53.0	
5		54.7	
Average		52.9	
VIIa-1-B-1		53.5	
2		53.0	
3	Ethylene Oxide	55.7	
4		54.7	
5		48.0	
Average		53.0	0
VIIb-1-C-1		54.7	
2		53.3	
3	Heat and Pressure Packing	54.8	
4		57.2	
5		53.4	
Average		54.7	+3
VIIb-1-D-1		54.5	
2	Ethylene Oxide + Heat and Pressure Packing	51.5	
3		52.3	
4		51.0	
5		56.0	
Average		53.1	0

TABLE XVIII (Cont)

EFFECT OF VARIOUS ENVIRONMENTAL EXPOSURES ON THE STRENGTH OF REINFORCED CANOPY RADIAL GORE SEAMS

Bias Seams

Specimen Identification	Exposure Condition	Seam Strength (lbs/inch)	Change On Exposure (%)
VIIa-2-A-1		75.5	
2		68.5	
3	Control	72.0	
4		74.5	
5		76.5	
Average		73.4	
VIIa-2-B-1		71.0	
2		77.0	
3	Ethylene Oxide	69.5	
4		75.0	
5		67.0	
Average		71.9	-2
VIIb-2-C-1		71.7	
2	Heat and Pressure	71.7	
3	Packing	78.6	
4		74.7	
5		69.0	
Average		73.1	0
VIIb-2-D-1		73.0	
2	Ethylene Oxide +	77.3	
3	Heat and Pressure	78.5	
4	Packing	69.0	
5		68.7	
Average		73.3	0

TABLE XIX

BREAKING ELONGATION OF BIAXIAL SPECIMENS OF REINFORCED CANOPY RADIAL GORE SEAMS

Specimen Identification	Seam Direction	Specimen Elongation (%)
VIIa-1-A-1		31.3
2	Perpendicular	30.5
3	to	28.8
4	Warp Yarns	28.7
5		32.0
Average		30.3
VIIa-2-A-1		58.8
2		52.9
3	Bias	56.0
4		54.5
5		60.7
Average		56.6

TABLE XX

EFFECT OF VARIOUS ENVIRONMENTAL EXPOSURES ON THE DIMENSIONAL STABILITY OF REINFORCED CANOPY RADIAL CORE SEAMS

		Seams Perpendicular to Warp Yarns				
Specimen Identification	Exposure Conditions	Ends/1/2 In. x Picks/1/2 In. Prior to Exposure	Ends/1/2 In. x Picks/1/2 In. After Exposure	Ends/Inch x Picks/Inch Prior to Exposure	Ends/Inch x Picks/Inch After Exposure	Change On Exposure (%)
VIIa-1-A						
1		80x12				
2		80x12				
3	Control	80x12				
4		78x12				
5		80x12				
Average		80x12		160x24		
VIIa-1-B						
1		82x12	80x12			
2	Ethylene	82x12	80x12			
3	Oxide	80x12	80x12			
4		80x12	80x12			
5		80x12	80x12			
Average		81x12	80x12	162x24	160x24	(-1)x(0)
VIIb-1-C						
1		80x12	80x12			
2	Heat and	82x12	80x12			
3	Pressure	80x12	80x12			
4	Packing	80x12	82x11			
5		80x12	82x12			
Average		80x12	81x12	160x24	162x24	(+1)x(0)
VIIb-1-D						
1	Ethylene	80x12	78x12			
2	Oxide +	80x12	80x12			
3	Heat and	80x13	80x12			
4	Pressure	82x12	82x12			
5	Packing	82x12	80x11			
Average		81x12	80x12	162x24	160x24	(-1)x(0)

TABLE XX (Cont)

EFFECT OF VARIOUS ENVIRONMENTAL EXPOSURES ON THE DIMENSIONAL STABILITY OF REINFORCED CANOPY RADIAL GORE SEAMS

Bias Seams

Specimen Identi-fication	Exposure Conditions	Ends/1/2 In. x Picks/1/2 In. Prior to Exposure	Ends/1/2 In. x Picks/1/2 In. After Exposure	Ends/Inch x Picks/Inch Prior to Exposure	Ends/Inch x Picks/Inch After Exposure	Change On Exposure (%)
VIIa-2-A						
1		76x12				
2		76x13				
3	Control	76x12				
4		78x11				
5		78x12				
Average		77x12		154x24		
VIIa-2-B						
1		78x12	84x12			
2		78x12	80x12			
3	Ethylene	78x12	80x12			
4	Oxide	78x12	82x12			
5		80x12	82x12			
Average		78x12	81x12	156x24	162x24	(+4)x(0)
VIIb-2-C						
1		80x12	80x12			
2	Heat and	80x12	82x12			
3	Pressure	80x12	80x12			
4	Packing	82x12	82x12			
5		80x13	84x12			
Average		80x12	82x12	160x24	164x24	(+3)x(0)
VIIb-2-D						
1	Ethylene	78x12	84x12			
2	Oxide +	82x12	84x12			
3	Heat and	82x12	84x12			
4	Pressure	82x12	82x12			
5	Packing	80x12	84x12			
Average		80x12	84x12	160x24	168x24	(+5)x(0)

Tensile Behavior and Dimensional Stability of Gap-Hem Radial Joint Specimens

Prior to environmental exposure, all specimens were marked with a four inch gauge length in the center of the hem section with the specimen under a 5.0 ± 0.1 lb preload, applied by deadweight loading as previously described for the seamed specimens. After environmental exposure, the gauge length was measured under the same load conditions. Tensile tests on the specimens was carried out using an Instron tensile tester. The specimens were gripped in flat, rubber lined jaws with a 10 inch separation between the jaws, and a jaw speed of 2 inches/minute was used. The breaking elongation of the control specimens was found from the jaw position at rupture. Results for the breaking load of the specimens exposed to various environmental conditions are shown in Table XXI, for the breaking elongation of the control specimens in Table XXII, and for the dimensional stability of the specimens in Table XXIII.

The breaking load of the specimens was increased considerably on exposure to ethylene oxide and to a lesser extent on exposure to ethylene oxide plus heat and pressure packing. It is probable that the increase in both cases is a manifestation of the relaxation of stresses set up during sewing of the composite specimens, this permitting more equal load sharing in the components of the specimens giving a higher total breaking load. Rupture in all cases started at the line of stitching in the radial joint reinforcing tape and propagated in a diagonal line up to the jaw, where the specimen finally ruptured. The overall breaking load is reasonably close to that of the reinforcing tape alone, and the overall breaking elongation is very close to that of the tape. The hem sections of the specimens are completely stable for all environmental exposures.

Tensile Behavior and Dimensional Stability of Suspension Line-Radial Tape Specimens

Prior to environmental exposure each specimen was marked with a four inch gauge length in the center of the hem section in the same way as was previously described for the Gap-hem Radial Joint specimens, and the gauge length was remeasured under identical load conditions after exposure. Tensile tests were carried out using an Instron tensile tester. The radial tape was gripped in the top jaw of the Instron in flat rubber-lined jaws; the suspension line was wrapped 2 1/2 turns around a 2 inch diameter capstan jaw with the center of the jaw 16 inches from the front edge of the top jaw. A jaw speed of 2 inches per minute was used. A 9 inch gauge length was marked on the tape of the control specimens with the specimens just taut and a photograph was taken. The specimen was then extended, and as the breaking load was approached, a further sequence of photographs was taken. The breaking elongation was found from measurements on the projected image of the film record; the nomenclature of Figure 3 was used in this calculation. Results for the breaking load of the specimens exposed to various environmental conditions are shown in Table XXIV, for the breaking elongation of the control specimen in Table XXV, and for the dimensional stability of the specimen in Table XXVI.

