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VOLUME II

SPACE VEHICLE INTEGRATED THERMAL PROTECTION/STRUCTURAL/ METEOROID PROTECTION SYSTEM

APPENDIXES TO FINAL REPORT

by
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16 Abstract

A program was conducted to determine the merit of a combined structure/thermal meteoroid protection system for a cryogenic space vehicle propulsion module. Structural concepts were evaluated to identify leastweight designs. Thermal analyses determined optimum tank arrangements and insulation materials. Meteoroid penetration experiments provided data for design of protection systems. Preliminary designs were made and compared on the basis of payload capability. Thermal performance tests demonstrated heat transfer rates typical for the selected design. Meteoroid impact tests verified the protection characteristics. A mockup was made to demonstrate protection system installation. The best design found combined multilayer insulation with a truss structure vehicle body. The multilayer served as the thermal/meteoroid protection system.

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INTRODUCTION

This is a companion document to Volume I, NASA CR-121103, "Final Report". The appendixes contained herein supplement the technical discussion in that document.

Appendix A is a description of the TATE (Tank Arrangement Thermal Efficiency) computer program. The results of the TATE analysis were discussed in Sections 1.1.2, 1.2.3, 1.3.2, 1.3.5 and 3.2 of Volume I.

Appendix B contains the detailed results of the Vehicle Structure Evaluation for the ten preliminary designs. Vehicle configurations and dimensions are shown. Tabulated weights for various construction methods and materials are presented. Structural concept weights are summarized in tables which include end attachment weight adjustments. The material in this appendix supplements the discussion and summary charts of Section 1.2.3 of Volume I.

Appendix C presents a description of the meteoroid environment, derivation of the earth-mars trajectory for this study and the entire quantity of design curves developed from the test data of this program. This material supplements the discussion of Sections 1.2.3 and 1.3.4 of Volume I.

Appendix D contains the detail design drawings and a discussion of the ten vehicle preliminary designs. These results were summarized in Section 1.2.3 of Volume I.

Appendix E contains the temperature data obtained in the thermal performance tests. This appendix also contains a description of the thermal model used in the analysis of results and gives the temperatures predicted for each test case. The test results are discussed in Section 2.2.3 of Volume I.

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APPENDIX A

TANK ARRANGEMENT THERMAL EFFICIENCY COMPUTER PROGRAM

This appendix discusses the construction and operation of the TATE program used to derive optimized weights for tanks, insulation, propellant vapor, helium and helium tank. The results obtained through use of this program were described in Sections 1.1.2, 1.2.3, 1.3.2, 1.3.5 and 3.2 of Volume I "Final Report", NASA CR-121103.

The program was designed to arrive at a least weight case for any vehicle configuration through an iterative random search process where search limits were narrowed after evaluation of every 2000 cases. This process was continued for 10 iterations or a total of 20,000 cases. A computerized search technique was necessary in order to find optimum values of multiple, independent variables, each with arbitrary constraints.

The program randomly selected thicknesses of insulation for all locations on a given vehicle and calculated heat flow to the cryogens. Two mission phases were considered, ascent and coast. Ascent heating included the effects of residual purge gas in the MLI (Multilayer Insulation) and higher temperatures due to near earth environment and random orientation. A thermal balance was maintained, therefore, heat could flow in or out of the propellants. The program calculated tank pressures and determined the critical point of the mission, i.e., launch, end boost, or end of mission. The tank sizes and gages were determined and a summary of insulation, tanks, propellant vapor and helium weights were made.

The assumptions for the study were:

1) The spacecraft was oriented during coast so that the payload was between the sun and the propulsion vehicle. The only heat to the propulsion vehicle came from the payload and the solar panels which were assumed to be 520°R (289°K) with ε = 1.0, and 620°F (344°K) with ε = 0.05, respectively.

2) The net heat that penetrated the insulation blanket was considered the heat into the cryogenic tank.

The internal and external insulation surface temperatures used in the analysis were derived from the steady state solution of the BETA (Boeing Engineering Thermal Analyzer) program.

The thickness of MLI on all surfaces was determined by:

$$t = t_{MINLIM} + (t_{MAXLIM} - t_{MINLIM}) \text{ RUNIF(A)}$$

RUNIF(A) is a subroutine that selects random numbers uniformly between 0 and 1.

$$t_{MAXLIM} = t_{MAX} + S(t_{MAX} - t_{MIN}) \leq 2.0 \text{ IN.}$$

$$t_{MINLIM} = t_{MIN} - S(t_{MAX} - t_{MIN}) \geq 0.01 \text{ IN.}$$

$\left.\begin{matrix} t_{MAX} \\ t_{MIN} \end{matrix}\right\}$ Extreme thicknesses obtained from 5 best cases from previous 2000 iterations.

$\left.\begin{matrix} t_{MAXLIM} \\ t_{MINLIM} \end{matrix}\right\}$ Insulation thickness limits to be used for next 2000 iterations.

$S = 0.5$ Factor to control search limit reduction rate.

After every 2000 cases T_{MAXLIM} and T_{MINLIM} were modified and set equal to the minimum and maximum thickness of the 5 leastweight cases. Each configuration was run for 20,000 cases.

The total heat transfer into the propellant tanks included heat transfer through the MLI during the ascent phase plus heat transfer through the MLI combined with heat leaks through tank supports and fluid lines during the coast phase.

The equations for heat transfer were:

$$\dot{Q}_T = (Q_{I_M} + Q_{I_A} + Q_S + Q_P + Q_{H_L}) / 4992 \text{ (Hours)}$$

where $\dot{Q}_T$ = Total average heat transfer rate to fuel or oxidizer.

Q_{I_M} = Total heat transferred thru MLI during coast.

Q_{I_A} = Total heat transferred thru MLI during ascent.

Q_S = Total heat transferred thru tank supports.

Q_P = Total heat transferred thru plumbing lines.

Q_{H_L} = Total heat transferred thru MLI by any other form.

$\underline{Q_{I_M}}$

Modifying the MLI heat transfer equation

$$\dot{Q}_{ji} = \left(\frac{k_{ji}}{t_{ji}} + K_{PEN}\right) A_{ji} \, (T_{1_{ji}} - T_{2_{ji}})$$

and $$Q_{I_M} = 4992 \sum_{ji} \dot{Q}_{ji} \quad \text{(for the coast phase)}$$

where $T_{1_{ji}}$ = Temperature on outside of MLI

$T_{2_{ji}}$ = Temperature on inside of MLI

A_{ji} = Surface area of MLI

t_{ji} = Thickness of MLI

k_{ji} = Thermal conductivity of MLI

K_{PEN} = Thermal conductance of nylon fasteners per unit MLI area

$\dot{Q}_{ji}$ = Average heat transfer rate to fuel or oxidizer during coast phase of mission

$T_{1_{ji}}$ and $T_{2_{ji}}$ are input constants for each insulation panel. These were obtained by a separate thermal analysis.

The insulation conductivity was generalized as

$$k_{ji} = K_{R_{ji}} \, (T_{1_{ji}}^{\;2} + T_{2_{ji}}^{\;2}) \, (T_{1_{ji}} + T_{2_{ji}}) + K_{C_{ji}} \, (T_{1_{ji}} + T_{2_{ji}})$$

The subscripts on the constants were required to identify the different types of MLI used on the vehicles.

The term K_{PEN} was assumed to be a constant.

$\underline{Q_{I_A}}$

$$Q_{I_{A_{ji}}} = A_{ji} \left(\frac{Q_{A1_{ji}}}{t_{ji}} + Q_{A2_{ji}} \, t_{ji}\right)$$

$$Q_{I_A} = \sum_{ji} Q_{I_{A_{ji}}} \quad \text{(for the ascent phase)}$$

$Q_{I_{A_{ji}}}$ = heat transferred thru MLI during ascent phase of mission for panel ji.

$Q_{A1_{ji}}$ = constant which depended on the type of MLI and location on vehicle.

$Q_{A2_{ji}}$ = Term required for use with perforated radiation shields

$Q_{A1_{ji}}$ and $Q_{A2_{ji}}$ were constants which depended on the type of insulation and location on the vehicle. These constants were determined by a curve fit to data from the evacuation analyses. In most cases, $Q_{A2_{ji}} = 0$.

