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Report Number

DEVELOPMENT OF A 40,000 GALLON, HIGH PROFILE, COLLAPSIBLE, RUBBERIZED FABRIC FUEL STORAGE TANK

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October, 1982

Final Report for the Period 12 May 1981 through 15 October 1982

Distribution Unlimited

Prepared for
U S ARMY MOBILITY EQUIPMENT RESEARCH AND DEVELOPMENT COMMAND
Research and Development Command
Procurement and Production Directorate
Fort Belvoir, Virginia 22060

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A120 733
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) Development of a 40,000 gallon High Profile, Collapsible, Rubberized Fabric, Fuel Storage Tank.	5. TYPE OF REPORT & PERIOD COVERED Final Report 12 May '81 - 15 Oct '82
	6. PERFORMING ORG. REPORT NUMBER GAC 19-1536
7. AUTHOR(s) R L Sosnowski	8. CONTRACT OR GRANT NUMBER(s) DAAK70-81-C-0056
9. PERFORMING ORGANIZATION NAME AND ADDRESS Goodyear Aerospace Corporation Engineered Fabrics Division Akron, Ohio 44315	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U S Army Mobility Equipment Research & Development Command Fort Belvoir, Virginia 22060	12. REPORT DATE October, 1982
	13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report) Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Tank, Collapsible, Rubberized Fabric, High-Profile, Nylon Cloth Reinforced, Nitrile Rubber Coated, Petroleum Fuel Storage.

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

This report describes the development and testing of an experimental 40,000 gallon collapsible, rubberized fabric, high-profile, petroleum fuel storage tank. The objective of the project was to develop a tank having a 40,000 gallon capacity which would occupy approximately the same ground area as a standard 20,000 gallon tank and meet the performance requirements of MIL-T-82123. The tank was developed based upon a military adaptation of a commercial item (MACI) study following which a prototype unit was fabricated and tested.

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The prototype tank assembly completed the functional testing without leakage but fitting collars were observed to lift during the stand test and overload test. A stress concentration was also seen to exist between the fill/discharge fittings and the body seams caused by the closeness of the fittings to the seams. The integrity of the tank was not affected by these conditions. During the overload test it was noticed that an approximate 2" long area of one end seam showed excessive elongation on the seam edge gum strip. The fitting collars and end seam were repaired prior to delivery of the tank to the Army.

All material tests were passed.

SUMMARY

This report describes the development of a high profile 40,000 gallon, collapsible, self-supporting, nitrile rubber coated nylon fabric tank for the storage of petroleum fuels. The project was executed in two phases, the first of which involved a MACI study in the development of the item, and the second the manufacture and test of a full scale prototype. The prototype tank had lay flat dimensions of 32′ x 28′ and was fabricated from 12 oz/sq yd nylon fabric coated with nitrile rubber coating compound. Two double rows of sewing were used in the body seams except for the final seam which had one double row of sewing. The end seams were unsewn. The tank was subjected to the functional tests of MIL-T-82123 which are reported in this document, and was delivered to the Army for field trials following testing.

PREFACE

The work described in this report was performed for the U.S. Army Mobility Equipment Research and Development Command (Army) under contract DAAK70-81-C-0056 and was performed by the Engineered Fabrics Division of the Goodyear Aerospace Corporation (GAC). All project management and design functions were performed in GAC's Akron, Ohio facilities. The prototype unit was fabricated in GAC's Rockmart, Georgia production facility using materials which were processed in Akron. All material and assembly testing was also performed in Akron.

The project was initiated in May 1981 and the completed prototype was shipped to the Army for field trials in September 1982.

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SECTION I - INTRODUCTION

This report describes the development of a 40,000 gallon, high profile fuel storage tank for the Army. The final configuration for the prototype unit was established in a MACI (Military Adaptable Commercial Item) program in Phase I. The Phase I effort involved the following tasks:

1. Perform a stress analysis for the 40,000 gallon tank.
2. Establish performance criteria for materials.
3. Conduct long term seam sample tests.
4. Correlate material properties to performance.
5. Study field repair procedures.
6. Propose specifications for the tank.
7. Present findings of the study to the Army.

The leading configuration identified in Phase I was fabricated as a prototype unit in Phase II, and was subjected to the functional tests of MIL-T-82123, except that the volume requirement was increased to 40,000 gallons, and the unit was stand tested for seven days with water rather than thirty days with fuel.

A. Project Goals

The objective of the project was to design and develop a 40,000 gallon self supporting storage tank meeting the service requirements of 20,000 gallon tanks in accordance with MIL-T-82123 using commercially available nitrile rubber coated fabric materials, state-of-the-art manufacturing technology, and based on tank flat dimensions of 32′ x 28′ or 32′ x 32′. A 32′ x 30′ tank was also considered.

B. Approach

The approach used to develope the 40,000 gallon tank was to study the factors which contribute to the performance of the 20,000 gallon tank in relationship to specification requirements and its observed service life, and then apply these factors to the design of the tank. Those factors felt to have the greatest affect on performance were studied in detail. These were the fabric stresses expected in the various designs under consideration, the affect of prolonged application of stress on tank seams and the tear characteristics of the fabrics considered for use in the tank. A structural analysis was conducted to develop the relationships between tank dimensions, volume and fabric stress for each candidate tank configuration. The physical properties of candidate materials were evaluated, which included evaluation of seam samples tested in dead load in fuel, and tear propagation properties of the candidate fabrics using a burst test.

These properties were related to tank performance, and the risks associated with each design were identified. A final configuration was selected and recommended to the Army for fabrication into a prototype unit.

A 32′ x 28′ configuration was selected based on using 12 oz/sq yd nylon fabric coated with nitrile rubber compound, and a prototype unit was fabricated and tested.

C. Scope of this Report

This document was prepared to satisfy the requirements of contract data item A007, Final Technical Report, and describes the development and testing of a prototype 40,000 gallon fuel storage tank.

SECTION II - PHASE I MACI STUDY

The rationale of the approach to the developement of the 40,000 gallon tank is shown in Figure 1. Fabric stresses in standard 20,000 gallon tanks were compared with specification requirements and with field experience to establish the factors which contribute to tank performance. These factors were then compared to the predicted requirements of the 40,000 gallon, high profile tank.

The project was limited to studying only nitrile rubber coated nylon fabric. Only currently available nitrile rubber coating compounds and adhesives were considered since the project involved modification of a commercially available item. Therefore, the only material factor to be determined is the strength of nylon fabric required. Material processing and tank fabrication methods are set by GAC's current manufacturing capability and therefore will not enter the analysis. The critical design factors in the 40,000 gallon tank are the increased stress expected and the ability of the coated fabric construction to resist high stresses over relatively long time periods. The developement effort involved calculating the stresses expected in the candidate tank sizes and evaluating the properties of candidate constructions under constant dead load. Since tear can influence the performance of the tank, particularly at the higher stress levels, the tear properties of candidate materials were also investigated. These efforts are discussed in the sections which follow.

FIGURE 1

PREDICTED SERVICE LIFE FACTORS

A. PRESENT 20,000 GALLON TANK

PRESENT SPECIFICATION TANK OPERATING AT 30 - 40 LBS/IN.	MANUFACTURING PROCESSES AND MATERIALS	LAB TEST RESULTS	FIELD TEST RESULTS	PREDICTED SERVICE LIFE

B. PROTOTYPE 40,000 GALLON TANK

PRFLIMINARY SPECIFICATION TANK OPERATING AT 63 - 110.8 LBS/IN.	MANUFACTURING PROCESSES AND MATERIALS	EXPANDED LAB TEST RESULTS TO INCLUDE LONG TERM LOADINGS	OTHER DATA	PREDICTED SERVICE LIFE

A. Structural Analysis Relationships to Tank Performance

Tank stress, design factor and fill fraction versus tank capacity were calculated for the candidate sizes. These relationships were also developed for a conventional 28′ X 24′ 20,000 gallon tank filled to 40,000 gallons, and a 54′ X 24′ 40,000 gallon tank based on a design factor of 15, the same as a standard 20,000 gallon tank. This data is shown in Figure 2 which also shows the height of the tanks at various capacities. Figure 3 shows these parametric relationships for the 32" X 28" tank separatly. Note that the stress in the fabric increases rapidly as the capacity of any design is increased above fill ratios of approximately 0.7 to 0.8. Fabric tension was calculated using the equation:

$$T = \frac{pH^2k^2}{4}, \text{ lbs./in.}$$

where $k^2 = 1 - \frac{h^2}{h^2}$

p = Fluid Density, lbs/sq in.

H = Height of fill fluid in the tank, ft.

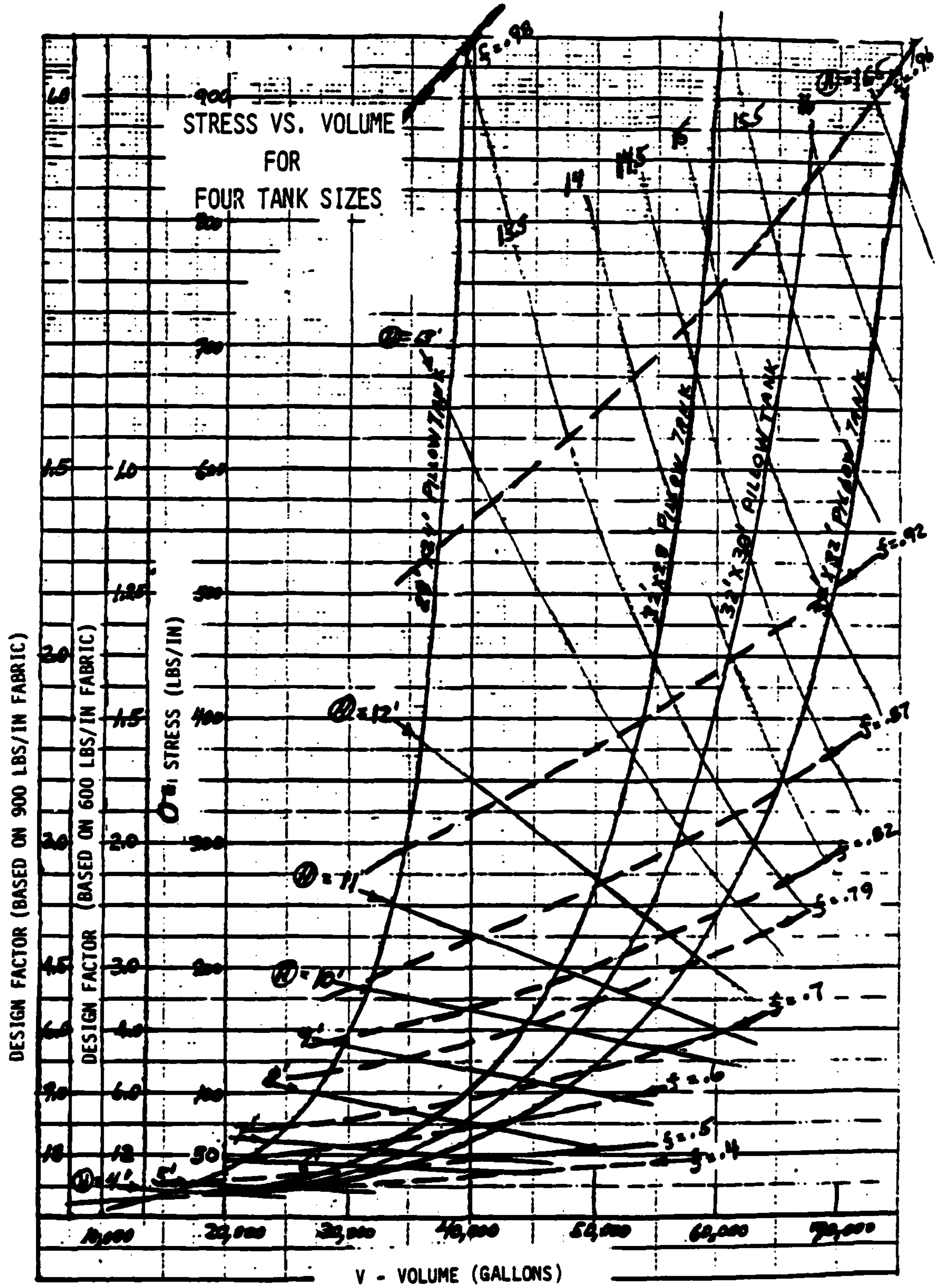


FIGURE 2 - STRESS VS. VOLUME FOR FOUR TANK SIZES

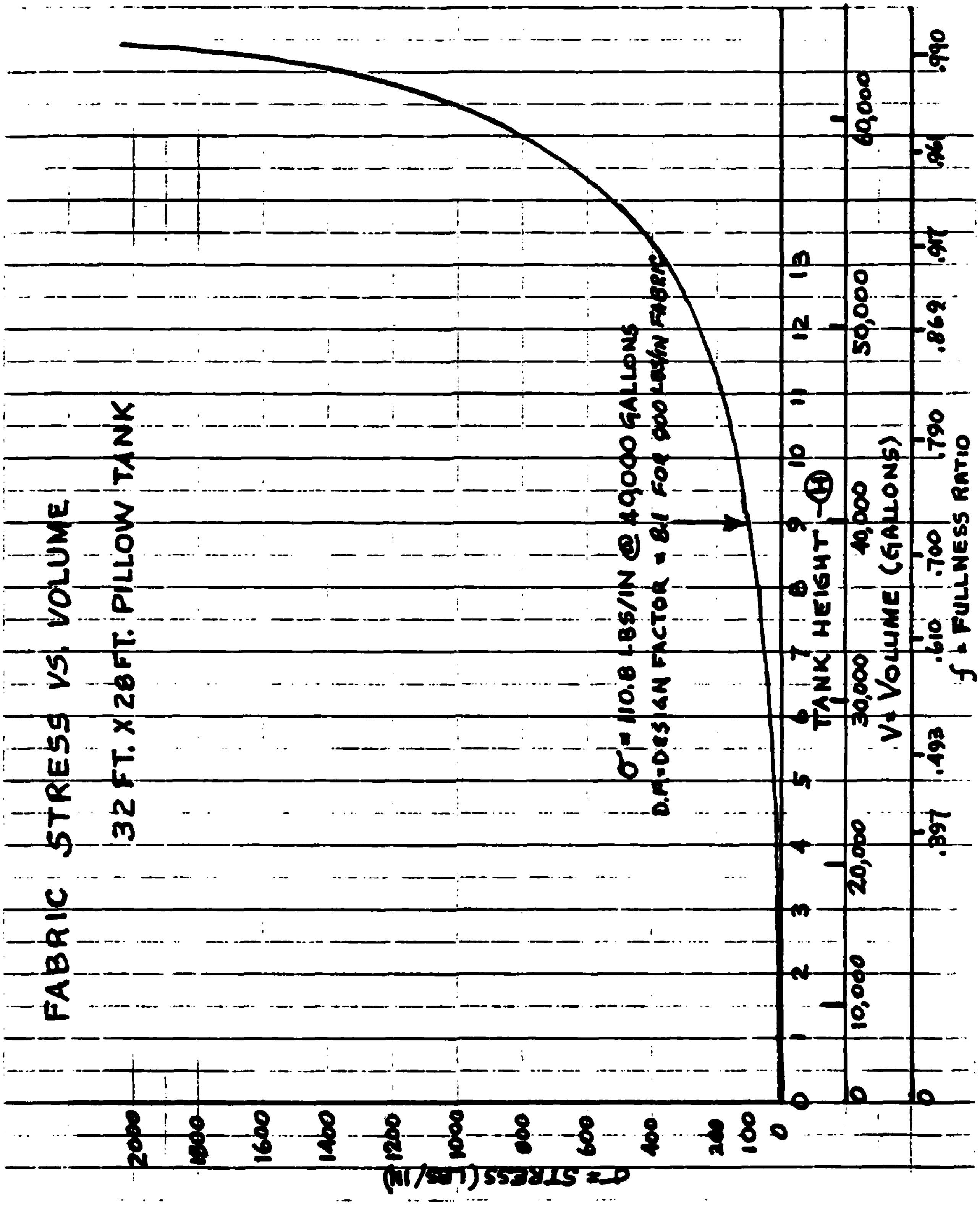
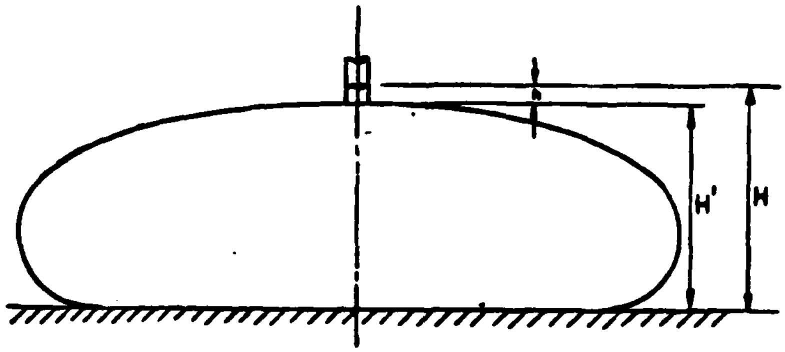


FIGURE 3 - FABRIC STRESS VS. VOLUME FOR 32' X 28' TANK

A sketch defining these parameters is shown below:



The height of each candidate tank size was calculated for various levels of fill based on an empirical dimensional relationship previously developed by GAC. Percent fill is defined as the cross sectional area of a tank at a particular fill level divided by the cross sectional area of a circle with a circumference equal to twice the width of the tank under consideration, i.e. $2W=\pi D$.