TABLE XXI

EFFECT OF VARIOUS ENVIRONMENTAL EXPOSURES ON THE

STRENGTH OF GAP-HEM RADIAL JOINT SPECIMENS

Specimen Identification	Exposure Conditions	Breaking Load (lbs)	Change On xposure (%)
VIII-A-1		570 J,S	
2		585 J,S	
3	Control	542 J,S	
4		550 J,S	
5		570 J,S	
Average		563	
VIII-B-1		607 J,S	
2	Ethylene	592 J,S	
3	Oxide	605 J,S	
4		600 J,S	
5		598 J,S	
Average		600	+7
VIII-D-1	Ethylene	586 J,S	
2	Oxide +	595 J,S	
3	Heat and	563 J,S	
4	Pressure	620 J,S	
5	Packing	543 J,S	
Average		581	+3

J,S Jaw Break; rupture initiated at stitching

TABLE XXII

BREAKING ELONGATION OF CONTROL SPECIMENS OF

GAP-HEM RADIAL JOINTS

Specimen Identification	Exposure Condition	Breaking Elongation (%)
VIII-A-1		41.2
2		42.2
3	Control	40.0
4		41.0
5		40.2
Average		40.9

TABLE XXIII

EFFECT OF VARIOUS EXPERIMENTAL EXPOSURES ON THE

DIMENSIONAL STABILITY OF GAP-HEM

RADIAL JOINT SPECIMEN

Specimen Identification	Exposure Condition	Measured Gauge Length (inches)	Change On Exposure (%)
VIII-A-1		4.00	
2		4.00	
3	Control	4.00	
4		4.00	
5		4.00	
Average		4.00	
VIII-B-1		4.04	
2		4.04	
3	Ethylene Oxide	4.04	
4		4.05	
5		4.00	
Average		4.03	+1
VIII-D-1		4.00	
2	Ethylene Oxide	4.00	
3	+ Heat and Pres-	4.09	
4	sure Packing	4.06	
5		4.00	
Average		4.03	+1

TABLE XXIV

EFFECT OF VARIOUS ENVIRONMENTAL EXPOSURES ON THE

BREAKING LOAD OF SUSPENSION LINE

RADIAL TAPE SPECIMENS

Specimen Identification	Exposure Condition	Breaking Load (lbs)	Change On Exposure (%)
IX-A-1		618 L	
2		590 J,S	
3	Control	597 J,S	
4		595 J,S	
5		560 L	
Average		592	
IX-B-1		620 J,S	
2		610 L	
3	Ethylene Oxide	605 J,S	
4		560 L	
5		545 J,S	
Average		588	-1
IX-D-1		575 J,S	
2	Ethylene Oxide	552 J,S	
3	+ Heat and Pres-	598 C	
4	sure Packing	605 C	
5		552 C	
Average		576	-3

J,S Jaw Break; rupture initiated at stitching
L Broke at loop
C Center of specimen

TABLE XXV

BREAKING ELONGATION OF CONTROL SUSPENSION LINE

RADIAL TAPE SPECIMENS

Specimen Identification	L_o[1]	L_r[1]	Breaking Elongation (%)
IX-A-1	5.86	7.94	35.5
2	5.90	7.90	33.9
3	5.90	7.50	27.1
4	5.85	7.75	32.5
5	5.82	7.70	32.2
Average			32.3

1 Measured on film reader

TABLE XXVI

EFFECT OF VARIOUS ENVIRONMENTAL EXPOSURES ON THE DIMENSIONAL STABILITY OF SUSPENSION LINE RADIAL TAPE SPECIMENS

Specimen Identification	Exposure Condition	Gauge Length (ins)	Change On Exposure (%)
IX-A-1		4.00	
2		4.00	
3	Control	4.00	
4		4.00	
5		4.00	
Average		4.00	
IX-B-1		4.00	
2		4.05	
3	Ethylene Oxide	4.00	
4		4.04	
5		4.02	
Average		4.02	0
IX-D-1		4.00	
2	Ethylene Oxide	3.93	
3	+ Heat and Pres-	4.00	
4	sure Packing	4.00	
5		4.00	
Average		3.99	0

The breaking load of the Suspension Line - Radial Tape Specimens is very similar to the breaking load of the Gap-hem Radial Joint Specimens, though for the former specimens the breaking load decreases slightly on exposure to the various environments. The specimens sometimes broke at the jaw, after rupture was inititated at the stitching in the center of the specimen, sometimes at the loop, and in the case of the condition D specimens, in the center of the gauge length. Clearly all the components of the specimen are approximately equal in strength, and the particular point of break is established by specimen to specimen variation in manufacture. The measured breaking elongation of these specimens is somewhat less than that of the Gap-hem Radial Joint specimens, though some of this difference may be attributed to the different methods of measuring breaking elongation for the two sets of specimens. The dimension of the hem section of the specimens are unchanged by the various environmental exposures.

Tensile Behavior and Dimensional Stability of Riser Webbing

The fabricated looped webbing specimens were mounted in stirrup-type fixtures attached to the upper and lower jaws of the tester; the load bearing members of the stirrups were finished to a radius of 1/4 inch. The dimensional stability of the webbing after various environmental exposures was found from measurements on a four inch gauge length marked under a 75 ± 5 lb preload and the breaking extension was found using the photographic technique previously described. Results for the breaking loads for the webbings exposed to various environmental conditions are shown in Table XXVII, for the breaking elongation of the control webbings in Table XXVIII, and for the dimensional stability in Table XXIX.

The tensile rupture load of the webbing is increased slightly on exposure to ethylene oxide and decreased considerably on subsequent exposures to the heat cycle. The decrease in strength is associated with a considerable shrinkage. These changes are the greatest of any found in the investigation, and result from the use of unstabilized Dacron in the riser. The measured breaking elongation is rather lower than would be expected for a webbing of this type, but the rupture process in the specimens starts prematurely at the stitching of the loops, and the measured breaking load and elongation are not necessarily representative of the material tested by usual methods, using capstan jaws; it is not possible to separate the effects of the environmental exposures on the webbing material and on the fabrication process by means of the present test.

TABLE XXVII

EFFECT OF VARIOUS ENVIRONMENTAL EXPOSURES ON THE

BREAKING LOAD OF WEBBING

Specimen Identification	Exposure Condition	Breaking Load (lbs)	Change On Exposure (%)
X-A-1		6400	
2		6500	
3	Control	6700	
4		6300	
5		6600	
Average		6500	
X-B-1		6700	
2		6500	
3	Ethylene Oxide	6700	
4		6700	
5		6700	
Average		6660	+2
X-D-1		5570	
2	Ethylene Oxide	5420	
3	+ Heat Only. No	5570	
4	Pressure Packing	5100	
5		5120	
Average		5360	-17

TABLE XXVIII

BREAKING ELONGATION OF CONTROL SPECIMENS OF WEBBINGS

Specimen Identification	Exposure Condition	L_o[1]	L_r[1]	Breaking Elongation (%)
X-A-1		8.75	10.00	14.3
2[2]		-	-	-
3	Control	8.80	10.00	13.6
4		8.60	10.00	16.3
5		8.60	9.60	14.0
Average				14.6

1 Measured on film reader
2 Film record unreadable; average breaking elongation measured on Instron chart very close to average of all specimens.

