GD/C-BTD65-078

STITCHED FOAM THERMAL INSULATION PROTECTION SYSTEM FOR THE LH_2 TANK WALL OF THE CENTAUR FLIGHT VEHICLE

PROGRESS REPORT

NASA CONTRACT NAS 3-3232

H. RUSCIGNO

30 APRIL 1965

GENERAL DYNAMICS/CONVAIR

FOREWORD

This report covers the work accomplished under contract NAS 3-3232, Change Order 32, Sales Order 333-1-356. Studies included preliminary evaluation of materials, design considerations, establishment of requirements for insulation systems and the fabrication and testing of unit specimens.

Past efforts were accomplished under Contract NAS 3-3232, Technical Direction 59. Documentation of the studies and tests will be included in the final report of the Stitched Foam Development.

Future work will be done under Contract NAS 3-3228 as a two phase program. Phase I will continue the development of the Stitched Foam concept including further evaluation of the most promising types of materials and design configurations, establishing the total system concept, as well as weight and conductivity determined through component testing. Phase II will involve simulated flight evaluation in the supersonic wind tunnel at NASA/LeRC.

This program is being conducted under the cognizance of NASA/LeRC, Mr. J. L. Collins is the Project Manager.

In addition to the author, the following personnel have contributed efforts to the development of the Stitched Foam Insulation Program:

J. Hertz, Material Research

R. R. Reimer, Thermodynamics, and

A.H. Taylor, Vehicle Insulation Structures.

ABSTRACT

A preliminary design study was made to compare the Stitched Foam concept with the current AC-6 Jettisonable Insulation System. It was shown to have less payload loss for a two burn mission than the AC-6 system, and a cost savings of approximately $300,000 per vehicle.

Preliminary structural and thermal component tests were completed.

CONTENTS

LIST OF FIGURES

1.0 INTRODUCTION

1.1 Previous Accomplishments

During the period from April 1963 to April 1964, insulation materials were screened, insulation systems developed and tested, and analytical studies were conducted. The work accomplished during this period is documented in References 1 through 5.

1.2 Scope and Purpose of Current Period

The present report relates to the design portion of a wind tunnel test program in which wind tunnel tests are to be accomplished on an insulated liquid hydrogen tank. The purpose of the wind tunnel tests is to further verify and establish the validity of previous test and calculations concerning the feasibility of a bonded external thermal insulation composite for the thermal protection of a liquid hydrogen tank during ground hold and ascent heating.

The basic requirements of the system should include:

a. State-of-the-art insulation materials.
b. Weight of system $\leq$ 150 pounds.
c. Capable of holding fuel boil-off rates to design limits.
d. Not be adversely affected by high heat flux/shear areas, as created by protuberances.
e. Adequate adherence to the tank during all flight conditions.
f. Resistant to ground handling.
g. Not react or degradate by exposure to vehicle liquids.
h. Not objectionably interfere with signal transmission.
i. Capable of field repair.
j. Inspectable.
k. Adequate supply, minimum lead time for procurement.
l. Reasonable costs for development, material and application.

1.2 (Continued)

A brief description of the stitched foam system is:
A Stitched Foam bonded panel system consisting of a 2 $\#/ft^3$ polyurethane foam stitched with teflon impregnated glass sewing threads between two layers of non-impregnated glass fabric. The panels are then heat formed to the desired curvature. A hard shell skin consisting of a lamination of H film, resin impregnated glass fabric and a solar paint is bonded to the panel with a room temperature curing adhesive. The completed panel is then bonded to the liquid hydrogen tank using a polyurethane adhesive.

1.3 Schedule

The wind tunnel test program for the development of the stitched foam insulation system is a 12 month program with wind tunnel testing to be initiated in January 1966. The complete schedule is shown in Figure 1.

2. ANALYTICAL STUDIES

2.1 Discussion

A preliminary comparison of the AC-6 Jettisonable Insulation System and the current Stitched Foam System was made. Four parameters were investigated: weight, cost, thermal performance and payload penalty.

2.2 Weight

2.2.1 AC-6 Insulation System

The AC-6 Insulation System weight is presented as a total jettisonable system which includes severance system, helium purging hardware, venting hardware, etc. The weights are grouped in the applicable stages, i. e., the actuator installation for helium venting supports the insulation panel system. However, it is located on the nose fairing barrel section, therefore, its weight will have a different payload factor than the insulation panels because of a different jettisonable time.

Insulation Panels - Lightweight Jettisonable

2.2.1 (Continued)

Drawing	Description	Weight
55-74200	Systems instl - Orig. Hdwe & Misc.	12.7
55-74345	Severance and jettison system instl.	92.1
55-74340	Hinge Installation	47.8
55-74211	Seal Angle	12.6
55-74202-811	Assy-Jettisonable Insulation Panel	296.1
55-74202-813	" " " "	261.8
55-74202-837	" " " "	236.8
55-74202-817	" " " "	246.0
	Estimated weight for fairing support	10.2
		(1,216.3)
55-74332	Seal Jettison with Panels	7.3
55-11961	Temp. Meas. Insulation Panels	.4
55-11414	Harness - Insul. Panel Quad I-II	3.0
55-11415	" " " " II-III	2.0
55-11416	" " " " III-IV	1.1
55-11417	" " " " IV-V	.9
	Estimate for Thermolag	50.0
	Estimate for Transducers	2.8
	Estimate for Instr. Mounts	11.9
	Total Weight	(1,295.7)

INTERSTAGE ADAPTER

55-74295	Detonator Transfer System	8.0
55-74345	" " "	10.4
55-75059	Hinge Installation	20.6
55-60157	Relay Installation	8.5
	Estimate He Bottle Installation	57.0
		(104.5)

NOSE FAIRINGS

55-72183	Actuator Installation	23.0
55-72186	Duct Purge Vent	2.0
55-72168	Seal Angle	3.7
		(28.7)

2.2.1 (Continued)

MAIN STAGE

Drawing	Description	Weight
55-73311	Clamps & Misc. Parts - Aft Seal	3.6
55-74219	Seal - Sta 413	5.5
55-72227	Supts - He Purge	.6
55-80096	Tube Instl. - He Purge	2.0
55-80088	Tube Instl. - He Purge	1.0
55-80028	Valve I - Sol. Shutoff	2.3
55-72169	Fabric Seal - Sta 208	16.1
55-80036	Valve - Purge	.3
55-80069	Tubing and Hardware	.7
55-74047	Seal I - Fill & Drain Outlet	1.2
		(33.4)

2.2.2 Stitched Foam Insulation System

The basic panel weight was obtained experimentally by fabricating a 30 inch by 30 inch panel and bonding a hard shell skin to the stitched foam (Figure 2). Each component and fabrication step was weighted. The results are as follows:

Stitched Foam Panel Area $A = 30 \times 30 = \frac{900}{144} = 6.25 \text{ ft}^2$

$Wt = 363 \text{ Grams} = (363)(2.2 \times 10^{-3}) = .800\#$

$Wt/ft^2 = \frac{.800}{6.25} = .128 \ \#/ft^2$

Hard shell skin (aluminized Mylar/120 Glass fabric - Phenolic pre-preg/Polyvinal Floride) = 156 Grams

$Wt/ft^2 = \frac{(156)\ (2.2 \times 10^{-3})}{6.25} = .0549 \ \#/ft^2$

Adhesive Hard Shell to Stitches

$Wt/ft^2 = \frac{(16 \text{ Grams})\ (2.2 \times 10^{-3})}{6.25} = .0056 \ \#/ft^2$

Basic Panel Weight

Skin	.0549
Adhesive	.0056
Stitched Foam	.1280
	.1885 $\#/ft^2$

2.2.2 (Continued)

Total System Weight

Basic Insulation (.19 #/ft^2) (500 ft^2) = 95#

Panel Junctures (Figure 3)

Area = (.25) (.1) = .025 In^2

Vol = $\frac{.025}{144}$ (128 linear feet of junctures)
= .0222 ft^3

Wt = (.0222) (80) = 1.78#

End Juncture Weight at Sta 219 and 412 Potting Compounds

Wt = $\frac{(.1)\ (.5)}{144}$ (63 ft) (80 #/ft^3) = 1.75#

Wiring Tunnel and Boost Pump Fairing Weight (Figure 4)

Skin Boost Pump Fairing	.030 Aluminum	- 5.9
Longitudinal Stringers	.030 Aluminum	- 3.7
Transverse Stiffeners	.030 Aluminum	- 1.6
Longitudinal Boss - Chem Milled		- 2.7
Transverse Boss - Chem Milled		- 1.3
Wiring Tunnel	.030 Aluminum	- 4.5
Transverse Stiffner	.030 Aluminum	- 2.9
Longitudinal Stiffeners	.030 Aluminum	- 1.1
30 NAS 1100 Screws & NAS 21043-3 Nuts		- .4
878 BJ5N Rivets		- 1.5
		25.6#
External Insulation		4.4
	Total	30.0#

SYSTEM TOTAL WEIGHT

Insulation	95.00
Juncture	1.78
Ends	1.75
Fairing	30.00
	128.53#

No parametric study to this date has been made to optimize the insulation thickness. The 95 pounds noted above reflects .45 inches of foam. Since an increase does show improved payload performance (Appendix 1). The maximum foam thickness that could be obtained and still be within the 150# total system weight requirement was

2.2.2 (Continued)

chosen from the following table.

Foam Thickness (in)	Total Insulation Weight (lbs)
.45	95.0
.50	99.2
.55	103.4
.60	107.6
.65	111.8
.70	116.0

A total system weight based on .65 inches thick foam would be:

Insulation	111.80
Juncture	1.78
Ends	1.75
Fairing	30.00
	145.33

2.3 COST

2.3.1 AC-6 Insulation System

INSULATION PANELS

The cost of the AC-6 Insulation Jettisonable System is based on 1/10 basic set-up cost plus parts

DRAWING	DESCRIPTION	COSTS
55-74200	Systems Instl - Original Hardware and Miscellaneous	$113,416
55-74345	Severance and Jettison System Instl.	68,700
55-74340	Hinge Installation	2,200
55-74211	Seal Angle	3,691
55-74202-811	Assy-Jettisonable Insulation Panel	)
55-74202-813	" " " "	127,000)
55-74202-837	" " " "	)
55-74202-817	" " " "	)
55-74332	Seal Jettison with Panels	--
55-11961	Temp Meas. Insulation Panels	--
55-11414	Harness-Insul. Panel Quad I-II	--
55-11415	" " " " II-III	--
55-11416	" " " " III-IV	--
55-11417	" " " " IV-I	--

2.3.1 (Continued)

	Estimate for Thermolag	2,000
	No Estimate for Transducers	
	No Estimate for Instr. Mounts	
	Sub-Total	$317,007

NOSE FAIRINGS

DRAWING	DESCRIPTION	COSTS
55-72183	Actuator Installation	$2,473
55-72186	Duct Purge Vent	424
55-72168	Seal Angle	1,055
	Sub-Total	$3,952

MAIN STAGE

55-73311	Clamps & Misc. Parts - Aft Seal	3,027
55-74219	Seal - Sta 413	638
55-72227	Supt - He Purge	17
55-80096	Tube Instl. - He Purge	512
55-80088	Tube Instl. - He Purge	119
55-80028	Valve I - Sol. Shutoff	873
55-72169	Fabric Seal - Sta 208	3,498
55-80036	Valve - Purge	3,226
55-72173	Seal - Purge	204
55-80069	Tubing and Hardware	1,929
55-74047	Seal I - Fill & Drain Outlet	737
	Sub-Total	$14,780

INTERSTAGE ADAPTER

55-74295	Detonator Transfer System	25,730)
55-74345	" " "	)
55-75059	Hinge Installation	4,741
55-60157	Relay Installation	2,085
	Estimate He Bottle Installation	1,000
	Sub-Total	$33,556

HELIUM PURGE

Average Cost AC-2, AC-3		$134,638
	TOTAL SYSTEM	$503,933

2.3.2 STITCHED FOAM COSTS

Material for Panel

Foam Panel .65 x 48 x 192	$ 50.00
Stitching	500.00
37 in^3 Silastic 140 Adhesive	5.00
64 ft^2 Dupont H Film	5.00
64 ft^2 Imidite	320.00
37 in^3 Solar Paint	5.00
Per Panel..........	$885.00

Labor to Coat Panel

Apply adhesive	- 4 hrs
Apply film	- 2 hrs
Apply Imidite	- 4 hrs
Apply Paint	- 16 hrs
Bonding	- 16 hrs
	42 hrs @ $10.00/hr = $420.00 per panel

8 Panels required @ $1305/panel $10,440.00

Tooling Costs

Heat Forming Fixture

1 Mtl Plywood	- 250.00
Aluminum	- 60.00
Misc.	- 40.00
Labor 180 @ $10.00	1,800.00
	2,150.00

Die for Boost Pump Fairing

Material	200.00
Labor	1,000.00
	1,200.00
Handling Fixtures	1,600.00

Trim Template

Material	100.00
Labor	2,400.00
	2,500.00

2.3.2 (Continued)

Total Tooling	7,450.00		$745.00
Assembly Costs			
Heat forming panels			
40 hrs. per panel	-	$3,200.00	
Trim panels			
20 hrs. per panel	-	1,600.00	
Bond panels to tank			
30 hrs each		2,400.00	
Mylar Honeycomb Seal			
Machining 80 hrs			
Install 80 hrs			
Material $150		1,750.00	
Potting and Filling Holes			
Seal End - 120 hrs		1,230.00	
Material $30		850.00	
Seal Duct Protuberances			
Labor 120 hrs			
Material $30		1,230.00	
Total Assembly Costs			$12,260.00
Boost Pump Fairing			
Labor to Form	20 hrs		
Material	$5.00		
Heat Treat	300.00		$505.00
Wiring Tunnel			
Material	50.00		
Labor to Form & Assemble			
250 hours	2,500.00		
Labor to			
Install - 40 hrs.	400.00		
Thermolag	350.00		
Labor to spray			
30 hours	300.00		
			$3,600.00

2.3.2 (Continued)

<u>Miscellaneous</u>

Cover various
Protuberances

1 Stitched Foam Panel	$1,320	
Cut - Trim & Fit		
40 hours	400	
Seal & Vacuum Bag		
120 hours	1,200	
		$2,920.00
TOTAL COST PER VEHICLE		$30,470.00

2.4 Thermal Performance

AC-6 Insulation Panel and Stitched Foam.

Appendix I presents a preliminary thermal performance comparison of the two systems. It will be noted that under the stitched foam, two configurations were analyzed; the B.4 and the A.66. The B.4 which has a thin sheet of cork between the skin and the foam, was available from previous studies. However, it is no longer considered competitive with the A.66 configuration (Figure 5). The data presented shows BTU/ft of wetted or dry tank length. From the data in Appendix I the following analysis can be made:

<u>AC-6</u> - Launch Phase 0-235 sec.

Q = 328.4 BTU/ft of tank wetted

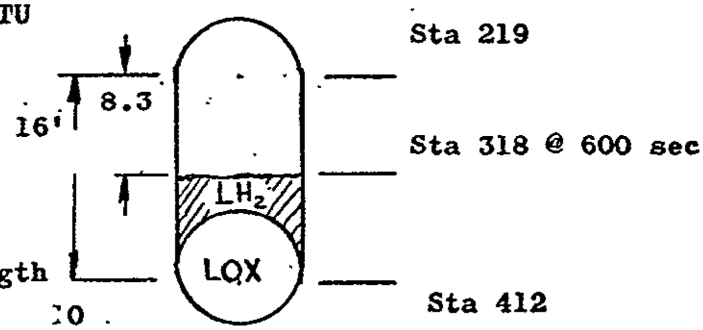
(328.4) (16 ft) = 5,260 BTU

$$\text{Vented } GH_2 = \frac{5,260}{191} = 27.5\#$$

<u>1st Burn Phase</u> - 235 - 600 sec.

Q = 272.4 BTU/ft of wetted length - average length $= \frac{7.7 + 16}{2} = 11.9$ ft

(272.4) (11.9) = 3,220 BTU



Q = 222.1 BTU/ft of dry length

2.4 (Continued)

Average length $= \frac{0 + 8.3}{2} = 4.15$ ft

(222.1) (4.15) = 924 BTU

Vented $GH_2 = \frac{3,220 + 924}{191} = 21.7\#$

Parking Orbit Phase 600-2100 sec.

Q = 1254.3 BTU/ft of wetted length

(1254.3) (7.7) = 9,660 BTU

Q = 830.6 BTU/ft of dry length

(830.6) (8.3) = 6,900 BTU

Vented $GH_2 = \frac{9,660 + 6,900}{191} = 86.6\#$

<u>Stitched Foam</u>

<u>Launch Phase</u> 0-235 sec

297.4 BTU/ft of tank wetted

(297.4) (16 ft) = 4,750 BTU

Vented $GH_2 = \frac{4,750}{191} = 24.8\#$

<u>1st Burn Phase</u> 235-600 sec.

413.7 BTU/ft of wetted length

Average length = 11.9 ft.

(413.7) (11.9) = 4,920 BTU

355.6 BTU/ft of dry length

Average length $= \frac{0 + 8.3}{2} = 4.15$ ft

(355.6) (4.15) = 1,470 BTU

Vented $GH_2 = \frac{4,920 + 1,470}{191} = 33.4\#$

<u>Parking Orbit Phase</u> - 600-2100 sec.

(609.6) (7.7) = 4,680 BTU

437.0 BTU/ft of dry length

(437.0) (8.3) = 3,630 BTU

Vented GH_2 $\frac{4,680 + 3,630}{191} = 43.5\#$

2.4 (Continued)

TIME	AC-6	STITCHED FOAM
0-235 sec.	27.5	24.8
235-600 sec.	21.7	33.4
600-2100 sec.	86.6	43.5

TABLE I VENTED GH_2 (POUNDS)

2.5 Payload Penalty

AC-6 insulation system vents 27.5 pounds hydrogen at 0-235 sec. from Figure 6 the δ of payload loss to vented hydrogen is .41. Therefore,

Payload loss = (.41) (27.5) = 11.3#

During 235-600 sec 21.7 pounds of gaseous hydrogen is vented. From Figure 4 we obtain:

Payload loss = (.58) (21.7) = 12.6#

During 600-2100 sec 86.6 pounds of gaseous hydrogen is vented. From Figure 4 we obtain:

Payload loss (.8) (86.6) = 69.3#

Total payload loss of AC-6 system attributed to thermal performance would be 11.3 + 12.6 + 69.3 = 93.2#

Payload loss for the AC-6 system must be considered from an effective weight because it is a jettisoning system. Figure 7 provides the partials of payload weight with respect to time. Since portions of the system jettisons at times differt from the main insulation panels, Table II shows how an effective system weight or payload penalty from weight may be obtained.

TABLE II

2.5 (Continued)

PART	WT LBS	FIG. 7 REF.	PAYLOAD LOSS LBS
Insulation Panels	1,245.7	.057	71
Adapter	104.0	.115	11.6
Main Stage Centaur	33.4	1.00	33.4
Subliming Thermal Protection	20	.040*	.82**
		Total	116.82

* Assume average sublimation rate

** Assume 40% debris retention

Stitched Foam system vents 24.8 pounds of gaseous hydrogen at 0-235 sec. From Figure 4 we obtain (.41) (24.8) = 10.2#

During 235-600 sec vented GH_2 is 33.4. From Figure 4 we have (.58) (33.4) = 19.4#

During 600-2100 sec vented GH_2 is 43.5. From Figure 4 we have (.8) (43.5) = 34.8#

Total payload loss of the stitched foam system attributed to thermal performance would be 10.2 + 19.4 + 34.8 = 64.4#

The payload loss for the stitched foam system attributed to the weight of the system would be, 145.33 pounds.

The total payload penalty for the two systems would then be

	AC-6	Stitched FOAM
Thermal	93.2 lbs	64.4 lbs
Weight	116.82 lbs	145.33 lbs
TOTAL	210.02 lbs	209.73 lbs

3.0 DESIGN

3.1 Discussion

The stitched foam concept, for design consideration, can be investigated in four main areas:

1. The basic insulation composite
2. Panel to panel junctures
3. Panel to tank ring (Sta 219 and Sta 412) closures

3.1 (Continued)

4. A non-jettisonable wiring tunnel/boost pump fairing.

3.1.1 The insulation composite shown in Figure 2 was the first configuration with a hard shell skin. Although the weight of the system was attractive (.19#/ft^2) several components needed to be upgraded because the system as shown, is limited to about 250°F. The polyvinal floride film will obviously lose its favorable solar absorptivity and emissitivity properties and the outer fibers of the polyurethane foam will darken and shrink during ascent heating. Figure 5 shows an upgraded composite. It will be noted that a zinc oxide solar paint has replaced the PVF film. Initial investigation indicates the solar paint to have values of .926 emissivity and .2035 solar absorptivity while showing no signs of degradation during a four hour exposure to 900°F. The Imidite Prepreg and "H" film were integrated into the composite because of similar properties. However, to date no satisfactory lamination has been accomplished. It will also be noted that the foam insulation is .65 inches thick. In addition, to improved thermal performance for a small increase in weight, this will allow a thin lamination of a high temperature foam on top of the regular polyurethane foam. A survey is being conducted to find a foam which will compliment the systems high temperature capabilities while providing the toughness needed for fabrication. Three (3) panels from Figure 8 were purchased for future component tests.

3.1.2 Panel to panel junctures must be elastomatic and provide reliable permeability. Figure 3 shows the current method. The loose glass roving should provide a sufficient temperature gradient to keep the silicone potting compound warm and elastic during tank pressure cycles.

3.1.3 Panel to tank ring closures are shown in Figures 9 and 10. The use of mylar honeycomb is to provide a warm potting compound.