The tank parameters established for five tank sizes at a 40,000 gallon fill level are shown in Table 1.

Table 1 - Tank Design Parameters at 40,000 Gallon Capacity

Tank Size	Stress (lbs/in)	Fill Fraction	Tank Height, ft
28′ x 24′	1170.0	.99	15.0
32′ x 28′	110.8	.71	8.7
32′ x 30′	79.8	.63	8.1
32′ x 32′	62.9	.55	7.5
54′ x 24′	33.7	.54	5.5

This data shows that a 28′ X 24′ tank will not survive being filled to 40,000 gallons. With a design factor of 5, a 60 oz/sq yd cloth would be required which would make the tank exceedingly heavy, not to mention the problems of designing seams capable of resisting the 1170 lb/in stress. The tank would be unstable since it would be essentially round (fill fraction of .99) and would roll on even a very gentle slope. Therefore, this configuration was eliminated as a candidate.

Nylon cloths are subject to some minor variations in breaking strengths as received from the mill. Therefore, selection of the cloth to be used in the 40,000 gallon tank was based on minimum acceptable breaking strengths. Based on the structural analysis, and considering the goal of increasing tank capacity while minimizing ground area, fabrics with breaking strength of at least 600 lbs/in were selected for study in this project. A 12 oz/sq yd and a 18 oz/sq yd cloth were selected as candidate materials. The design factors associated with using each of these cloths in each of the tank sizes under study is shown in Table 2.

Table 2 - Design Factor versus Cloth Weight and Tank Size

Configuration	Predicted Tank Stress (lbs/in.)	Design Factor 12 oz	18 oz
32′ x 28′	110.8	5.6	8.4
32′ x 30′	79.8	7.5	11.3
32′ x 32′	62.9	10.0	15.0
54′ x 24′*	33.7	17.8	26.7

* Design factor would be 14.8 with 10 oz/sq yd cloth having a minimum breaking strength of 500 lb/in.

Design factor here is defined to mean the minimum quick break strength of the fabric divided by the stress which will be imposed on the fabric. The design factor is not to be confused with a safety factor. Standard 20,000 gallon tanks have design factors of 15. However, based on more recent data and service experience, it is felt that tanks can be designed with design factors lower than 15.

Table 3 shows the percentage increase of capacity with each larger tank size under consideration. Note that capacity can be doubled with a 33.3% increase in tank area by increasing the 28′ X 24′ dimensions of the standard 20,000 gallon tank to 32′ X 28′. However, fabric tension will be increased over three times that of the standard 20,000 gallon tank.

TABLE 3

COMPARISON OF TANK AREAS VS VOLUME INCREASE

(USING 20,000 GAL. ENVELOPE SIZE AS BASE)

CAPACITY	FLAT SIZE (NOMINAL)	AREA INCREASE %	VOLUME INCREASE %
* 20,000 GALLON	28 FT X 24 FT	-----	-----
40,000 GALLON	32 FT X 28 FT	+ 33.3%	100%
40,000 GALLON	32 FT X 30 FT	+ 43.0%	100%
40,000 GALLON	32 FT X 32 FT	+ 52.4%	100%

* BASELINE

B. Material Physical Property Relationships to Performance

Two fabrics based on 12 oz/sq yd and 18 oz/sq yd basket weave nylon cloth with nitrile rubber compound were selected for study in this Phase of the project. These fabrics have nominal breaking strengths of 600 lb/in and 900 lb/in respectively. Data on samples prepared from these fabrics and tested to MIL-T-82123 requirements are shown in Tables 4 through 8. This data was obtained in the development and qualification testing of a 5,000 barrel tank produced for the Army and is typical of the performance of GAC's tank materials and construction. The seams tested were unsewn with a 2" lap in the XA22A579 and a 3" lap in the XA22A568.

1. Fabric Strength Considerations

Experience from the production of 20,000 gallon tanks indicates that coated fabrics, seams and fittings will perform satisfactorily in service if they meet the peel adhesion and tensile strength requirements of MIL-T-82123 for fuel, water and weathering resistance. The data in Tables 6 through 8 shows that the two candidate fabrics meet these requirements. The data also shows that the tensile strength of the 18 oz/sq yd fabric is approximately 50% greater than that of the 12 oz/sq yd material. However, the critical physical property in terms of tank performance is the ability of seams to survive continuous load application at the higher stresses expected in the 40,000 gallon tank.

TABLE 4 - PHYSICAL PROPERTIES OF CANDIDATE CLOTHS

Property	Requirement	Test Method Fed Std No. 191	290N	3624N
Thread Count, warp and fill	Record	5050	39X40	40X30
Weave	Record	Visual	2X2	3X4
Weight, oz/sq yd	Record	5041	11.6	17.59
Thickness, inches (1)	Record	5030.2	.020	.037
Tearing Strength, warp and fill, lbs	Record	5134	149X156	252X276
Breaking Strength, warp and fill, lbs/in (2)	Record	5104	720X718	1087X1067
Weathering resistance (after 100 hrs exposure at 5% elongation), % (2)(3)	50% Retention of original break strength, min.	5804	104X95	97X99

FOOTNOTES:

(1) The edges of the tear-test specimens were coated by dipping with an adhesive to preclude yarn slippage while under test.

(2) Alternate Corex D filters were removed. Specimens were raveled for Method 5104 after accelerated weathering.

(3) Ends of specimens for breaking strength test were coated by dipping into an adhesive that precluded yarn slippage under test. Only those parts that were held in the clamps during test were treated.

TABLE 5 - CHARACTERISTICS OF CURED ELASTOMERIC COATING COMPOUND M908

Property	Goal	Test Para or Test Method of Fed Std 601	Actual Data
Initial			
A. Tensile Strength, psi	Record	4111	1914
B. Stress at 200% Elongation, psi	record	4131	754
C. Ultimate Elongation, %	Record	4121	630
After Immersion in Distilled Water (ph 7.0±0.2) at 160±2 F.			
A. Volume Change			
A1. 14 Day, %	Record	6211	+8.9
A2. 70 Day, %	Record	6211	+6.0
B. Initial Tensile Strength Retained (1)			
B1. 14 Day, %	60 (min.)	6111 (5)	89.4
B2. 70 Day, %	40 (min.)	6111 (5)	87.8
After Immersion in fuel (4) at 160±2 F.			
A. Volume Change			
A1. 14 Day, %	Record	6211	+12.8
A2. 70 Day, %	Record	6211	+11.8
B. Initial Tensile Strength Retained			
B1. 14 Day, %	40 (min.)	6111 (5)	63.6
B2. 70 Day, %	30 (min.)	6111 (5)	57.5
After Accelerated Weathering for 500 hrs (3), Initial Tensile Strength Retained (1), %	75 (min.)		84.8
Fuel Contamination			
A. Unwashed Existent Gum, mg/100ml	20 (max.)	4.4.1	12.6
B. Heptane Washed Existent Gum, mg/100ml	5 (max.)	4.4.1	0.1

FOOTNOTES:

(1) The percentage tensile strength retained is:

$$\frac{\text{Tensile strength retained after immersion or weathering X 100}}{\text{Average initial tensile strength value obtained}}$$

(2) Tolerance for immersion periods ± 2 hours
(3) Exposed at 10% elongation with alternate Corex D filters in place
(4) 60% iso-octane and 40% toluene per ASTM D-471.
(5) Para. 4.8.1 of Method 6111 applies

TABLE 6 - PHYSICAL PkOPERTIES OF CANDIDATE CURED COATED FABRICS

Property	Requirement	MIL-T-82123 Para. or Method of FMTS 601	XA22 579	Axxx 568
Thickness, inches	0.040, min.	5030-1	0.070	0.082
Weight, oz/sq yd	30, min.	5041	61.27	68.58
Diffusion Rate, fl oz/sq ft/day	0.1, max.	4.4.2	0.092	0.082
Tearing Strength, warp and fill, lbs	35, min.	5134	105X89	77X77
Breaking Strength, warp and fill, lbs/in	600, min.	5102	828X730	863X814
Weathering resistance after 500 hrs exposure at 100 lbs/in(initial tension), warp and fill, %	80% retention of initial breaking strength, min.	5804/5102	70X59	--
Puncture resistance, lbs.	150, min.	4.4.3/5120	240	226
Low Temperature Crease Resistance:				
a. Appearance after unfolding	No cracking, peeling or delaminating	4.4.4	OK	Crack
b. Diffusion rate after low-temperature crease resistance test	0.10 fl oz/sq yd per 24 hrs., max	4.4.2	0.098	0.154
Fungus Resistance	No cracking, blistering or delamination of coating	5672	OK	OK
Breaking Strength after fungus exposure, % of original	50%, min.	5762/5102	100X83	95X136
Blocking	Specimens to separate within 5 seconds	4.4.5	OK	--
Coating Adhesion (initial) lbs/in	20, min.	4.4.6	86	51
Coating Adhesion after immersion in distilled water at 160 ± 2 F for the following durations:				
a. 14 days, lbs/in (%of org.)	10 lb/in or 30% of initial (3)	4.4.6	83(96%)	38(75%)
b. 42 days, lbs/in (%of org.)	5 lb/in or 20% of initial (3)	4.4.6	75(87%)	29(57%)
Coating adhesion after immersion in fuel (4) at 160 ± 2 F for the following durations:				
a. 14 days, lbs/in (%of org.)	10 lb/in or 40% of initial (3)	4.4.6	60(70%)	17(34%)
b. 42 days, lbs/in (%of org.)	10 lb/in or 40% of initial (3)	4.4.6	51(59%)	13(25%)

FOOTNOTES:

(1) Specimens were 1" wide. Care was taken to cut specimens parallel to and following the curvature of the threads of the fabric.
(2) Specimens were exposed to accelerated weathering before stripping or cutting to 1" width. (Note 1) Specimens were tensioned in the direction of the 6" length, under a stress of 100$\pm$5 lbs/in for 60 seconds. While still under stress, the specimens were clamped to maintain the initial (one minute) elongation without slippage. While still so elongated, specimens were exposed by Method 5804. Alternate Corex D filters were removed during test.
(3) Whichever is the greater requirement.
(4) 60% iso-octane and 40% toluene per ASTM D-471.

TABLE 7 - PHYSICAL PROPERTIES OF CURED SEAMS

Property	Requirement	Test Paragraph or Test Method of Fed. Std. No. 601	Data, XA22Axxx 579	Data, XA22Axxx 568
Breaking Strength, (initial)	600 lbs/in,min(2)	8311/4.4.7	698	962
Breaking Strength after Immersion in Distilled Water @ 160±2 F. for the following durations:				
14 Days	500 lbs/in,min	8311/6001/4.4.7	556	790(5)
42 Days	450 lbs/in,min	8311/6001/4.4.7	523	---
Breaking Strength after Immersion in Fuel (4) @ 160±2 F. for the following durations:				
14 Days	500 lbs/in,min	8311/6001/4.4.7	593	585(5)
42 Days	450 lbs/in,min	8311/6001/4.4.7	741	---
Dead Load Shear Resistance Under 100 lbs/in Stress @ 200 F. for 8 hours	.125 in. slippage (max)	4.4.8	Passed	(6)
Peel Adhesion (initial)	20 lbs/in,min	8011	79	(6)
Peel Adhesion after Immersion in Distilled Water @ 160±2 F. for the following durations:				
14 Days	10 lbs/in or 30% of initial, min (3)	6011/6001/4.4.7	79(100%)	(6)
42 Days	5 lbs/in or 20% of initial,min (3)	8011/6001/4.4.7	66(84%)	(6)
Peel Adhesion after Immersion in Fuel (4) @ 160±2 F. for the following durations:				
14 Days	10 lbs/in or 40% of initial,min (3)	8011/6001/4.4.7	43(54%)	(6)
42 Days	10 lbs/in or 30% of initial,min (3)	8011/6001/4.4.7	42(53%)	(6)

FOOTNOTES:

(1) Properties after cure.
(2) All specimens broke in the coated fabric. Failure of any specimen in a seam area at any value shall constitute failure of the test.
(3) Whichever is the greater requirement.
(4) 60% iso-octane and 40% toluene per ASTM D0471.
(5) After 7 days exposed at 160 F.
(6) Data will be similar to that obtained for XA22A579.

TABLE 8 - CHARACTERISTICS OF ALUMINUM BONDED FITTINGS (1)

Property	Requirement	Test Paragraph or Test Method of Fed. Std. No. 601	Data
Bond Strength, (initial)	600 lbs/in,min	4.4.9 / 4.4.9.1	988
Bond Strength after Immersion in Distilled Water @ 160±2 F. for the following durations:			
14 Days	500 lbs/in,min	4.4.9.2	89
42 Days	450 lbs/in,min	4.4.9.2	940
Bond Strength after Immersion in Fuel (3) @ 160±2 F. for the following durations:			
14 Days	500 lbs/in,min	4.4.9.2	574
42 Days	450 lbs/in,min	4.4.9.2	822
Dead Load Shear Resistance Under 100 lbs/in Stress @ 200 F. for 8 hours	.125 in. slippage (max)	4.4.9.3	Passed
Peel Adhesion (initial)	20 lbs/in,min	4.4.10	61
Peel Adhesion after Immersion in Distilled Water @ 160±2 F. for the following durations:			
14 Days	10 lbs/in or 30% of initial, min (2)	8031/4.4.10.1	50(82%)
42 Days	5 lbs/in or 20% of initial,min (2)	8031/4.4.10.1	58(95%)
Peel Adhesion after Immersion in Fuel (3) @ 160±2 F. for the following durations:			
14 Days	10 lbs/in or 40% of initial,min (2)	8031/4.4.10.1	30(48%)
42 Days	10 lbs/in or 30% of initial,min (2)	8031/4.4.10.1	38(62%)

FOOTNOTES:

(1) Properties after cure.
(2) Whichever is the greater requirement.
(3) 60% iso-octane and 40% toluene per ASDM D-471.

2. Dead Load Resistance of Seams

The performance of seams in the high profile tank is of considerable importance. They will have to survive loads at least three times higher than those in a conventional 20,000 gallon tank. The concern is the performance of the seams under continuous high dead load stress. Present military specifications for collapsible tanks require seams to be tested at relatively high loading rates which may not relate to the stress conditions seams see in actual service. At higher operating stress there is greater likelihood of tank failure due to prolonged stress application in the seam or fabric. Our experience is that a cloths ability to survive dead load exposure is a semi-logarithmic function of time and percentage of quick break strength of the fabric. GAC has obtained dead load performance data in previous company sponsored studies which indicate that XA22A579 nitrile rubber coated 12 oz/sq yd basket weave nylon fabric tested in water with no seams present, will survive dead load exposure for more than five years at 110 lbs/in with no seams present. Ideally, seamed fabric should also show this dead load performance.