$\underline{Q_S}$

$$Q_S = 4992 \sum_{ji} \dot{Q}_{S_{ji}}$$

$$\dot{Q}_S = K_S \left(T_{1_{ji}} - T_{\substack{FU \\ OR\ OX}}\right)$$

where: K_S was an input constant for each configuration,

$T_{1_{ji}}$ was one of the boundary temperatures specified for the MLI,

T_{FU} was fuel temperature

T_{OX} was oxidizer temperature

Q_S was heat leak through structure

$\underline{Q_P}$

$$Q_P = 4992 \sum \dot{Q}_P$$

$$Q_P = K_{FILL}\left(T_{1_{ji}} - T_{\substack{FU \\ OROX}}\right) + K_{VENT}\left(T_{1_{ji}} - T_{\substack{FU \\ OROX}}\right) + K_{FEED}\left(T_{ENG} - T_{\substack{FU \\ OROX}}\right),$$

where

K_{FILL} was thermal conductivity of fill line

K_{VENT} was thermal conductivity of vent line

K_{FEED} was thermal conductivity of feed line

T_{ENG} was engine temperature

These were all input constants.

Q_{HL}

$$\dot{Q}_{HL} = K_{HL} (T_1 - T_2)$$

where T_1 was temperature outside

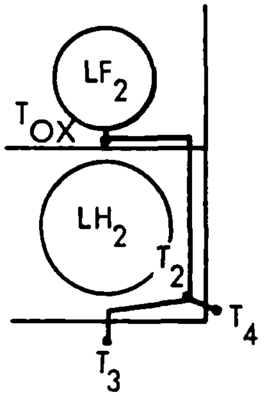
T_2 was temperature inside

K_{HL} was conductivity from BETA program

This form of $\dot{Q}$ was used for special cases, e.g., where the LF_2 feed line penetrated the LH_2 compartment on Vehicle 1-14.

$$K_{FEED}(T_{ENG} - T_{OX})$$

which was divided into:



K_{HL_1} $(T_{OX} - T_2)$ where T_2 was the temperature on the feed line in the LH_2 compartment.

K_{HL_2} $(T_2 - T_3)$ where T_3 was a point near the engine but outside the MLI.

K_{HL_3} $(T_4 - T_2)$ where T_4 was a feed line support.

The representative Q's were accumulated and the $\dot{Q}$ was determined by dividing by the mission time and checked against the $\dot{Q}$ constraints. The $\dot{Q}$ constraints were the heat flow values which resulted in limiting pressures (5 psia (34.5 kN/m^2) minimum pressure and critical maximum pressure). If either of the Q's was outside the constraints then the case was cancelled and the program proceeded to the next case. If the constraints were satisfied then the MLI weight was calculated.

$$WT_{ins} = \sum_i (A_i t_i)$$

A_i = Area of panel

t_i = Thickness of MLI

ρ = Density of MLI

With non-vented tanks, any heat added to the propellant was reflected in a change in internal energy, U. Assuming saturated liquid and vapor always in equilibrium, the pressure, temperature, liquid density and vapor density was also changed continuously with change in U. The total internal energy was made up of contributions of the liquid and the vapor:

$$U = U_L + U_G$$

or

$$uM = u_L M_L + u_G M_G$$

$$u = u_L \left(\frac{M_L}{M}\right) + u_G \left(\frac{M_G}{M}\right) = u_L m_L + u_G m_G$$

The mass ratios m_L and m_G could be defined in terms of the specific volume of liquid (ν_L), gas (ν_G) and total system (ν):

$$\nu = \frac{V}{M} = \frac{\nu_L M_L + \nu_G M_G}{M} = \nu_L m_L + \nu_G m_G$$

Since the sum of the liquid and vapor masses was equal to the total mass,

i.e., $$m_L + m_G = 1$$

$$\nu = \nu_L (1 - m_G) + \nu_G m_G$$

$$m_G = \frac{\nu - \nu_L}{\nu_G - \nu_L}$$

substituting

$$u = u_L (1 - m_G) + u_G m_G$$

$$u = u_L + m_G (u_G - u_L)$$

$$u = u_L + \frac{\nu - \nu_L}{\nu_G - \nu_L} (u_G - u_L)$$

At any given set of conditions, the only unknown was ν

A table of Q versus vapor pressure was derived for both cryogens, assuming that the liquid and vapor existed in equilibrium. Also used were tables of pressure versus densities of vapor and liquid in addition to helium gas used to pressurize tanks for the engine burn. The helium gas was assumed to be at the cryogen temperature and pressure plus N.P.S.P. From this information was found:

1. Vapor Weight $= \frac{x M_p}{(1-x)} \left(\frac{\rho_v}{\rho_L} \right)$

M_p = mass propellant usable plus residuals

x = ullage required at mission end

ρ_v = density of vapor

ρ_L = density of liquid

2. Helium Weight $= M_p \frac{\rho_{he}}{\rho_L}$

ρ_{he} = density of helium gas

This assumed the required helium equalled the replacement of all the cryogenic liquid.

3. Helium bottle weight = 2.74 (wt. helium)

assuming:

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5000 psia (34.5 MN/m^2 design limit pressure

f_{ty} = 265 KSI @ - 320°F (1827 MN/m^2 @ 77.7°K)

yield F.S = 1.33

$$2.74 = \frac{\text{wt. helium bottle}}{\text{wt. helium}}$$

The sizing and weighing of the fuel and oxidizer tanks is shown below:

LH_2 - LF_2 System

Fuel Tank

The helium was stored in the oxidizer tank

W_{he} in fuel tank = 0

Fuel tank operating pressure = $P_{fuel\ vapor}$ + NPSP $\geq$ 14.7 psia (101 3 kN/m^2)

Then call tank sizing subroutine corresponding to the kind of tank.

Oxidizer Tank

W_{he} = wt. helium in oxidizer tank

Oxidizer tank operating pressure = $P_{oxidizer\ vapor}$ + NPSP $\geq$ 14.7 psia (101.3 kN/m^2)

Call Tank sizing subroutine corresponding to the kind of tank.

NOTE: *The sizing of the oxidizer tank included the volume of helium.*

CH_4 - FLOX Uninsulated System (Both propellants at same temperature)

Fuel Tank

The helium was stored in the oxidizer tank

W_{he} in fuel tank = 0

Fuel tank operating pressure = $P_{fuel\ vapor}$ + 14.7* (101.3 kN/m^2)

Call fuel tank sizing subroutine corresponding to the kind of tank.

Oxidizer Tank

W_{he} = wt. helium for oxidizer tank plus wt. helium for fuel tank

Oxidizer tank operating pressure = $P_{oxy\ vapor}$ + NPSP $\geq$ 14.7 psia (101.3 kN/m^2)

Call tank sizing subroutine corresponding to the kind of tank.

* Based on initially adding helium to prevent tank collapse prior to launch due to vapor pressure less than one atmosphere.

CH_4 - FLOX Insulated System

Fuel Tank

The helium was stored in the fuel tank

$W_{he} = W_{he\ fuel} + W_{he\ oxidizer}$

Fuel tank operating pressure = P_{FV} + NPSP $\geq$ 14.7 psia (101.3 kN/m^2)

Call tank sizing subroutine corresponding to the kind of tank

Oxidizer Tank

W_{he} = 0 since it was stored in fuel tank

Oxidizer tank operating pressure = $P_{oxy\ vapor}$ + NPSP $\geq$ 14.7 psia (101.3 kN/m^2)

Call tank sizing subroutine corresponding to the kind of tank.

The kinds of tanks included in this program were spherical, cylindrical, oblate spheroid, toroidal, and a common bulkhead tank. Following is a description of the sizing and weighing of each.