TABLE XXIX

EFFECT OF VARIOUS ENVIRONMENTAL EXPOSURES ON THE

DIMENSIONAL STABILITY OF WEBBING

Specimen Identification	Exposure Condition	Measured Gauge Length (inches)	Change On Exposure (%)
X-A-1		4.00	
2		4.00	
3	Control	4.00	
4		4.00	
5		4.00	
Average		4.00	
X-B-1		4.05	
2		4.10	
3	Ethylene Oxide	4.05	
4		4.00	
5		4.05	
Average		4.05	+1
X-D-1		3.72	
2	Ethylene Oxide	3.84	
3	+ Heat Only. No	3.78	
4	Pressure Packing	3.80	
5		3.83	
Average		3.79	-5

CONCLUSIONS

With the exception of the riser webbing, the components and fabricated samples of the various assemblies are dimensionally stable within a very small range for all the exposure conditions. The canopy fabric is stable within 1% under small uniaxial loads, within 4% under high biaxial load conditions, and within 2% when seamed, either perpendicular to the warp yarns, or on the bias. The braid is stable within 2%, and the reinforcing tape, either alone or in conjunction with canopy fabirc seams, is stable within 1% in the warp direction. In the filling direction the tape is much less stable, showing a range from 5% shrinkage to 8% extension; however, since the tape is essentially a warp structure, these changes are of small importance. The riser webbing, however, which is also a predominately warp way structure, shows a significant 5% shrinkage in the warp direction on exposure to heat cycling, probably as a consequence of the lack of heat-setti .

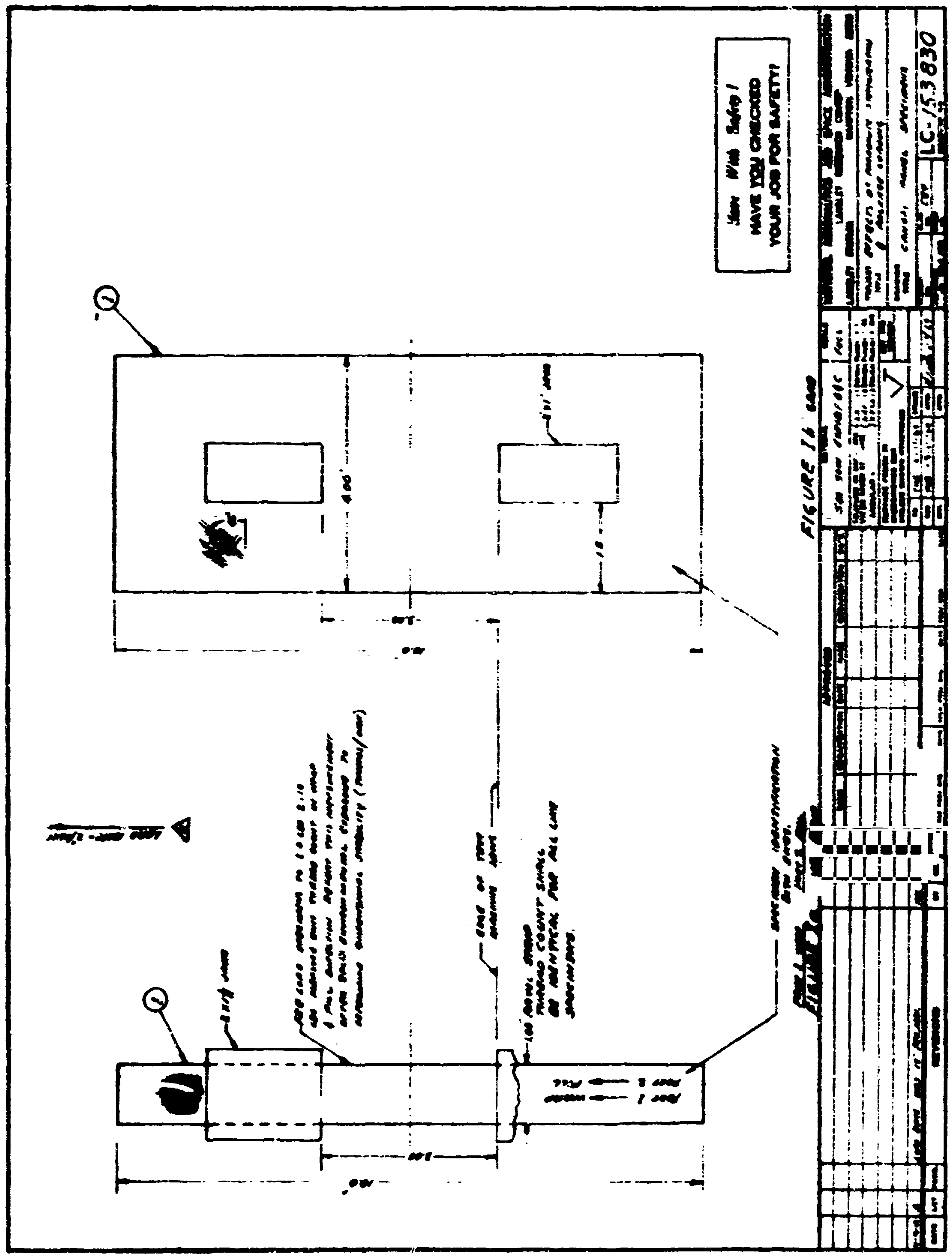
The mechanical behavior of the various components are, in general, affected only to a small degree by the environmental conditions. A significant strength reduction was found for only single specimens of the canopy fabric and the reinforcing tape, and the braid was completely unaffected. The air permeability of the canopy fabric shows changes of up to 5%, reflecting the small dimensional changes under biaxial load. The only marked change in the mechanical behavior of components were found for the riser webbing, which shows a 17% loss of strength after Ethylene Oxide exposure and Heat Cycling, and for the grab strength of bias specimens of canopy fabric, which showed a 22% increase. The former is attributable to the lack of heat setting of the riser webbing, and the latter is a consequence of the relaxation of inter yarn forces and a reduction in shear resistance of the fabric.

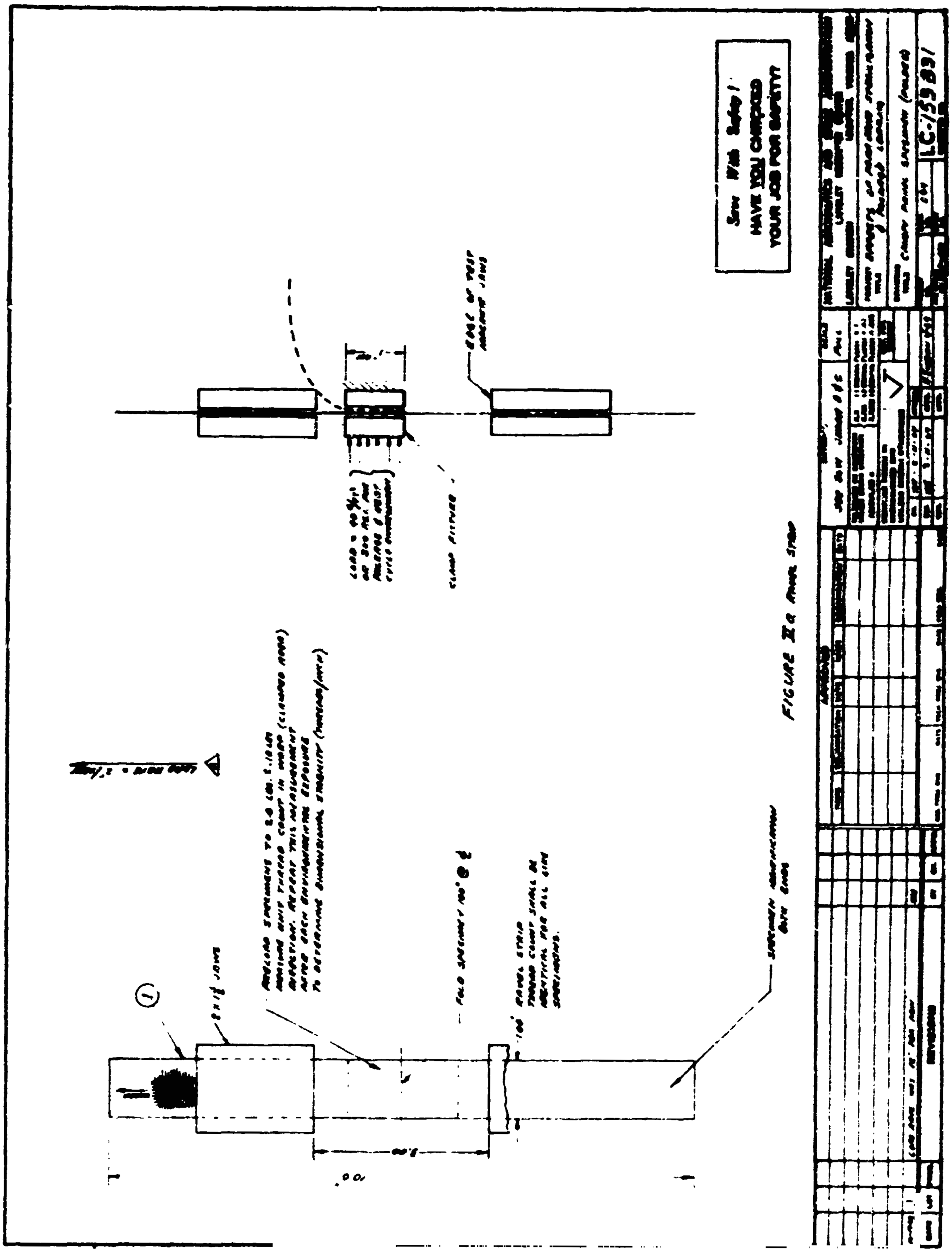
The fabricated components showed a varied response in their mechanical behavior. The strength of French fell and tape reinforced seams were either slightly increased (seams perpendicular to warp yarns), or were essentially unchanged (bias seams). The strength of the gap-hem radial joint specimens was increased 3-7% while that of the suspension line-radial tape specimens was decreased slightly. All the small increases in strength are tentatively ascribed to the stress relaxing effect of the elevated temperature exposure common to all the environments, which reduces stress concentrations in the composite specimens; the results for the suspension line-radial tape samples are complicated by the various failure modes shown by the individual specimens.