In addition to the seam data shown in Table 7, seam samples were also subjected to dead load exposure in fuel at ambient temperature. The samples were 2" wide specimens made from both candidate coated fabrics with

2 1/2" lap seams. Seams were tested unsewn, sewn with one double row of stitching and with two double rows of stitching as shown in Figure 4. No. 4 nylon thread was used with 5-7 stitches per inch. Constant dead loads of 400, 300, and 200 lbs/in were imposed on the samples and the time to failure was recorded. The test set up is shown in Figure 5. These tests are continuing but the data obtained is shown in Table 9. The data is also shown graphically in Figures 6 through 9.

Dead load seam data obtained in the development of the 5000 barrel tank project is shown in Figures 10 and 11 for comparison. The XA22A565 fabric used is the same fabric as the XA22A579 used in the present project except for the width of the processed fabric. The XA22A566 fabric used was a special 18 oz/sq yd material. Two inch wide seams were used in the XA22A565 fabric and three inch wide seams were used in the XA22A566 material. Seams were unsewn in both cases. In addition, 2 1/2" wide unsewn seams in the XA22A579 material have been subjected to dead load testing at 75 and 150 lbs/in in fuel at company expense. These seams have been on test for over two years without failure.

GAC feels that laboratory dead load seam tests are considerably more severe than conditions in actual tanks for two reasons. The first is that the sample is totally immersed in fuel. Fuel can wick into the yarns of the sample at its cut edges and reach the seam which will tend to accelerate

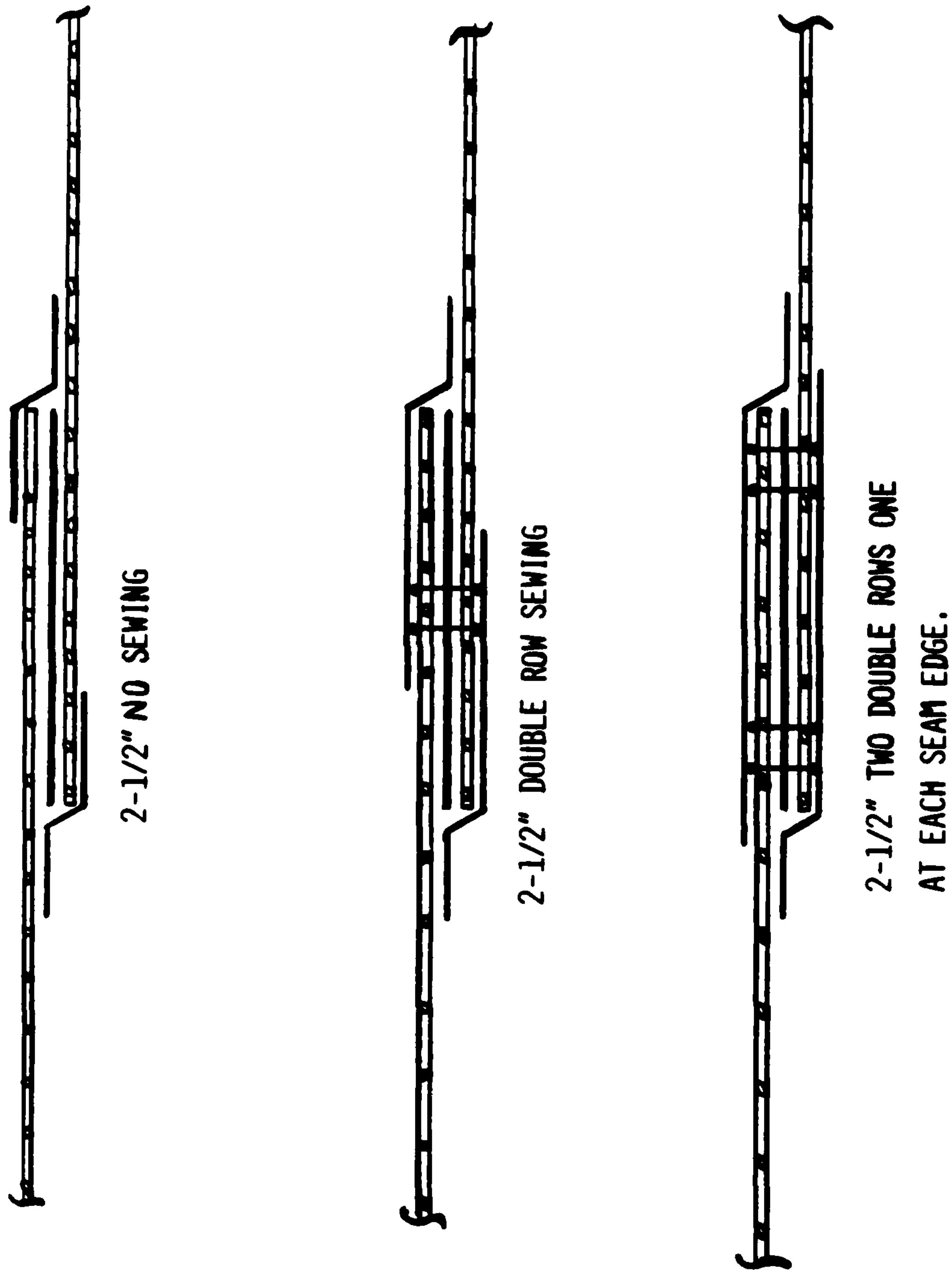
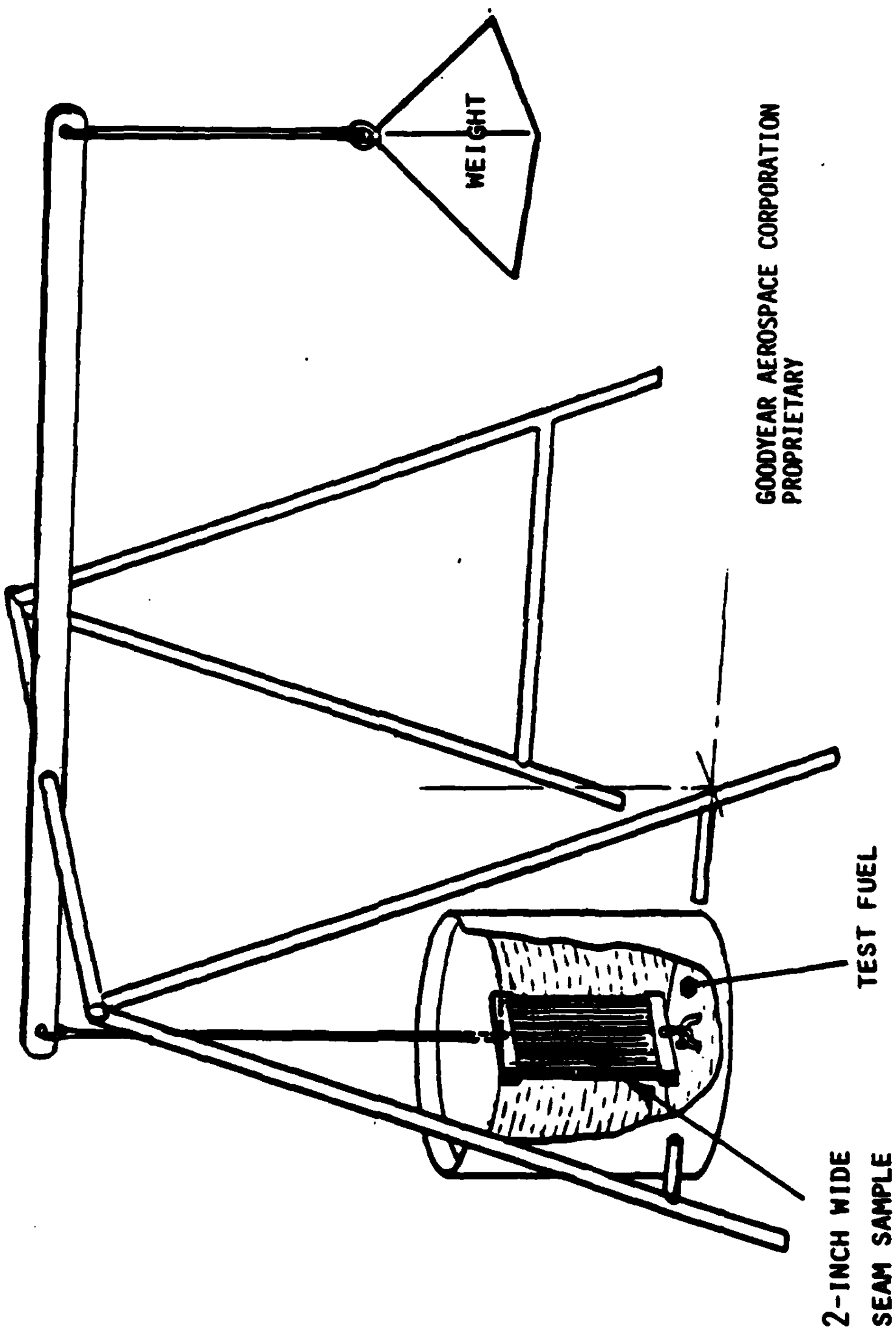


FIGURE 4 - SEAM DESIGNS STUDIED IN DEAD LOAD

FIGURE 5

DEAD LOAD SEAM TESTER



GOODYEAR AEROSPACE CORPORATION
PROPRIETARY

TABLE 9
Seam Dead Load Results
Hours to Failure in JP-4 Fuel

Load lbs/in	XA22A579 (12 oz nylon) Unsewn	Sewn 1dbl rw	Sewn 2dbl row	XA22A568 (18 oz nylon) Unsewn	Sewn 1dbl row	Sewn 2dbl row
	7.1	0.7	88.6	26.5	28.8	67.2
	9.0	0.3	54.8	10.5	13.5	30.5
	13.0	0.7	32.3	19.7	14.0	28.6
	26.2	9.4				
400	36.0	28.7				
	36.3	28.0				
	50.4	323.8				
	124.0	44.3				
	131.3	426.0				
	151.5	256.0				
	114.0					
	77.4					
	8.9	11.0	9200+	45.0	87.0	9926+
	24.2	2.0	636.8	54.0	30.7	455.8
	8.5	13.0	9816+	36.0	54.0	9796+
300	109.2	164.0				
	65.6	244.7				
	209.6	376.1				
	247.7	7996+				
	290.1	8526+				
	544.6	9996+				
	303.6	8376+				
	1017.9	8376+				
	275.2	9426+				
	38.3	9505+				
200	102.0					
	7396+					

+ means accumulated hours with no failure as of 9/1/82.

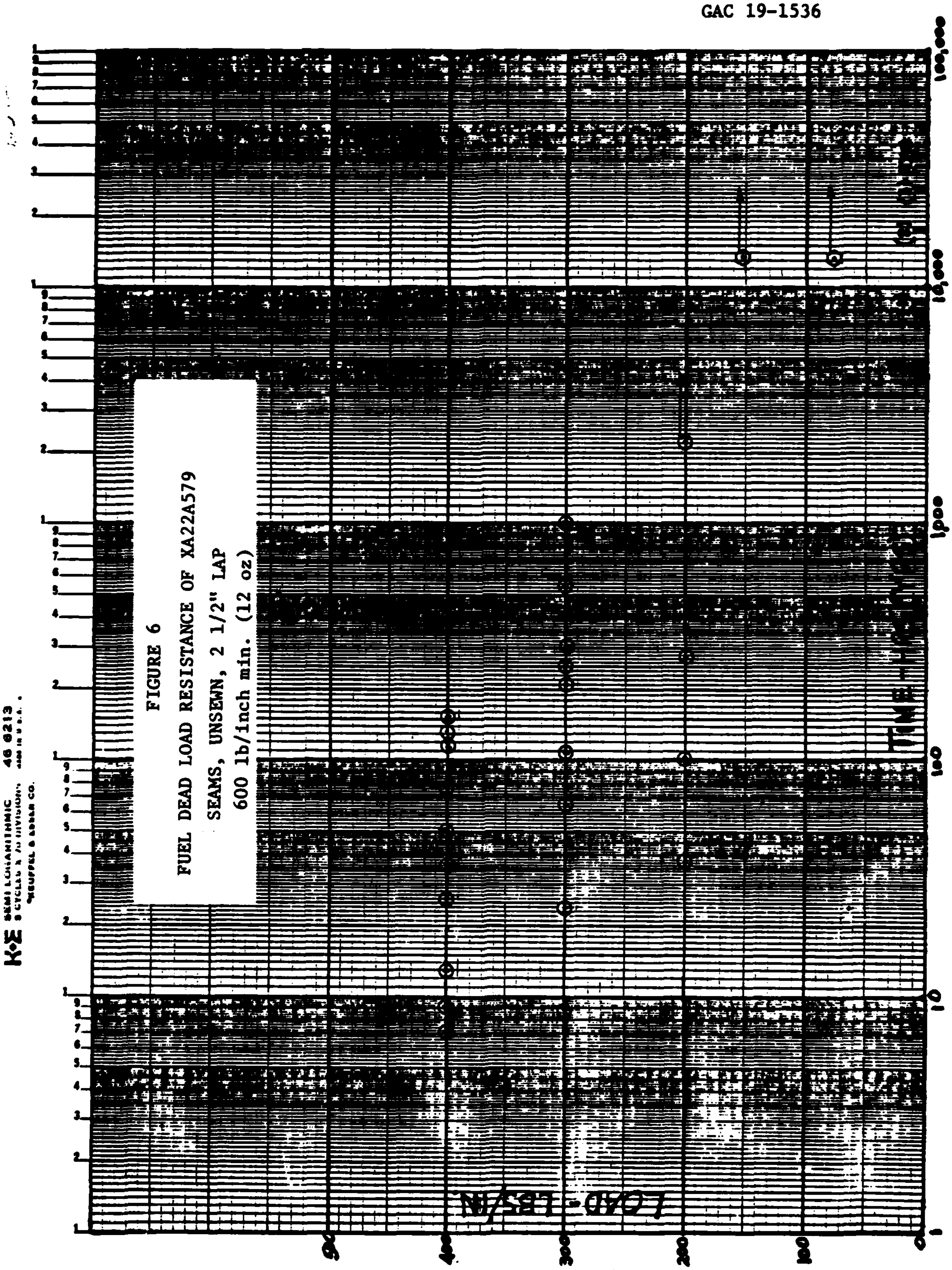


FIGURE 6
FUEL DEAD LOAD RESISTANCE OF XA22A579
SEAMS, UNSEWN, 2 1/2" LAP
600 lb/inch min. (12 oz)