The baseline tank parameters were:

Factors

$$\frac{PROOF}{F_{ty}} = 1.25\ P_{op}$$

<u>Allowables</u> (2219-T6E46 Aluminum Alloy)

	F_{ty} psi (MN/m^2)	F_{ty} psi (MN/m^2)
Room Temp.	39,000 (268.9)	54,000 (372.3)
Methane -260°F	43,500 (299.9)	61,700 (425.4)
F_2-FLOX -306°F	44,900 (309.6)	64,800 (446.8)
H_2 -423°F	51,900 (357.8)	75,600 (521.2)

Pressures

$$P_{op} = P_{vp} + P_{npsh}$$

Oxidizers - $P_{op} = P_{vp} + 12.0$ psia (82.7 kN/m^2)

Fuels - $P_{op} = P_{vp} + 8.0$ psia (55.2 kN/m^2)

Design pressure = proof pressure = 1.25 P_{op}

Weight

Based on calculated or minimum gage x area x density

ρ = 0.102 lb/in^3 (2823 kg/m^3)

Minimum Gage = 0.025 in (0.064 cm)

1. Spherical Tank

$$V = 1728 \left(\frac{M_L}{.95 \rho_L} + \frac{W_{he}}{7.7} \right)$$

V = total volume stored in all tanks (in^3)

M_L = mass of liquid (lbs)

ρ_L = density of liquid (lbs/ft^3)

W_{he} = wt. helium stored in tank (lbs)

$$R = \left(\frac{V}{AN\ (4.1888)} \right)^{1/3}$$

R = radius of each tank (in)

AN = number of tanks

$$T = \frac{1.25\ (P_{op})\ R}{2\ F_{ty}}$$

T = wall thickness (in)

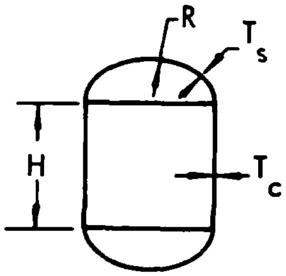
P_{op} = operating pressure of tank

F_{ty} = yield stress of tank (psi)

$$WT = AN\ (1.2818)\ R^2\ T$$

WT = weight of all tanks (lbs)

2. Cylindrical Tank - Oblate Spheroid Heads



$$V = 1728\ \left(\frac{M_L}{.95\ \rho_L} + \frac{W_{he}}{7.7}\right)$$

R = Radius is fixed (in.)

$$H = \frac{\left(\frac{V}{AN} - 2.9600\ R^3\right)}{3.1416\ R^2}$$

H = height of cylindrical portion of tank (in.)

$$T_s = \sqrt{2}(1.25)\ (P_{op})\ R/2\ F_{ty} \geq .025$$

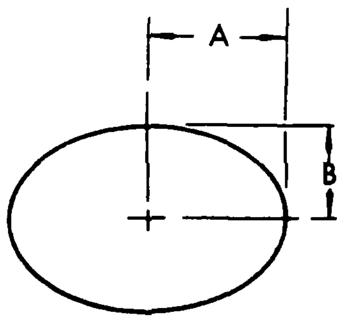
T_c = thickness of cylindrical wall (in.)

T_s = thickness of spherical cap wall (in.)

$$WT = AN\ (1.0392\ R^2\ T_s + .64089\ R\ H\ T_c)$$

WT = weight of all tanks

3. Oblate Spheroid Tank



$$V = 1728\ \left(\frac{M_L}{.95\ \rho_L} + \frac{W_{he}}{7.7}\right)$$

$$A = \left(\frac{V}{AN\ (2.96)}\right)^{1/3}$$

$$B = .7071\ A$$

A = major radius of tank

B = minor radius of tank

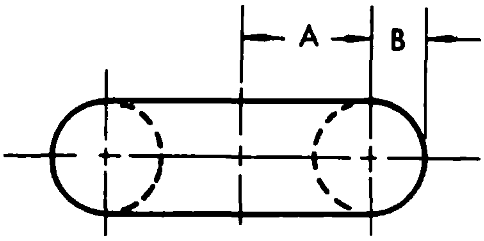
$$T = \frac{\sqrt{2}(1.25)P_{op}\ A}{2\ F_{ty}} \geq .025$$

T = thickness of wall (in.)

$$WT = AN\,(1.0392\ A^2 T)$$

WT = weight of all tanks (lbs)

4. Torus Tank



A is fixed major radius

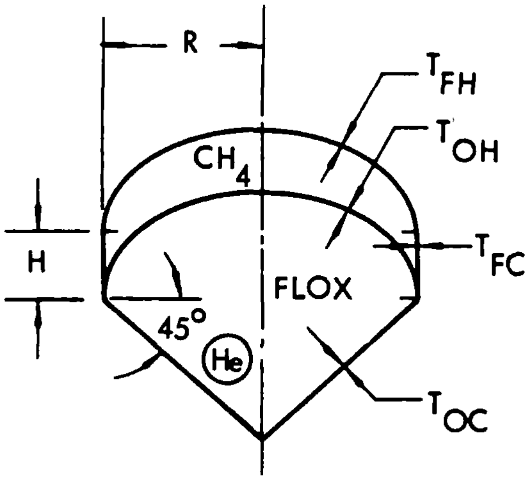
$$V = 1728\left(\frac{M_L}{.95\ \rho_L} + \frac{W_{he}}{7.7}\right)$$

$$B = \left(\frac{V}{AN\ (19.739)\ A}\right)^{1/2}$$

$$T = \frac{1.25\ P_{op}\ B}{F_{ty}}\left(\frac{2 - B/A}{2 - 2\ B/A}\right) \geq .025$$

$$WT = AN\,(4.0268\ A\ B\ T)$$

5. Common Bulkhead Tank - Conical Base



$$V_{FLOX} = 1728\left[\frac{M_{FLOX}}{.95\ \rho_{L_{FLOX}}} + \frac{W_{he}}{7.7}\right]$$

$$V_{CH_4} = 1728\left[\frac{M_{CH_4}}{.95\ \rho_{L_{CH_4}}}\right]$$

$$R = (V_{FLOX}/2.528)^{1/3}$$

$$H = V_{CH_4}/(3.1416\,R^2)$$

$$T_{FH} = \frac{(\sqrt{2})\,(1.25)\,P_{op\ CH_4}\,R}{2\,F_{ty\ FLOX}} \geq .025$$

$$T_{FC} = \frac{1.25\ P_{op\ CH_4}\,R}{F_{ty\ FLOX}} \geq .025$$

$$T_{OH} = \frac{(\sqrt{2})\,(1.25)\,P_{op_{FLOX}}\,R}{2\,F_{ty\ FLOX}} \geq .025$$

$$T_{OC} = \frac{(\sqrt{2})\,(1.25)\,P_{op\ FLOX}\,R}{F_{ty\ FLOX}} \geq .025$$

$$WT = 0.5196\,R^2\,(T_{FH} + T_{OH}) + .64089\ RH\,T_{FC} + .4531\ R^2\ T_{OC}$$

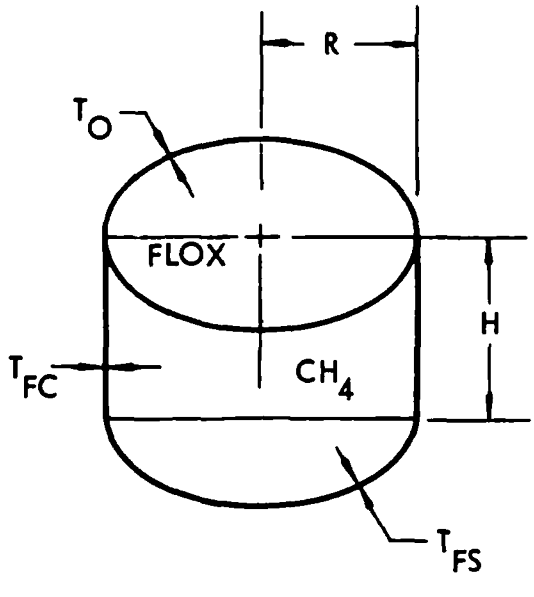
6. Common Bulkhead Tank - Oblate Spheroid Heads

$$V_{FLOX} = 1728\ \left(\frac{M_{FLOX}}{.95\ \rho_{L\ FLOX}} + \frac{W_{he}}{7.7} \right)$$

$$V_{CH_4} = 1728\ \left(\frac{M_{CH_4}}{.95\ \rho_{L_{CH_4}}} \right)$$

$$R = \left(\frac{V_{FLOX}}{2.961} \right)^{1/3}$$

$$H = V_{CH_4} / (3.1416\ R^2)$$



$$T_O = \frac{(\sqrt{2})\,(1.25)\,P_{op_{FLOX}}\,R}{2\,F_{ty_{FLOX}}} \geq .025$$

$$T_{FC} = \frac{1.25\,P_{op\,CH_4}\,R}{F_{ty_{FLOX}}} \geq .025$$

$$T_{FS} = \frac{(\sqrt{2})\,(1.25)\,P_{op\,CH_4}\,R}{2\,F_{ty_{FLOX}}} \geq .025$$

$$WT = 1.0392\,R^2\,T_O + .64089\,RH\,T_{FC} + .5196\,R^2\,T_{FS}$$

At this point, all weights were accumulated (insulation weight, vapor weights, helium weights, helium bottle weight and fuel and oxidizer tank weights). If this total weight was less than any of the 5 previous least weight cases, then it was inserted in its appropriate place and the heaviest previous case was dropped.