3.1.4 The wiring tunnel and boost pump fairings are shown in Figure 4. Crossections of the fairing are shown in Figures 11 and 12

3.2 JET ENGINE TEST STRUCTURE

The exhaust of a jet engine is to be used as a preliminary test for the Stitched foam insulation system prior to a large scale wind tunnel test. A typical type of a test set-up is shown in Figure 13 . The purpose is to verify the structural integrity of the concept. A stripping of the insulation panels protecting the LH_2 filled tank in a hot wind tunnel could do considerable damage to the test structure and wind tunnel. Figure 14shows a preliminary installation of test panels on the jet engine test tank.

3.3 WIND TUNNEL TEST STRUCTURE

Figure 15shows the actual LH_2 test tank which will be used to test the Stitched Foam Insulation system in the LeRC wind tunnel. Figures 16/17 and 18 show the preliminary installation drawing. It should be noted that due to the increase of insulation thickness, a new fairing ring will be required. Figure 19 shows an enlarged section of theleading edge transition ring which is detailed in Figure 18.

4.0 COMPONENT TEST

Preliminary component tests were completed and are described in Appendix II. It should be noted that the Stitched Foam has the ability to distribute a concentrated load over a large area reducing its net effect on the immediate adhesive substrate. In addition to the testing described in Appendix I, thermal tests were run on various cork and Thermolag T-230 coated cork for a possible wiring tunnel insulation system. The main effort was in fabrication of an ultra thin layer of T-230 on Armstrong 7326. However, the thinnest layer obtainable was 7 mils. Each of five 6 inch x 6 inch panels were exposed to a Quartz heat lamp and the temperature on the back side was monitored. Results are shown in Figure 20 . All of the thermolag/cork samples burst into flame indicating the outgassing of the cork when combined with the subliming gases of the T-230 are combustible. Further work in this direction has been discontinued.

5. PLANS FOR NEXT PERIOD

The major effort during the next period will be directed toward further development of the hard shell skin and the adhesive system which bonds it to the stitched foam panel. High temperature, permeability and solar radiation properties will be the main requisites.

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5. Reimer, R. R., Test Results of Heat Blockage Characteristics of Thermolag T-230 and Armstrong Cork B-50 at Low Heat Rates
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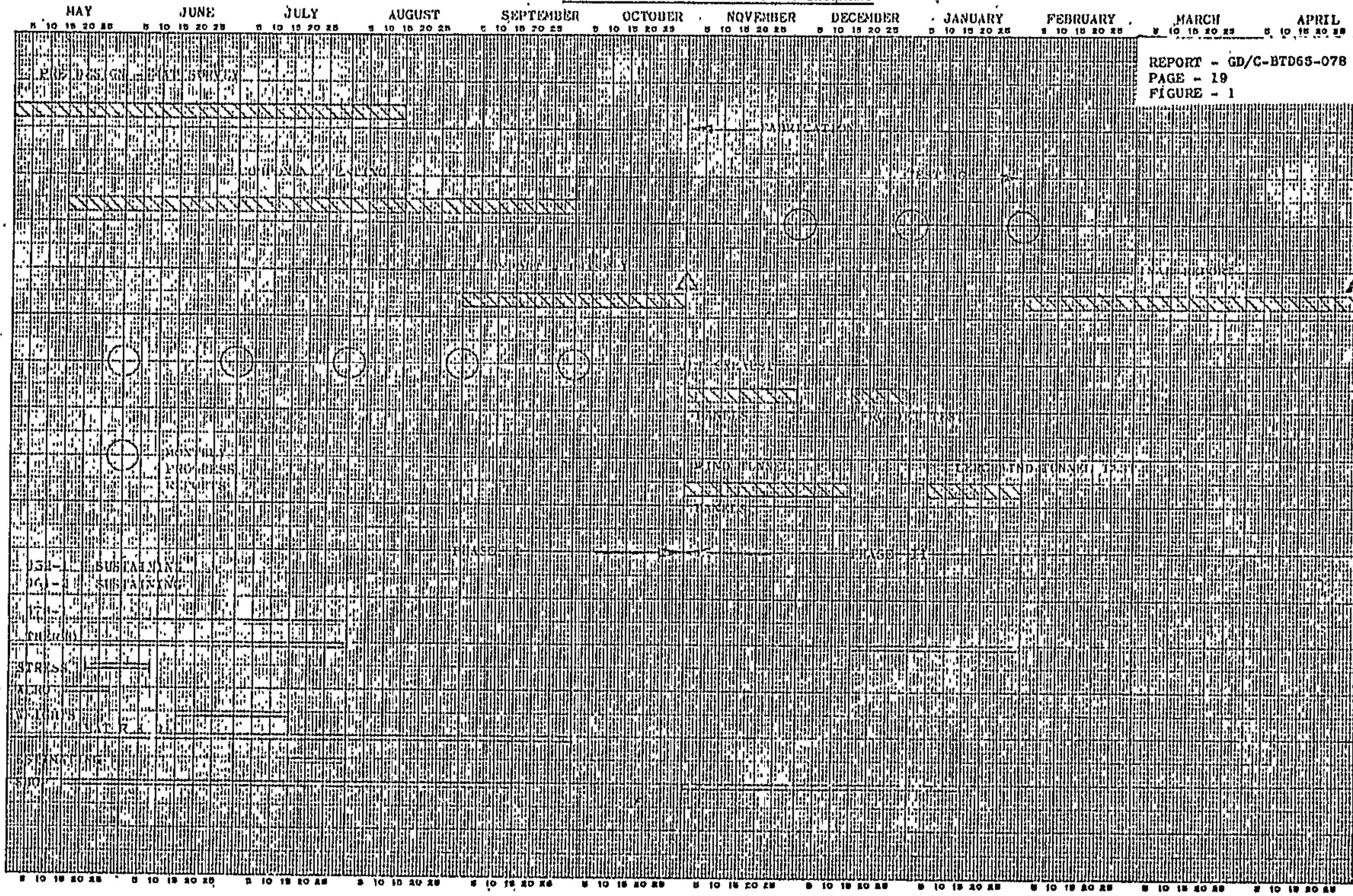
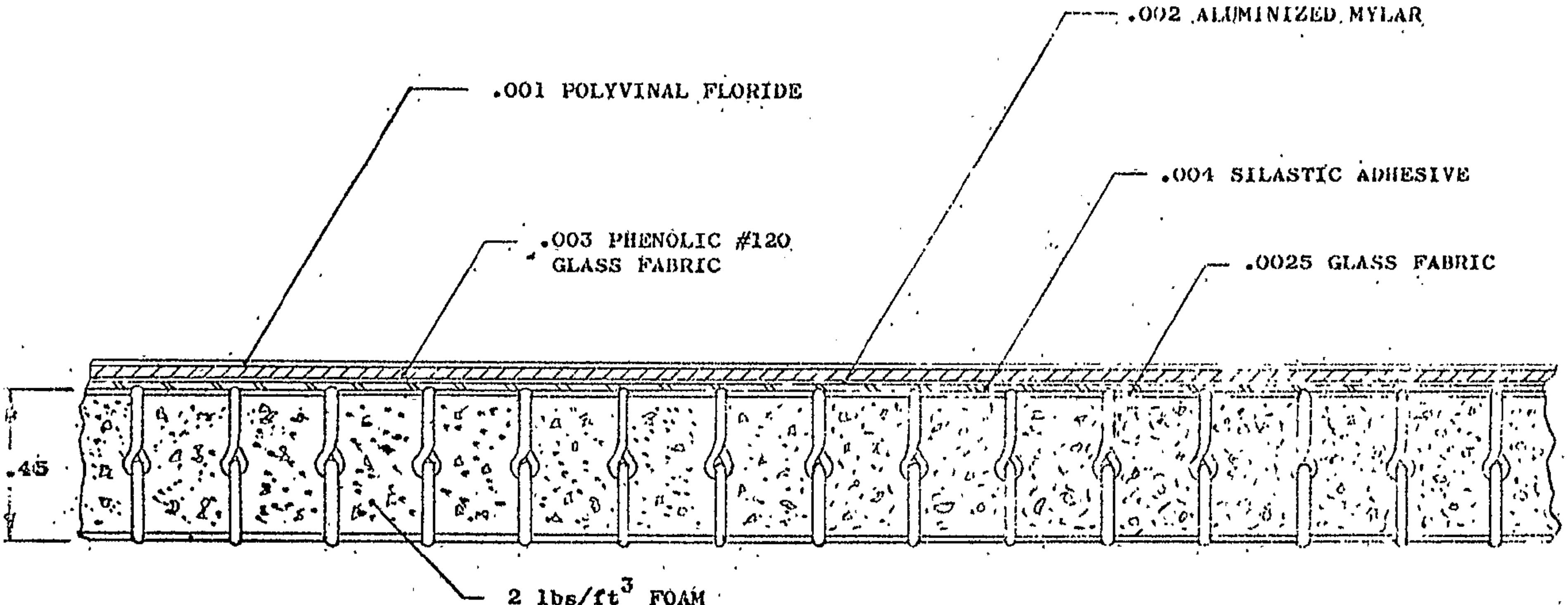
FIGURE - 1

STITCHED FOAM INSULATION DEVELOPMENT





STITCHED FOAM INSULATION

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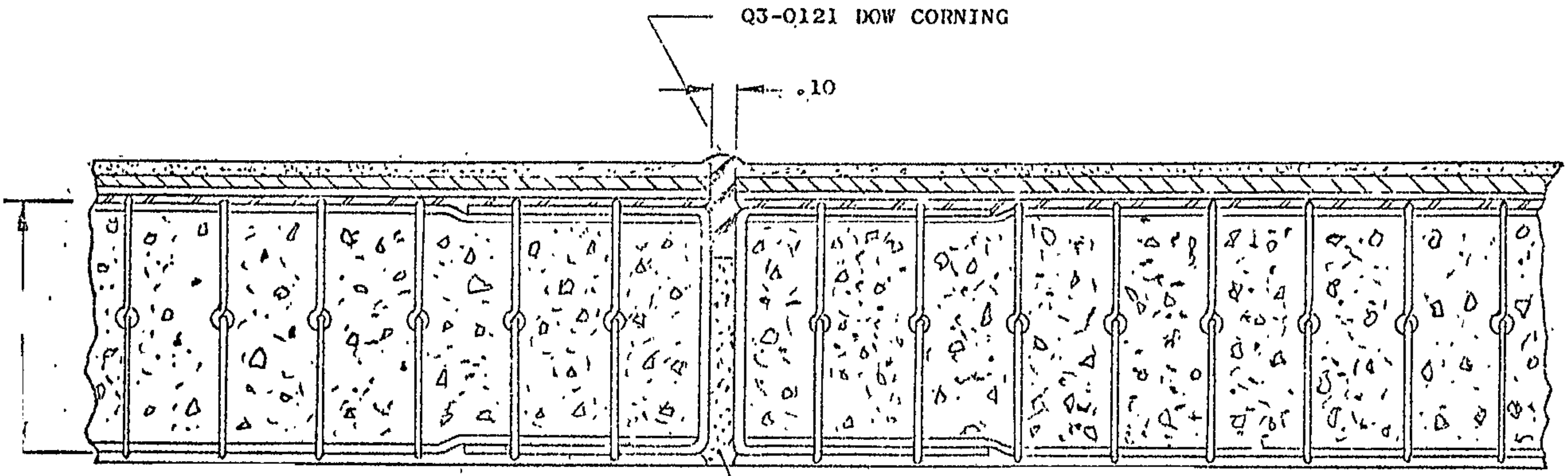
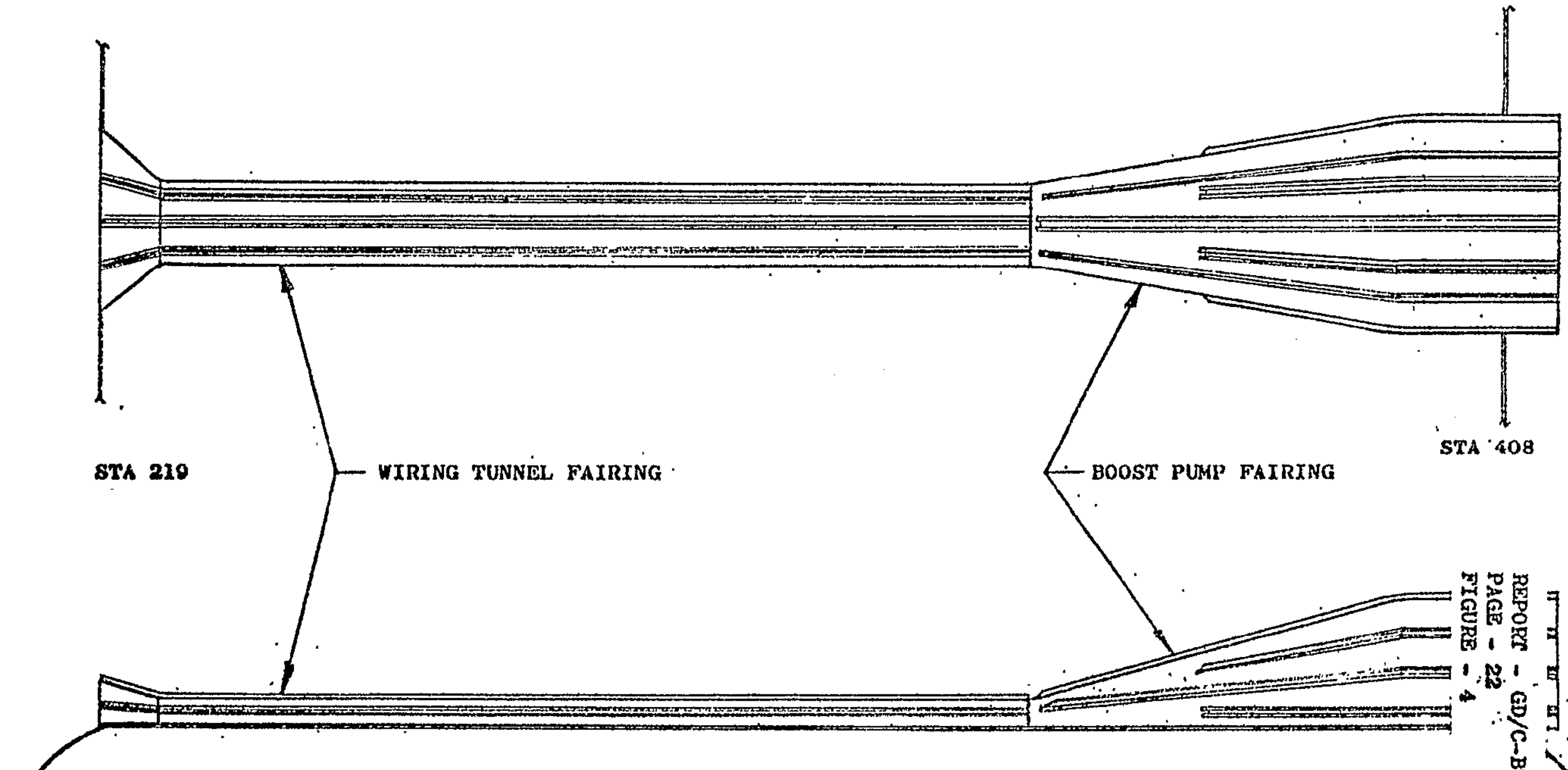
FIGURE - 2



STITCHED FOAM JUNCTURE



FAIRING ASSEMBLY

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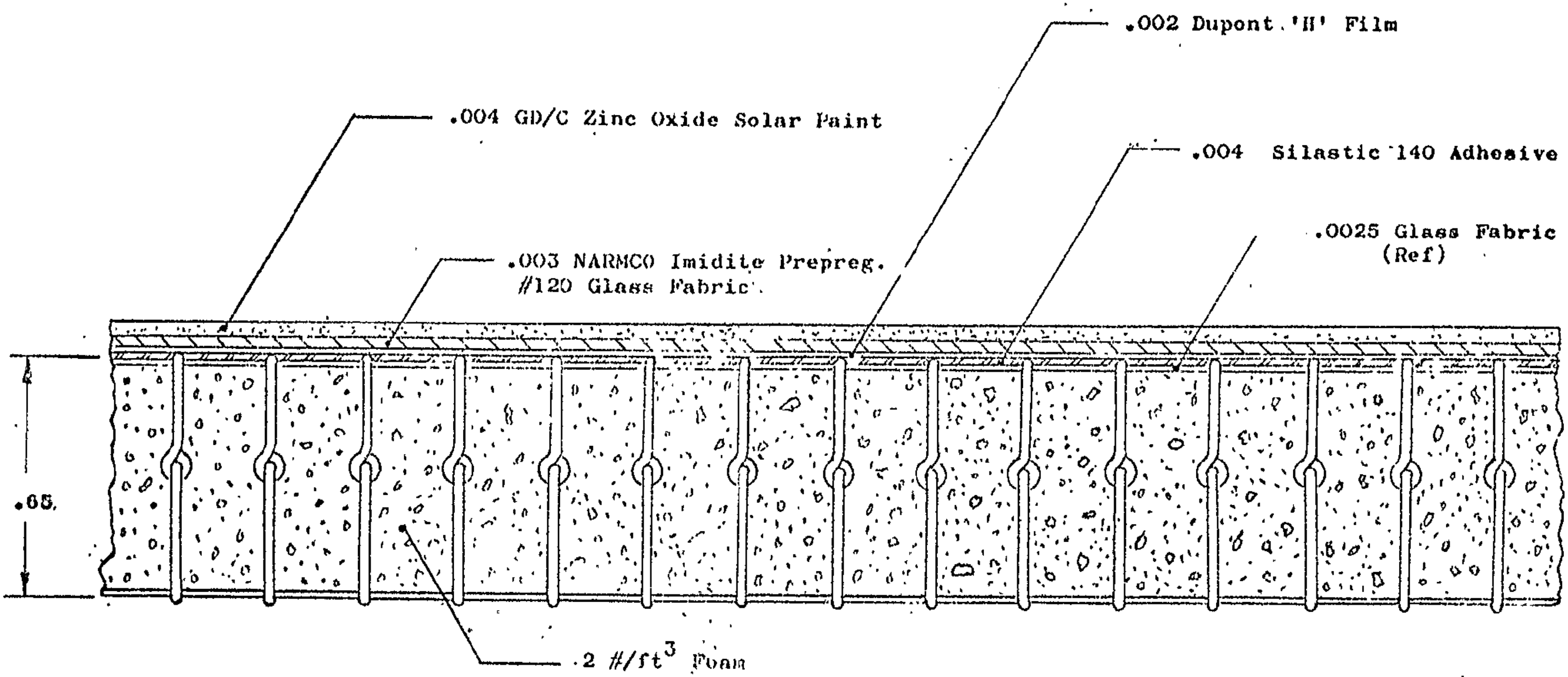
FIGURE - 4