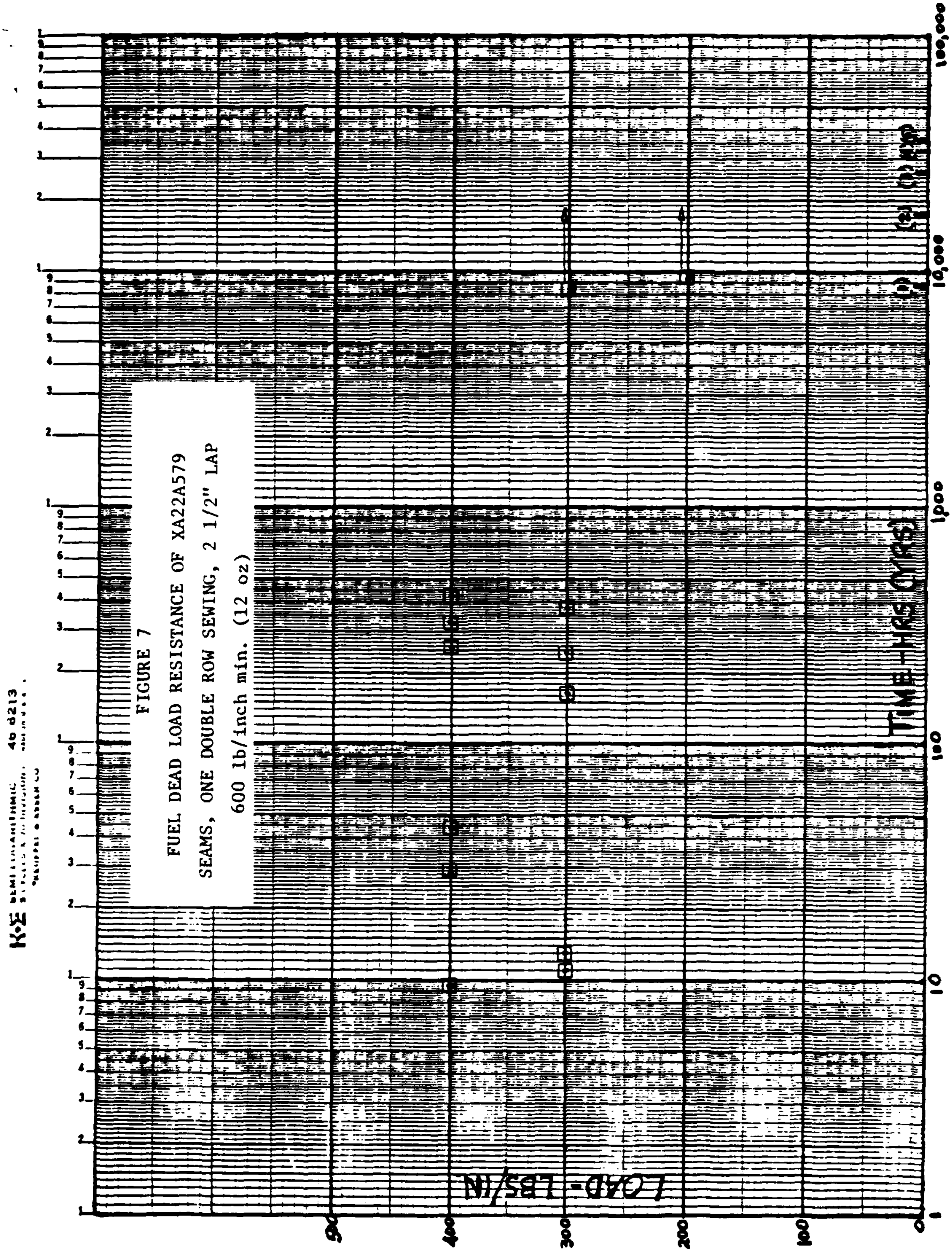


FIGURE 7

FUEL DEAD LOAD RESISTANCE OF XA22A579 SEAMS, ONE DOUBLE ROW SEWING, 2 1/2" LAP 600 lb/inch min. (12 oz)

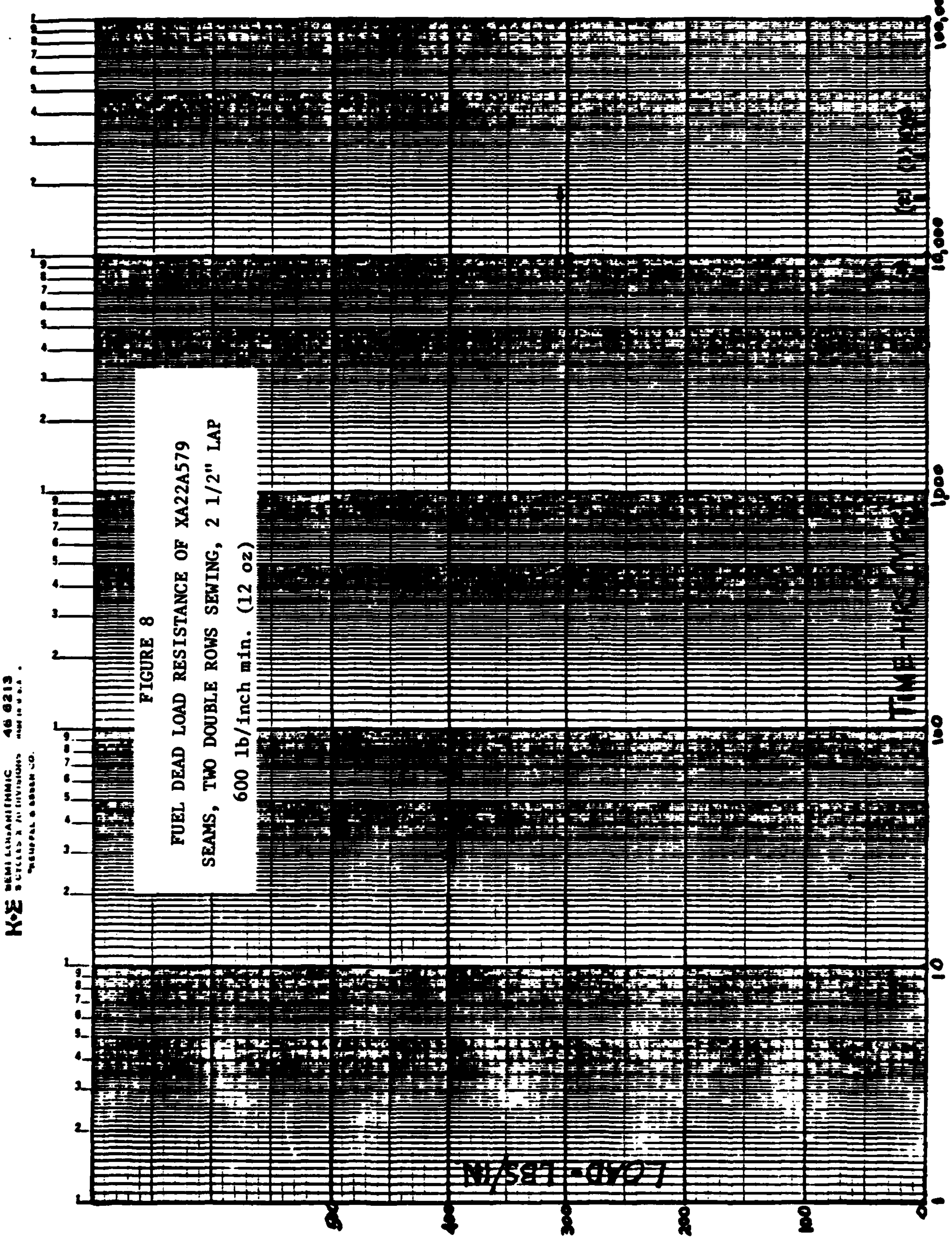


FIGURE 8
FUEL DEAD LOAD RESISTANCE OF XA22A579
SEAMS, TWO DOUBLE ROWS SEWING, 2 1/2" LAP
600 lb/inch min. (12 oz)

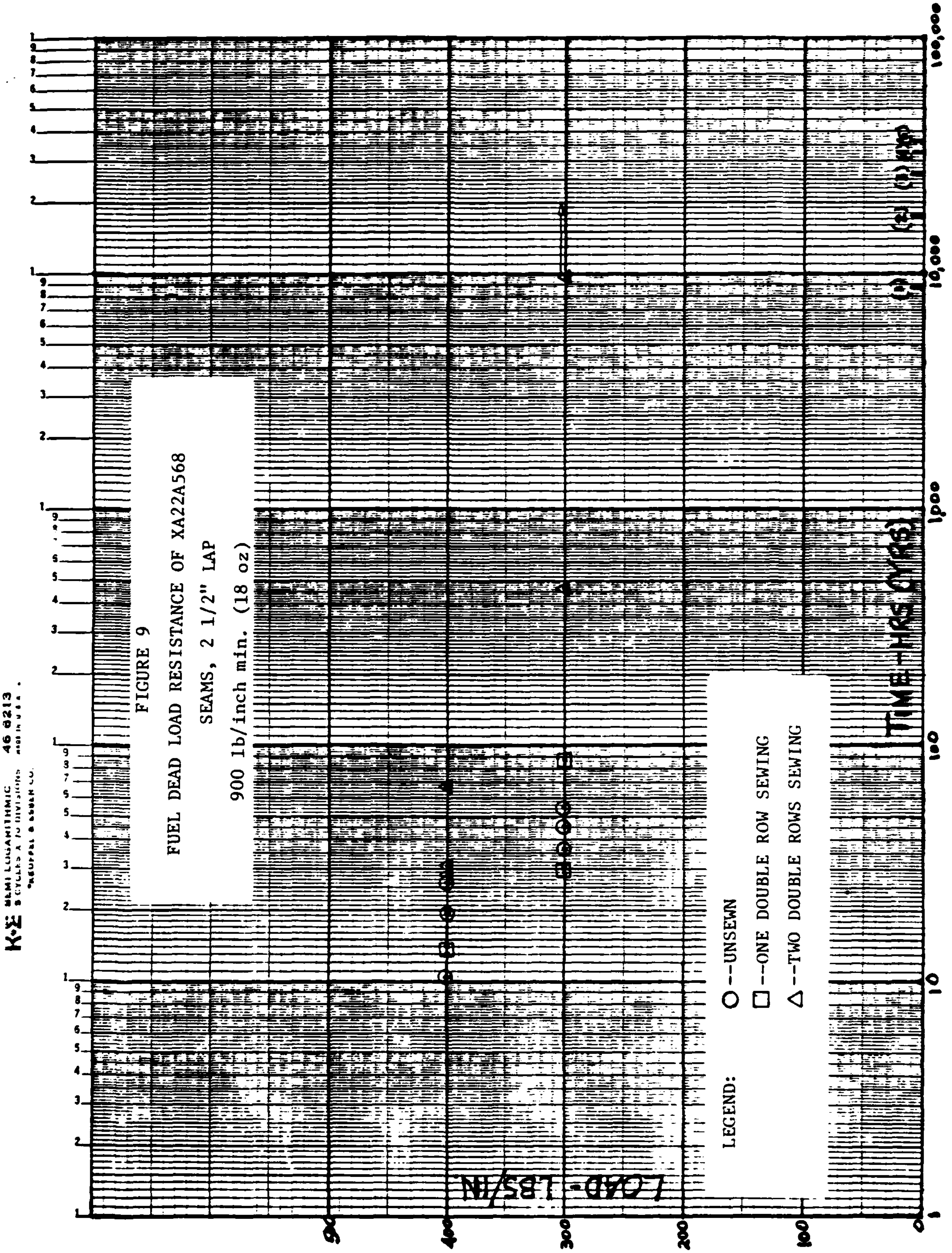


FIGURE 9
FUEL DEAD LOAD RESISTANCE OF XA22A568
SEAMS, 2 1/2" LAP
900 lb/inch min. (18 oz)

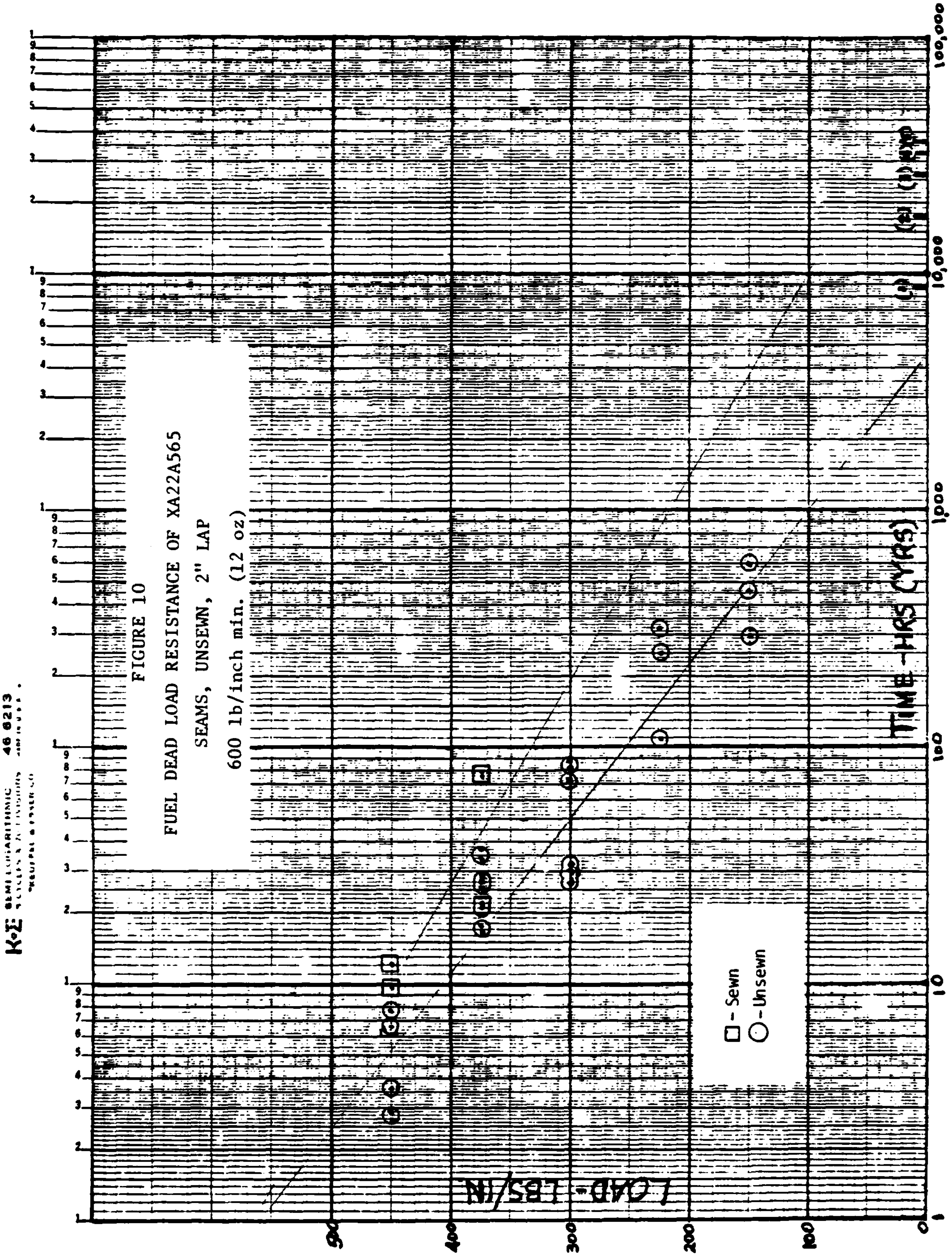


FIGURE 10
FUEL DEAD LOAD RESISTANCE OF XA22A565 SEAMS, UNSEWN, 2" LAP
600 lb/inch min. (12 oz)