APPENDIX B

VEHICLE STRUCTURE EVALUATION - PRELIMINARY DESIGN

Section 1.2.3 of Volume I, "Final Report", NASA CR-121103, described the structural evaluation for the ten preliminary vehicle designs. Structural weights for the main body and Centaur adaptor for each of the study vehicles were summarized in Figures 1.2-10 and 1.2-11 of that report.

This appendix presents sketches of the vehicles, the major dimensions and weight assignments, and the detailed results of the computer aided OPTRAN (Optimization by Random Search) structural optimization program. The OPTRAN program operations were discussed in Section 1.1.3 of the Volume I document.

Three payload heights were evaluated for each of the study vehicles. These heights were approximately 1/2 and 1/5 of the vehicle diameter and a minimum case of 4 inches (10.2 cm) above the top deck insulation. Two continuous shell construction methods, and truss structures were evaluated in combination with three materials. The shells consisted of honeycomb sandwich and ring stiffened corrugations. The materials were aluminum, carbon/epoxy, and fiberglass/epoxy composites.

Sketches of the vehicle configurations with the dimensions and weights used for the study are shown in Figures B-1 through B-10.

The results of the study are presented in Tables B-1 through B-13. The case numbers refer to payload heights, Case 1 being the lowest payload position. The limits on member sizes as well as the optimum design point are shown. The results of the honeycomb sandwich evaluation indicated that shell loading was too low to make this approach competitive on a weight basis. In the majority of the cases, minimum gage configurations were selected. Examination of the weight results shows that optimum configurations were not achieved in all cases. For example, in Table B-1 for Vehicle 1-14 (upper body) with an aluminum structure, the highest shell loading produced the least weight case. To achieve more nearly optimum designs for all cases the design limits were narrowed as shown in Table B-4 with the result that minimum gages were selected for all vehicles and all payload heights. Finalized shell weights are also shown in Table B-4. Several "non-optimum" cases were noted in the truss structure data also; however, since these cases tended towards minimum gage designs, it was concluded that the least weight case could be used where discrepancies existed.

It should be noted that the weights of Tables B-1 through B-13 do not include end attachments. The weights are for the structural configuration, extending between the panel points shown in Figures B-1 through B-10.

Vehicle 2-19 carried axial, bending and internal pressure loads in the tank wall, therefore, a stiffened skin was necessary to avoid shell buckling. It appeared that this configuration could combine tank mounted and shell mounted MLI effectively.

An analysis was made to determine stiffener size and spacing options for the three payload heights and vehicle configuration shown in Figure B-10. The stiffener chosen was a 1.00 inch high leg, integral with the tank wall and aligned with the longitudinal axis of the vehicle. Several design points were evaluated to establish stiffener proportions in terms of compression load carrying capacity. The results are presented in Figure B-11. A tank gage of .025 in. (0.064 cm) stiffener thickness of .040 in. (0.10 cm) and spacing of 2.00 in. (5.1 cm) were set as minimum values. The table below shows the compression loads and stiffener proportions at the top and bottom of the cylindrical shell for the three loading conditions (three payload heights).

		PAYLOAD HEIGHT (above skirt)		
		28.5 in (0.7 m)	37.5 in (0.9m)	67.5in(1.7m)
Top of Cylindrical Shell	$N_x \sim$ lb/in (kN/m)	260 (45.5)	288 (50.5)	377 (66.0)
	$t_{skin} \sim$ in (cm)	.029 (.074)	.031 (.079)	.040 (.102)
	$t_{stiff} \sim$ in (cm)	.046 (.117)	.049 (.125)	.060 (.152)
	Spacing ~ in (cm)	2.30 (5.85)	2.50 (6.35)	3.00 (7.60)
	$\bar{t} \sim$ in (cm)	.050 (.013)	.052 (.013)	.060 (.152)
Bottom of Cylindrical Shell	$N_x \sim$ lb/in (kN/m)	300 (52.5)	326 (57.0)	417 (73.0)
	$t_{skin} \sim$ in (cm)	.032 (.081)	.035 (.089)	.044 (.112)
	$t_{stiff} \sim$ in (cm)	.051 (.130)	.053 (.135)	.064 (.163)
	Spacing ~ in (cm)	2.50 (6.35)	2.70 (6.85)	3.22 (8.18)
	$\bar{t} \sim$ in (cm)	.053 (.135)	.055 (.140)	.064 (.163)

The $\bar{t}$ values defined the shell thickness assuming the stiffeners were "smeared" over the surface. The average dimensions between top and bottom of the cylindrical shell were used in the vehicle design and meteoroid protection evaluation of the Volume I document.

The conical shell was checked for buckling stability when subjected to an engine thrust load of 12,500 lbs (55.5 kN). The minimum gage required for internal pressure loads was found to be adequate for the thrust load condition. A "Y" ring was necessary at the intersection of the conical and cylindrical surfaces to carry the radial loads. A cross section of 0.26 square inches (1.68 cm^2) was required. The weights of the "Y" rings, shell stiffening and tank skirt plus ring were respectively;

Case 1:	5.1 lb (2.3 kg),	4.5 lb (2.0 kg),	7.1 lb (3.2 kg)
Case 2:	5.1 lb (2.3 kg),	4.6 lb (2.1 kg),	7.2 lb (3.3 kg)
Case 3:	5.1 lb (2.3 kg),	6.1 lb (2.8 kg),	8.0 lb (3.6 kg)

The Vehicle Structure Evaluation was concluded by calculating end fitting and attachment bracket weights for all of the vehicles and adaptors using the curves of Figures 1.2-6 and 1.2-7, and the methods described in Section 1.2.2 of the Volume I document. The final results are presented in Tables B-14 through B-23.