STITCHED FOAM INSULATION

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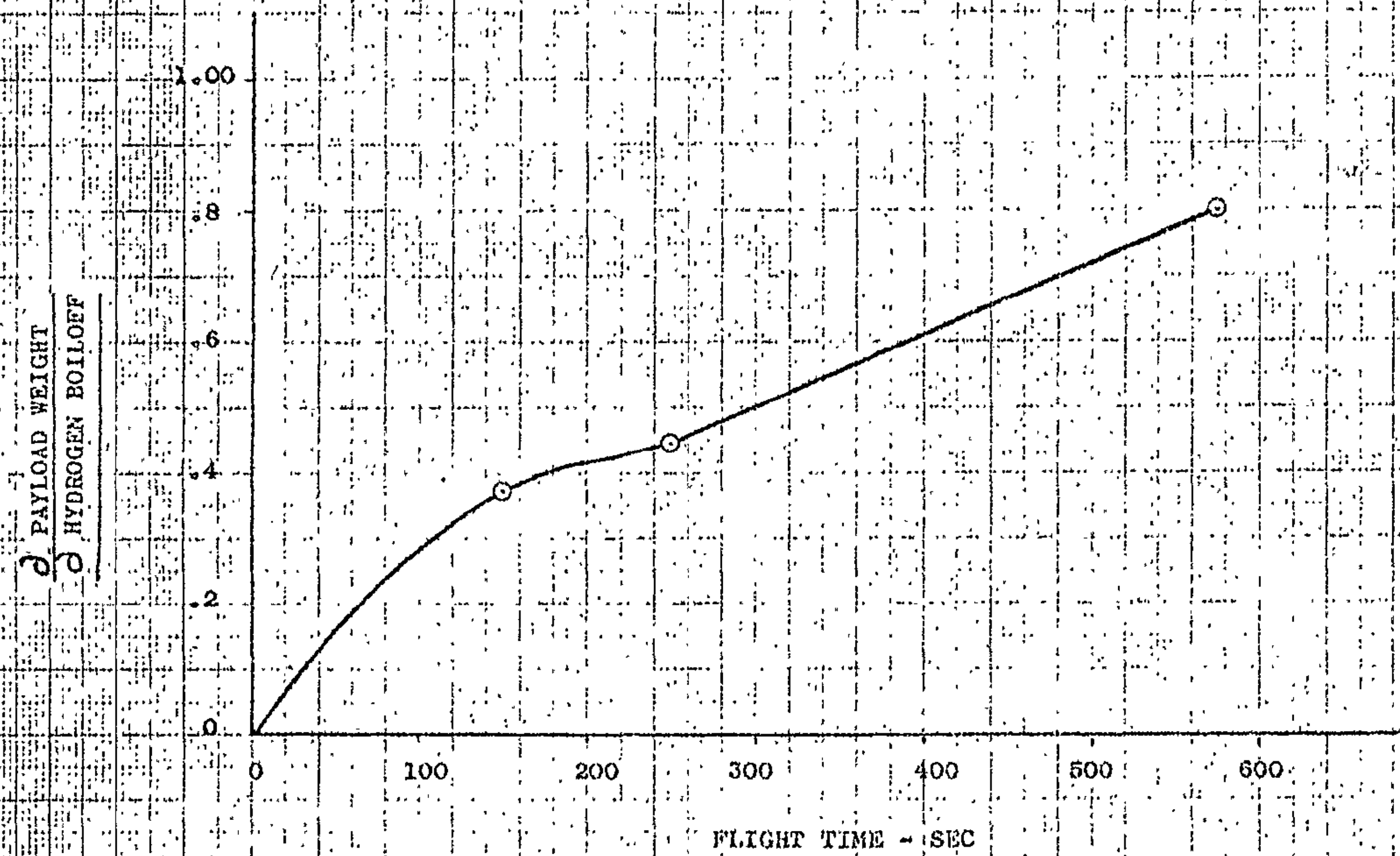
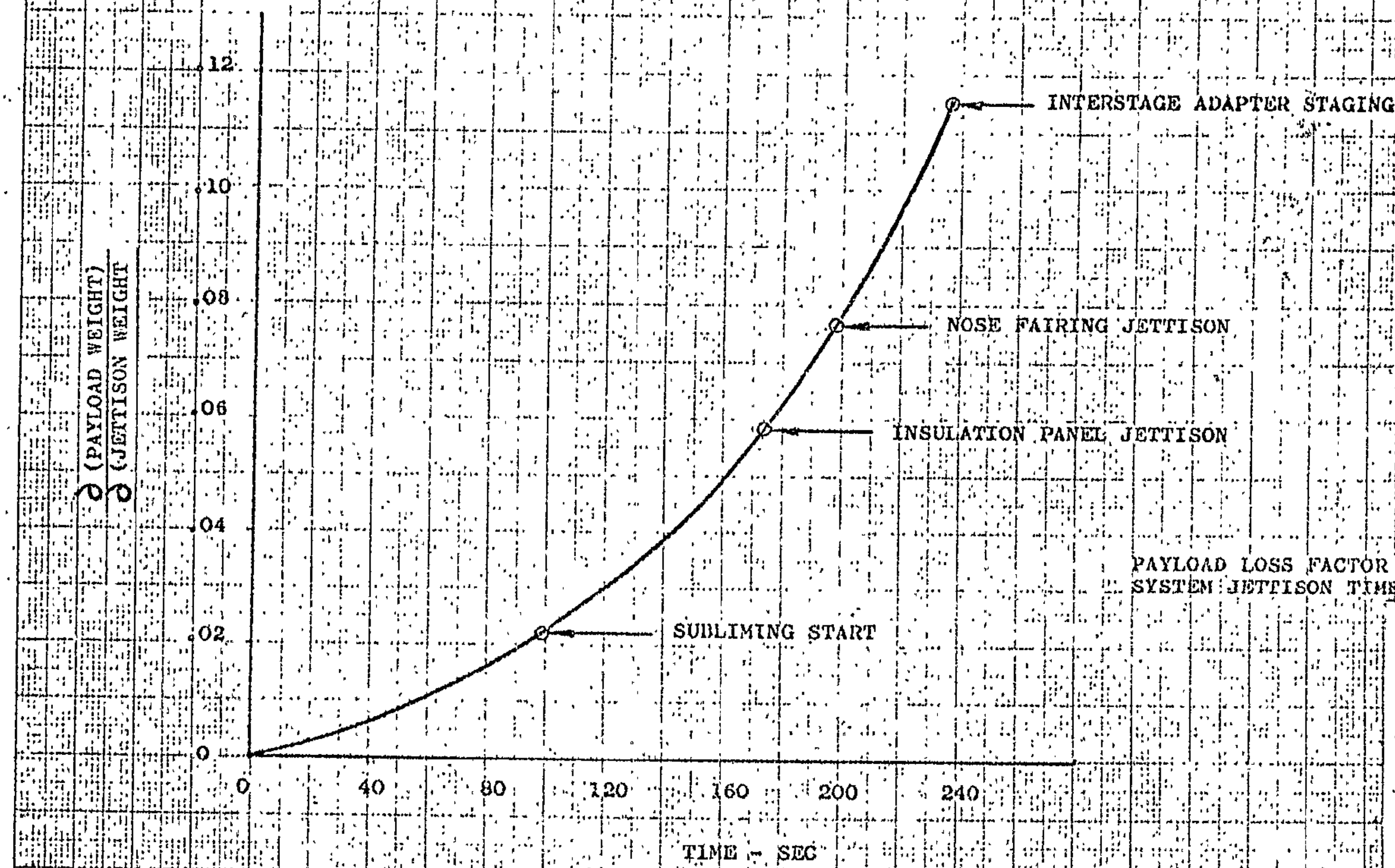
FIGURE - 5