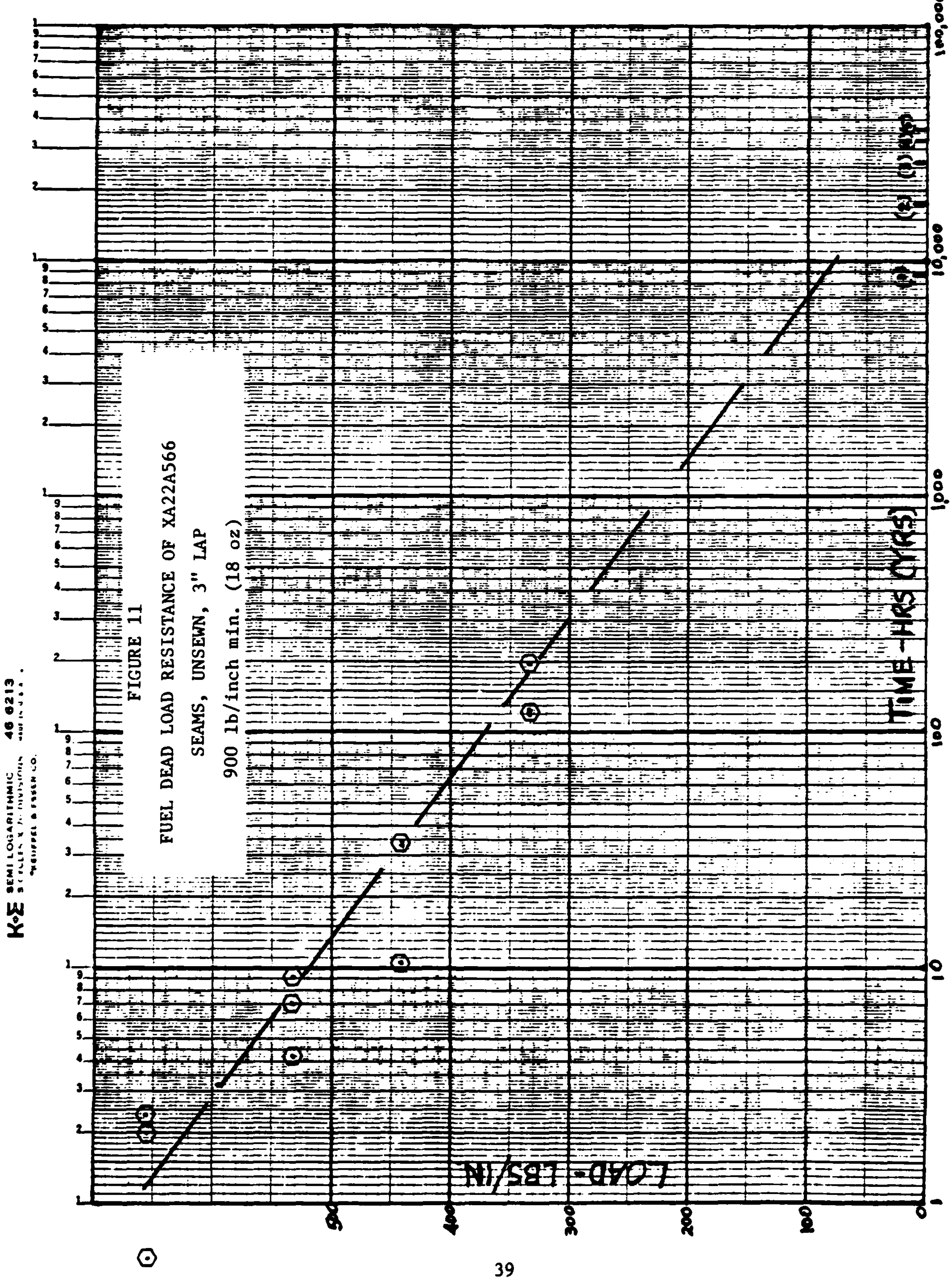


FIGURE 11

FUEL DEAD LOAD RESISTANCE OF XA22A566

SEAMS, UNSEWN, 3" LAP

900 lb/inch min. (18 oz)

the affect of fuel exposure on the performance of the seam. Second, and more critical, is that the success of a 2" wide sample is greatly dependent on the allignment of cords running accross the seam, i.e. upon their being parallel with the load path. If cords are skewed in the sample, or not parallel with the load path, a few degrees difference in the angle of cords across the seam can result in severe stress concentrations at its edges during test. The number of cords running from grip to seam can be reduced since cords are likely to be cut in the 21" length of the samples with a resulting stress concentration at the edge which can cause zipper like failure from one edge of the seam to the other. Tanks do not see this condition since seams run the full length of the unit and loads are distributed uniformly along the length of the fabric patterns. Stress concentrations at seam edges in test samples also tends to place the corners in peel rather than shear which can also lead to premature failure. Again, seams in tanks will not see this condition since they run the full length of the tank. The test problems just described could have been reduced if wider samples had been used, but we could not exercise this option because of the limited load carrying capacity of the test fixtures.

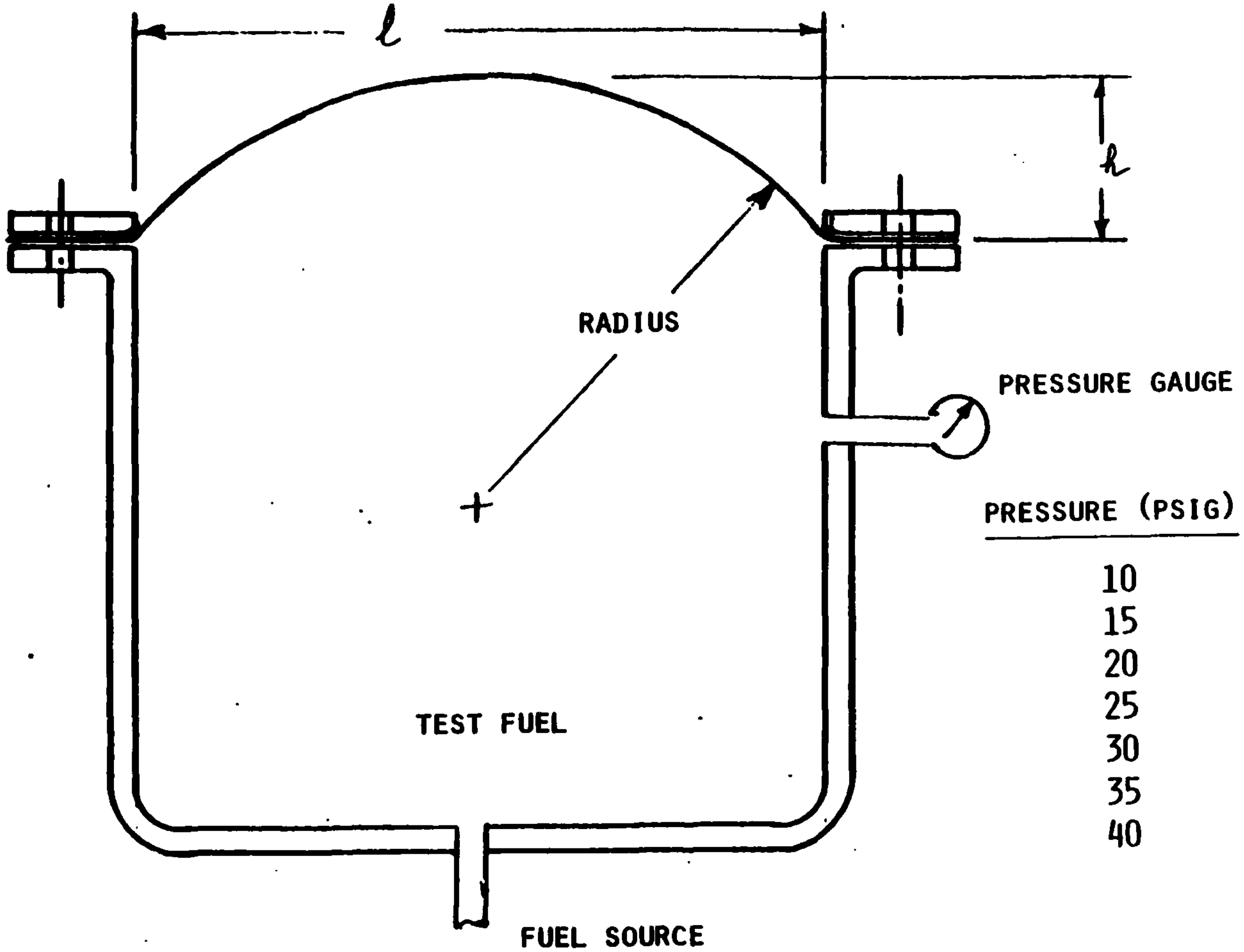
A second type of seam dead load test was also conducted which involved fabricating a seam in a panel of 12 oz/sq yd material which was then mounted to a 18" pressure pot test fixture. The fixture was filled with fuel and pressurized to impose a stress on the seam in the center of the panel as shown in Figure 12. The pressure was maintained over time and the performance of the panel observed. The data resulting from this effort is shown in Table 10. This table also shows the results of dead load tests on 1" wide samples conducted under elevated temperature and humidity. The relationship between pressure in the pressure pot and the stress imposed on the fabric sample is shown in Figure 12. This test has the advantage that edge effects are eliminated and loads are applied more uniformly across the seam, but has the disadvantage that only relatively low loads can be applied to the sample.

The critical issue in analyzing the dead load performance data is the relationship of laboratory seam dead load performance to the service life it represents in actual tanks. We will assume that tanks have a service life of one year under continuous dead load. This is probably a more severe condition than what they actually see, since they will be subjected to cyclical loading as fuel is removed for vehical use and refilled as fuel supplies are replenished, and will not be subjected to continuous high stress.

The seam dead load test results suggests that all of the constructions tested will provide one years service at a 111 lb/in stress level regardless of which seam type is considered. The time to failure indicates that seams will survive the service requirement if properly fabricated

FIGURE 12

PRESSURE POT TEST



PRESSURE (PSIG)	STRESS LBS/IN
10	67
15	89
20	92
25	112
30	133
35	153
40	171

TABLE 10

SEAM TEST DATA

GOODYEAR AEROSPACE CORPORATION
PROPRIETARY

PRESSURE POT

SAMPLE	LOAD (LBS/IN)	DURATION (HRS).	ENVIRONMENT
#1 (SEWN)	32.0	6,500	160°F HOT FUEL
1 "	52.0	2,000 - 3,000	" " "
#2 (UNSEWN)	41.5	6,500	AMBT FUEL
2 (UNSEWN)	52.0	2,000 - 3,000	" "
#3 (SEWN)	26.0	6,500	" "
#4 (UNSEWN)	40.5	6,500	160° HOT FUEL
4 (UNSEWN)	52.0	2,000 - 3,000	" " "

DEAD LOAD - STRIPS (1-INCH)

	LOAD (LBS/IN.)	DURATION (HRS)	ENVIRONMENT
UNSEWN	100	11,500 PLUS	95% RH @ 140-160°F
SEWN	100		
SEWN	50		
UNSEWN	50		
UNSEWN	100		
SEWN	50		

regardless of the seam construction, but the data shows a great deal of variablity except for that obtained on the double sewn seams. Notice that the performance of these seams approaches that of the unseamed fabric, and that they consistently out performed unsewn samples or those with only one double row of sewing.

3. Tear Propagation Properties of Candidate Fabrics

The tear propagation properties of the candidate coated fabrics were measured using a cylinder burst test apparatus proprietary to GAC which is shown schematically in Figure 13. The data resulting from this test was used to supplement the tear and puncture data shown in Table 6. The cylinder burst test involved fabricating cylinders of fabrics which are slit a prescribed distance and temporarily sealed. Samples were mounted on the test machine and a large volume of air instantaneously introduced into the cylinder. The pressure required to force tearing of the slit is measured using appropriate instrumentation, which is then converted to a fabric stress value at the tear pressure. Cylinders with different slit lengths are tested in each material and a tear versus stress profile is developed. Figure 14 shows the results of this testing.

In considering tear propagation, one must decide upon the size of a cut or puncture that the tank must survive. Table 11 shows the critical slit

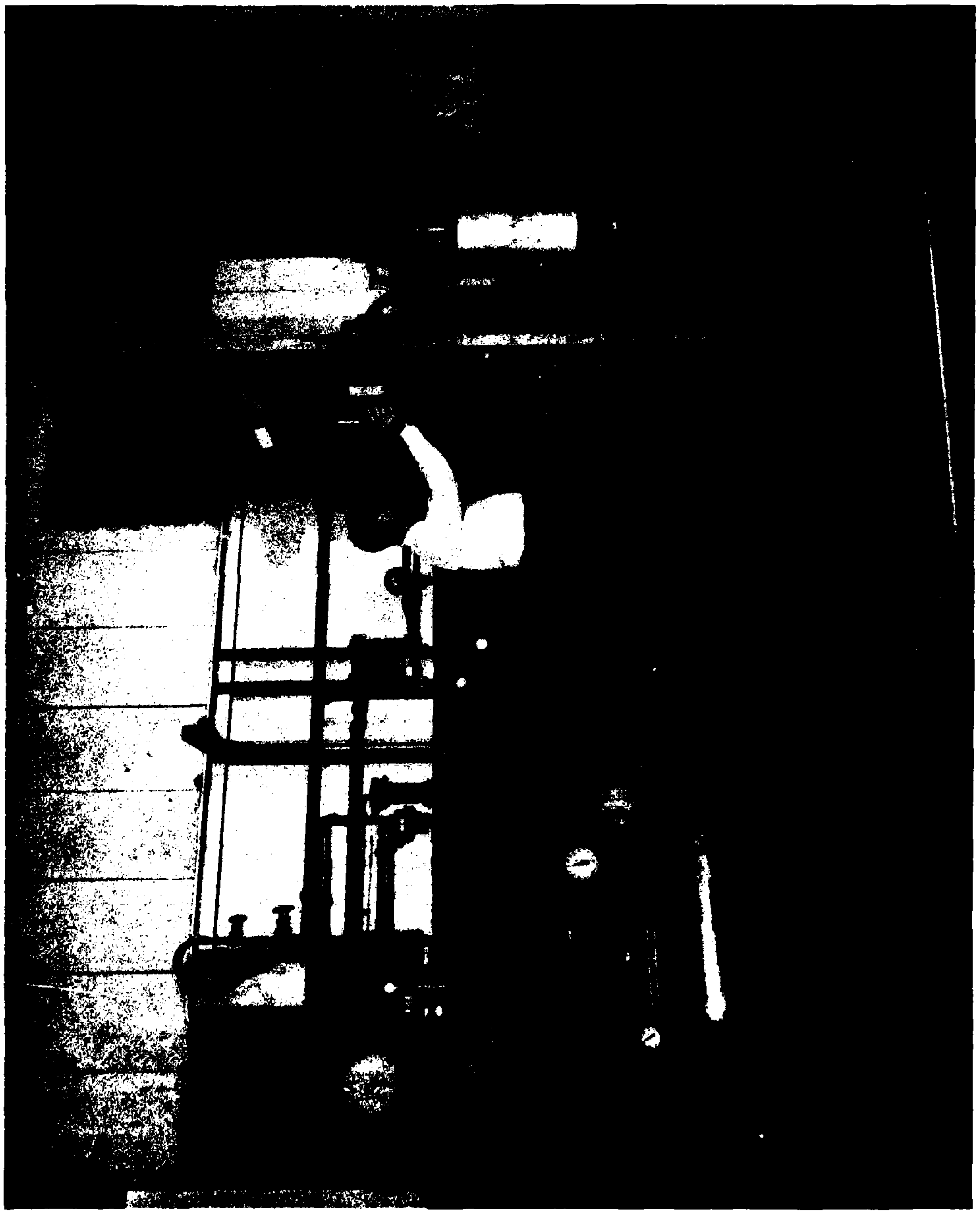


Figure 13 - Cylinder Burst Test Apparatus

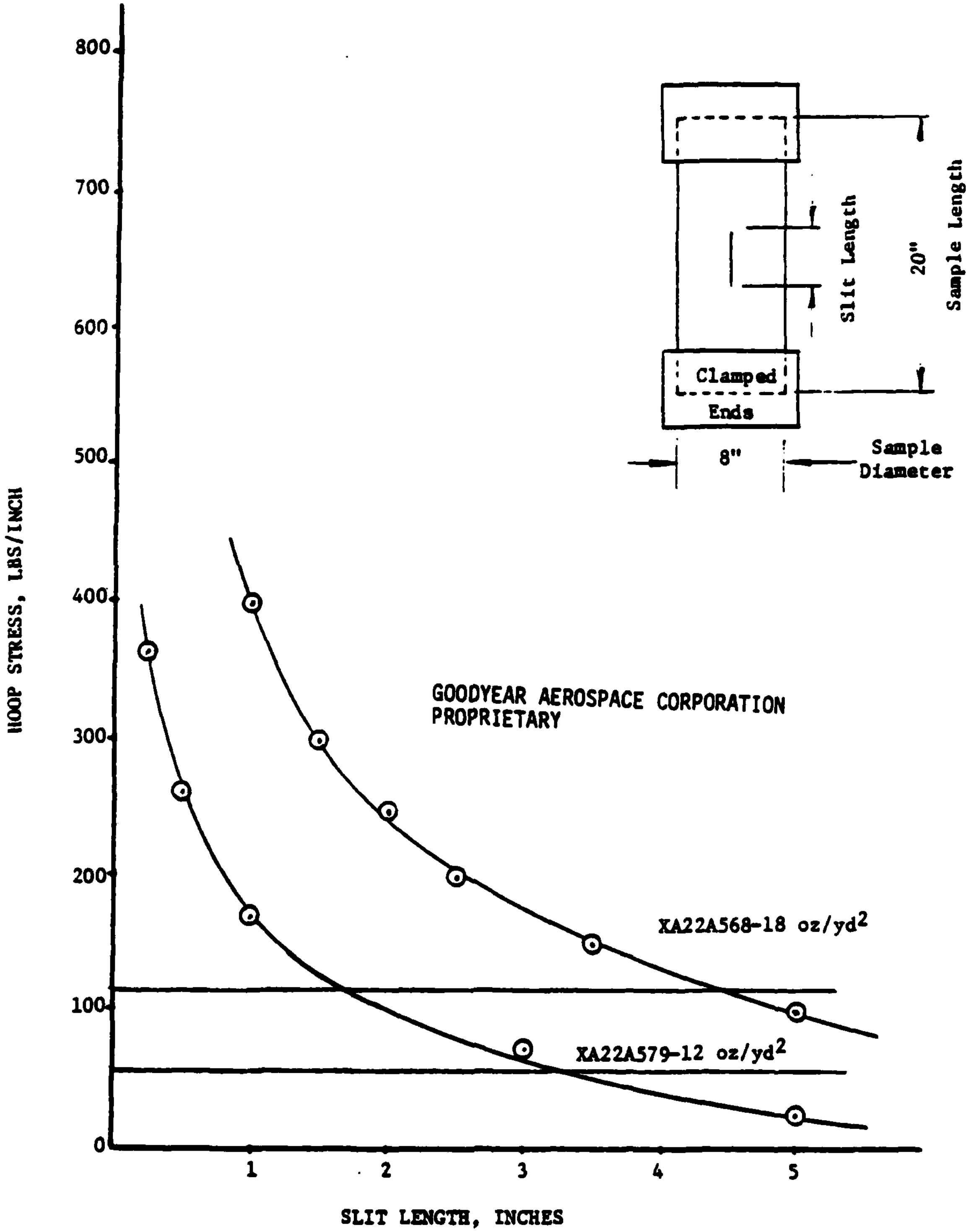


FIGURE 14 - FABRIC STRESS AT WHICH TEARS PROPOGATE VS SLIT LENGTH

length for tear propagation in each of the two candidate fabrics for each of the tank sizes under consideration.