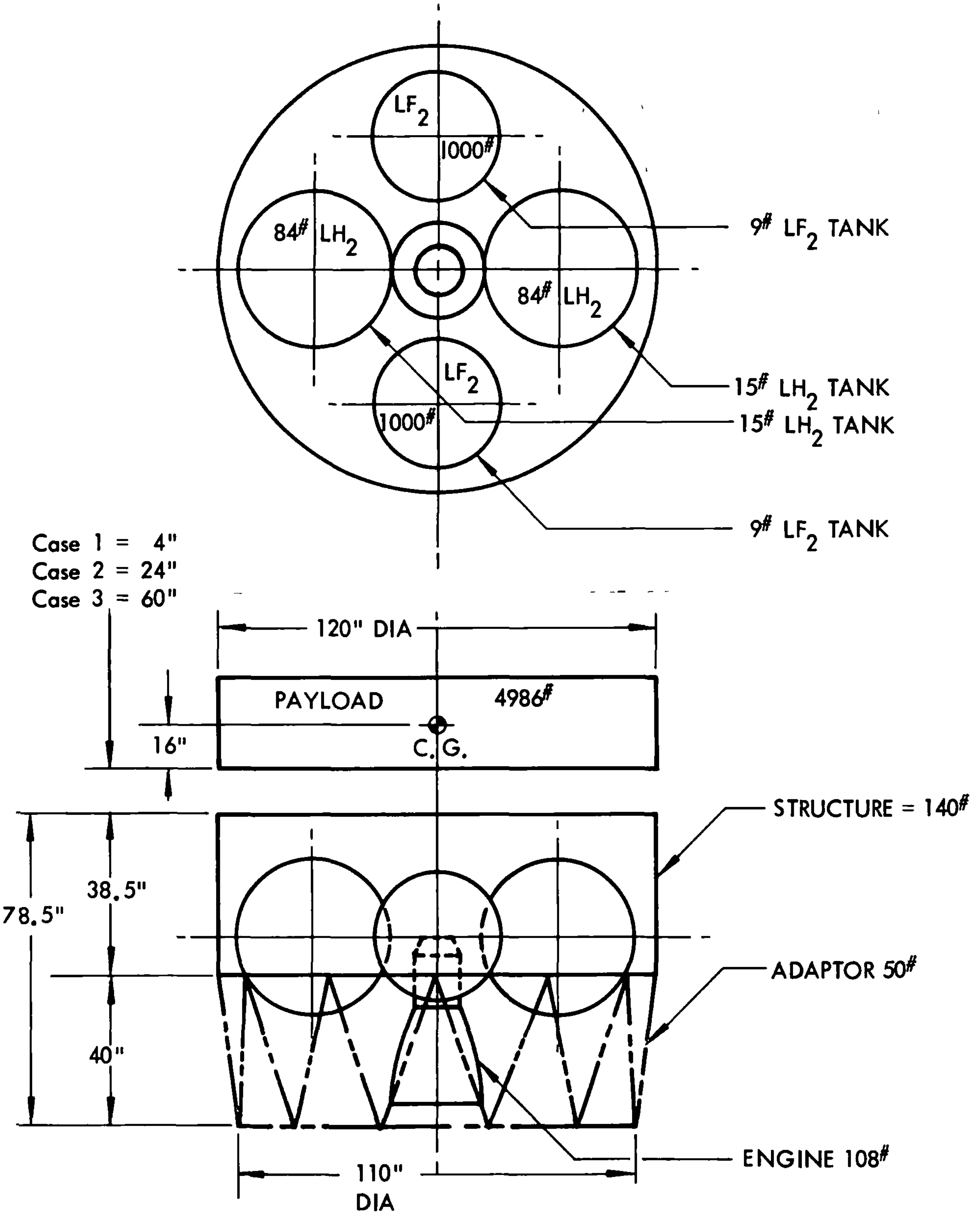


Figure B-1: VEHICLE 1-3

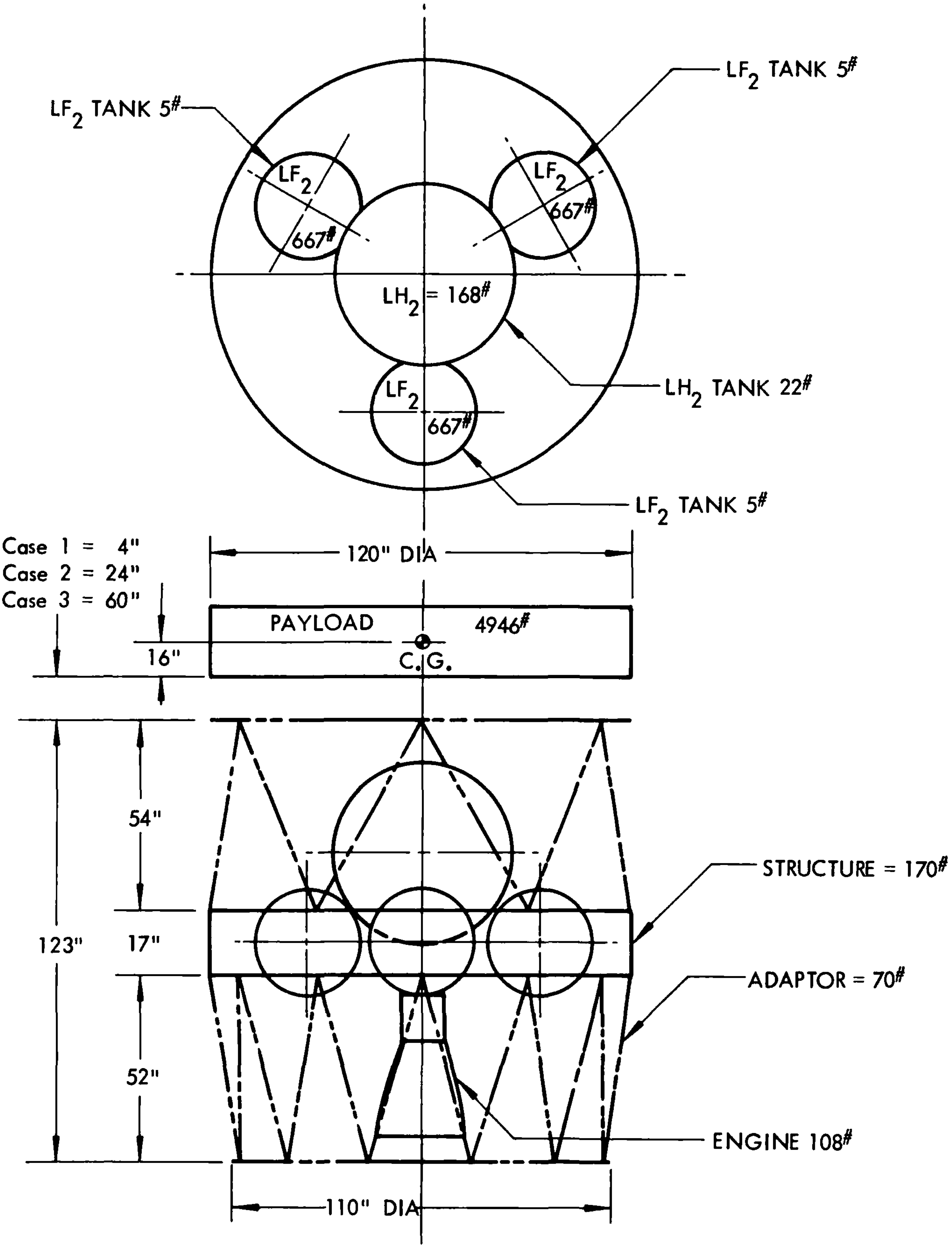


Figure B-2: VEHICLE 1-2A