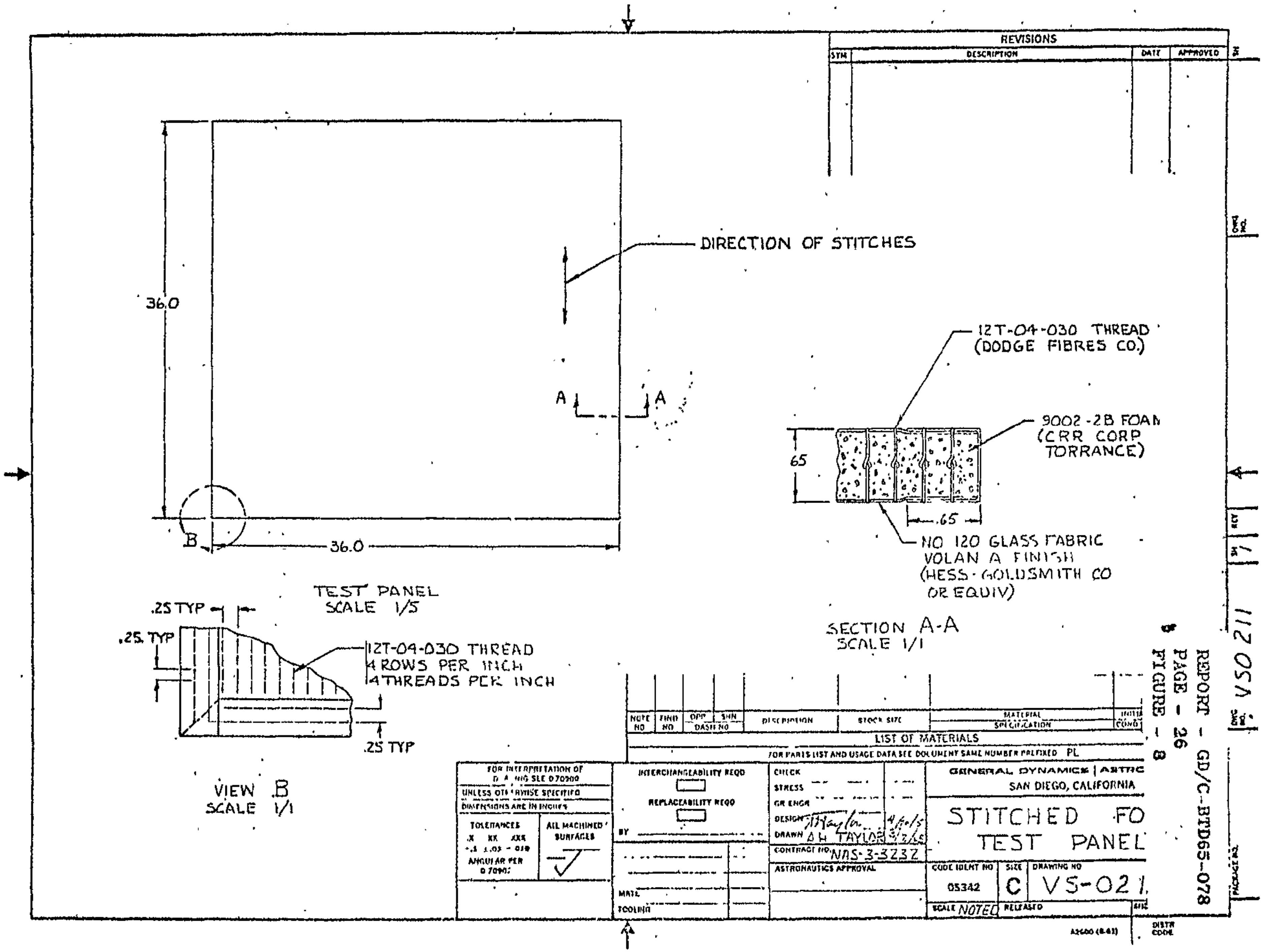


PAYLOAD LOSS FACTOR VS. TIME OF HYDROGEN BOILOFF

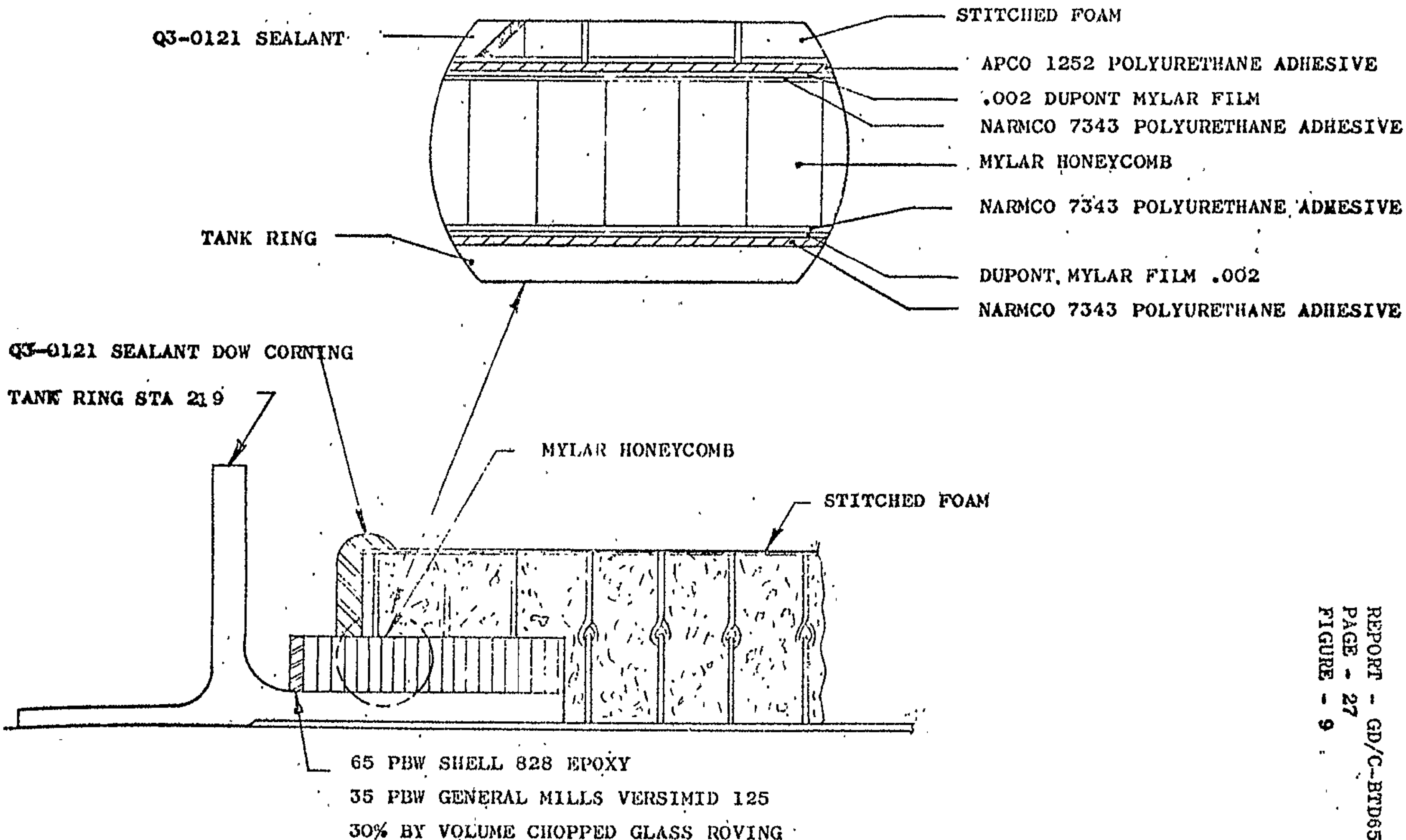
REPORT - GD/C-BTD65-078
PAGE - 24
FIGURE - 6



PAYLOAD LOSS FACTOR VS SYSTEM JETTISON TIME



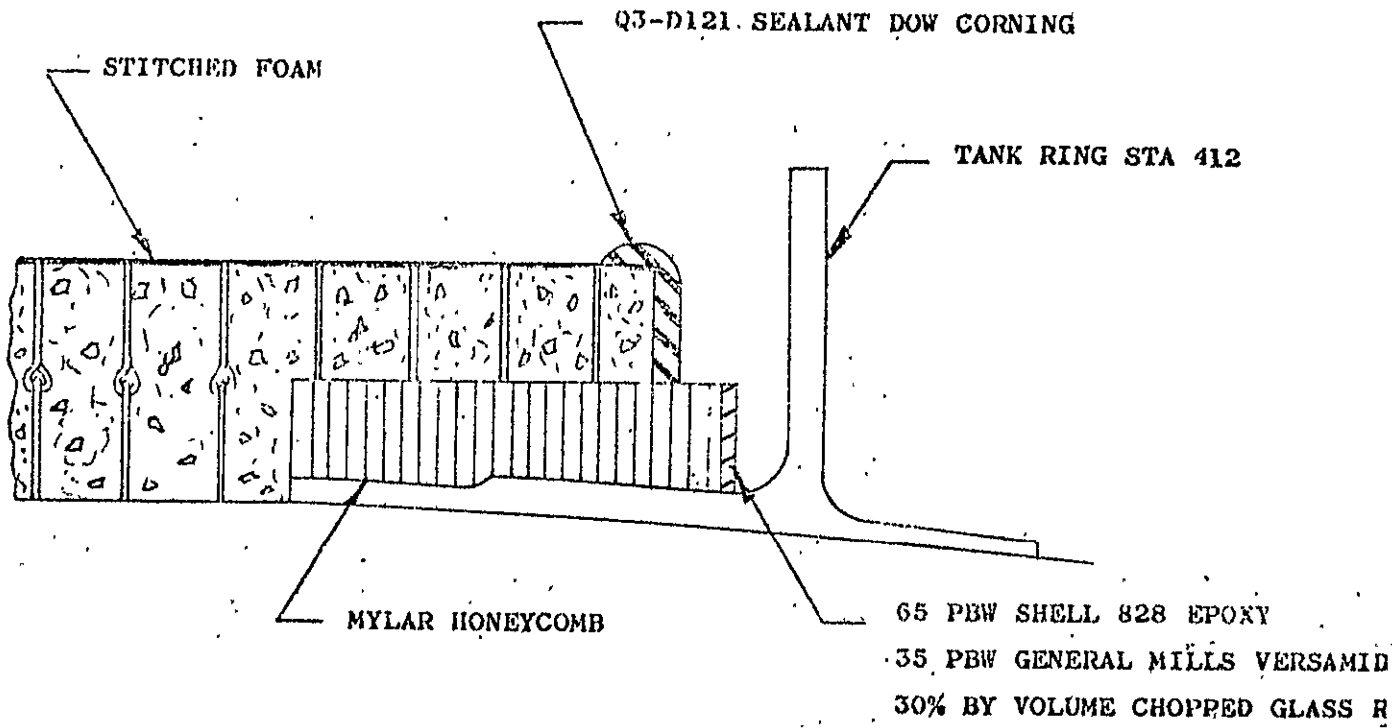
REPORT – GD/C-BTD65-078
PAGE – 26
FIGURE – 8



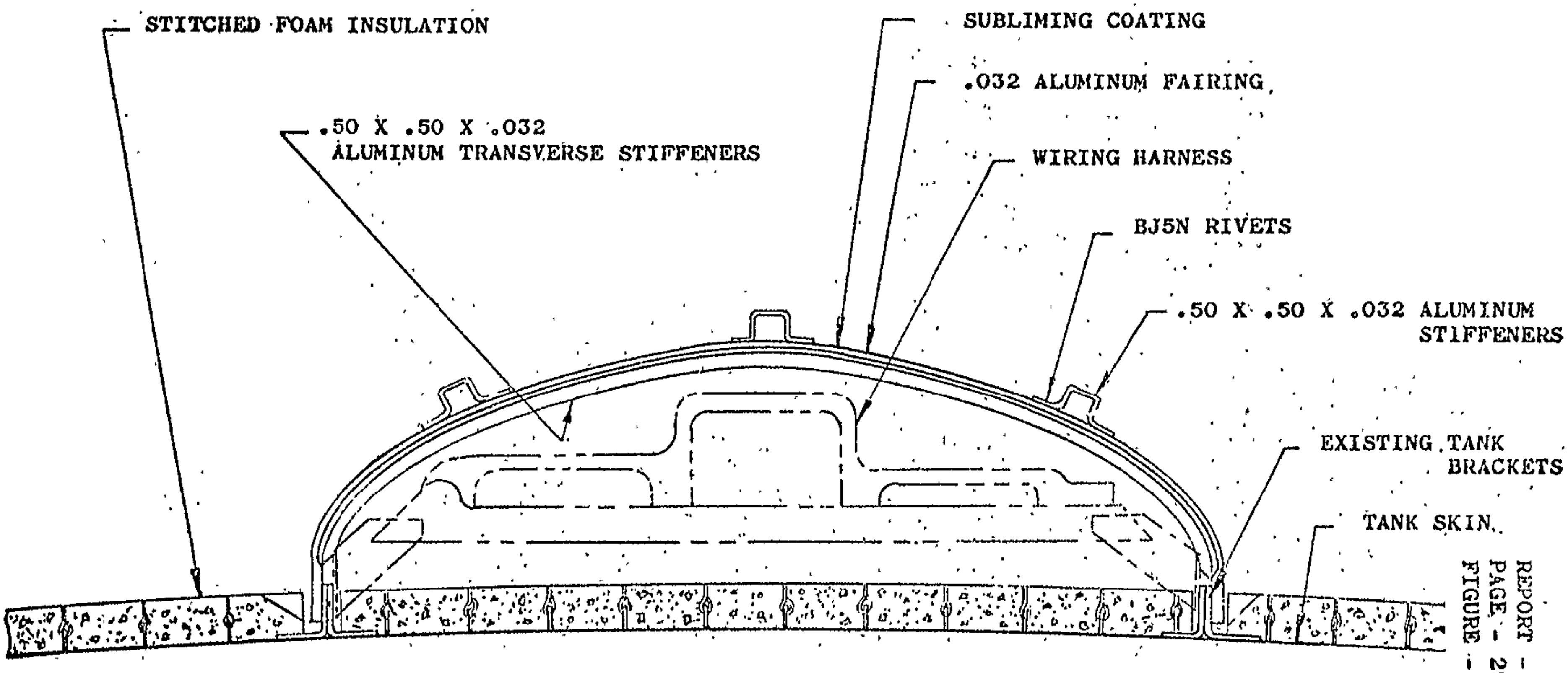
END SEAL - STA 219

REPORT - GD/C-BTD65-078
PAGE - 27
FIGURE - 9

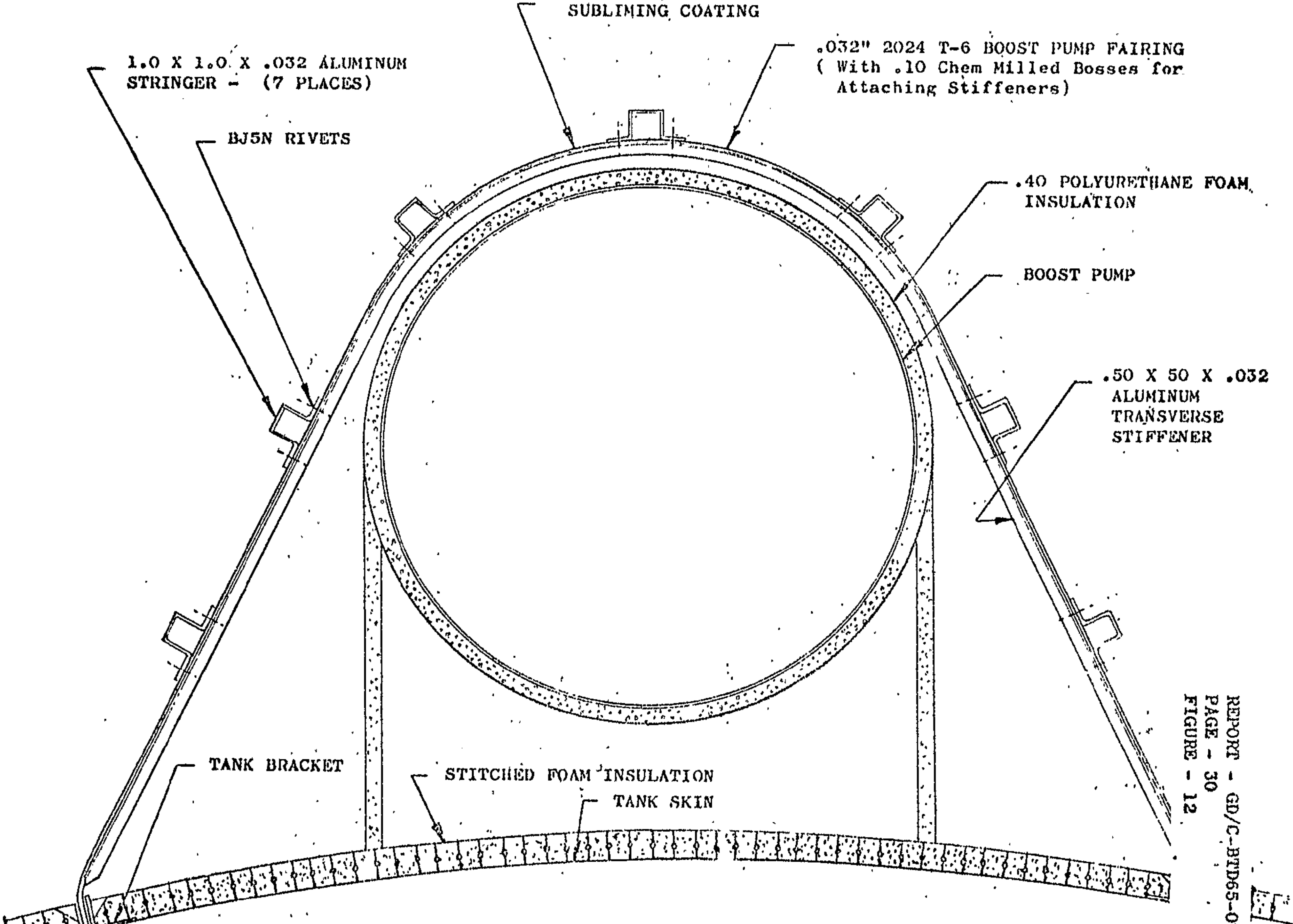
27



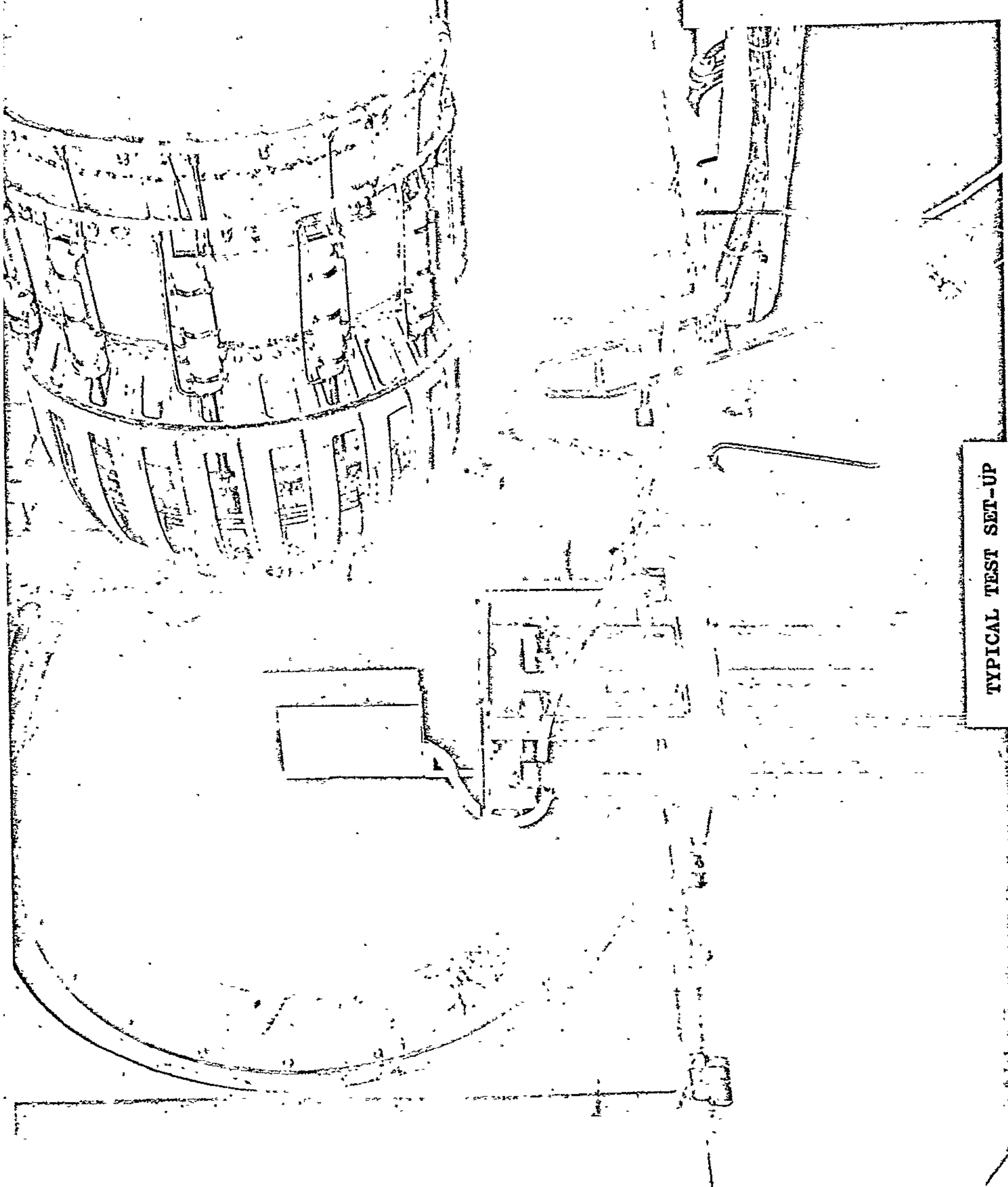
END SEAL - STATION 412



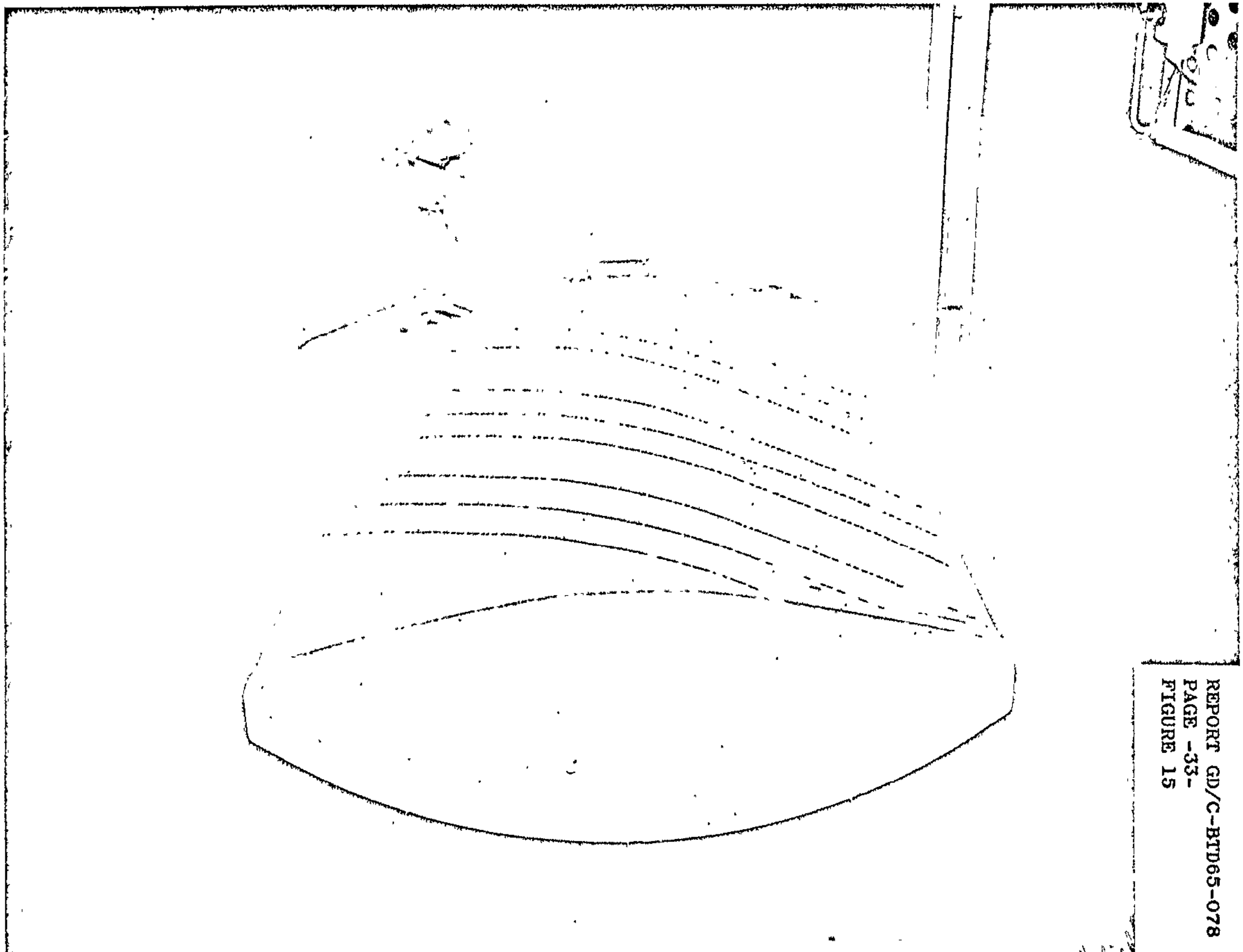
WIRING TUNNEL FAIRING



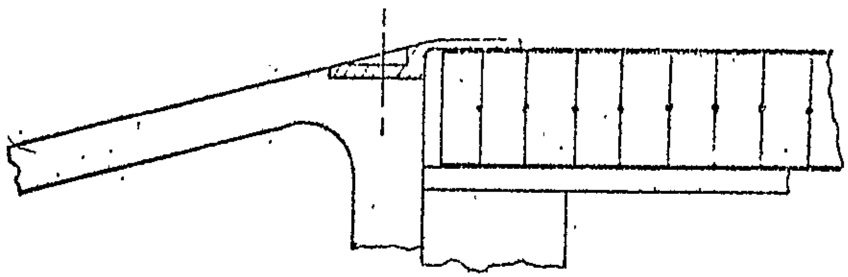
BOOST PUMP FAIRING



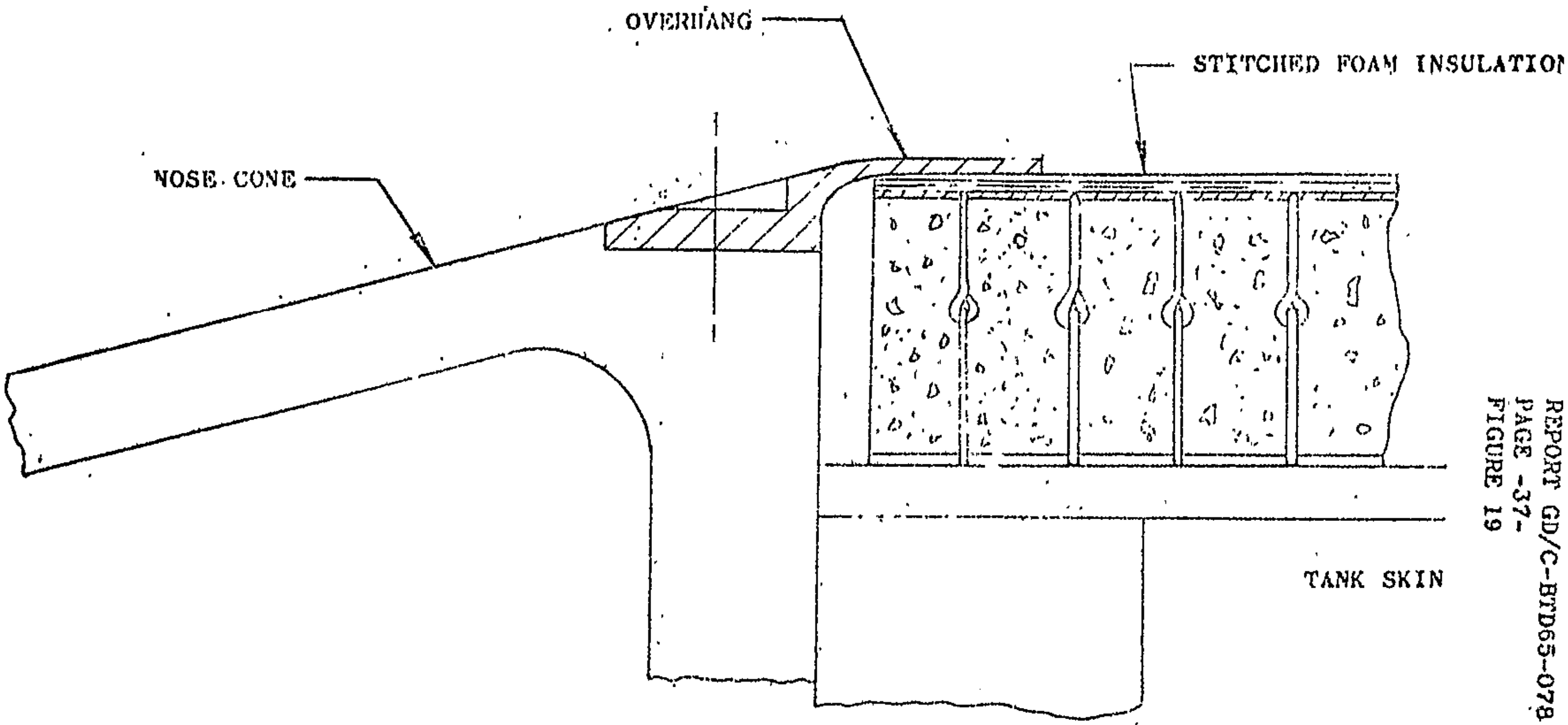
TYPICAL TEST SET-UP



ACTUAL WIND TUNNEL TEST TANK



FULL SIZE



BICONVEX TANK INSULATION

FIGURE 19

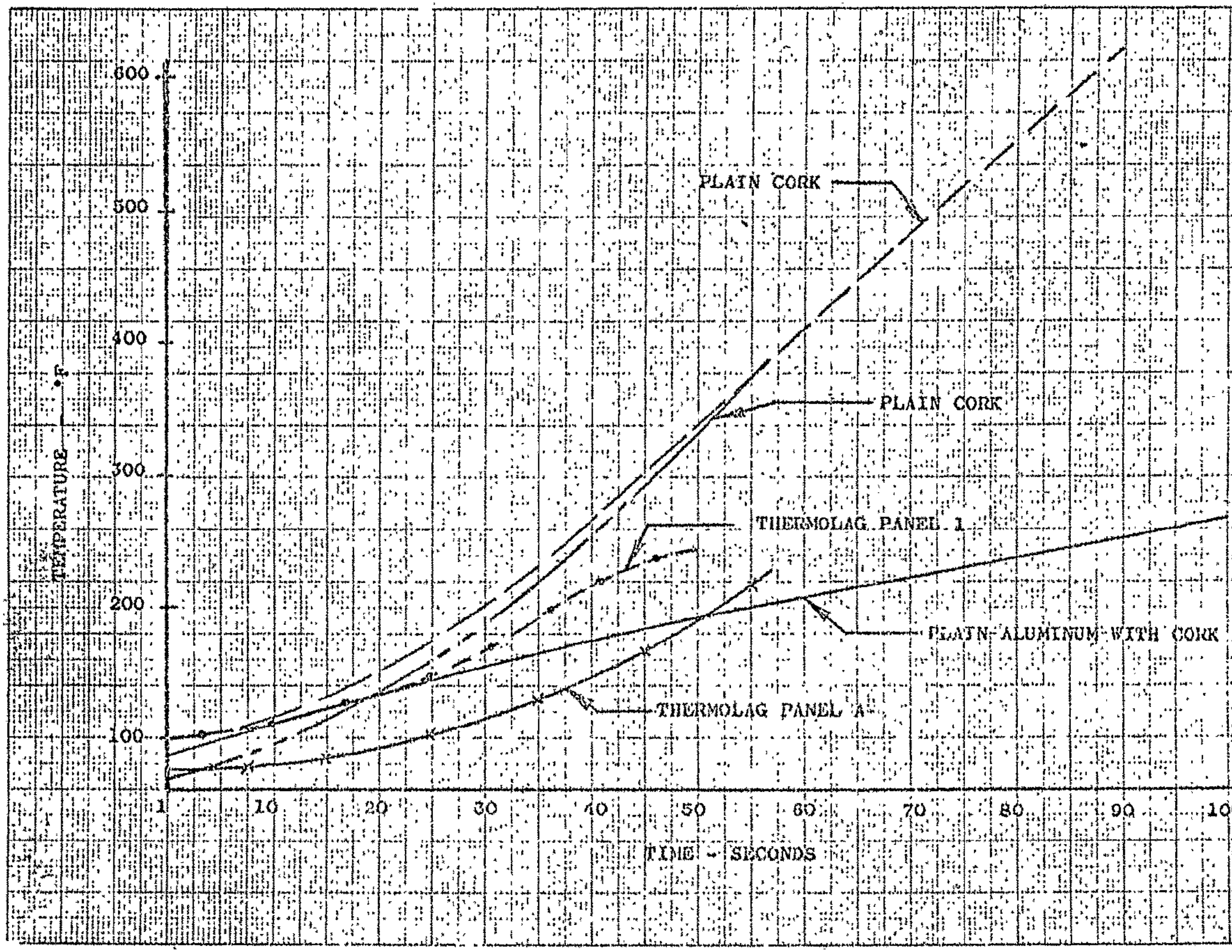

TEMPERATURE — °F
600
500
400
300
200
100
PLAIN CORK
PLAIN CORK
THERMOLAG PANEL 1
PLAIN ALUMINUM WITH CORK BACKING
THERMOLAG PANEL A
1
10
20
30
40
50
60
70
80
90
100
TIME - SECONDS

FIGURE 20

APPENDIX I

CONVAIR REPORT NO. CTL-65-065

SUBJECT: Comparison of Efficiency of Non-Jettisonable Stitched Foam Insulation with AC-6 Type Panels on the LH_2 Tank of a Centaur Vehicle during Ground Hold, Launch and Orbit at 90 n. mi.

REFERENCES:
1) Yurczyk, R. F., "Insulation Panel In-Flight Purge Study", CTL-64-322, 24 November 1964.

2) Hartung, R. O., "Hydrogen Tank Heating Rates Prior to Lightweight Insulation Panel Jettison for a Parking Orbit and Direct Ascent Mission", CTM-180, 15 May 1964.

3) Hartung, R. O., "Jettison Times for LH_2 Tank Insulation Panels," CTM-198, 13 May 1964.

4) Barkdoll, R. O., "Convective Heat Transfer in Rarefied Atmosphere", Convair Report TG-218, 13 June 1960.

5) Braun, C. E., "Maximum Space Heating of Centaur Vehicle in 90 n.mi. and 300 n.mi. Orbits with Sun Orientation During Coast", CTM-59, 19 November 1962.

6) Braun, C. F., "Space Coast Thermal Analysis of Partially Unwetted LH_2 Tank Walls Under Low Gravity Conditions", CTM-164, 20 November 1963.

7) Cornwell, J. F., "Vehicle Design Trajectory Data Atlas/ Centaur/Surveyor", Revision A, GDA63-1096A, 14 May 1964.

Problem

A logical step in the development of a cryogenic propellant tank insulation system is to compare its efficiency in preventing excessive boil-off with that of a system already in use. This comparison must be made throughout a complete operational cycle during which the system must perform its function. This includes, in the case of a booster vehicle, the period from pre-launch through the coast phase.

Discussion

The study resulting in the enclosed comparison of wetted and unwetted LH_2 tank side-wall heating with two different types of insulation systems was necessarily simplified to permit a preliminary evaluation of the stitched foam. A complete and accurate analysis is quite involved and time consuming and was not warranted at this time.

The heat rate histories shown on Figures 2 and 3 are the results of this cursory analysis. Unwetted tank wall heating rates are not shown prior to Centaur MES because of the relatively small ullage volume prior to this time.

Two different kinds of stitched foam were studied and are detailed on Figure 1. The designations A.66 and B.4 were established in prelimary studies to describe the physical characteristics of the insulation. The letter prefix identifies the kind of external protection, either a fiberglass cloth system (A) or cloth and cork combination (B), and the numerical suffix indicates the foam thickness (.4 = 0.4 inches, .66 = 0.66 inches).

The tank heating rates are presented in terms of BTUs per foot of length of a ten foot diameter cylinder and liquid level histories must be known to determine total sidewall tank heating. Not included in this report are forward bulkhead, Station 219, boost pump, electronic and mechanical equipment heating, which contribute to total tank heating but are independent of sidewall insulation heat transfer analyzed and compared herein.

The period from t-40 to t-20 seconds shows ground hold tank heating rates and, in the case of the AC-6 type panels, reflects tank heating due to the helium purge. Purge heating for this period, and during airborne purge operation, was calculated assuming that the hydrogen tank absorbed all the heat introduced by the purge gas. Airborne purge flow rate history was based upon an 0.06 inch diameter orifice as shown on Figure 1 of Reference 1. Conduction heating through both insulation systems during ground hold was obtained by assuming an ambient air temperature of 60°F and a 10 knot crosswind (h_c = 5 BTUs/hr-ft^2 - °F).

In-flight tank heating prior to panel jettison at t + 195 seconds was taken from Reference 2 for the AC-6 type panels. Tank heating through the stitched foam up to t + 150 seconds included the effects of the small angles of attach and the resulting heat rates were applied to the entire 360° segment. From t + 150 to t + 350 seconds the angles of attack are quite large and this higher heating was applied only to the windward (Quads II and III) side of the vehicle. Both the bare tank and stitched foam received the same aerodynamic heating after panel jettison, which corresponds to the minimum heating case of Reference 3 for the bare tank. The increased heating due to angle of attach between t + 150 seconds and panel jettison had insignificant effects on tank heating through the AC-6 type panels because of the evacuated gap between the panels and tank wall. The leeward side of the vehicle received flat plate values after t + 150 seconds.

Transition from continuum to free molecular heating was assumed to occur instantaneously whenever continuum values exceeded free molecular. This was found to be at about 240 seconds after launch. The neglection of the fact that true heating during the transition period is less than continuum results in insignificant error in total heating values. Free molecular heating was calculated as shown in Reference 4.

The largest source of error in this study is believed to be in the application of the relatively high angle of attack heating rates to a full 180° section of the tank from t + 150 to t + 240 seconds. This heating, in reality, exists only on a line formed on the windward surface by a plane that is parallel to the flow and passes through and contains the vehicle axis. The surfaces on both sides of this line, up to an angular distance of about 80° (θ) from this line, receive heating that is a function of the angular location (θ) and the heat flux at the line. This function is qs cos 7/6 θ and it is apparent that it decreases as θ increases. This error is readily seen to penalize the stitched foam since the AC-6 type panels are most efficient at this time because of the evacuated gap. After panel jettison, however, the bare tank receives the greatest penalty since its efficiency as an insulator is essentially zero.