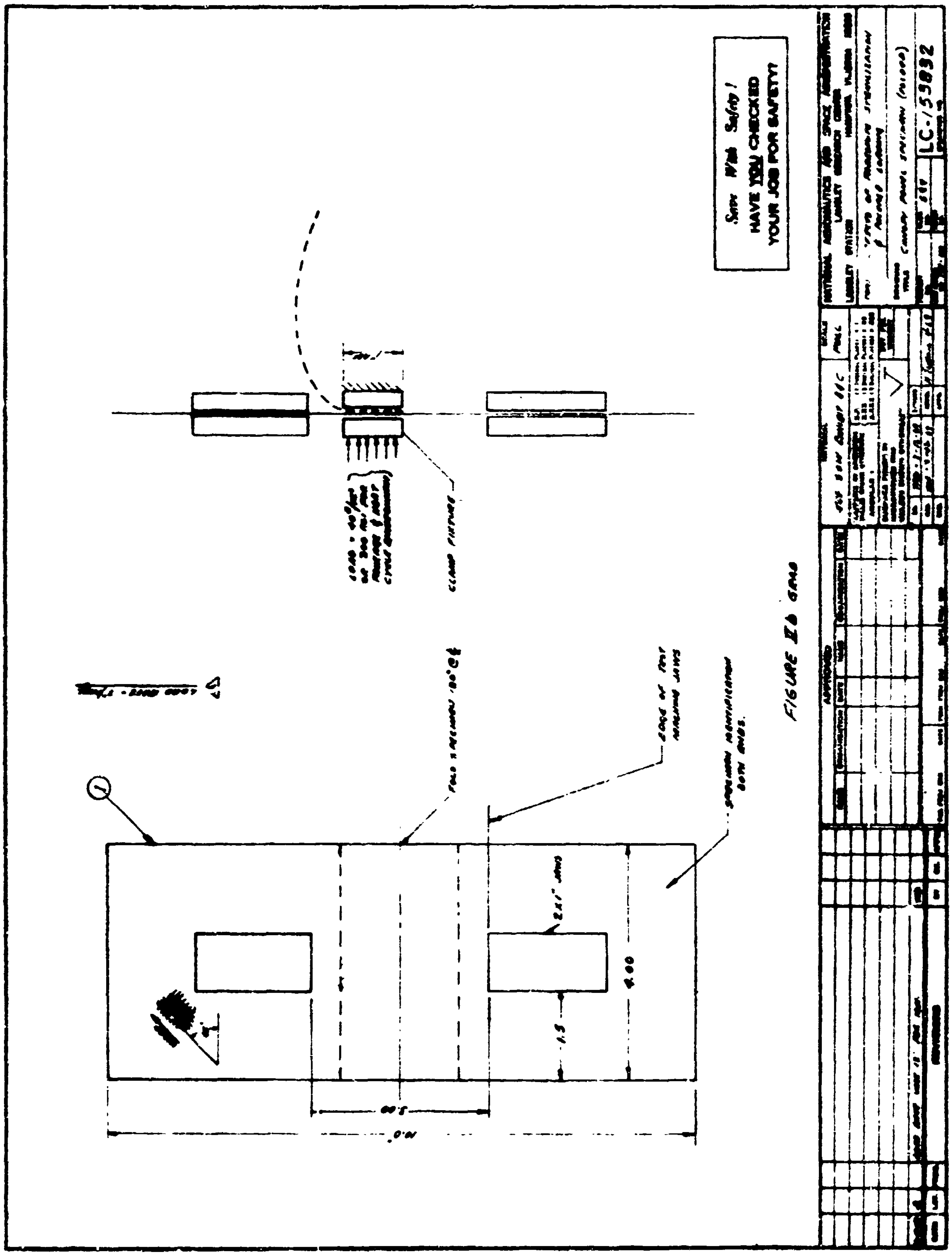
In summary, the heat-set Dacron components show no significant loss of stability or deterioration in mechanical properties on exposure to the sterilization environment, and the performance of certain assemblies may even be enhanced. The riser webbing is evidently not heat-set and shrinks and is degraded by the heat cycle; in order to attain the standards of stablility and performance shown by the other components it should be made from heat-stable Dacron, or be heat-set after weaving.

APPENDIX

NASA Langley drawings LC-153,830 through LC-153,840: Details of Test Specimens


HAVE YOU CHECKED
YOUR JOB FOR SAFETY!
FIGURE 16
LC-153830


Save With Safety!
HAVE YOU CHECKED
YOUR JOB FOR SAFETY?
FIGURE II a PANEL STRIP
LC-159891


Save With Safety!
HAVE YOU CHECKED
YOUR JOB FOR SAFETY?