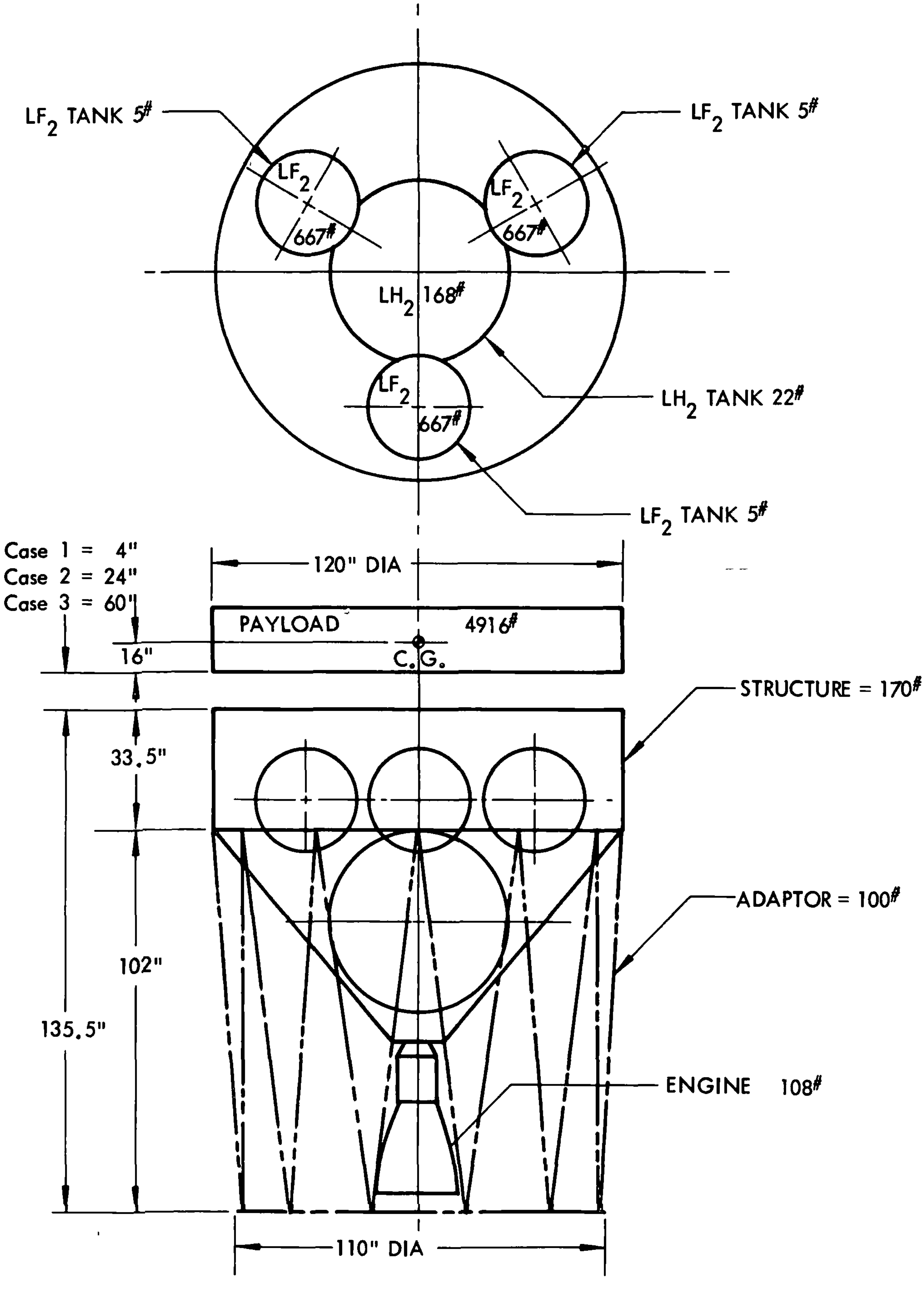


Figure B-3: VEHICLE 1-2B

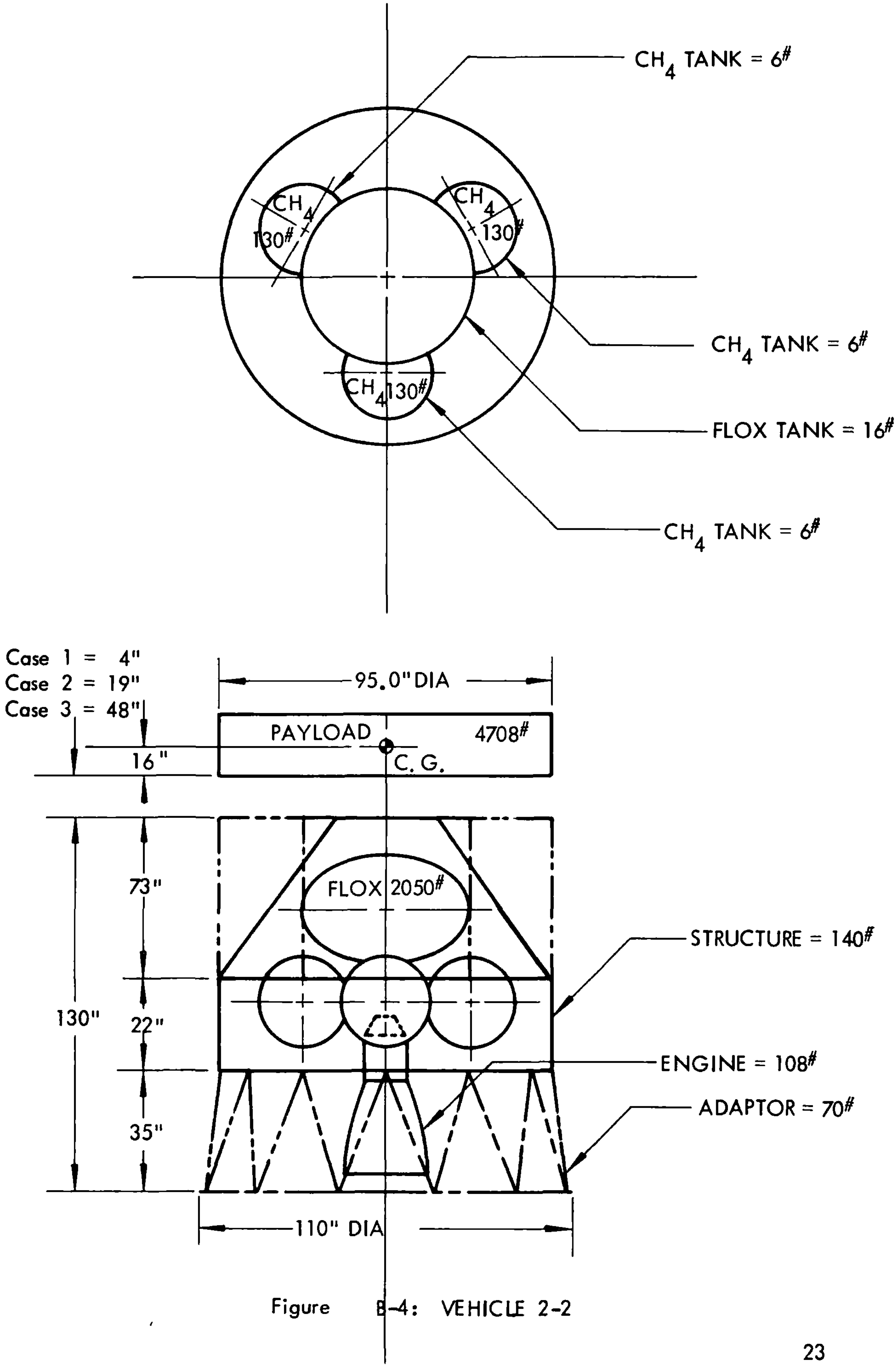


Figure B-4: VEHICLE 2-2

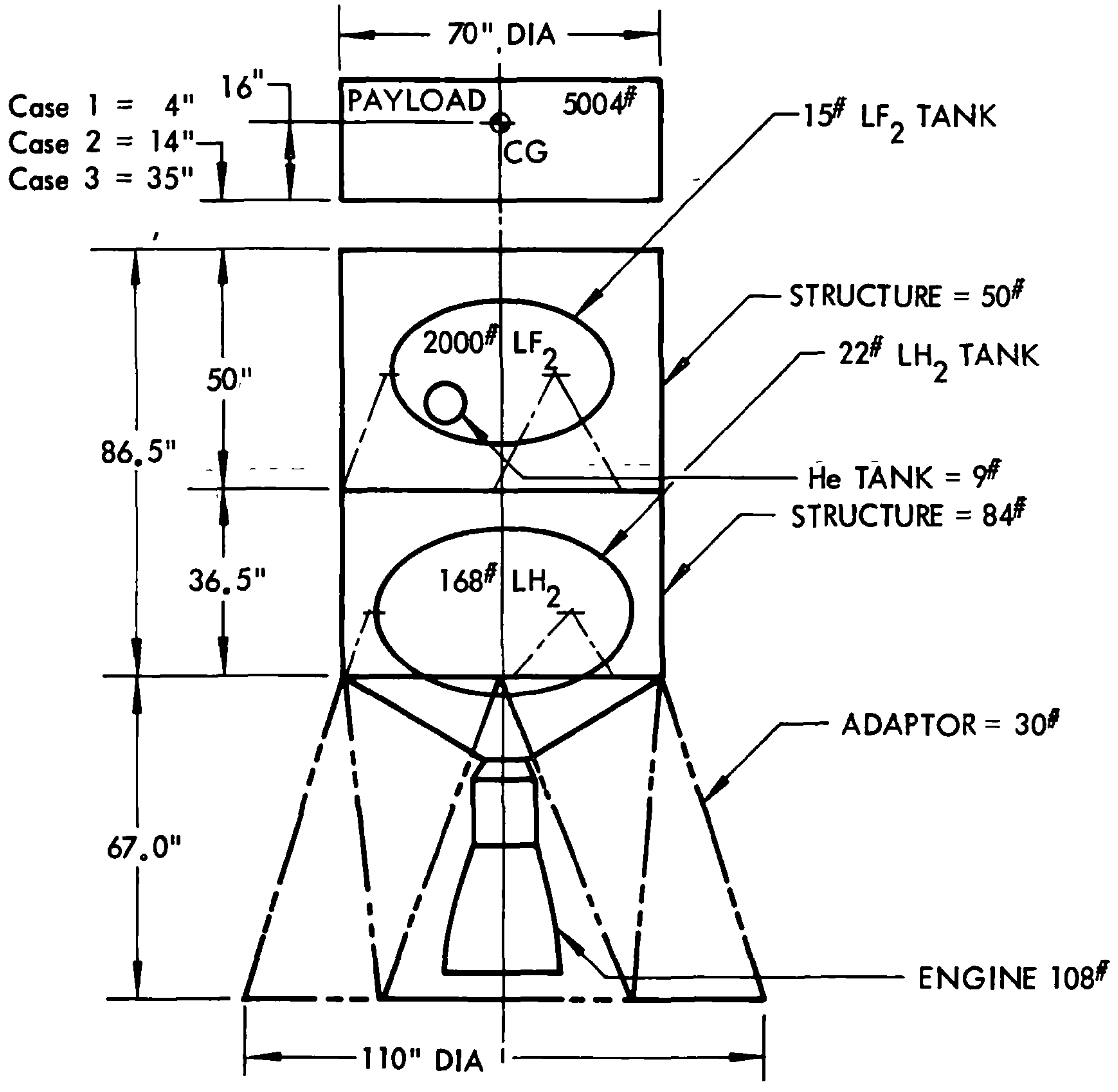