At panel jettison the space heating sources of solar, ablede and terrestial radiation become significant and were applied to the vehicle as though it was velocity oriented and in a 90 n.mi. circular orbit. The only consideration of the orientation of the earth-sun vectors was to extrapolate the heating curves of Reference 5, which was the source of the radiation heating values used in this study. Here again no attempt was made to properly distribute this heat flux except to apply solar values to only the sun side and albedo and terrestial to the earth side. This method resulted in the vehicle receiving the correct total radiation heating but penalized the stitched foam by reducing space reradiation, which is a function of surface temperature raised to the fourth power.

Emissivity and absorptivity values used were 0.18 and 0.48 respectively for the bare stainless steel tank, and 0.95 and 0.15 respectively for the stitched foam. The stitched foam surface radiation properties are those of a high temperature paint presently under development in Convair laboratories. This paint will purportedly retain these properties after having been subjected to a temperature of 900°F for several hours, which is higher than any temperature expected on the outer insulation surface. If this paint, or a coating with the same radiation properties, could be applied to the bare tank then there would be insignificant difference between the stitched foam and bare tank space coast heating values, since these are primarily dependent upon the surface radiation properties. Since the stitched foam is a relatively ineffective space heating insulation, the same coating on the bare tank would control tank heat input to the same extent as the coating on the stitched foam, with the tank heating due to stored aerodynamic energy in the insulation offsetting the small reduction in space environment heating achieved by a higher insulation surface reradiation temperature.

The thermophysical properties of the stitched foam (excluding the cork, fiberglass and adhesive) were calculated considering the contribution of the stitching and are shown in Table 1 as a function of temperature.

TEMP. °R	C_p (BTU's/lb-°R	k(BTUs/ft-hr-°R	(lb/ft^3)
20	0.35	0.0013	2.35
60		0.003	
200		0.0093	
300		0.0133	
435		0.0168	
480		0.0175	
600		0.022	
800	0.35	0.0273	2.35

TABLE 1: STITCHED FOAM THERMOPHYSICAL PROPERTIES

Free convection heating of the ullage gas was calculated for the period of t + 240 to t + 600 seconds for the bare tank, and from t + 240 to t + 2100 seconds for the stitched foam. Bare tank sidewall ullage heating from t + 600 to t + 2100 seconds was taken from Reference 6. A constant ullage temperature of 40°R was assumed in all cases.

The trajectory given in Reference 7 was used in accomplishing this analysis.

Prepared by ______________
R. R. Reimer

Checked by______________
R. O. Barkdoll

Approved by______________
G. C. Wilson
Thermodynamics Group Engineer

PHYSICAL CHARACTERISTICS OF THE

STITCHED FOAM INSULATION SYSTEMS

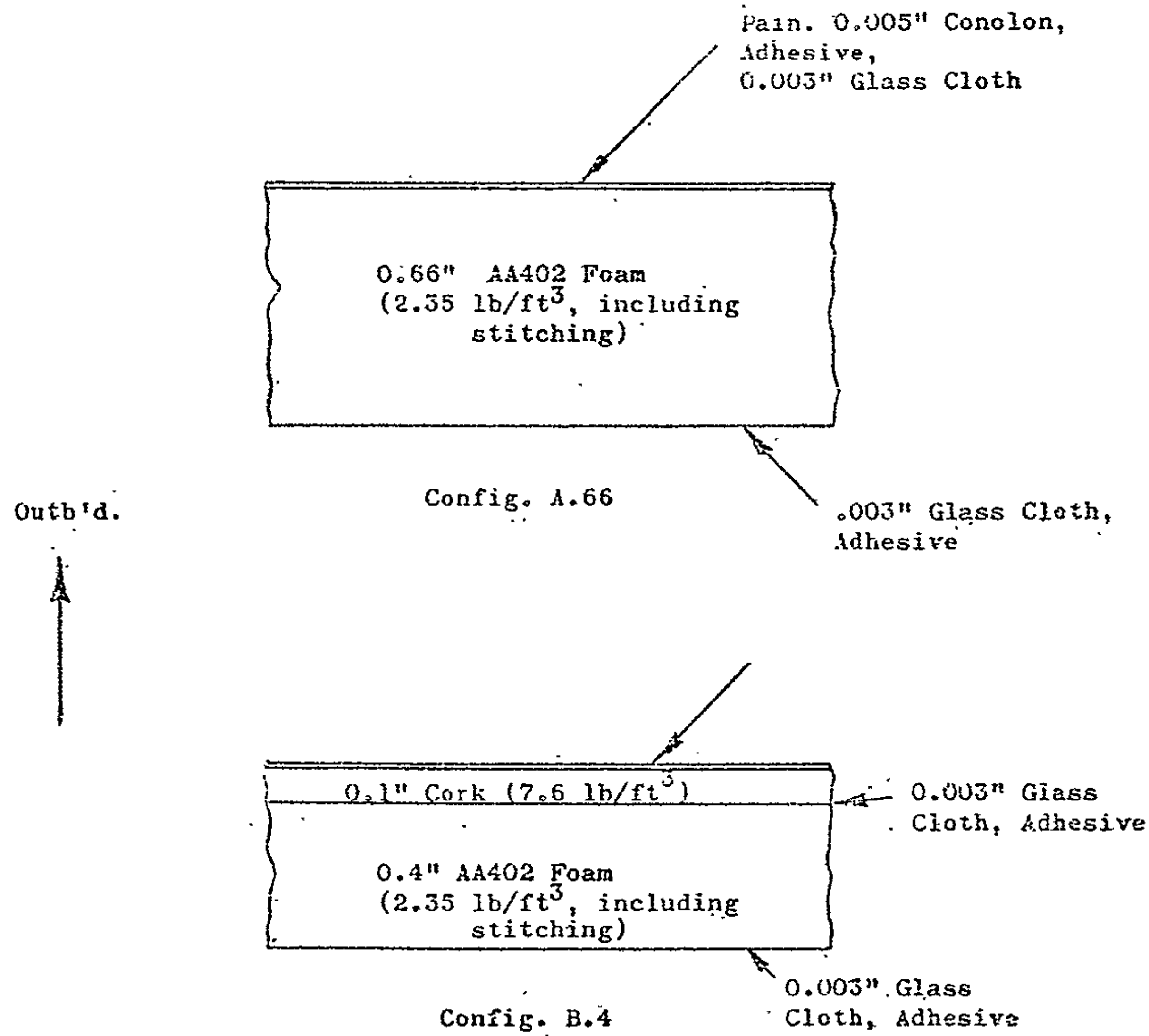
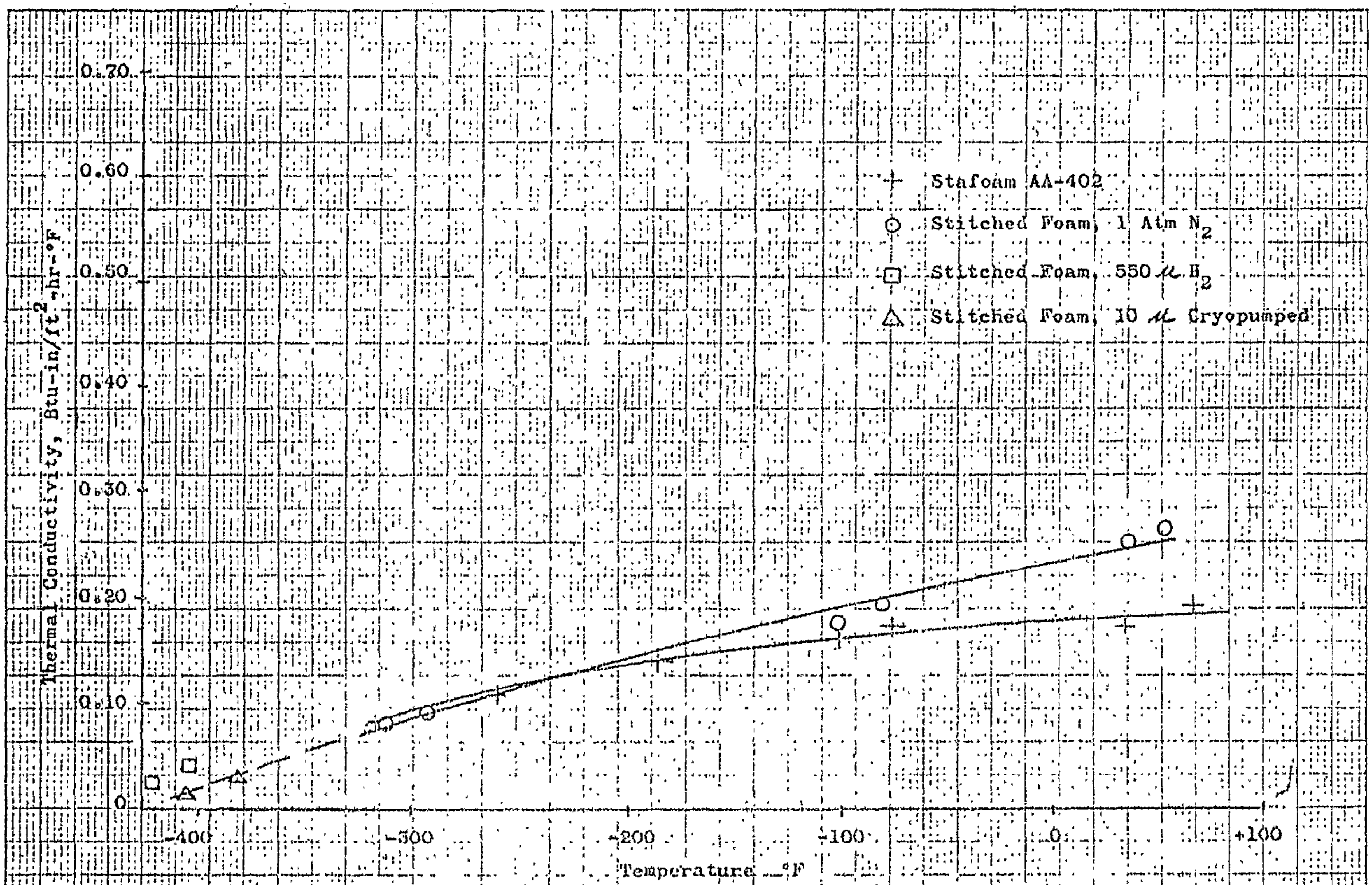


FIGURE -1



THERMAL CONDUCTIVITY OF SEVERAL INSULATIONS

FIGURE -2-

41

FIGURE 3. FAILED TENSILE SPECIMENS

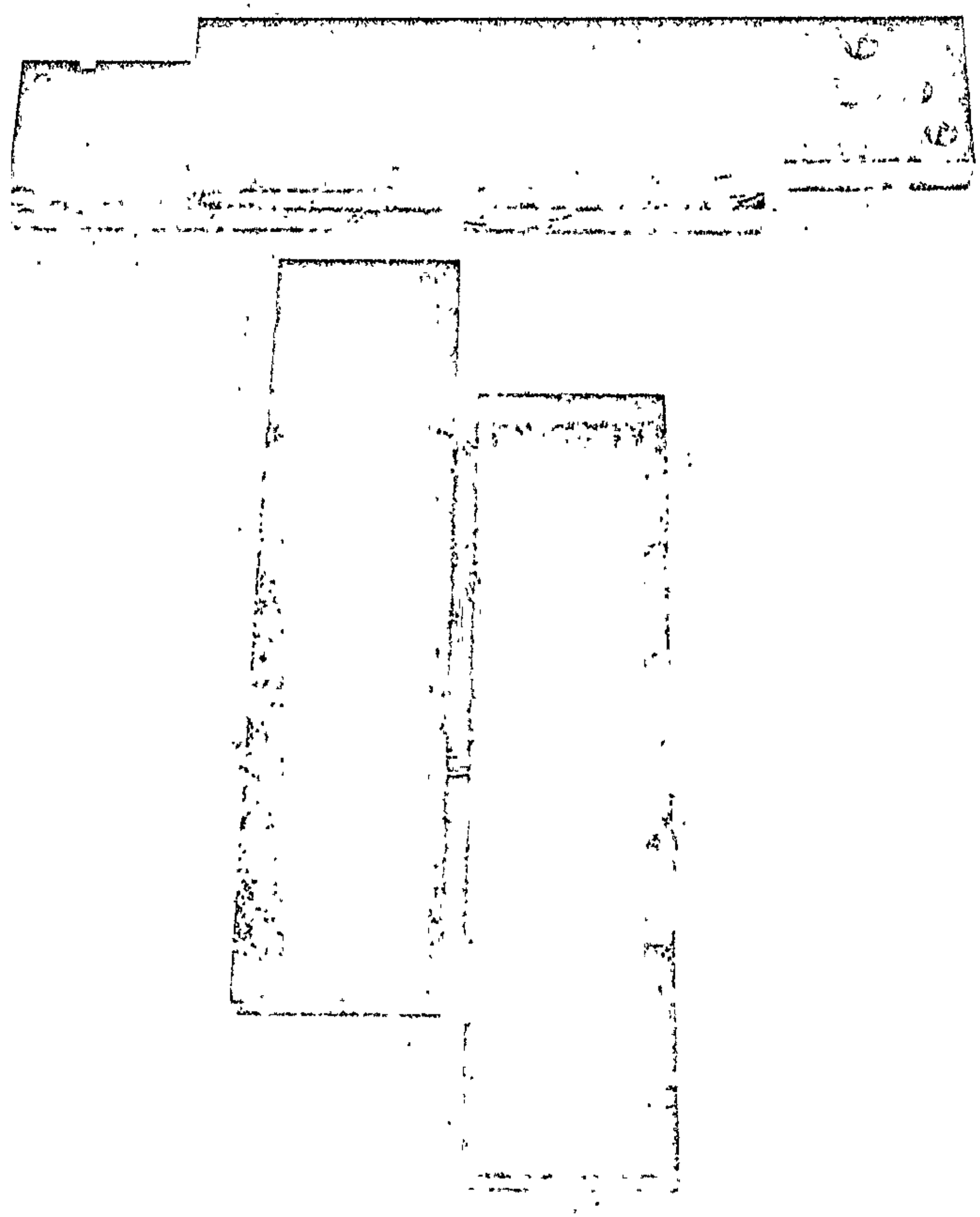


FIGURE 4. FAILED PLATE SHEAR SPECIMENS

APPENDIX II

CONVAIR REPORT M-325

M-325
12 March 1965
STITCHED FOAM INSULATION TESTING

The thermal conductivity, tensile strength and shear strength of stitched foam insulation were determined over a temperature range of -423°F to 75°F The stitched foam insulation was supplied by H. Ruscigno, Dept. 961-2 and conforms to the configuration in Figure 1.

The thermal conductivity of the stitched foam insulation was run on panels that were approximately 7.5 in x 7.5 in x 0.42 in. Testing was accomplished using the GD/C modified guarded hot plate technique (Ref. 1). From room temperature down to -320°F the testing was accomplished in the presence of one atmosphere of gaseous nitrogen. The specimen holding container was allowed to cryopump at temperatures below -320°F. The data obtained is tabulated in Table 1 and plotted in Figure 2. Some pinhole leaks were present in the box when points 8 and 9 were measured, thus leading to the presence of hydrogen in the specimens and excessively high values. The foam used in the stitched foam insulation was Stafoam AA-402. Figure 2 includes the data obtained on Stafoam AA-402 when evaluated without stitching (Ref. 1). The largest deviation in conductivity between the stitched foam and the plain foam sheet stock occurs at room temperature, and at this temperature the conductivity of the stitched foam is approximately 40% higher than that obtained in the pure foam.

Tensile strength of the stitched foam was obtained at 75°, -320° and -423°F. Pieces of the stitched foam, 3 in x 3 in., were bonded between 1.5 in. diameter stainless steel loading blocks with Narmco 7343/7139 polyurethane adhesive. Five specimens were tested at 75°F and resulted in an average tensile strength of 240 psi (see Table 2). This was much higher than anticipated, and the appearanc of the failure indicated some distribution of the applied load over the full area of the 3 in x 3 in square specimen. Additional specimens were then bonded, trimmed to the area of the loading blocks and pulled at the three test temperatures. The results are tabulated in Table 3. The room temperature tensile strength averaged 179 psi or approximately 75% of the strength obtained with the 3 in x 3 in specimens. The tensile strength of the stitched foam is approximately three times higher than that of unstitched Stafoam AA-402. Typical failed specimens are shown in Figure 3. The tensile strength more than doubled when going from 75°F to -320°F and was essentially the same at -423°F and -320°F.

Plate shear testing was run per MIL-STD-401A. Testing was run at 75°, -320° and -423°F in both the stitching direction and cross-wise to the stitching. The test results are listed in Table 4. Failed specimens are shown in Figure 4. The shear strength in the crosswise direction was higher than in the stitch direction at each of the test temperatures. The shear strengths showed an increase of approximately 30-50% when going from 75°F to -320°F. The shear strength continued to increase down to -423°F for the specimens tested in the crosswise direction but decreased slightly for the specimens tested in the stitching direction. The shear strength at room temperature for the stitched foam insulation is approximately 4 to 5 times higher than that of unstitched Stafoam AA-402.

Prepared by:______________
J. Hertz
Design Specialist

Approved by:______________
James F. Haskins
Research Group Engineer

45 10

LIST OF REFERENCES

1. Haskins, J. F. and Hertz, J., "Thermal Conductivity of Plastic Foams from -423°F to 75°F", General Dynamics/Convair, Report No. MRG-242, July 1961.

TABLE 1

THERMAL CONDUCTIVITY MEASUREMENTS ON STITCHED FOAM INSULATION

Point No.	Mean Temperature °F	Thermal Conductivity BTU-in/ft^2-hr-°F	Environment
1.	-100.0	[illegible]	1 atm N_2
2.	- 79.6	.195	1 atm N_2
3.	53.7	.268	1 atm N_2
4.	36.5	.254	1 atm N_2
5.	-291.4	.091	1 atm N_2
6.	-310.2	.081	1 atm N_2
7.	-418.9	.025	550 μ H_2
8.	-401.8	.041	550 μ H_2
9.	-380.0	.030	10 μ (cryopumped)
10.	-404.1	.014	10 μ "

TABLE 2

TENSILE TEST RESULTS ON 3 in. x 3 in. SQUARES OF STITCHED FOAM

Specimen No.	Test Temperature °F	Ult. Load Lbs	Ult. Strength psi
1.	75°	386	218
2.		501	283
3.		336	190
4.		457	258
5.		445	251
			0

TABLE 3

TENSILE TEST RESULTS ON 1.5 in. DIA. DISCS OF STITCHED FOAM

Specimen No.	Test Temperature °F	Ult. Load lb.		Ult Strength psi
1.	75°	370		209
2.		260		147
3.		364		206
4.		276		156
5.		320		171
			Average	179
6.	-320°	555		314
7.		740		436
8.		705		399
9.		605		342
10.		670		379
			Average	374
11.	-423°	660		373
12.		668		378
13.		726		410
14.		632		358
15.		783		443
			Average	392

TABLE 4

PLATE SHEAR STRENGTH OF STITCHED FOAM

Specimen No.	Test Temperature °F	Type of Specimen	Ult. Load lbs.		Ult. Strength psi
1.	75°	Stitched Direction	928		82
2.			1026		91
3.			908		80
4.			1000		89
5.			1042		92
				Average	87
6.	-320°		1632		143
7.			1435		126
8.			1315		115
9.			1460		128
10.			1515		133
				Average	129
11.	-423°		1110		98
12.			1480		131
13.			1630		144
14.			875		81
15.			1175		104
				Average	112
16.	75°	Crosswise Direction	1238		108
17.			1258		107
18.			1190		106
19.			1205		105
20.			1190		103
				Average	106
21.	-320°		1358		120
22.			1540		136
23.			1485		131
24.			1560		138
25.			1515		134
				Average	132
26.	-423°		1750		155
27.			1900		168
28.			1930		171
29.			2000		177
30.			2250		199
				Average	174