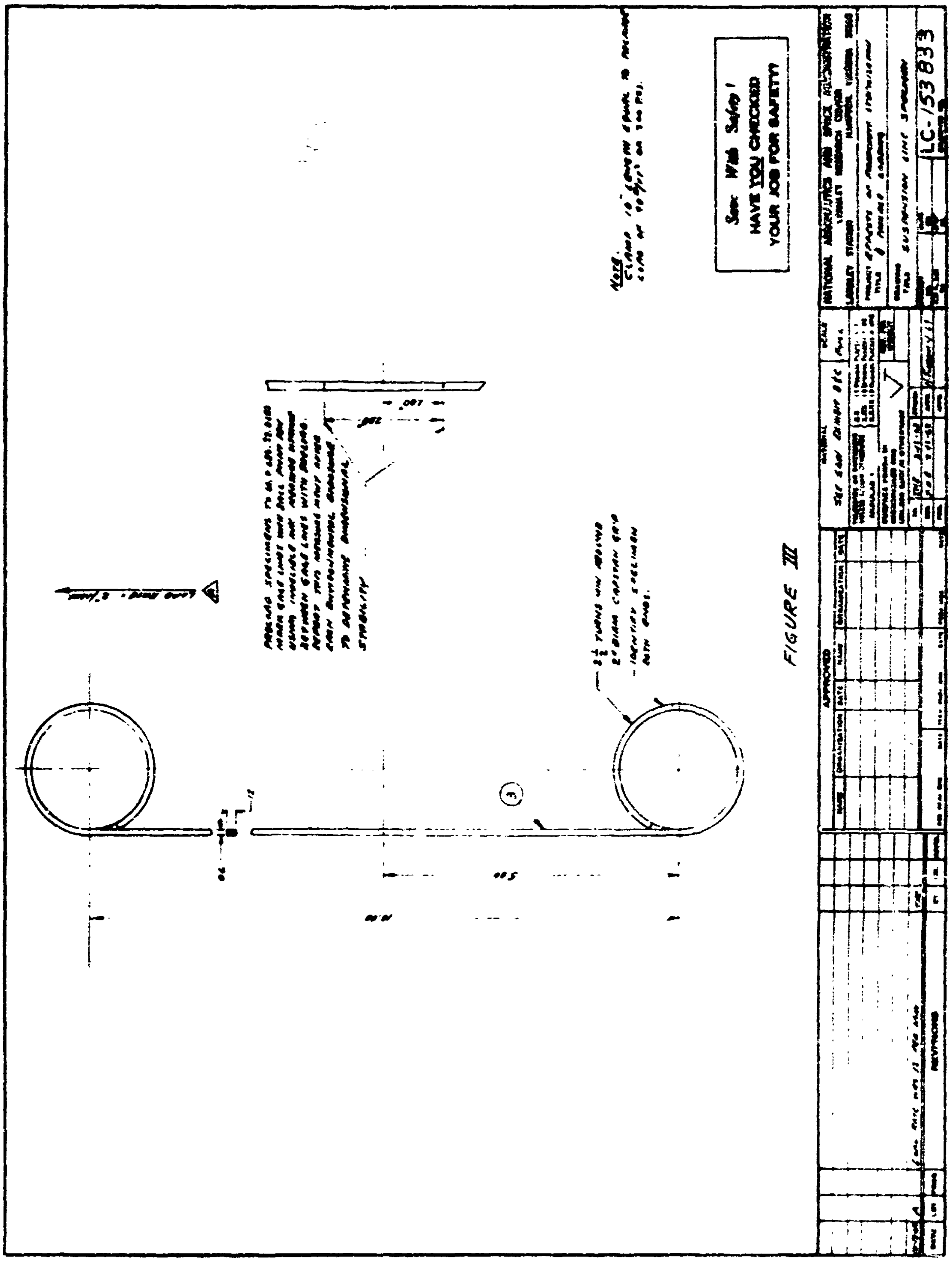
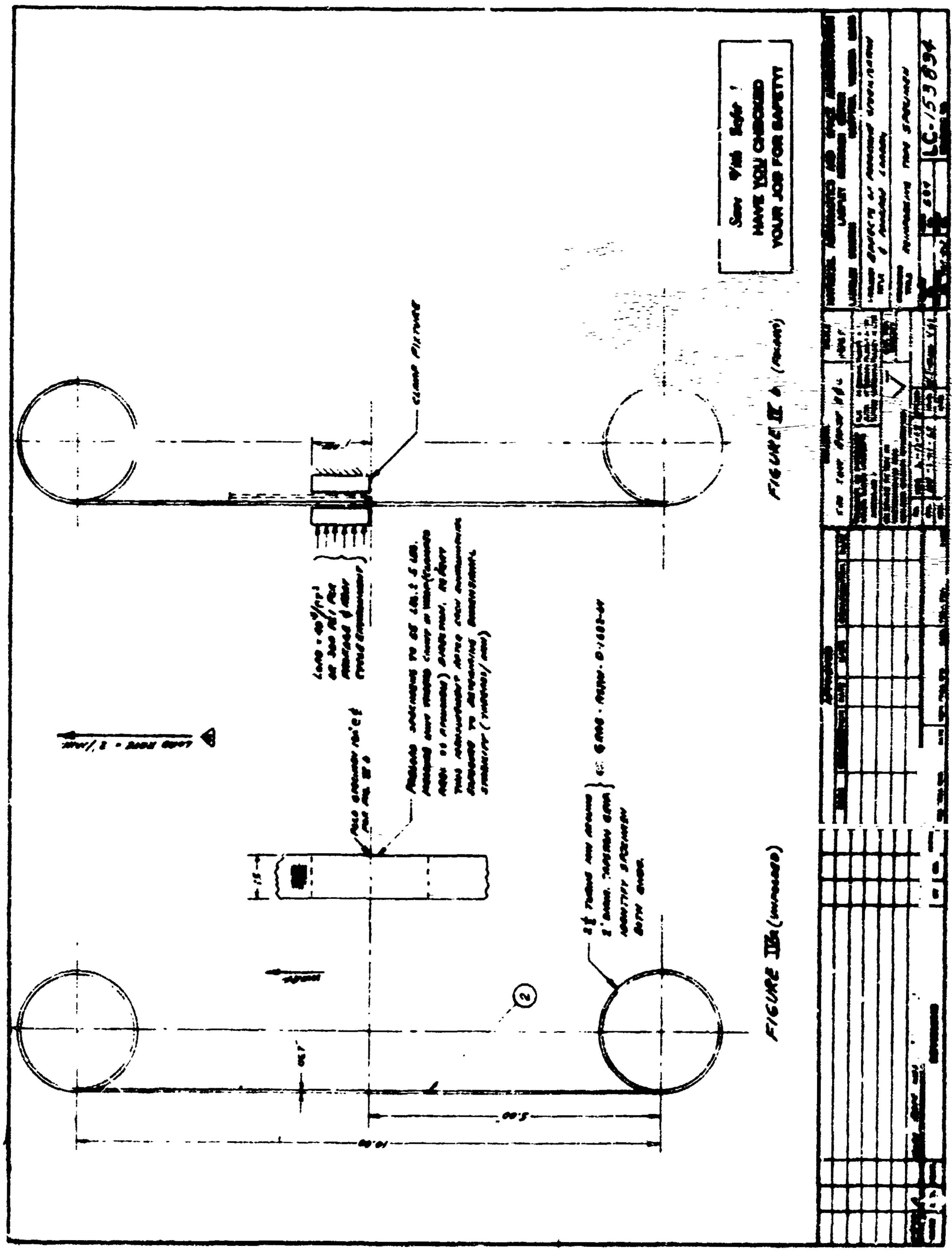
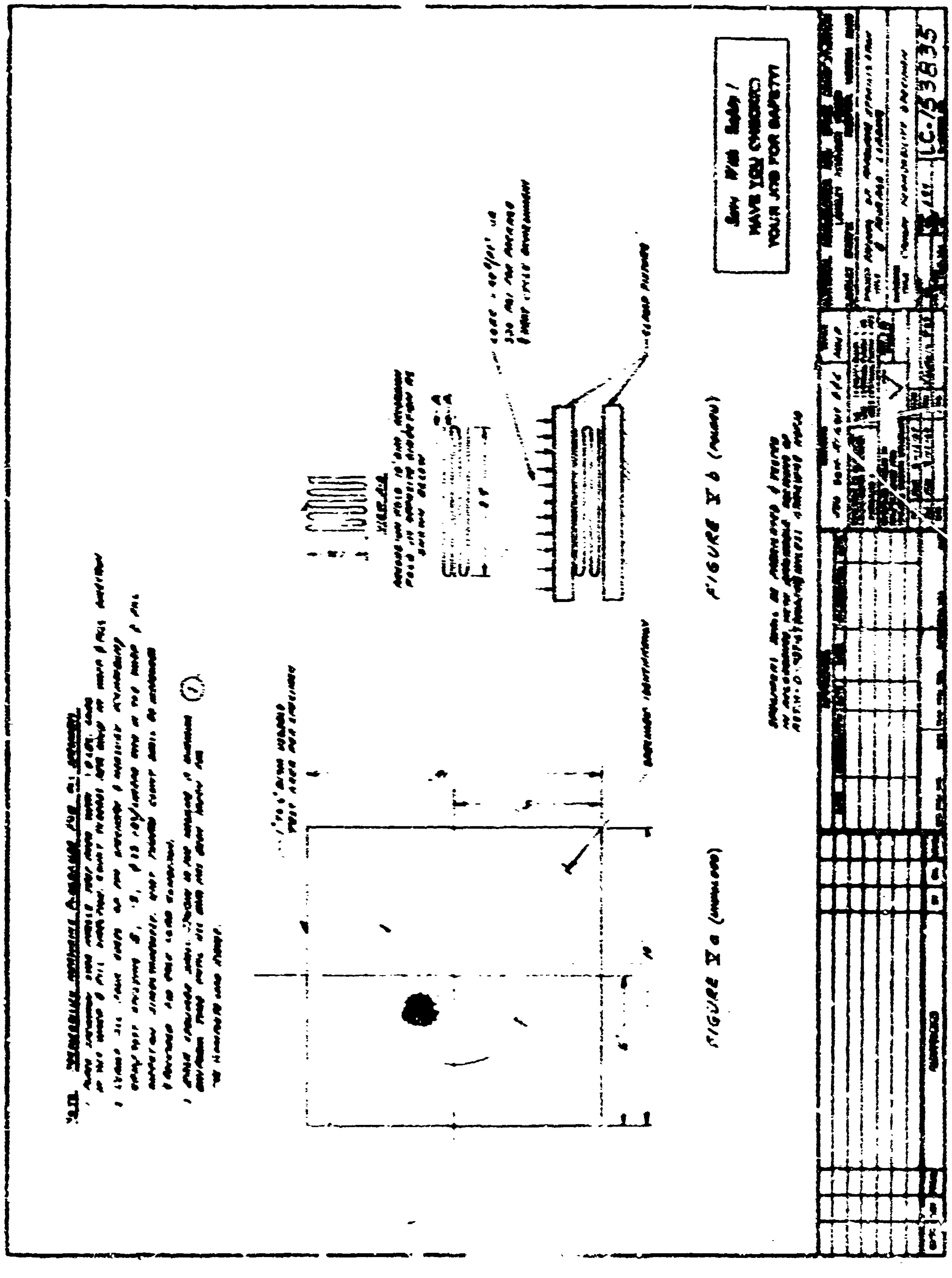