Figure B-5: VEHICLE 1-14

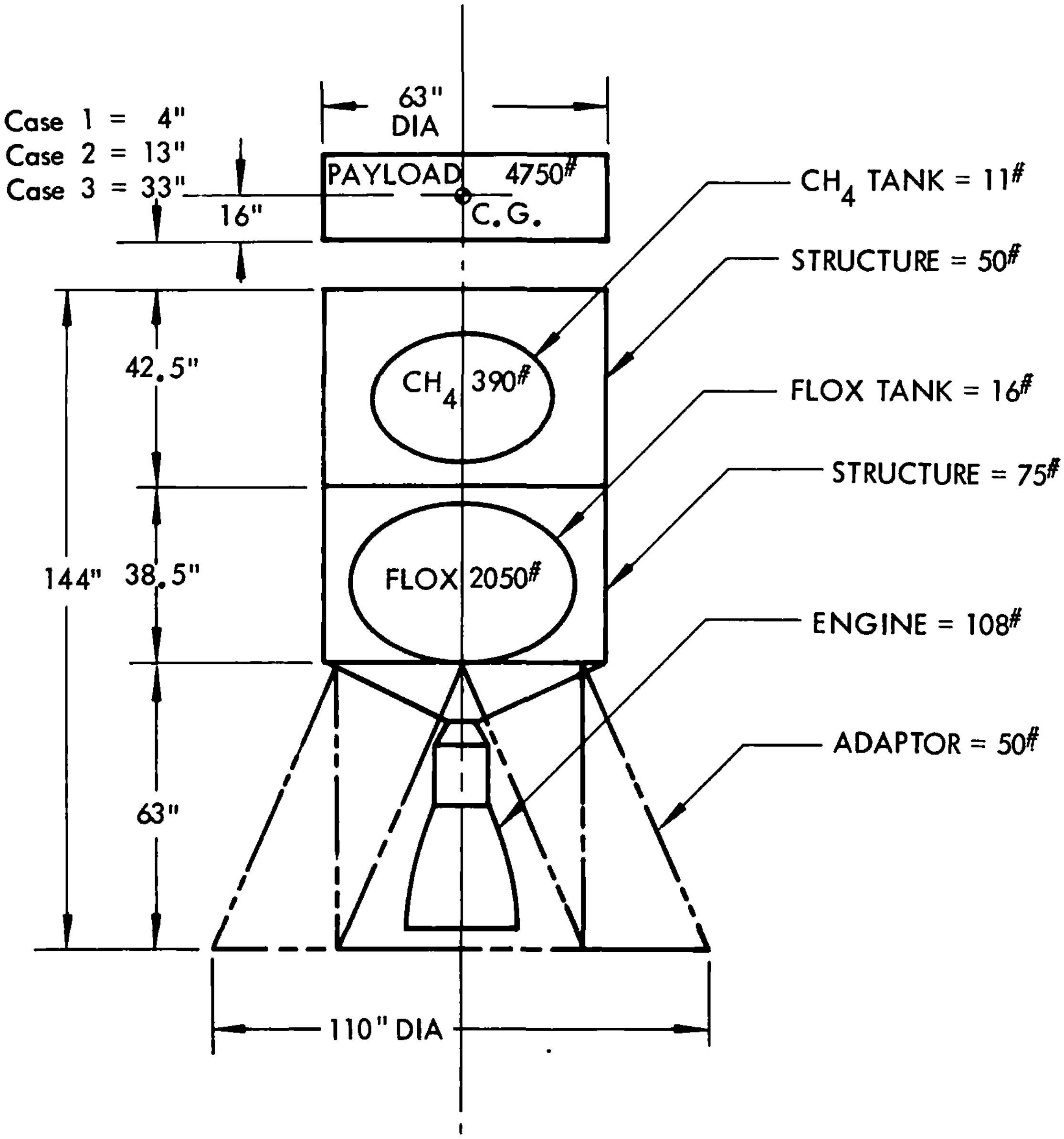


Figure B-6: VEHICLE 2-14

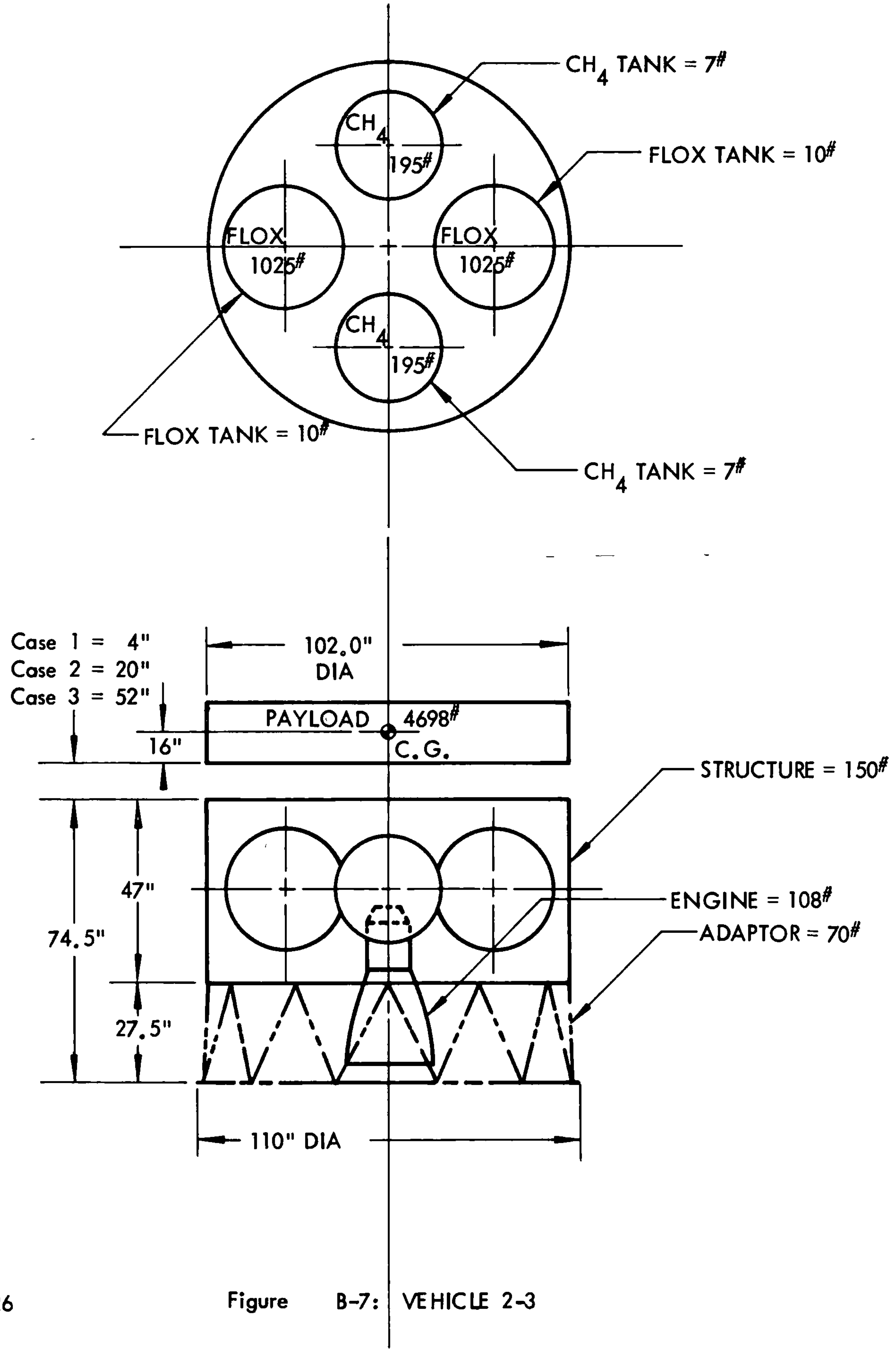