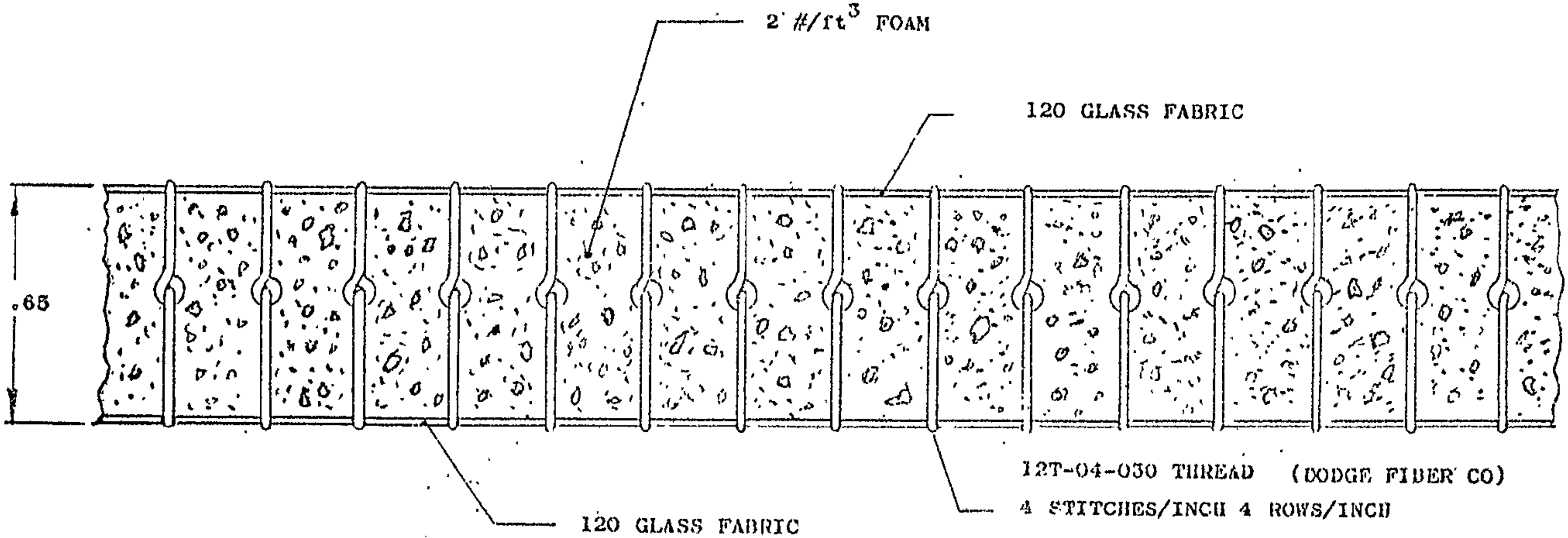
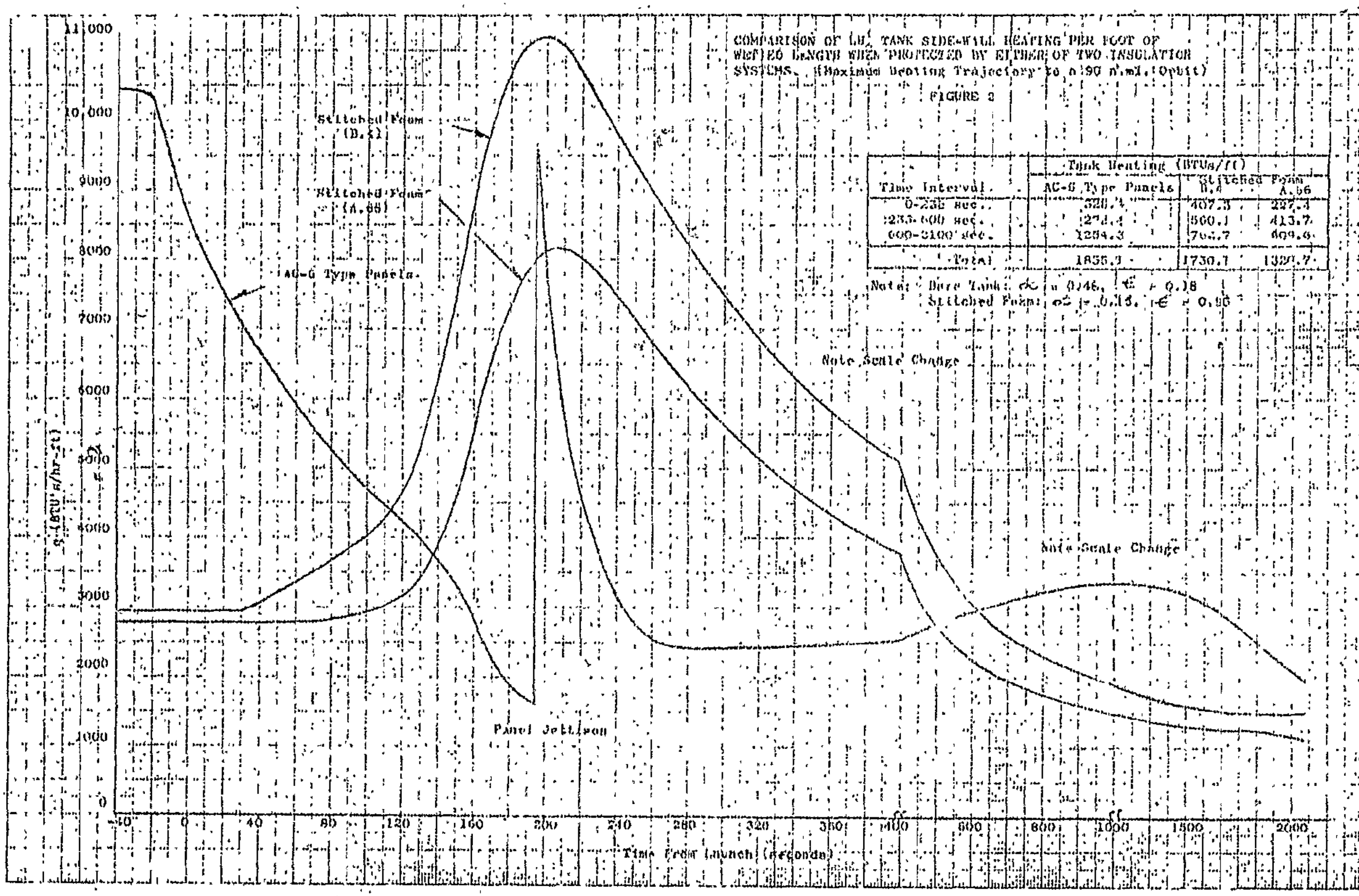


FIGURE 1. STITCHED FOAM INSULATION

17



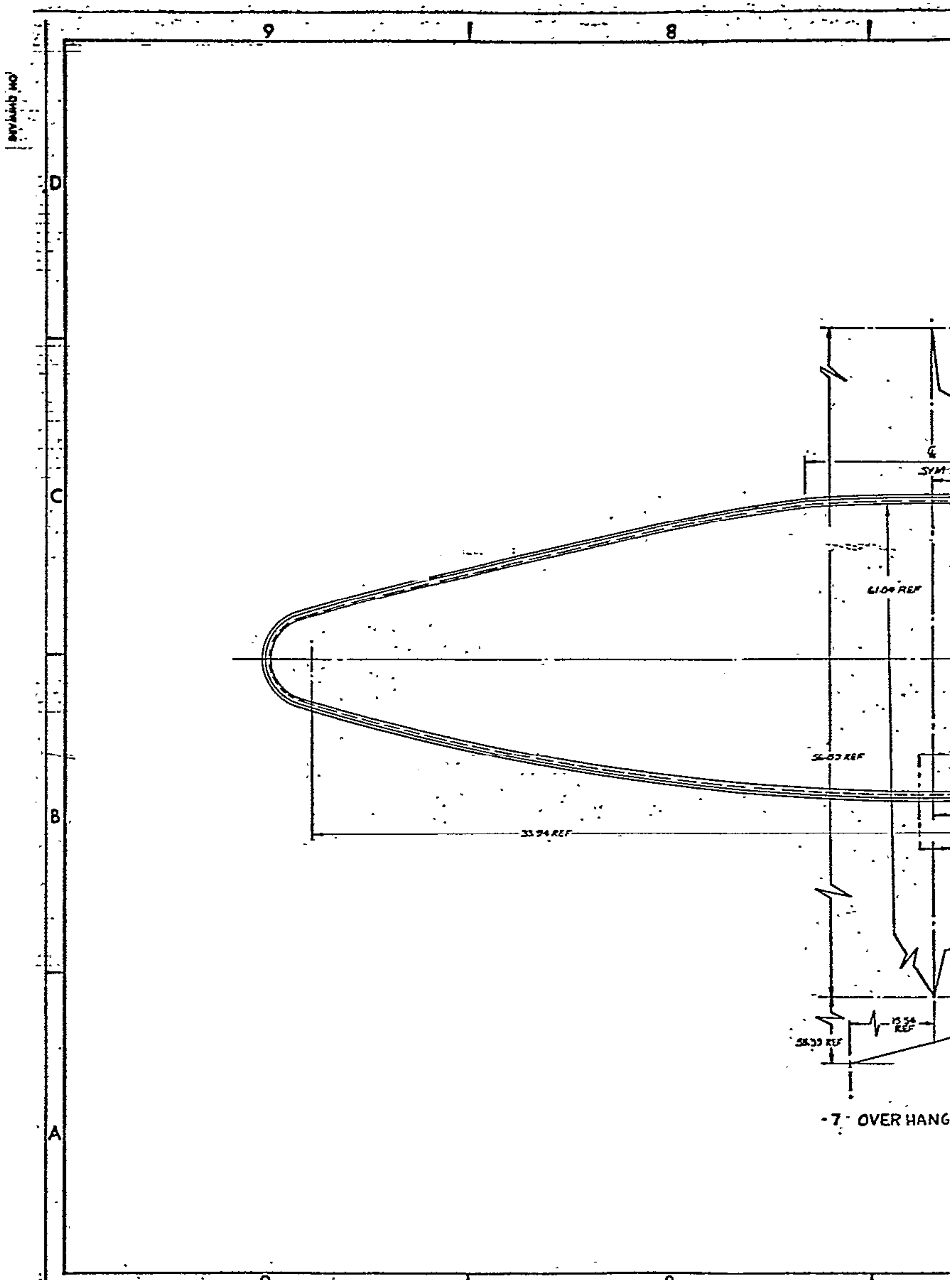
COMPARISON OF LH2 TANK SIDE-WALL HEATING PER FOOT OF WETTED LENGTH WHEN PROTECTED BY EITHER OF TWO INSULATION SYSTEMS. (Maximum Heating Trajectory to a 90 n.mi. Orbit)

FIGURE 2

Time Interval	Tank Heating (BTUs/ft)		
	AC-6 Type Panels	Stitched Foam B.4	Stitched Foam A.56
0-235 sec.	328.4	407.3	297.4
235-600 sec.	274.4	560.1	413.7
600-2100 sec.	1254.3	763.7	609.6
Total	1855.3	1730.7	1320.7

Note: Bare Tank: α = 0.46, ϵ = 0.18
Stitched Foam: α = 0.13, ϵ = 0.90

52



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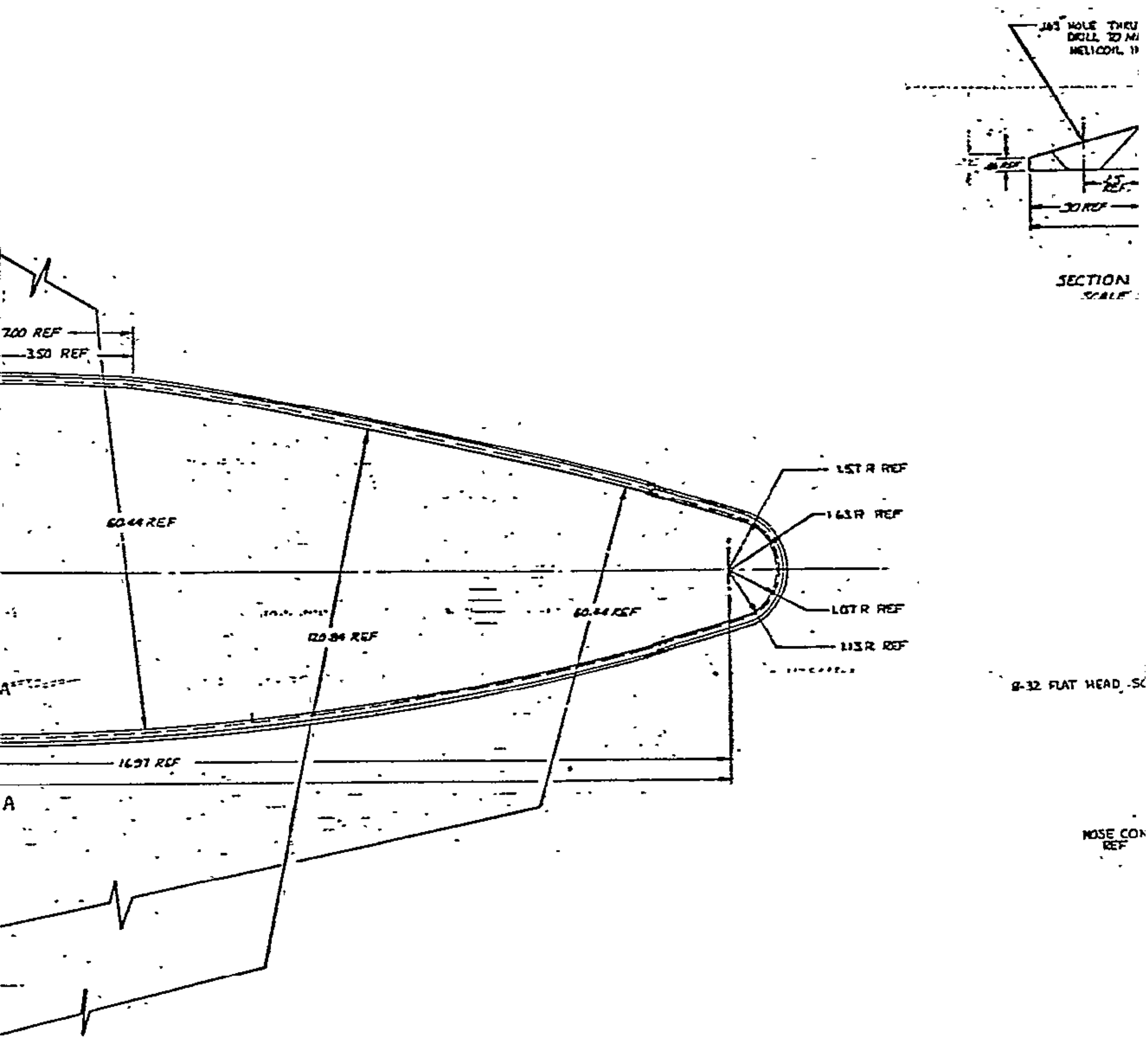
SECTION
7.00 REF
3.50 REF
60.44 REF
120.84 REF
60.44 REF
1.57 R REF
1.63 R REF
1.07 R REF
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8-32 FLAT HEAD
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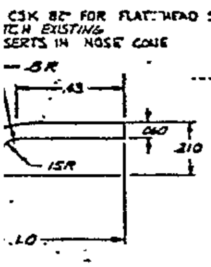
REVISIONS

REVISIONS



A-A TYP
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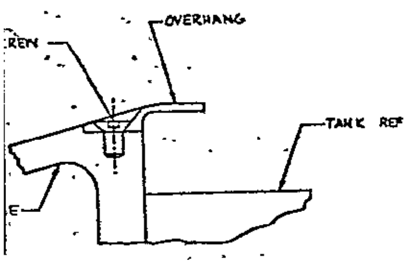

TYPICAL ATTACHMENT

L +7 TO BE FABRICATED FR
FIBERGLASS. TO BE CURE
OPERATING TEMP OF 6

APPLICATION

APPLICATION

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FIGURE 14

REVISIONS

REVISIONS

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ES

NATED TO
THICKNESS

VS-0216

NAS 3-3232

LIST OF MATERIAL

APPLICATION

INSULATION PANEL
HIGH TEMPERATURE
AERODYNAMIC
TEST MODEL

GENERAL DYNAMICS
ASTRONAUTICS
SAN DIEGO, CALIFORNIA

VS-0216

53C

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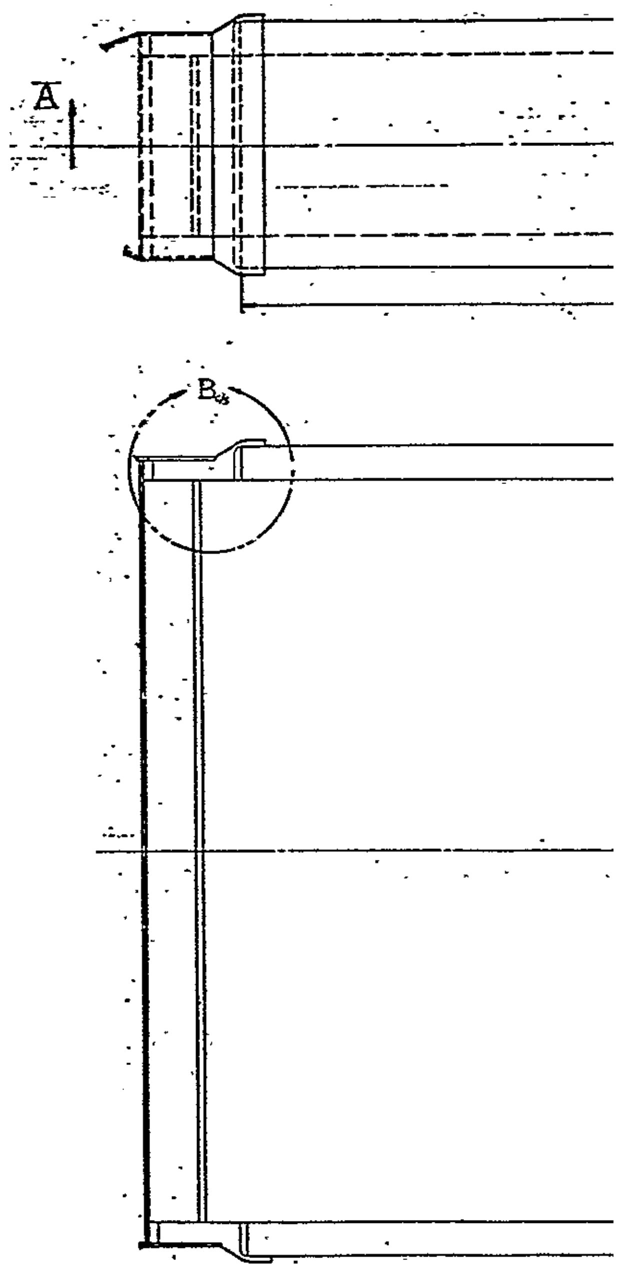
D



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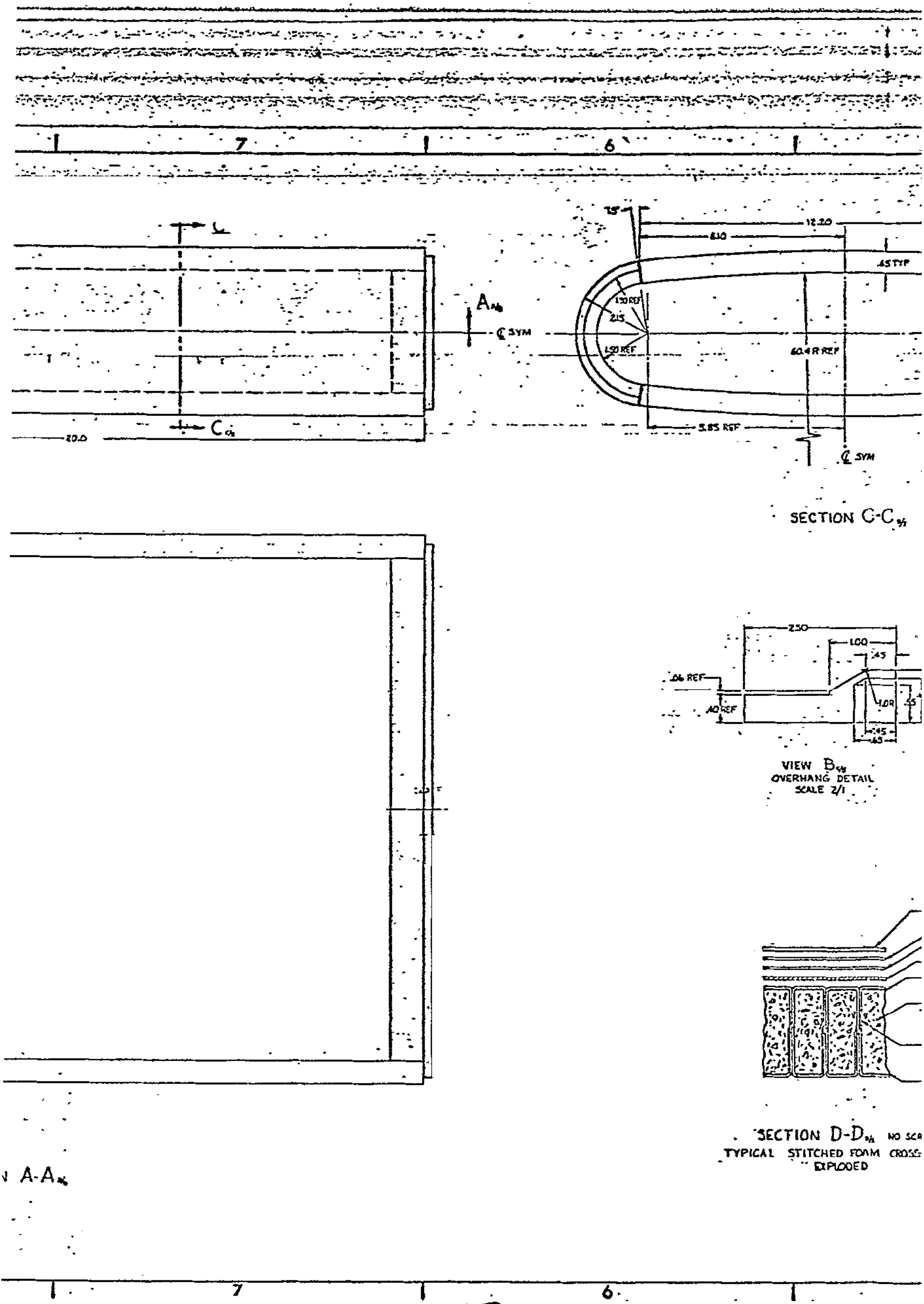

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20.0
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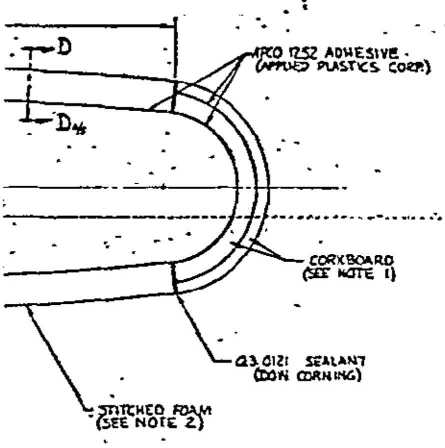
8.10
.45 TYP
1.50 REF
2.15
1.50 REF
60.4 R REF
5.85 REF
℄ SYM
SECTION C-C
2.50
1.00
.45
.06 REF
.40 REF
.55
.45
.65
VIEW B
OVERHANG DETAIL
SCALE 2/1
SECTION D-D NO SCA
TYPICAL STITCHED FOAM CROSS
EXPLODED
A-A
7
6

2

54a

5 4 3

REVISIONS | REVISIONS



—.004 ZINC OXIDE SOLAR PAINT (GD CONVAIR)
—.003 PHENOLIC 120 GLASS FABRIC
—.002 DUPONT 'H' FILM
—.004 SILASTIC 140 ADHESIVE
—.0025 120 GLASS FABRIC (HESS GOLDSMITH & CO)
— 9002-2B FOAM (CRR CORP)
— 12T-04-030 THREAD (DODGE FIBRES CO)
—.0025 120 GLASS FABRIC (HESS GOLDSMITH & CO)