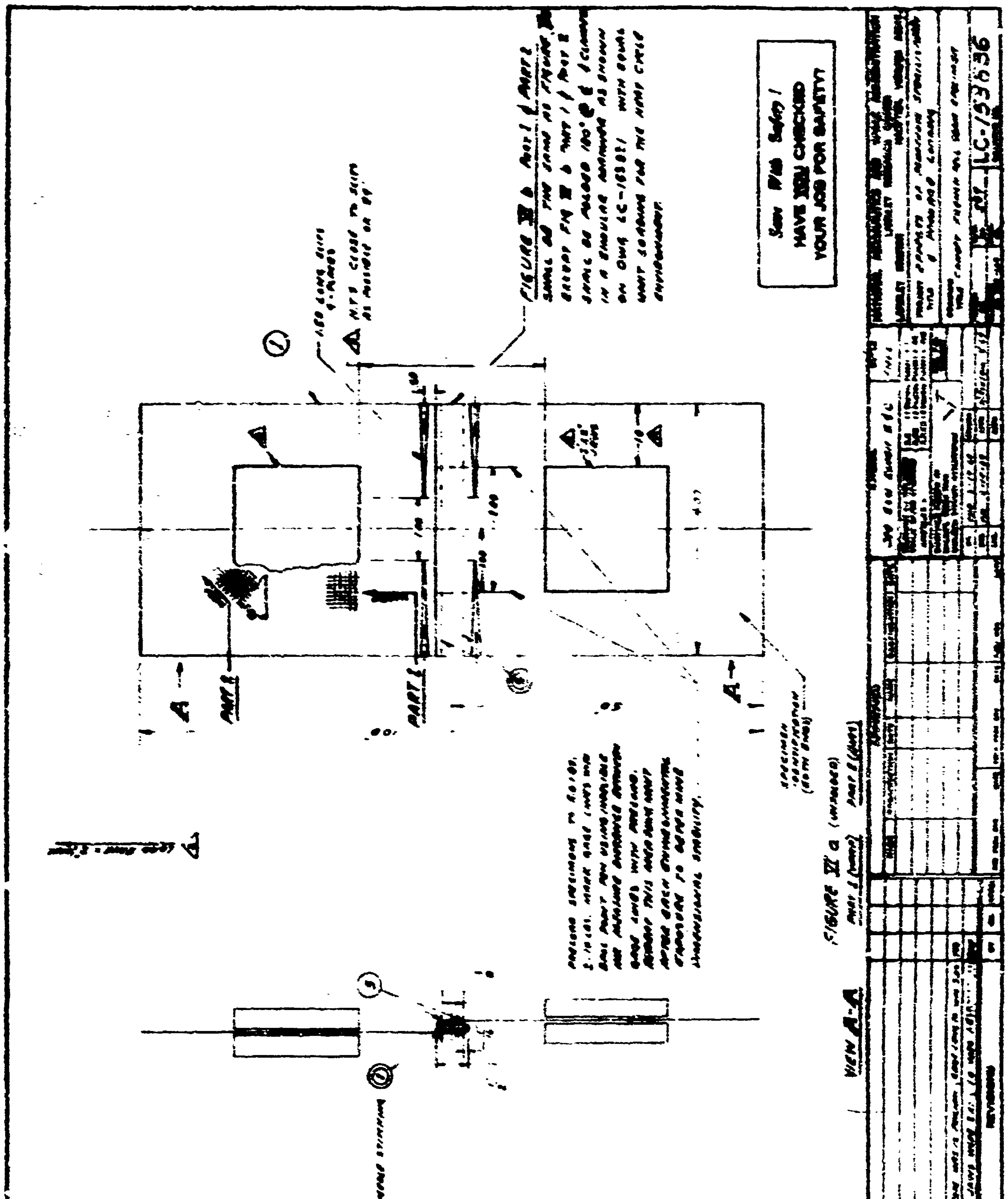
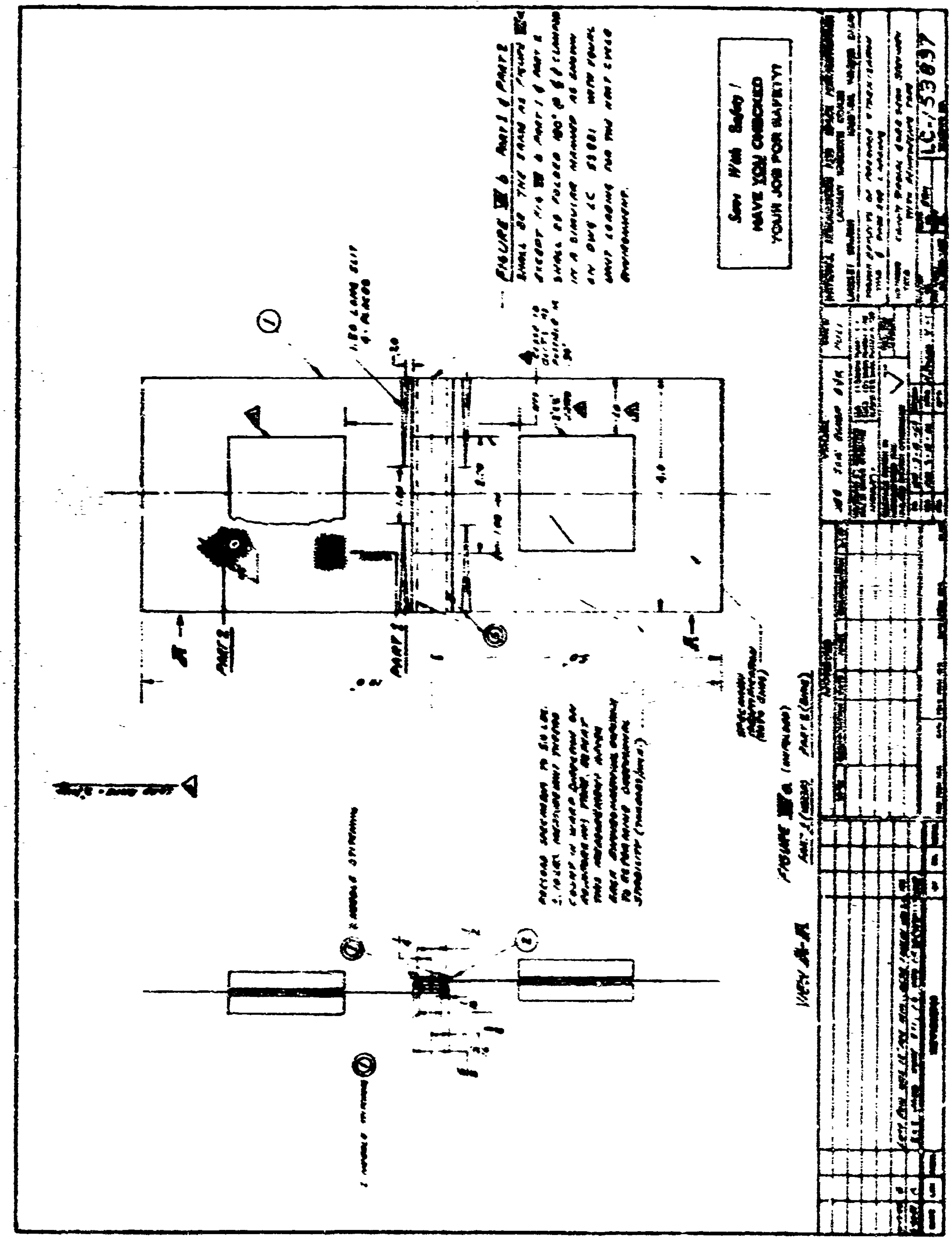