Table 11 - Critical Slit Length for Rupture of a Cut

Configuration	Stress (lbs/in.)	Critical Slit XA22A579	Length, inchs XA22A568
32′ x 28′	110.8	1.75	4.5
32′ x 30′	79.8	2.5	5.6
32′ x 32′	62.9	3.50	6.0+

The assumption is made that a one inch tear or puncture can be tolerated since this would be the largest cut or puncture expected from accidental damage or small arms fire. Under these conditions either candidate fabric will perform satisfactorily.

4. Strength of Bonded Fittings

Fitting pull out data was obtained in addition to the fitting adhesion and breaking strength data shown in Table 8. The panels were made using a 6" dia. vent fitting in a 22" dia. panel of each of the candidate coated fabrics. These panels were tested on an Instron tester at a 1" per minute cross-head speed. The test set up and resulting data are shown in Figure 15. The panel made from XA22A579 failed by pull out at 531 lbs/in. The panel made from XA22A568 failed by fabric pull out at 540 lbs/in. This performance will be satisfactory for the 40,000 gallon tank since it

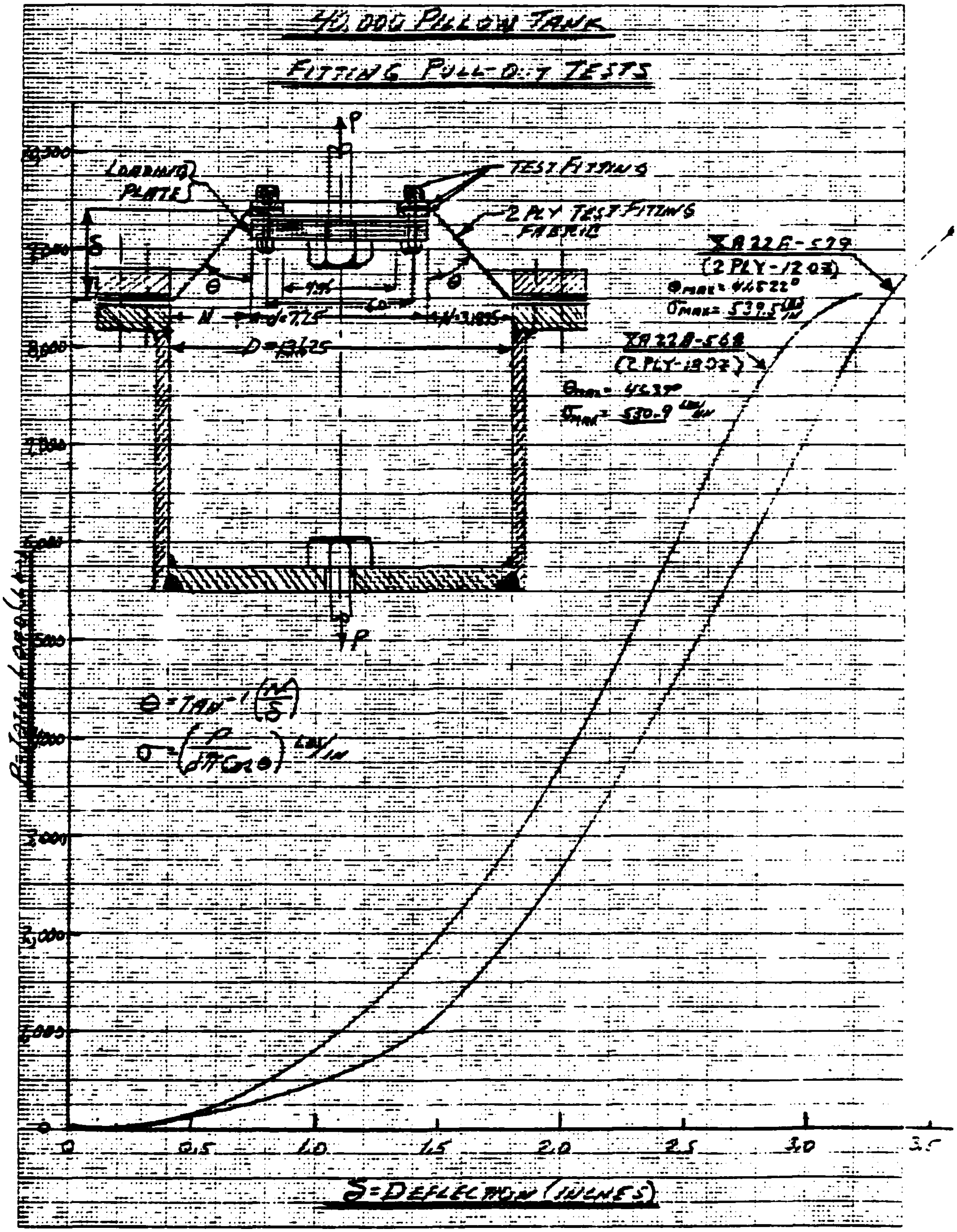


FIGURE 15 - FITTING PULL OUT TEST

represents a breaking strength nearly equal to that of the 12 oz/sq yd fabric and almost ten times greater than the fabric stress expected in the 32′ X 28′ tank size.

5. Tank Durability Considerations

Durability is defined to mean a tanks ability to withstand normal wear and tear in repeated use. As such, durability is a function of tank size, weight, puncture resistance and resistance to environmental conditions. The puncture resistance of both the candidate fabrics is greater than that of the 20,000 gallon tank material, and the empty weight per unit area of the 40,000 gallon configurations will not be considerably different from that of a standard 20,000 gallon tank. Puncture stresses imposed on the fabric during deployment of the 40,000 gallon tank will, therefore, not be much greater than those experienced by the 20,000 gallon tanks which easily survive deployment. Also, the data in Table 6 shows that both candidate fabrics provide excellent resistance to weather, water and fuel. Therefore, we can conclude that all tank configurations should be at least as durable as standard 20,000 gallon tanks.

C. Risk Analysis of Candidate Configurations

The risk associated with the use of either fabric in the tank sizes under study was objectively evaluated on the basis of the foregoing discussion. The results of this analysis are shown in Table 12. The general approach taken was to assume that risk increased as the operating stress of each tank configuration increased. Similarly, it was assumed that the degree of risk was reduced as the strength of the fabric used in each configuration was increased and as sewing was included in the seam designs being considered. Based on the results of the dead load tests, the candidate construction exhibiting the least risk is the one involving two double rows of sewing. While the dead load data from the unsewn seams and the seams with one double row of sewing suggests that these constructions will provide the required performance, there is so much variability in the data that GAC feels that the least risk option would be with the double sewn seam construction. Unfortunately, GAC's present manufacturing capability will not allow double sewing the final seam used to form the tank or the end seams used to close the tank. However, it is felt that these potential problems can be handled by judicious design of the prototype tank. If the final body seam is placed under the tank so that it contacts the ground, the seam will potentially see less stress since the friction between the fabric and the ground will tend to reduce fabric stresses in the bottom of the tank. The end seams will not see stresses as large as those in body

TABLE 12 - PROPERTIES AND RISK ASSOCIATED WITH CANDIDATE TANK CONFIGURATIONS

Configuration		Comparison to Std. 20.000		Operating		Risk Versus Seam Type*		
Size	Material	Weight Increase, %	Footprint Increase, %	Stress lb/in	Design Factor	Unsewn	One Row Double Sewing	Two Rows Double Sewing
32′x28′	XA22A579 (12 oz)	46	33	111	5.4	6	5	2
	XA22A568 (18 oz)	63	33	111	8.1	6	4	1
32′x30′	XA22A579 (12 oz)	56	43	80	7.5	4	3	1
	XA22A568 (18 oz)	75	43	80	11.3	3	2	1
32′x32′	XA22A579 (12 oz)	67	52	63	9.5	2	1	1
	XA22A568 (18 oz)	86	52	63	14.3	2	1	1

*Degree of Risk

1 Extremely Low
2
3
4
5
6 Moderate

GAC 19-1536

large as those in body seams for tanks having rectangular configurations. Wider end seams can be designed which should provide the strength required to resist the higher stresses likely to be encountered. The stress in the end seams of the 32′ x 28′ tank will be approximately 85 lbs/in as compared to 111 lbs/in in the body seams.

D. Repair Materials Study

The objective of the repair study was to establish field repair materials and techniques that can be used by untrained personnel, with repair materials having a minimum storage life of five years.

During the past thirty years, Technical Orders like TO 37A12-15-1 (Air Force) have been used to describe infield maintenance and inspection of fuel tanks. They generally specify procedures for both permanent repair using air curing or vulcanizing adhesives as well as temporary repair using mechanical devices. Permanent infield repair of tanks has never been very successful due to the lack of personnel trained in the proper use of the repair materials, and partly due to not having the proper repair materials on hand when needed whose shelf life had not been exceeded. However, we attempted to determine if the state-of-the-art in adhesive technology had changed in recent years and to find a system of materials which would meet the infield tank repair objectives.

An extensive survey was conducted to find materials which would meet the permanent repair criteria. It has been established, and determined by past experimentation, that adhesives based on nitrile, urethane, or polysulfide elastomers are compatible with both the nitrile coatings used in GAC tanks and with fuel environments. Our approach was to determine if repair materials of these types were available which meet the five year shelf life requirement. Materials produced by GAC as well as by outside sources were considered. Sources were searched out using the Adhesives Red Book published by Palmerton, and Adhesives Books A & B published by the International Plastic Selectors Guide. Direct contacts were also made with various adhesive manufactures like Hughson, Lord, B.F. Goodrich, du Pont, Bostik, H.B. Fuller, 3M, Whitaker, General Mills, Eastman, General Adhesive and Henkel.

Based on this review and previous GAC experiments, it was established that the state-of-the-art in adhesive technology has not changed significantly in recent years. Adhesive materials meeting the five year shelf life requirement are not commercially available. Most available adhesives have shelf lives of from six to twelve months and require personnel trained in their use to obtain reliable repairs.

Having established that there are no adhesive materials available for permanent in field repairs which exhibit a five year service life, emergency repair methods using mechanical devices need to be considered. These devices involve tapered wooden plugs and metal sealing clamps per MIL-R-22368. Care must be exercised in using these devices since the high profile tank operates at relatively high fabric stress levels compared to conventional rubberized fabric tanks. Tear data shows that a 1 3/4" slit can be tolerated without tank failure. However, a 2 1/2" slit is required to insert the smallest metal clamp. Since these clamps provide little if any mechanical support for the tank fabric, they are not expected to provide a bridge for the stress in the wall of the tank to prevent tearing, and therefore should not be used to repair this tank. Tapered plugs, on the other hand, tend to stress the edges of the cuts they are sealing, which can lead to additional tearing of the highly stressed tank wall. Therefore, plugs should only be used on punctures of 1" or less, and preferablly should be installed with the tank empty or at least partially deflated.

E. Conclusions

The MACI study has shown that a 40,000 gallon tank with flat dimensions of between 32′ X 28′ and 32′ X 32′ is feasible if slightly more risk is accepted. The risk associated with each design consideration is dependent upon the material selected for use in the tank and the type of seam used in its construction. Both of the coated fabrics studied in this program will perform adequately depending on the type of seam used. In other words, performance of the tank is a function of the seam design used and not of the fabric selected. There is relatively little risk in using two double rows of sewing and only moderate risk with using one double row. Unsewn seams would be somewhat more risky than either sewn configuration. It appears as though two double rows of stitching will perform as well as the unseamed fabric in dead load.

Of the fabrics studied, the XA22A568 which uses 18 oz/sq yd nylon fabric will provide a tank with better resistance to tear propagation as measured by the cylinder burst test, but will result in a tank which is heavier and which may not meet the diffusion or cold flex resistance requirement. The XA22A579 fabric based on 12 oz/sq yd nylon cloth will meet the tear, diffusion and cold flex requirements of MIL-T-82123, and will produce a lighter tank.

Therefore, the XA22A579 fabric should be used in constructing the prototype unit and seams should be designed with two double rows of stitching. Considering the objective of the project of increasing the amount of fuel stored in a given ground area, the 32′ x 28′ tank should be selected for fabrication of a prototype unit. The dead load testing of seams should be continued to verify these conclusions.

F. Recommendations

It is recommended that a 32′ X 28′ 40,000 gallon prototype tank be fabricated using 2 1/2" lap seams with two double rows of sewing in XA22A579 fabric. This tank should be subjected to a seven day water stand test at a tank height equivalent to that the tank would see if filled with fuel. In addition, the tank should be subjected to the functional tests specified for the 20,000 gallon tank in MIL-T-82123.

Dead load testing of seam samples should be continued to confirm the performance of the recommended configuration.

SECTION III - PHASE II PROTOTYPE MANUFACTURE AND TEST

A. Prototype Design

Design of the prototype unit was based on the results of the Phase I effort and the fitting and accessory requirements of MIL-T-82123. The tank was designed with two fill/discharge fittings, and a drain and a vent fitting as shown in Figure 16. A 16" high stand pipe was used in the vent assembly to allow for a greater fill height. Handles were provided approximately every 11′.

The tank was fabricated from XA22A579 fabric composed of M908 nitrile rubber compound coated on 12 oz/sq yd, 2x2 basket weave nylon cloth. Seams in the tank were 2 1/2" lap seams with two double rows of stitching in all body seams except the final seam which had one double row of stitching. The end seams were made 3 1/2" wide and were unsewn.

B. Prototype Fabrication

The prototype unit was fabricated in the company′s Rockmart, Georgia production facility. The finished tank had dimensions of 28′ 1" by 31′ 10" and weighed approximately 900 pounds.