E
SECTION

2. DIRECTION OF STITCHING TO BE ALONG L AXIS. FOUR ROWS PER INCH AND FOUR STI PER INCH

1. CORKBOARD TIP INSULATION SHALL BE OBTAIN .65 THICKNESS. MAXIMUM LAMIN TO BE .40 AND MINIMUM OF 2 LAYERS.

NOTES:

APPLICATION

5 4 3

3

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FIGURE 14

IGITUDINAL
CHES

AMINATED TO
TE THICKNESS

VS-0216
SHEET 1 OF 1
NAS 3-3232

INSULATION PANEL
HIGH TEMPERATURE
AERODYNAMIC
TEST MODEL

GENERAL DYNAMICS
ASTRONAUTICS
SAN DIEGO CALIFORNIA

J VS 0216
SHEET 1 OF 1

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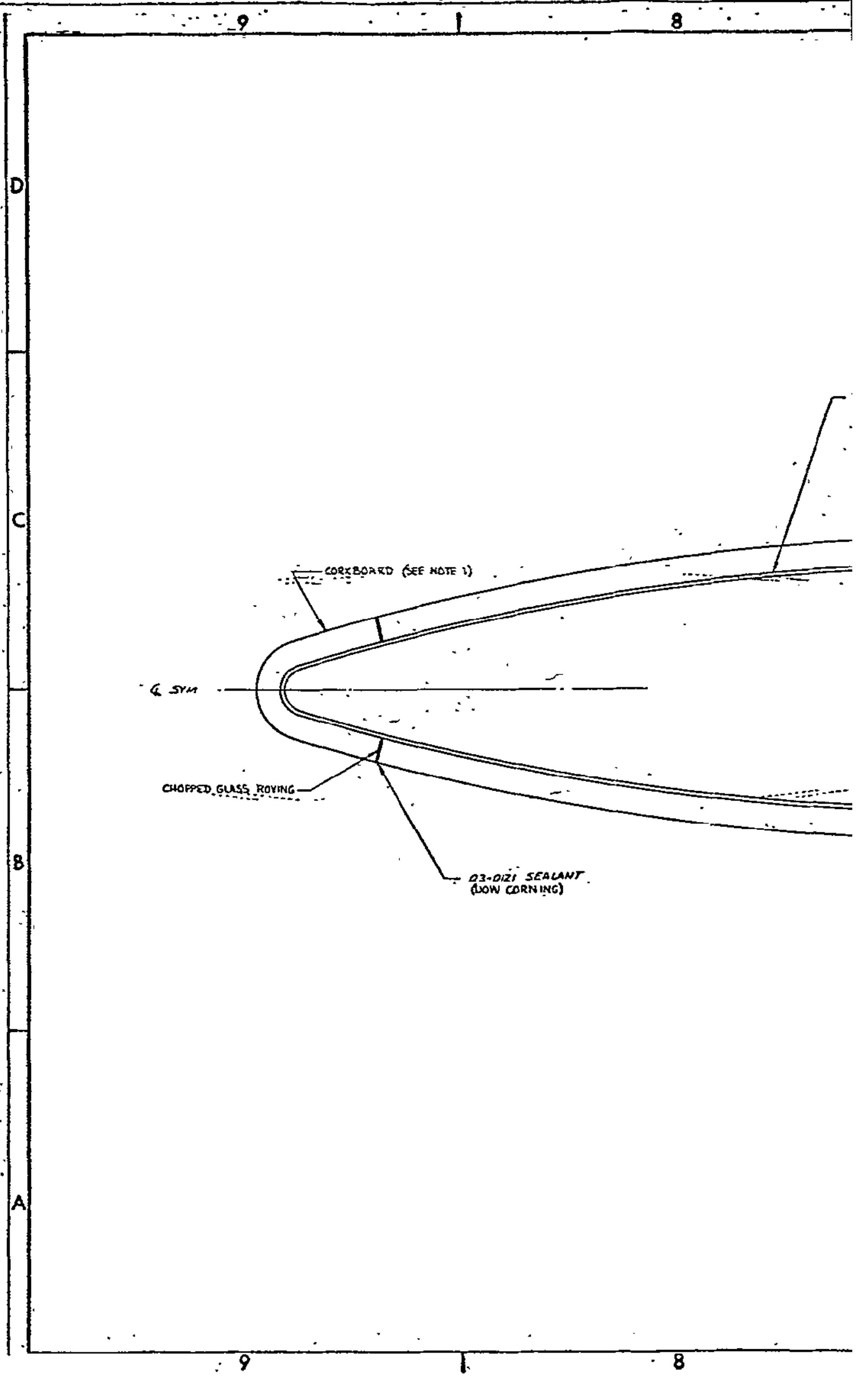
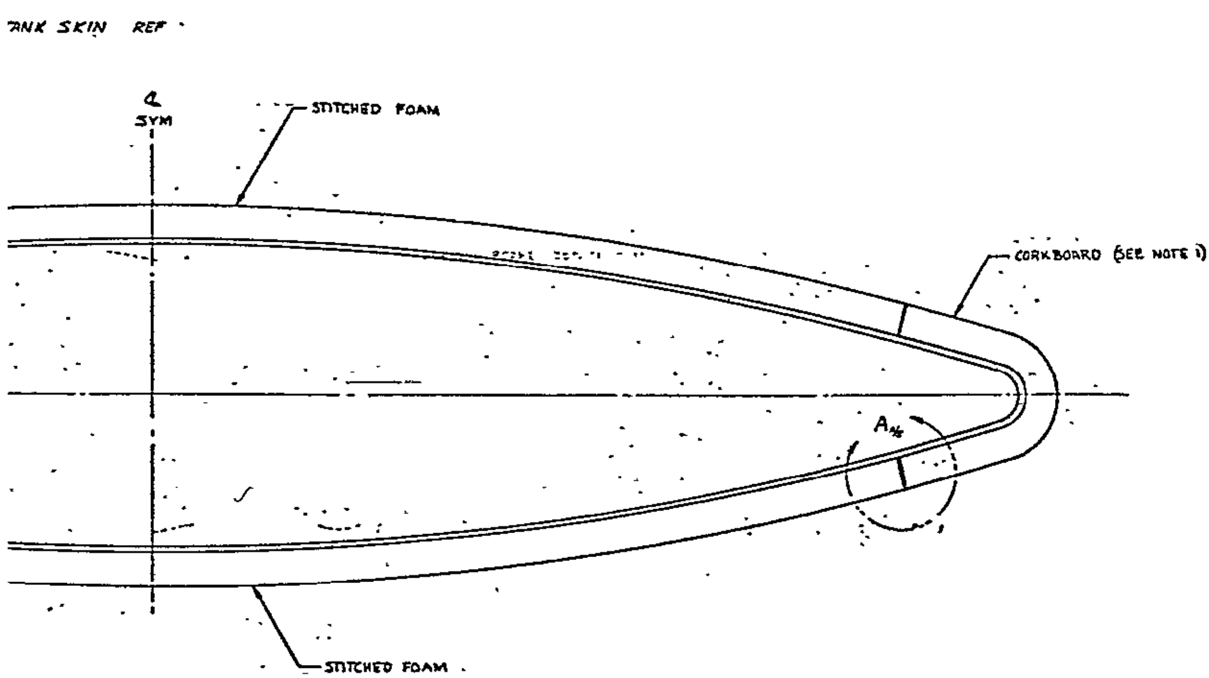

CORKBOARD (SEE NOTE 1)
℄ SYM
CHOPPED GLASS ROVING
Q3-0121 SEALANT
(DOW CORNING)

7 6



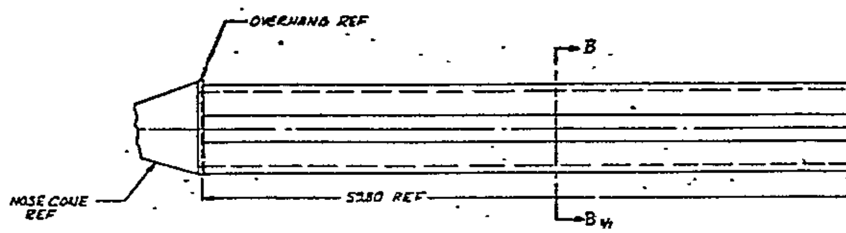
SECTION B-B
SCALE 1/1

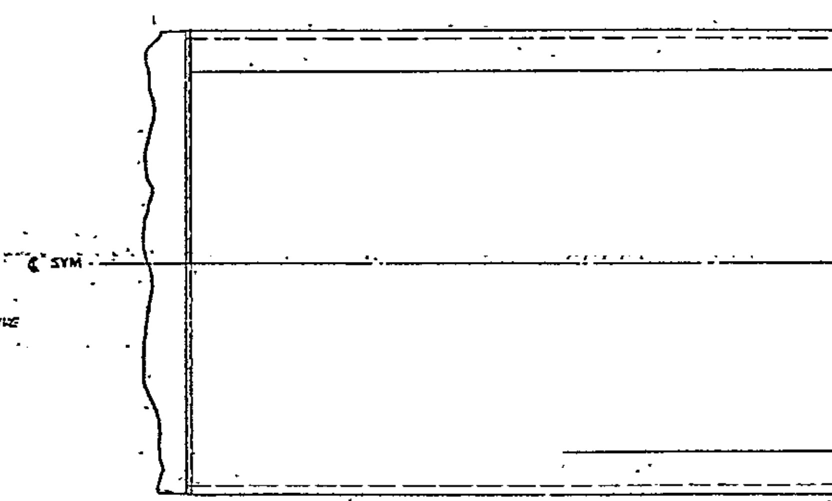
7 6

2

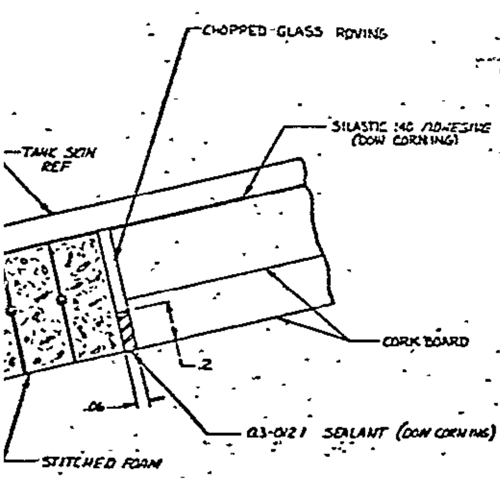
55

5 | 4 | 3





INSULATION ASSEMBLY
SCALE 1/4



VIEW A TYP
SCALE 4/1

1. CORKBOARD TIP INSULATION SHALL BE L
OBTAIN .65 THICKNESS. MAXIMUM LAMIN
TO BE .40 AND MINIMUM OF 2 LAYERS.

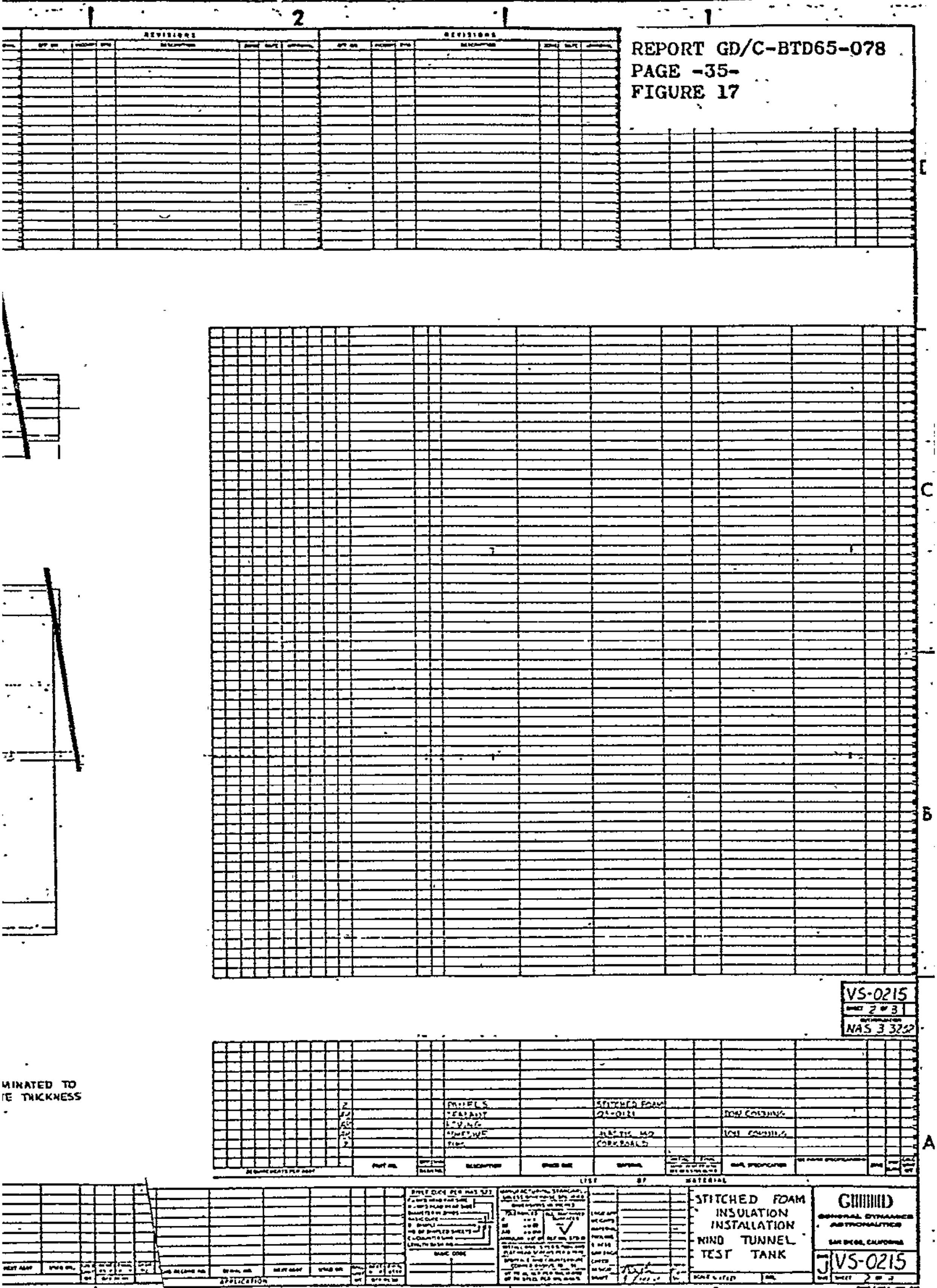
NOTES:

5 | 4 | 3

3

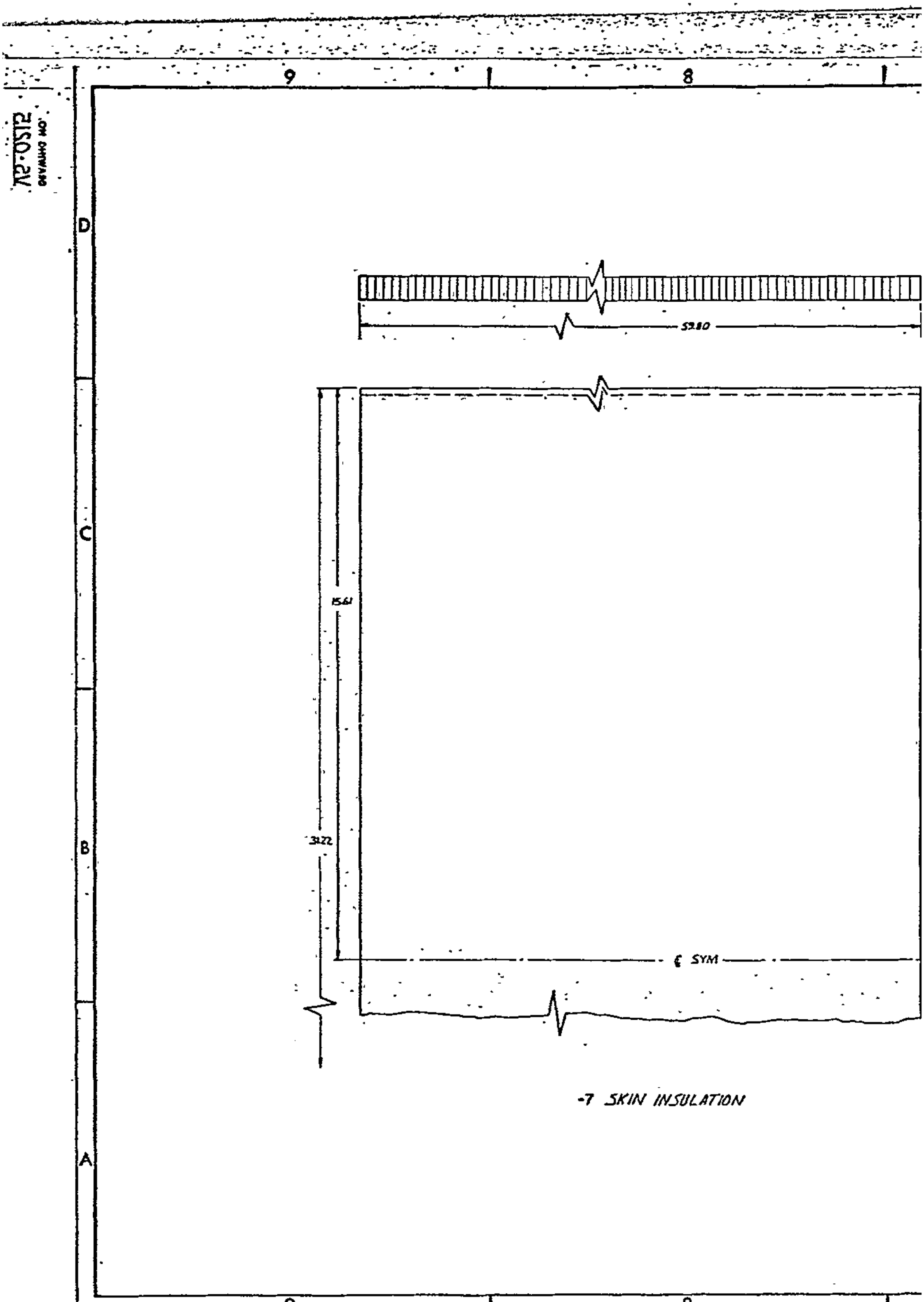
55b

REPORT GD/C-BTD65-078
PAGE -35-
FIGURE 17



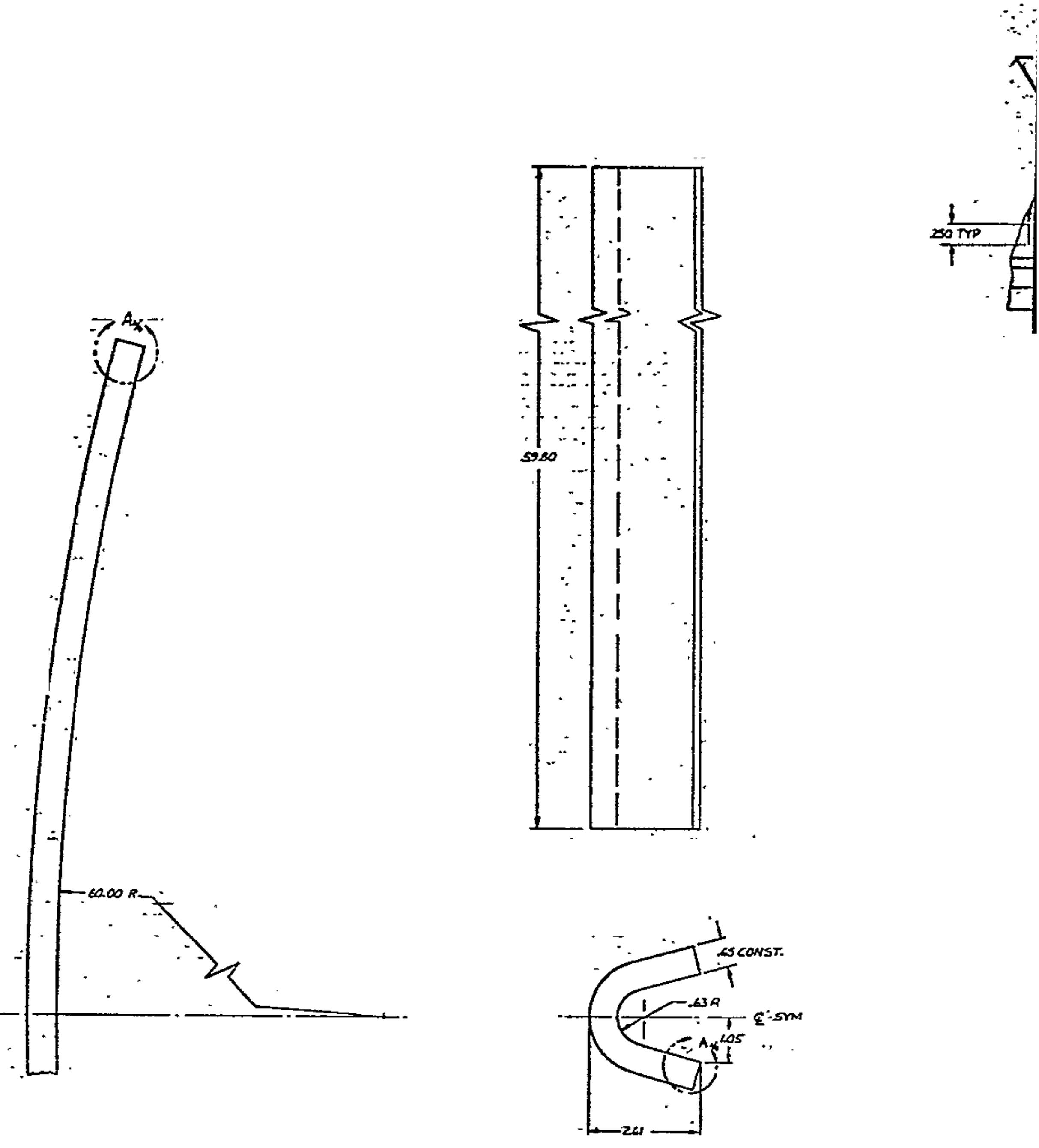
4

55C



-7 SKIN INSULATION

1

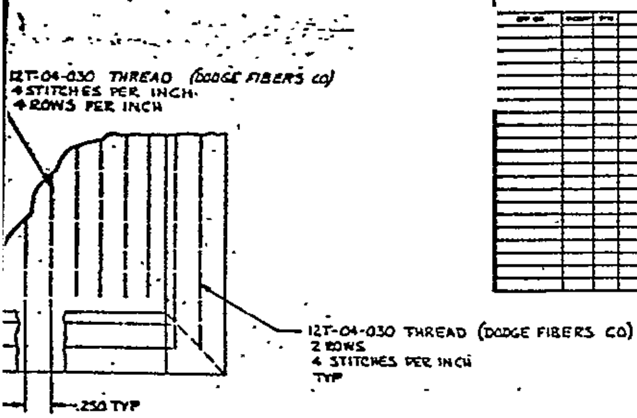


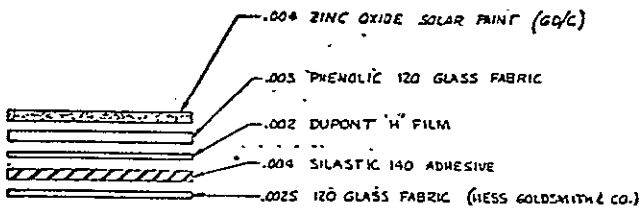
2

56a

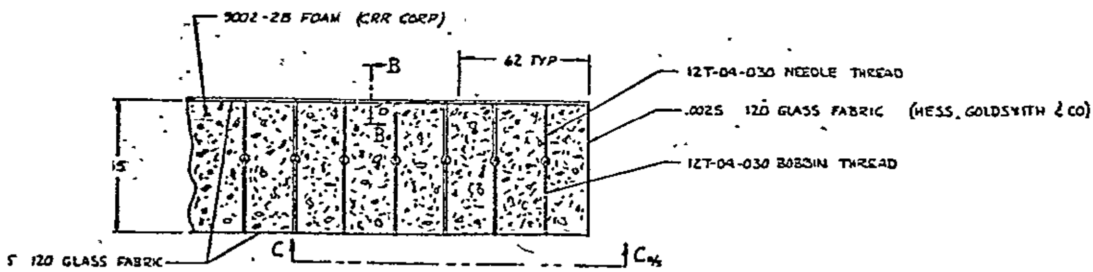
5 4 3

REVISIONS | REVISIONS





SECTION B-B 4/4
TYP EXTERIOR SURFACE



VIEW A 4/4 TYP

APPLICATION | APPLICATION

5 4 3

3

5tb

FIGURE 16

Description	Material	Spec
PAINT	[illegible]	[illegible]
[illegible] CLOTH	120 GLASS	
FILM	[illegible]	[illegible]
ADHESIVE	[illegible]	[illegible]
GLASS FABRIC	120 GLASS	[illegible]
THREAD	[illegible]	[illegible]
FOAM	[illegible]	[illegible]