Save With Safety!
HAVE YOU CHECKED
YOUR JOB FOR SAFETY?
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LC-153833

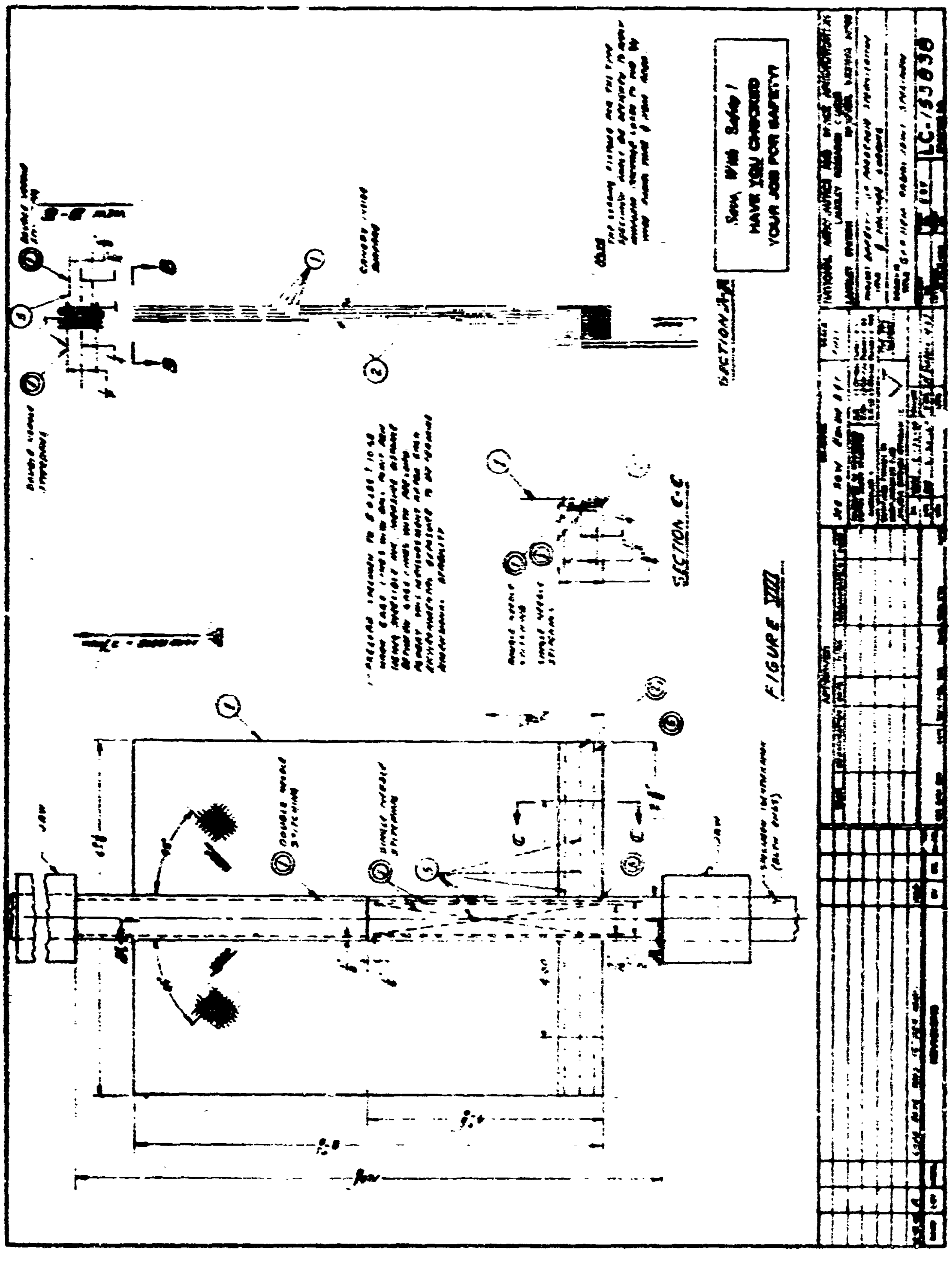
FIGURE III

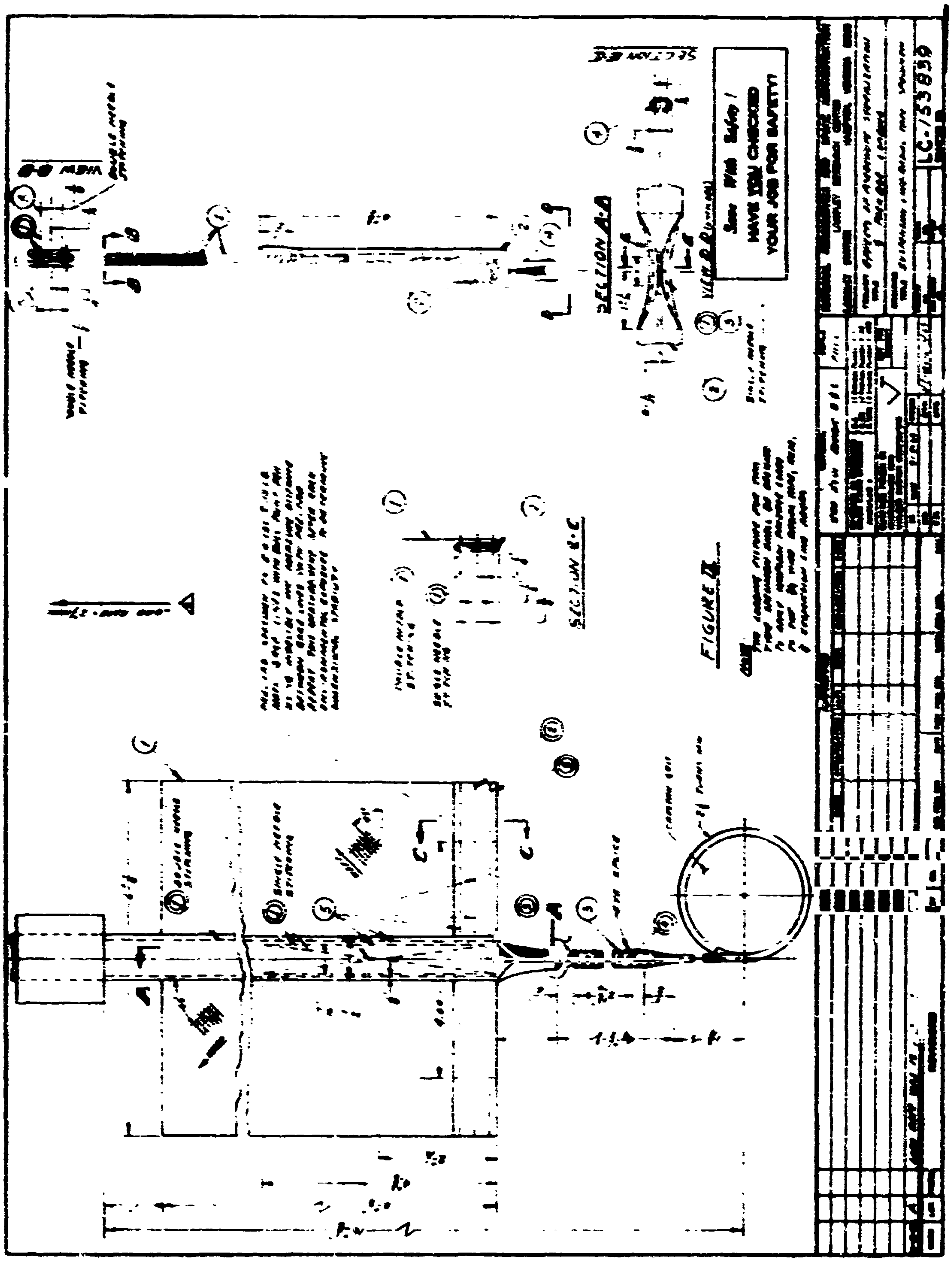


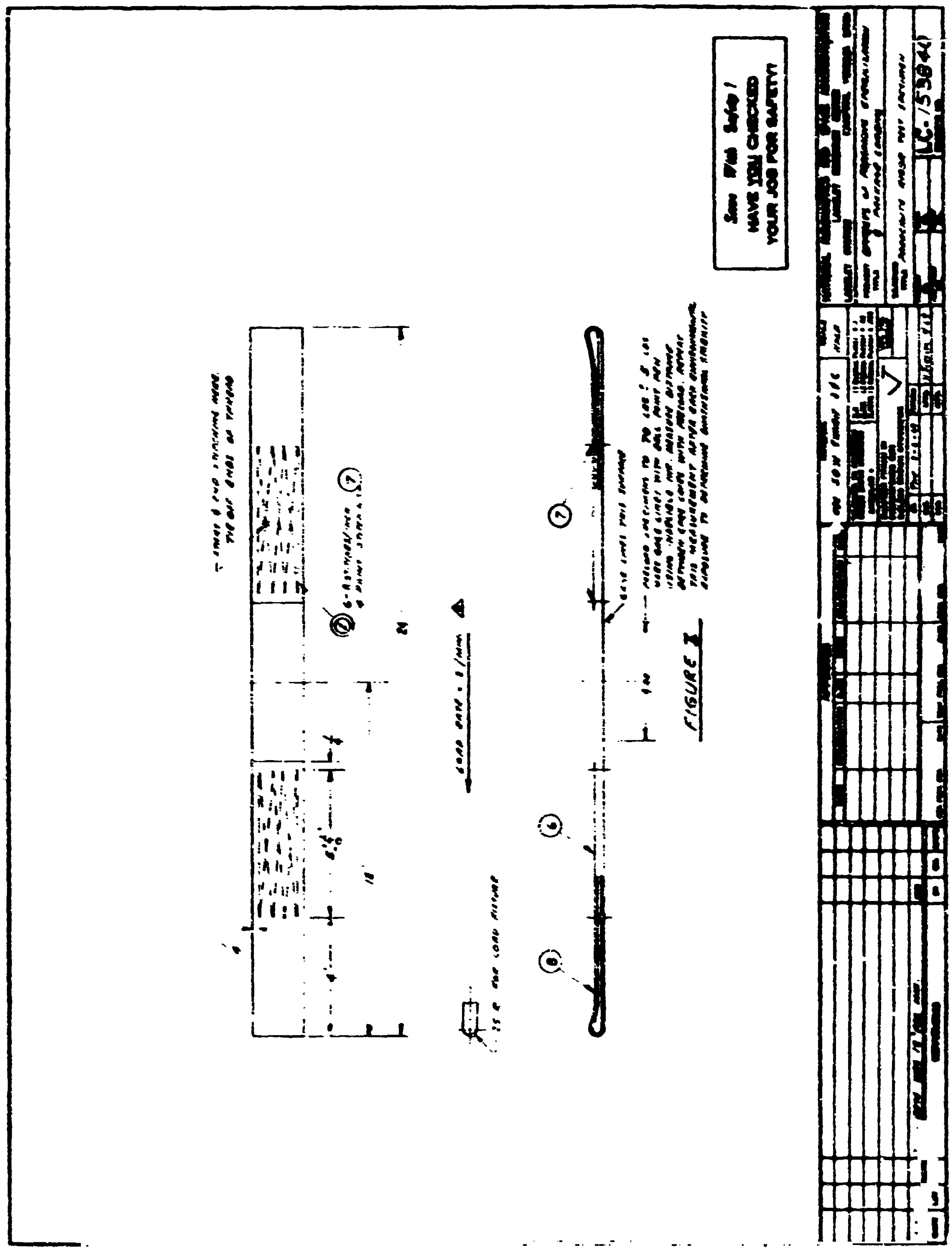

HAVE YOU CHECKED
YOUR JOB FOR SAFETY?
FIGURE V b
FIGURE V a


Save With Safety!
HAVE YOU CHECKED
YOUR JOB FOR SAFETY?
VIEW A-A
PART 1
PART 2


HAVE YOU CHECKED
YOUR JOB FOR SAFETY?
LC-153697


SECTION A-A
SECTION C-C
FIGURE VIII


SECTION A-A
SECTION C-C
HAVE YOU CHECKED
YOUR JOB FOR SAFETY?



REFERENCES

1. Rittenhouse, John B. and Singletary, John B.: Space Materials Handbook, Third Edition, NASA SP-3051, 1969, p 678.

2. Spence, David C.: Effects of Mission Environments on the Mechanical Properties of Dacron Parachute Material AIAA Paper No. 69-1018, presented at AIAA/ASTM/IES 4th Space Simulation Conference, Los Angeles, California, Sept. 8-10, 1969.