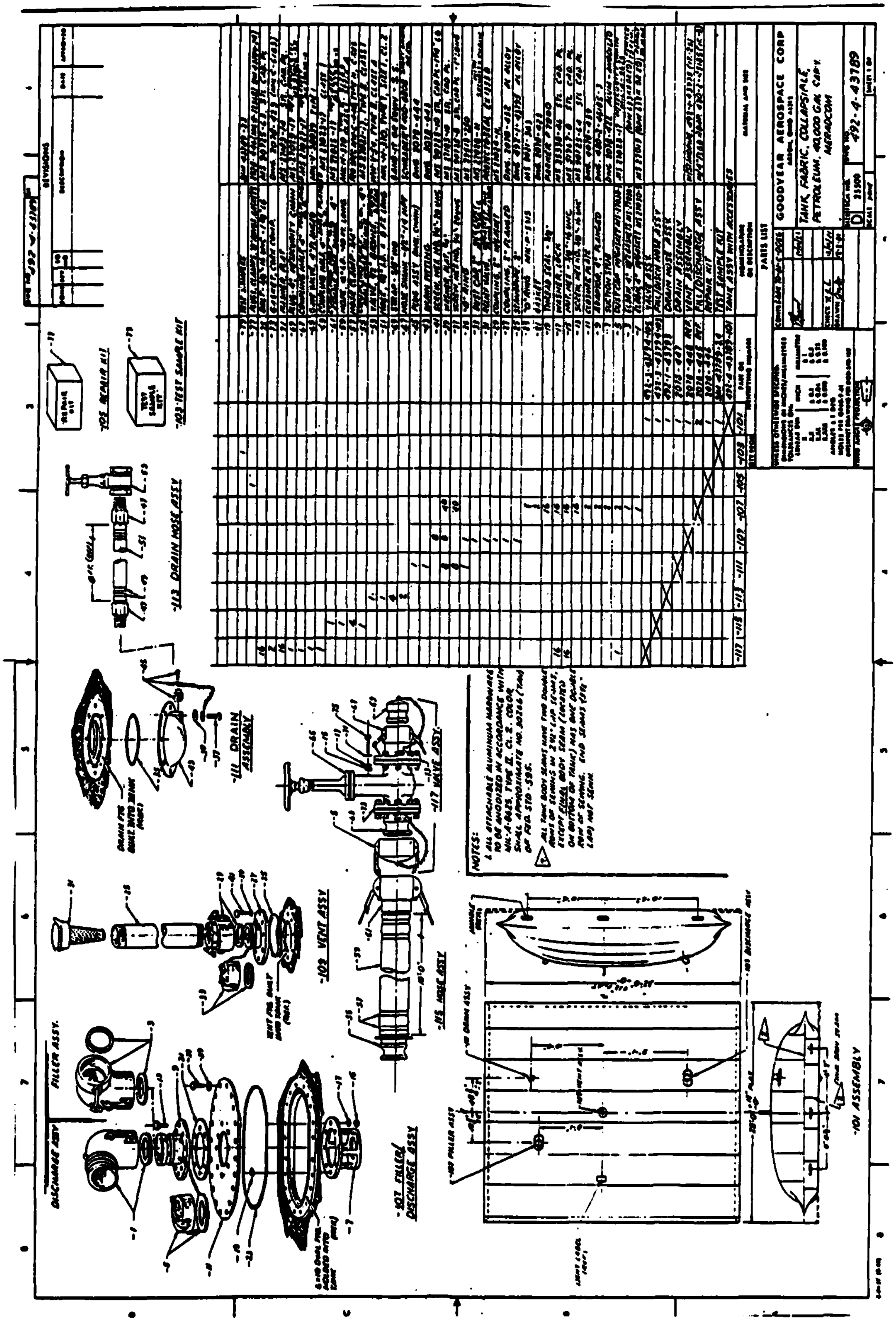


FIGURE 16 - PROTOTYPE TANK ASSEMBLY

The unit was slightly more difficult to handle on the production floor than a standard 20,000 gallon tank, but not unreasonably so. Sewing took longer than anticipated, partly due to the requirement for twice as much stitching as a standard 20,000 gallon tank, but also due to the increased thickness of the fabric. These problems were not severe and were associated with fabricating a one of a kind experimental unit.

C. Functional Testing of Prototype

The prototype tank assembly was subjected to the functional tests of MIL-T-82123 paragraphs 4.6.1 through 4.6.7 as amended by the contract and in accordance with Test Plan GAC 19-1560. The amendment involved a seven day stand test with water rather than a 30 day stand test with fuel. The results of these tests are reported in Table 13.

The relationship between the stresses in a tank filled with water versus fuel is shown in Figure 17. The stand test and overload test of the prototype tank were conducted using volumes of water which would place equivalent stresses in the tank if it had been filled with fuel. Figure 18 shows the prototype tank on stand test with 38,300 gallons of water. The height of the tank was measured during the filling operation and a plot of volume versus tank height prepared as shown in Figure 19. The tank stood 95" high with a 101 3/16" water height measured through the vent pipe. On

TABLE 13 - PROTOTYPE ASSEMBLY TEST RESULTS (1)

Test	Test Para.	Reqm't. Para.	Result
Vent assembly	4.6.1	3.5.4	Passed
Air leakage	4.6.2	3.6	Passed
Low temperature	4.6.3	3.6	Passed
High temperature	4.6.4	3.6	Passed
Fuel storage	4.6.5	3.6	Passed (2)
Overload	4.6.6	3.6	Passed (2)
Internal inspection	4.6.6.1	3.6	Passed
Handle pull test	4.6.7	3.5.2	Passed

Footnotes:

1. Tank and accessories tested in the order shown.
2. Fabric collars on fittings lifted and high elongation in a small area of one end seam observed. (See discussion for further detail)

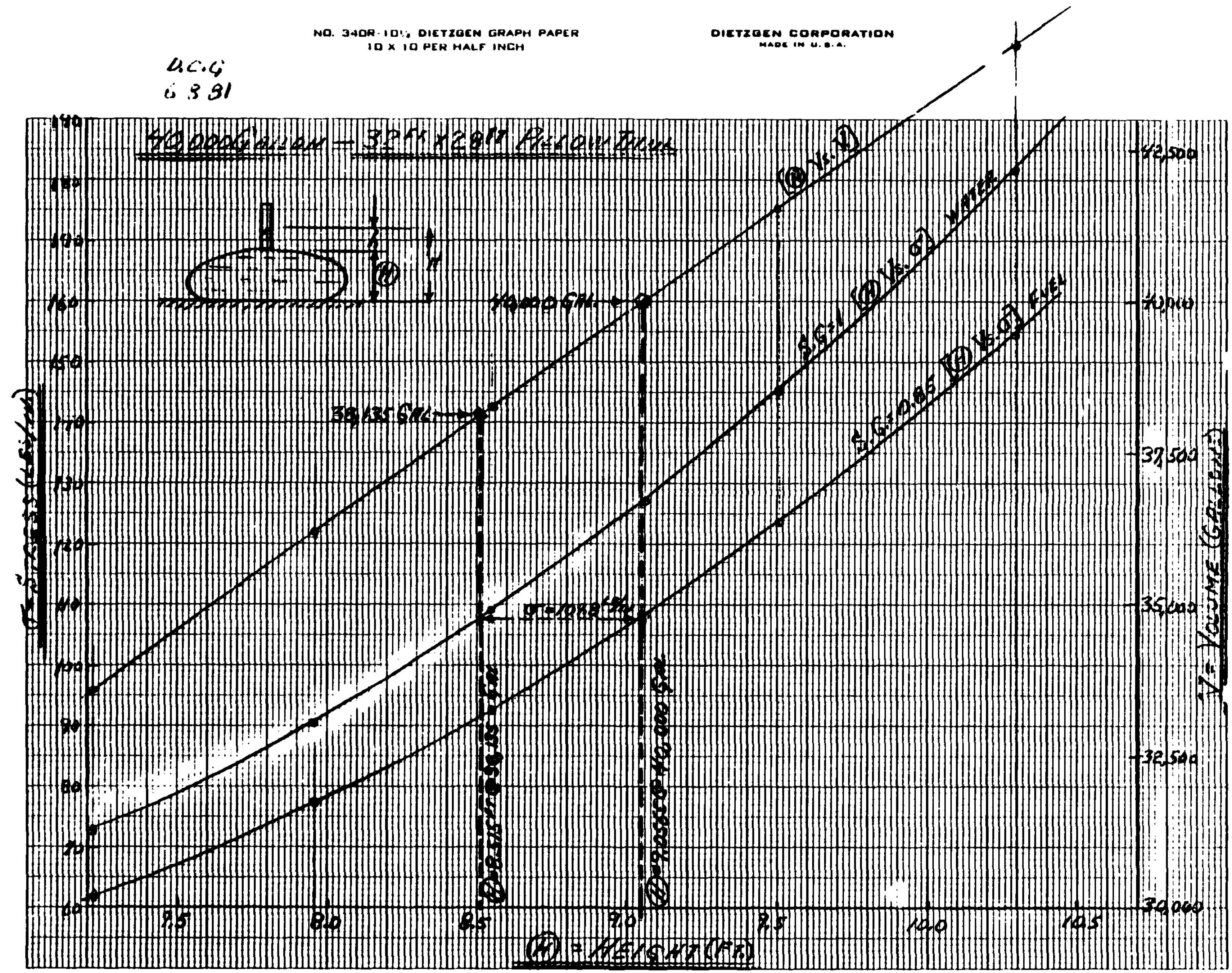


FIGURE 17 - TANK FABRIC STRESS VS HEIGHT WITH FUEL AND WATER

Figure 18 - Prototype Tank on Stand Test with 38,300 Gallons of Water

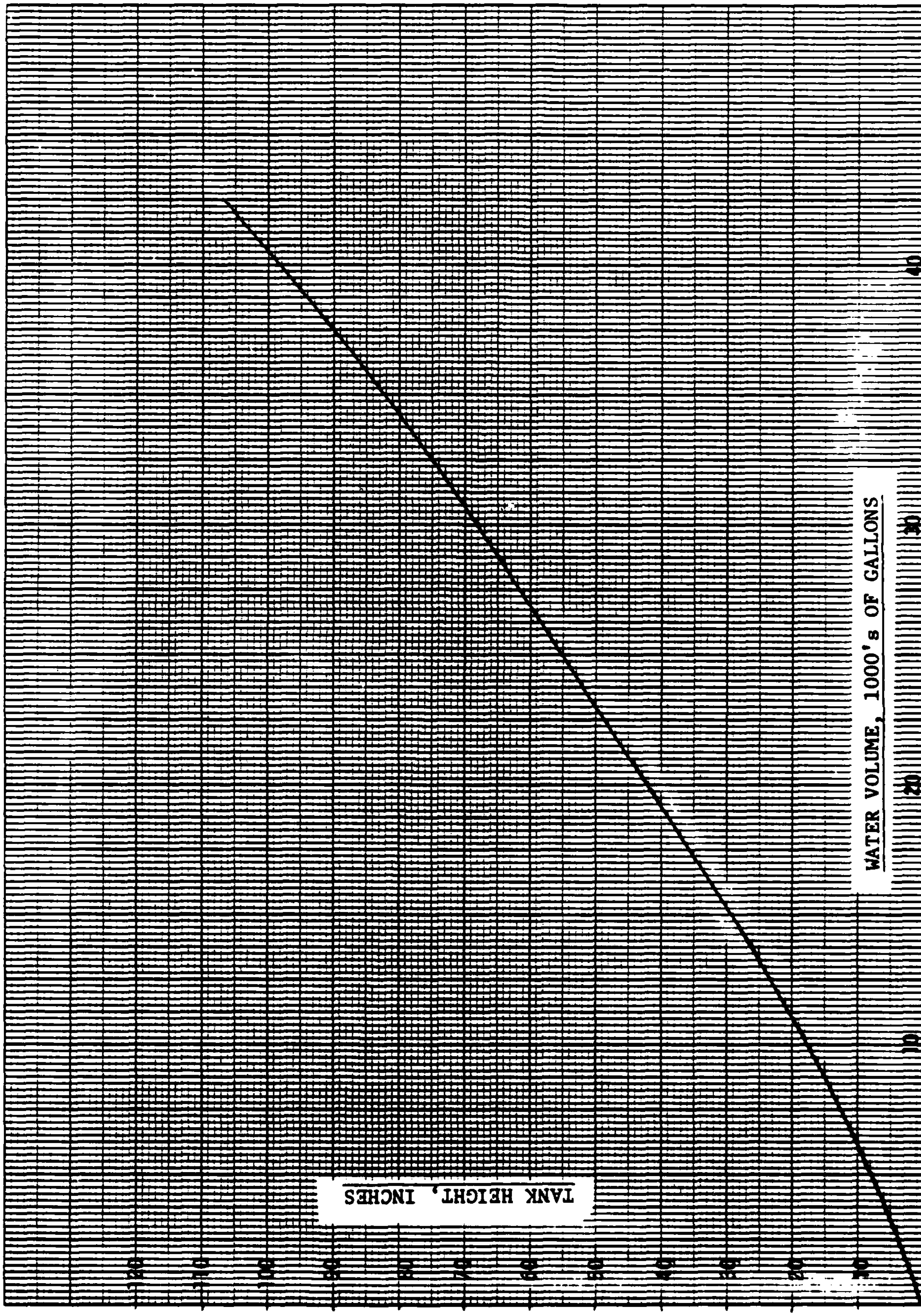


FIGURE 19 - PROTOTYPE TANK HEIGHT VS WATER VOLUME DEICING FILLING

the seventh day, the height of the water in the vent pipe was 98 5/16". Elongation of the fabric was measured at this time and found to be approximately 5% in the warp cords and 19% in the fill cords. The tank was emptied following the stand test and allowed to lay empty for five days. The tank was then filled with 42,000 gallons of water for the overload test and is shown in Figure 20. The height of the tank during the overload test was 104 7/8" with a water height of 114", and fabric elongation was the same as in the stand test.

It was observed during the stand test that the fabric collars around fittings began to lift slightly. During the overload test the collar on the vent fitting and one fill/discharge fitting began to wrinkle as shown in Figure 21. This condition was caused by the difference in stress between the fabric collar on the fitting and the body fabric. It will not affect the integrity of the fitting in the tank since the metal fittings are vulcanized to the body fabric. These collars were repaired prior to shipment of the tank to the Army.

During the overload test it was noticed that an approximate 2" long area of one end seam showed excessive elongation on the seam edge gum strip. There was no indication of leakage and all functional tests were completed. Latter inspection revealed a small loose area in the outer edge of the lap seam. The reason for the looseness appeared to be a small area of low

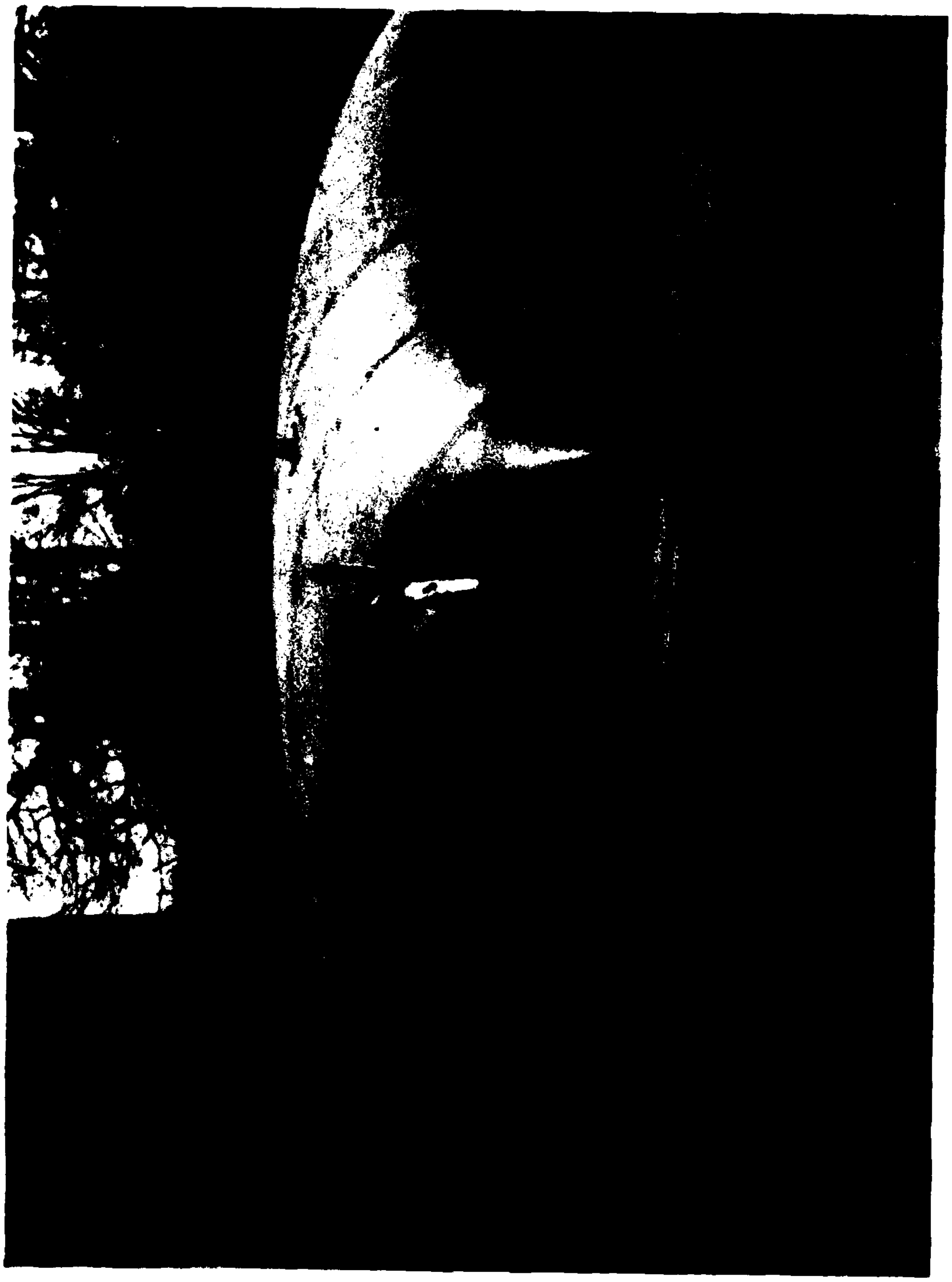


Figure 20 - Prototype Tank on Overload Test with 42,000 Gallons of Water

Figure 21 - Fabric Collar on Vent Fitting During Overload Test

adhesion caused by possibe contamination. This minor defect did not affect the satisfactory completion of all the functional tests, including the stand and overload at very high stress levels. The area was repaired by recementing the loose lap and vulcanizing a reinforcing strip over the edge. The high stress levels under which this tank operates dictated the use of the reinforcing strip to assure satisfactory completion of all field testing.