VS-0215
SHEET 1 OF 3
NAS-3-3232

2	9	TIP
2	7	SKIN

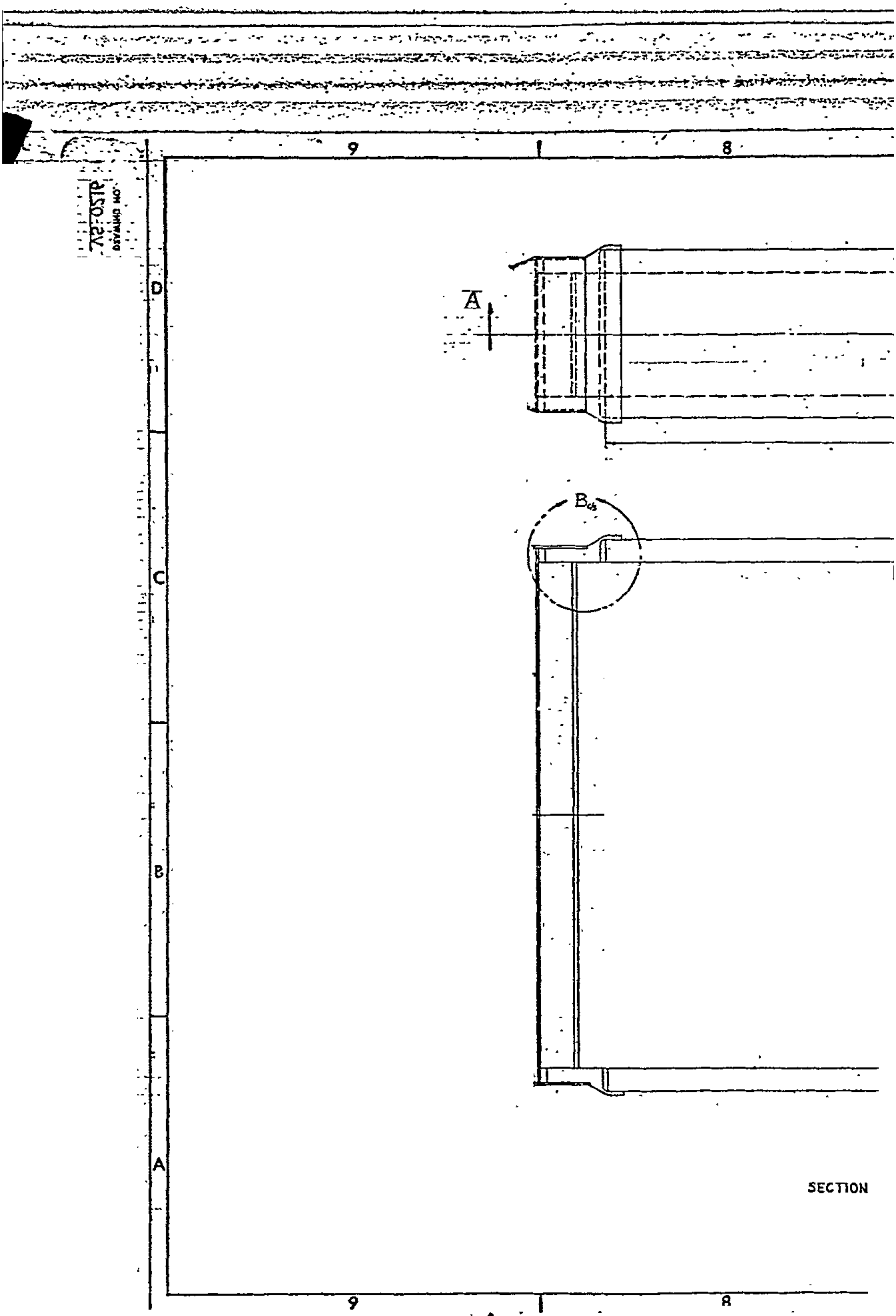
LIST OF MATERIAL

STITCHED FOAM INSULATION BICONVEX WIND TUNNEL TANK

GENERAL DYNAMICS ASTRONAUTICS
SAN DIEGO, CALIFORNIA

J VS-0215
SHEET 1 OF 1

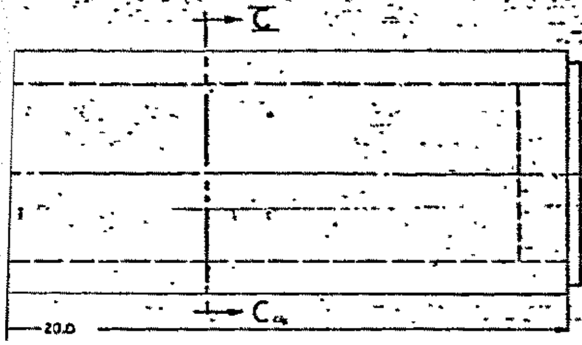
4

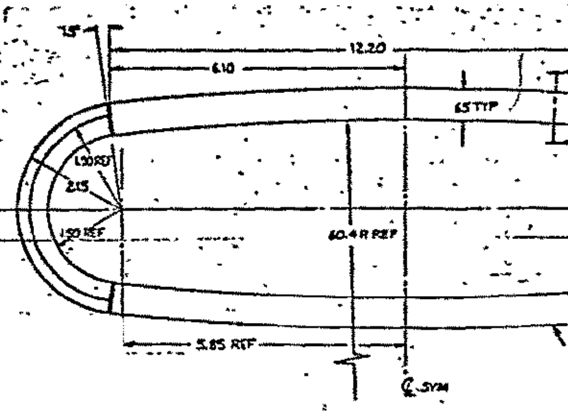


1

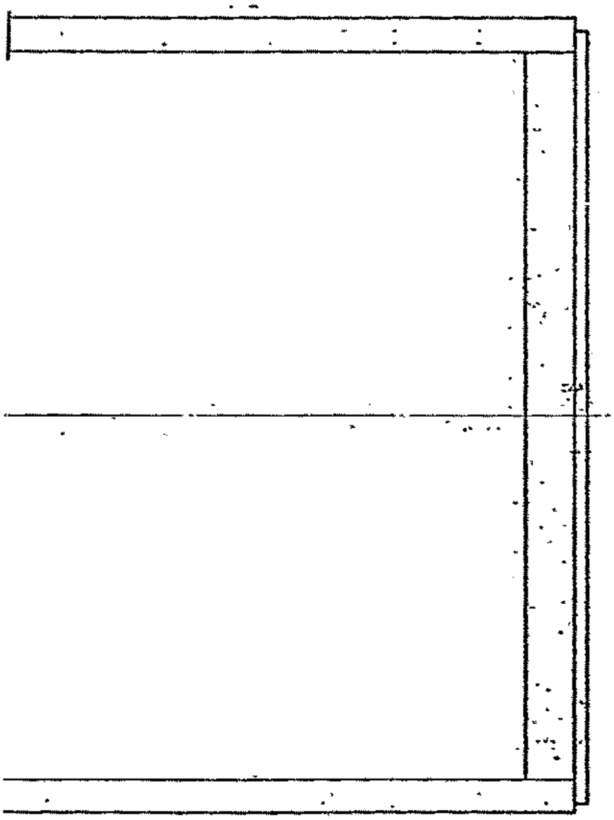
57

7 6

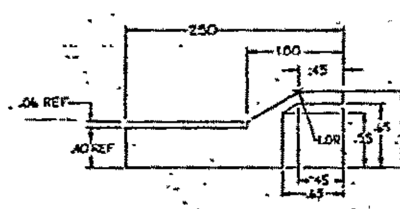




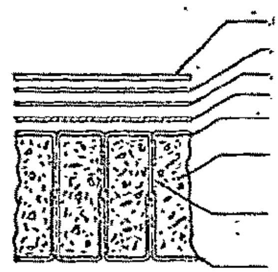
SECTION C-C



A-A



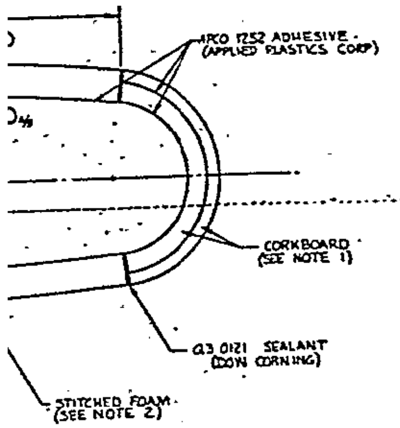
VIEW B
OVERHANG DETAIL
SCALE 2/1



SECTION D-D NO SCALE
TYPICAL STITCHED FOAM CROSS S
EXPLODED

7 6

2



)4 ZINC OXIDE SOLAR PAINT (GD CONVAIR)

03 PHENOLIC 120 GLASS FABRIC

02 DUPONT "H" FILM

)04 SILASTIC 140 ADHESIVE

)025 120 GLASS FABRIC
HESS GOLDSMITH & CO)

)002-2B FOAM
CRR CORP)

2T-04-030 THREAD (DODGE FIBRES CO)

0025 120 GLASS FABRIC
HESS GOLDSMITH & CO)

CTION

2 DIRECTION OF STITCHING TO BE ALONG LONG AXIS. FOUR ROWS PER INCH AND FOUR STITCH PER INCH

1 CORKBOARD TIP INSULATION SHALL BE LAM OBTAIN .65 THICKNESS. MAXIMUM LAMINATE TO BE .40 AND MINIMUM OF 2 LAYERS

NOTES:

3

5/6.

FIGURE 18

... NARMCO 506 CONOLON
... FOR TUNNEL
... °F.

VS 0215
SHEET 3 OF 3
NAS-3-3232

42	... SCREW (FLAT HEAD ALLEN SOCKET)		
1	... RING	FIBERGLASS	SEE NOTE 1

LIST OF MATERIAL

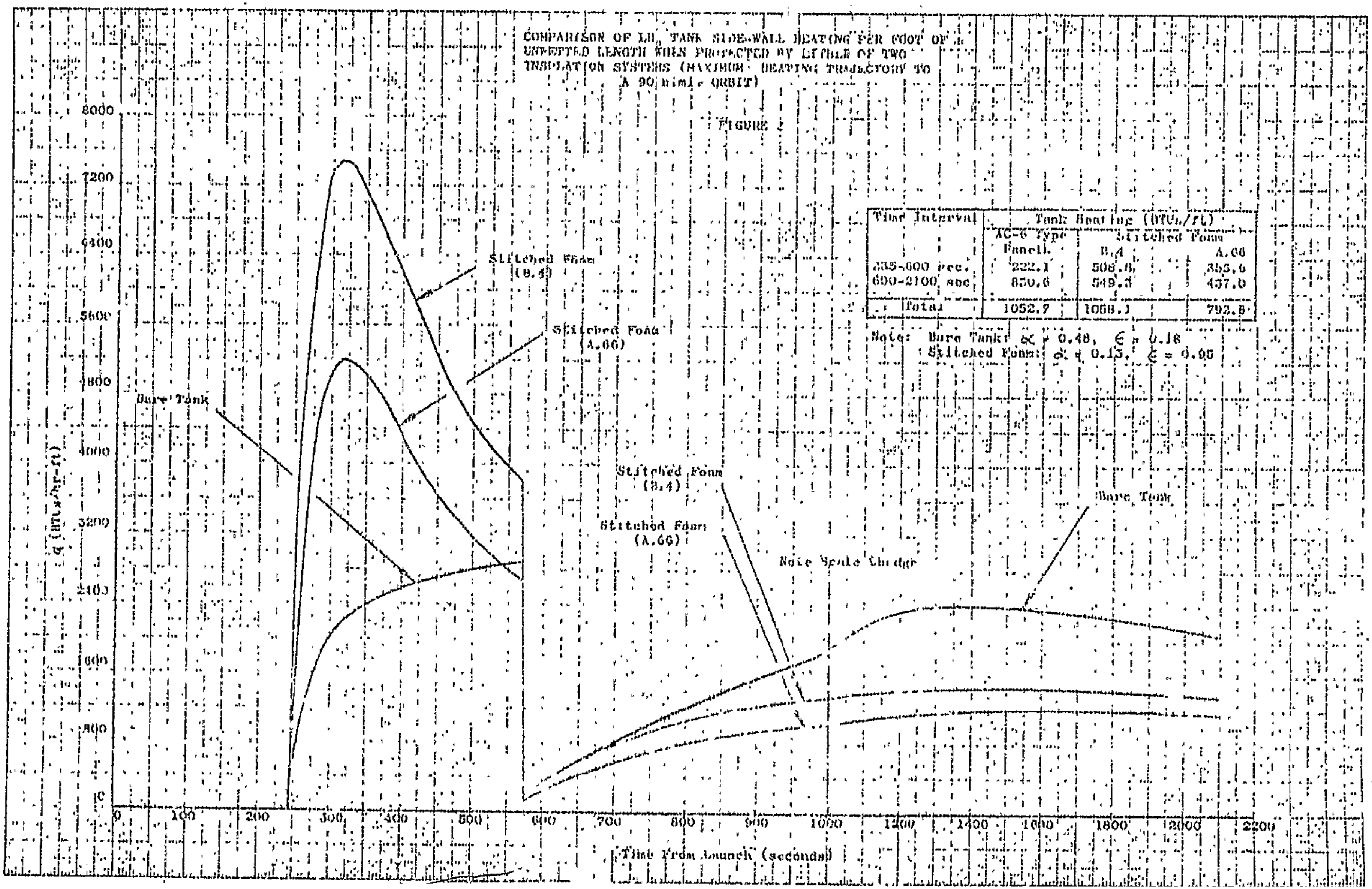
OVERHANG
NOSE CONE
STITCHED FOAM
WIND TUNNEL
TEST TANK

GENERAL DYNAMICS
ASTRONAUTICS
SAN DIEGO, CALIFORNIA

J VS-0215

SCALE FULL

57C



COMPARISON OF LH_2 TANK SIDE-WALL HEATING PER FOOT OF UNWETTED LENGTH WHEN PROTECTED BY EITHER OF TWO INSULATION SYSTEMS (MAXIMUM HEATING TRAJECTORY TO A 90 n.mi. ORBIT)

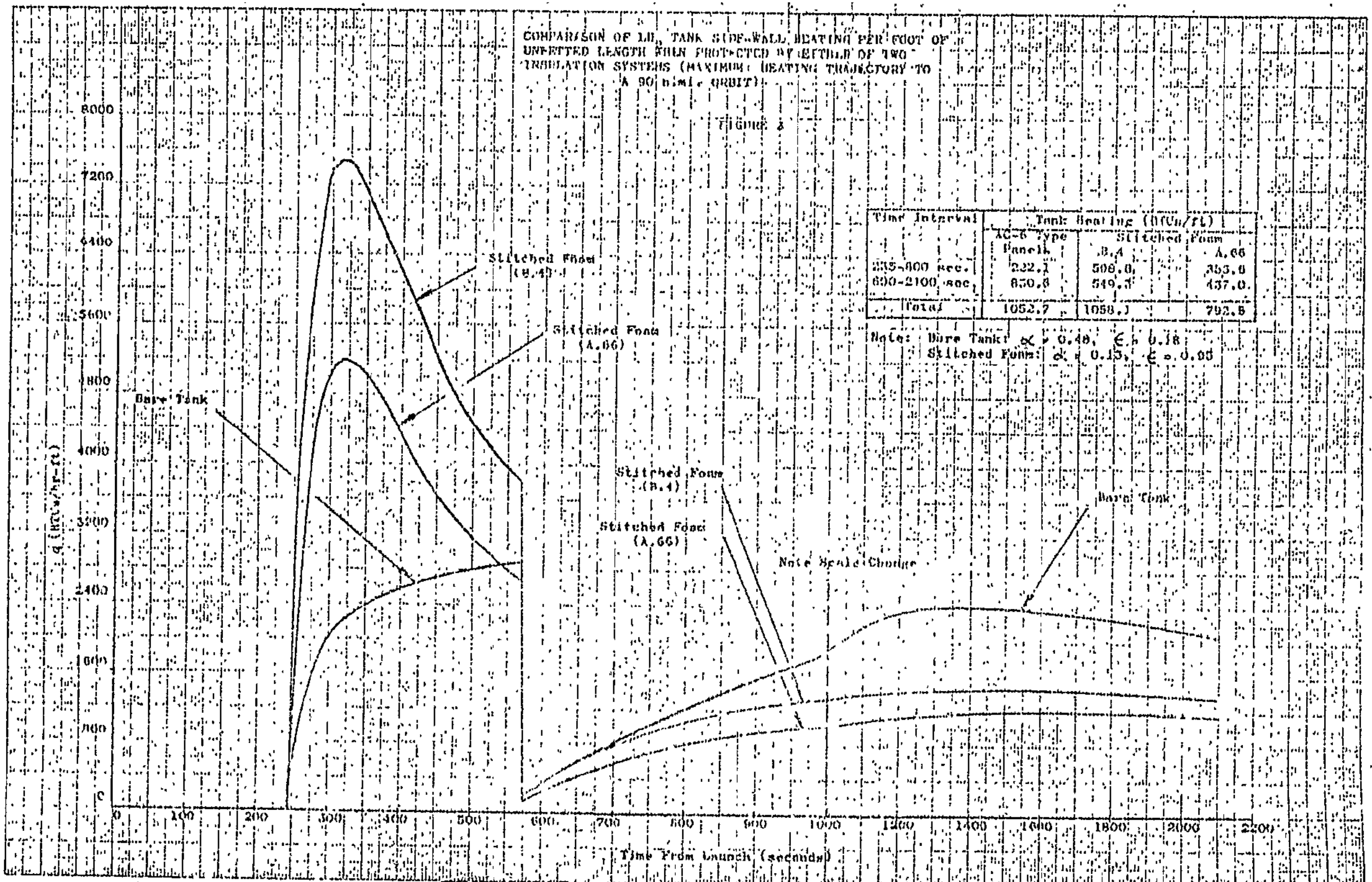
FIGURE 2

Time Interval	Tank Heating (BTUs/ft)		
	AC-6 Type Panel.	Stitched Foam	
		B.4	A.66
235-600 sec.	222.1	508.8	355.6
600-2100 sec	830.6	549.3	437.0
Total	1052.7	1058.1	792.6

Note: Bare Tank: $\alpha = 0.40$, $\epsilon = 0.16$
Stitched Foam: $\alpha = 0.13$, $\epsilon = 0.95$

58

'81



Time Interval	Tank Heating (BTUs/ft)		
	AC-6 Type Panels	Stitched Foam B.4	Stitched Foam A.66
235-600 sec.	222.1	506.0	353.6
600-2100 sec.	830.6	549.5	437.0
Total	1052.7	1058.1	792.6

Note: Bare Tank: $\alpha = 0.48$, $\epsilon = 0.18$
Stitched Foam: $\alpha = 0.15$, $\epsilon = 0.05$