Figure 22 shows a body seam next to a fitting. The curve in the body seam shows that a stress concentration exists in the fabric between the fitting and the seam. Fittings should be located in the center of fabric body panels in future tanks.

D. Destructive Tests of Prototype Material

Destructive tests were performed on samples of materials used in fabricating the prototype. Samples were prepared using production equipment and cured to the same state as materials in the prototype tank. Tests were performed in accordance with MIL-T-82123 and Test Plan GAC 19-1560, and the results are presented in Tables 14 through 18. The data shows that the XA22A579 material and seams made from it meet all of the design requirements.

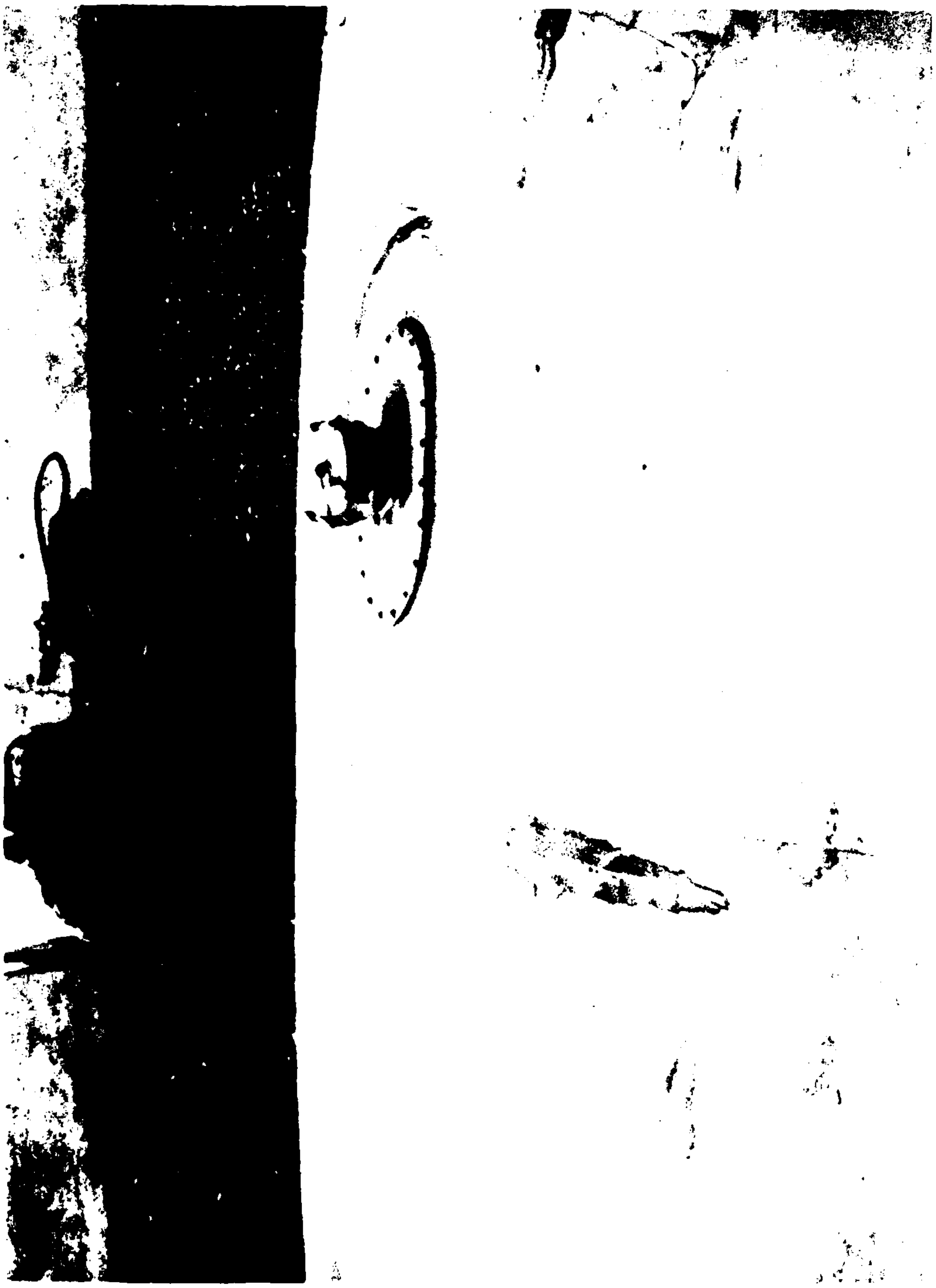


Figure 22 - Stress Concentration in Body Seam Near Fill/Discharge Fitting

TABLE 14 - PHYSICAL PROPERTIES OF THE PROTOTYPE CLOTH (1)

Property	Requirement	Test Method Fed Std No. 191	Actual Data
Thread Count, warp and fill	Record	5050	40X40
Weave	Square, 2X2 Basket	Visual	2X2
Weight, oz/sq yd	Record	5041	11.5
Thickness, inches	Record	5030.2	.026
Tearing Strength, warp and fill, lbs (2)	Record	5134	175X165
Breaking Strength, warp and fill, lbs/in (4)	Record	5104	707X724
Weathering resistance (after 100 hrs exposure at 5% elongation), % (2)(3)	45% Retention of original break strength, min.	5804	102X102

FOOTNOTES:

(1) Properties after heat setting.

(2) The edges of the tear-test specimens were coated by dipping with an adhesive to preclude yarn slippage while under test.

(3) Alternate Corex D filters were removed. Specimens were raveled for Method 5104 after accelerated weathering.

(4) Ends of specimens for breaking strength test were coated by dipping into an adhesive that precluded yarn slippage under test. Only those parts that were held in the clamps during test were treated.

TABLE 15 - CHARACTERISTICS OF CURED PROTOTYPE COATING COMPOUND M908

Property	Requirement	Test Para or Fed Std and ASTM Test Method	Actual Data
Initial			
A. Tensile Strength, psi	1500 (min)	ASTM D412	1711
B. Ultimate Elongation, %	300%	ASTM D412	660
Tensile Strength After Immersion in Distilled Water (ph 7.0±0.2) at 160±2 F.			
A. 14 Day, %	40 (min.)	6001/6111(5)	97
B. 42 Day, %	25 (min.)	6001/6111(5)	93
Tensile Strength After Immersion in Fuel (4) @ 160±2 F.			
A. 14 Day, %	40 (min.)	6001/6111(5)	59
B. 42 Day, %	30 (min.)	6001/6111(5)	66
After Accelerated Weathering for 500 hrs (3), Initial Tensile Strength Retained (1), %	75 (min.)	ASTM D750 (3)	93
Fuel Contamination			
A. Unwashed Existent Gum, mg/100ml	20 (max.)	4.6.8	18.8
B. Heptane Washed Existent Gum, mg/100ml	5 (max.)	4.6.8	<0.1

FOOTNOTES:

(1) The percentage tensile strength retained is:

$$\frac{\text{Tensile strength retained after immersion or weathering X 100}}{\text{Average initial tensile strength value obtained}}$$

(2) Tolerance for immersion periods ± 2 hours
(3) Exposed at 10% elongation with alternate Corex D filters in place
(4) 60% No. 4, 25% No. 8 and 15% No. 9 per FED-STD-601, Method 6001.
(5) Para. 4.8.1 of Method 6111 applies

TABLE 16 - PHYSICAL PROPERTIES OF THE PROTOTYPE CURED COATED FABRIC

Property	Requirement	Test Paragraph or FED-STD 601 and ASTM Test Method	Actual Data
Thickness, inches	0.040, min.	5030-1	0.067
Weight, oz/sq yd	30, min.	5041	59.35
Diffusion Rate, fl oz/sq ft/day	0.1, max.	4.6.9	0.092
Tearing Strength, warp and fill, lbs	35, min.	5134	73X63
Breaking Strength, warp and fill, lbs/in	600, min.	5102	836X724
Weathering resistance after 500 hrs exposure at 5% elongation, warp and fill, %	80% retention of initial breaking strength, min.	5804/5102	89X79
Puncture resistance, lbs.	150, min.	4.6.10/5120	215
Low Temperature Crease Resistance:			
a. Appearance after unfolding	No cracking, peeling or delaminating	4.6.11	OK
b. Diffusion rate after low-temperature crease resistance test	0.10 fl oz/sq yd per 24 hrs., max	4.6.9	0.098
Fungus Resistance	No cracking, blistering or delamination of coating	5672	OK
Breaking Strength after fungus exposure, % of original	50%, min.	5762/5102	86X73(5)
Blocking	Specimens to separate within 5 seconds	4.6.12	OK
Coating Adhesion (initial) lbs/in	20, min.	4.6.13	74
Coating Adhesion after immersion in distilled water at 160 ± 2 F for the following durations:			
a. 14 days, lbs/in (%of org.)	10 lb/in or 30% of initial (3)	4.6.13	62(84%)
b. 42 days, lbs/in (%of org.)	5 lb/in or 20% of initial (3)	4.6.13	49(66%)
Coating adhesion after immersion in fuel (4) at 160 ± 2 F for the following durations:			
a. 14 days, lbs/in (%of org.)	10 lb/in or 40% of initial (3)	4.6.13	56(76%)
b. 42 days, lbs/in (%of org.)	10 lb/in or 40% of initial (3)	4.6.13	53(72%)

FOOTNOTES:

(1) Specimens were 1" wide. Care was taken to cut specimens parallel to and following the curvature of the threads of the fabric.
(2) Alternate Corex D filters removed.
(3) Whichever is the greater requirement.
(4) 60% No. 4, 25% No. 8 and 15% No. 9 per FED-STD-601, Method 6001.
(5) After 42 days. 84 day data will be presented when available.

TABLE 17 - PHYSICAL PROPERTIES OF CURED PROTOTYPE SEAMS

Property	Requirement	Test Paragraph or FED-STD 601 and ASTM Test Method	Actual Data
Breaking Strength, (initial)	500 lbs/in,min(1)	8311	756
Breaking Strength after Immersion in Distilled Water @ 160+2 F. for the following durations:			
14 Days	400 lbs/in,min	8311/6001/4.6.14	665
42 Days	200 lbs/in,min	8311/6001/4.6.14	649
Breaking Strength after Immersion in Fuel (3) @ 160+2 F. for the following durations:			
14 Days	400 lbs/in,min	8311/6001/4.6.14	843
42 Days	200 lbs/in,min	8311/6001/4.6.14	832
Dead Load Shear Resistance Under 100 lbs/in Stress @ 200 F. for 8 hours	.125 in. slippage (max)	4.6.15	Passed
Peel Adhesion (initial)	25 lbs/in,min	ASTM D413,MM*	68
Peel Adhesion after Immersion in Distilled Water @ 160+2 F. for the following durations:			
14 Days	10 lbs/in or 40% of initial, min (2)	ASTM D413MM*/6001 /4.6.14	62(91%)
42 Days	5 lbs/in or 15% of initial,min (2)	ASTM D413MM*/6001 /4.6.14	68(100%)
Peel Adhesion after Immersion in Fuel (3) @ 160+2 F. for the following durations:			
14 Days	15 lbs/in or 50% of initial,min (2)	ASTM D413MM*/6001 /4.6.14	42(62%)
42 Days	15 lbs/in or 50% of initial,min (3)	ASTM D413MM*/6001 /4.6.14	41(60%)

FOOTNOTES:

(1) All specimens broke in the coated fabric. Failure of any specimen in a seam area at any value shall constitute failure of the test.
(2) Whichever is the greater requirement.
(3) 60% No. 4, 25% No. 8 and 15% No. 9 per FED-STD-601, Method 6001.
* MM = Modified Method.

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TABLE 18 - CHARACTERISTICS OF ALUMINUM BONDED FITTINGS (1)

Property	Requirement	Test Paragraph or FED-STD 601 and ASTM Test Method	Actual Data
Bond Strength, (initial)	600 lbs/in,min	4.6.16	972
Bond Strength after Immersion in Distilled Water @ 160±2 F. for the following durations:			
14 Days	300 lbs/in,min	4.6.16	779
42 Days	200 lbs/in,min	4.6.16	791
Bond Strength after Immersion in Fuel (3) @ 160±2 F. for the following durations:			
14 Days	400 lbs/in,min	4.6.16	571
42 Days	300 lbs/in,min	4.6.16	589
Dead Load Shear Resistance Under 100 lbs/in Stress @ 200 F. for 8 hours	.125 in. slippage (max)	4.6.16	Passed
Peel Adhesion (initial)	25 lbs/in,min	4.6.16	89
Peel Adhesion after Immersion in Distilled Water @ 160±2 F. for the following durations:			
14 Days	10 lbs/in or 40% of initial, min (2)	4.6.17/ASTM D429B	65(73%)
42 Days	5 lbs/in or 15% of initial,min (2)	4.6.17/ASTM D429B	(4)
Peel Adhesion after Immersion in Fuel (3) @ 160±2 F. for the following durations:			
14 Days	15 lbs/in or 50% of initial,min (2)	4.6.17/ASTM D429B	73(81%)
42 Days	15 lbs/in or 50% of initial,min (2)	4.6.17/ASTM D429B	(4)

FOOTNOTES:

(1) Properties after cure.
(2) Whichever is the greater requirement.
(3) 60% No. 4, 25% No. 8 and 15% No. 9 per FED-STD-601, Method 6001.
(4) Data will be presented when available.

SECTION IV - CONCLUSIONS

This study has shown that a 40,000 high profile, collapsible fabric POL tank having flat dimensions of 32′x28′ can be made using commercially available materials and state-of-the-art manufacturing methods which meet the performance requirements of MIL-T-82123.

SECTION V - RECOMENDATIONS

It is recommended that the prototype 40,000 gallon tank be tested in a field environment to determine its ultimate performance and service life. It is suggested that the tank be filled with fuel and allowed to stand for thirty days, following which fuel be cycled between one third full and full in seven day cycles of one third increments of capacity for a period of six months.

Based on our observation of the tank on stand test with water, the fill/discharge fittings should be relocated so that they are not as close to body seams as they are in the prototype. This will prevent stress concentrations in the body seams near the fittings and should add to the service life of the tank.

Testing of seam constructions under continuous dead load should be continued to demonstrate the integrity of the various seams designs under simulated use conditions. This testing could ultimately reduce the cost of the unit.

Having established the required dead load performance of seams, a test of this property should be included in the military specification for the high profile 40,000 gallon tank.