Figure B-7: VEHICLE 2-3

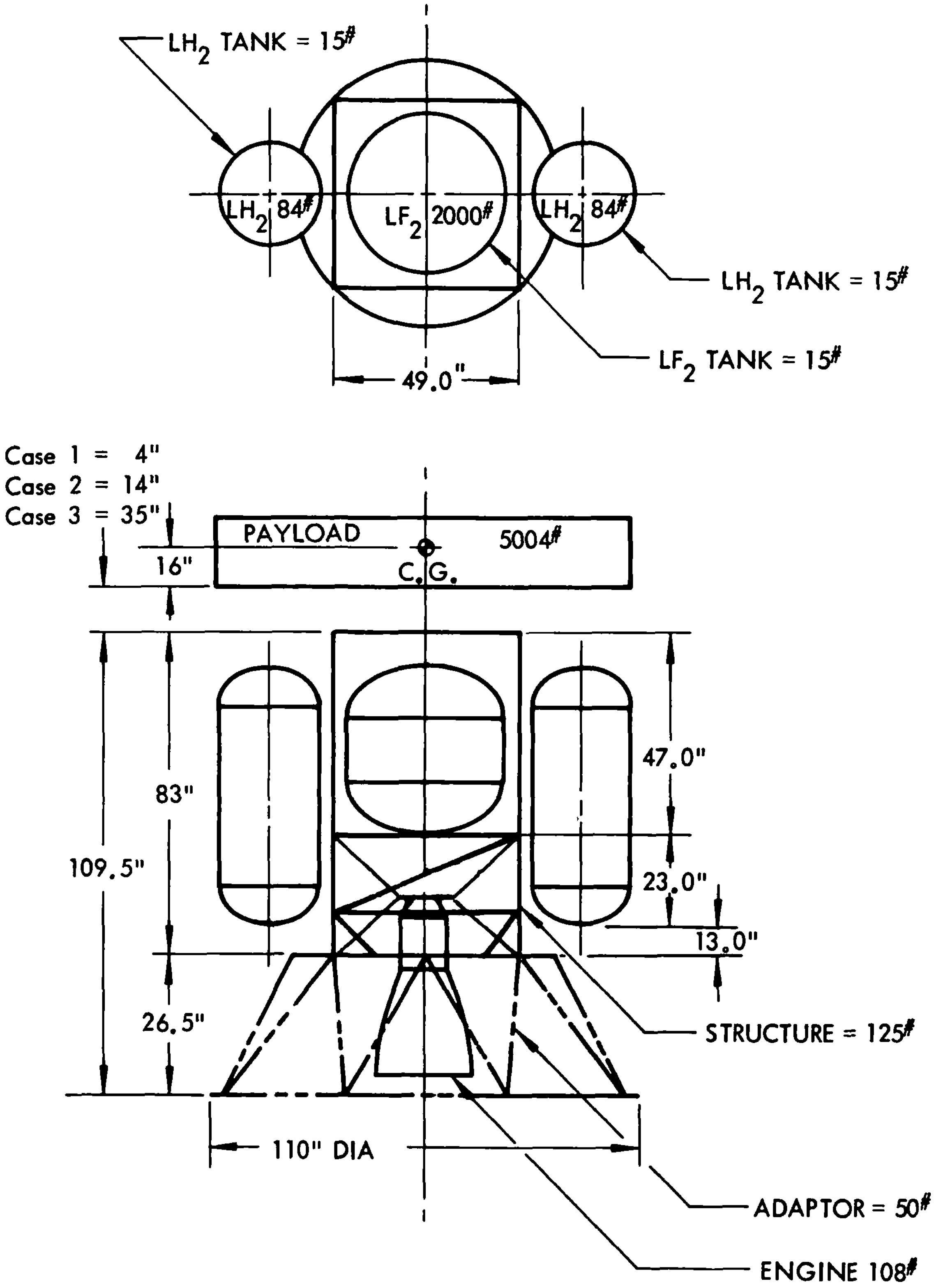


Figure B-8: VEHICLE 1-7

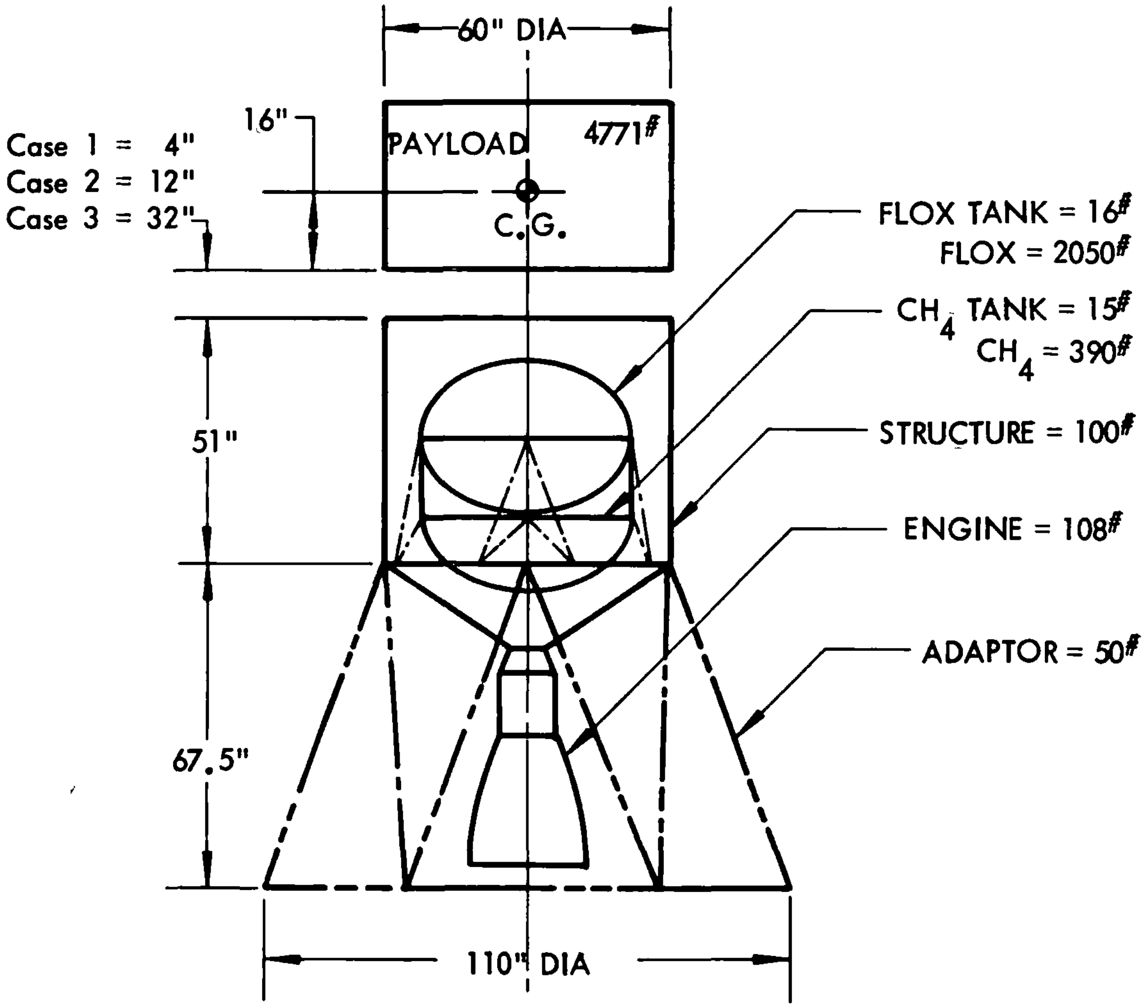


Figure B-9: VEHICLE 2-18

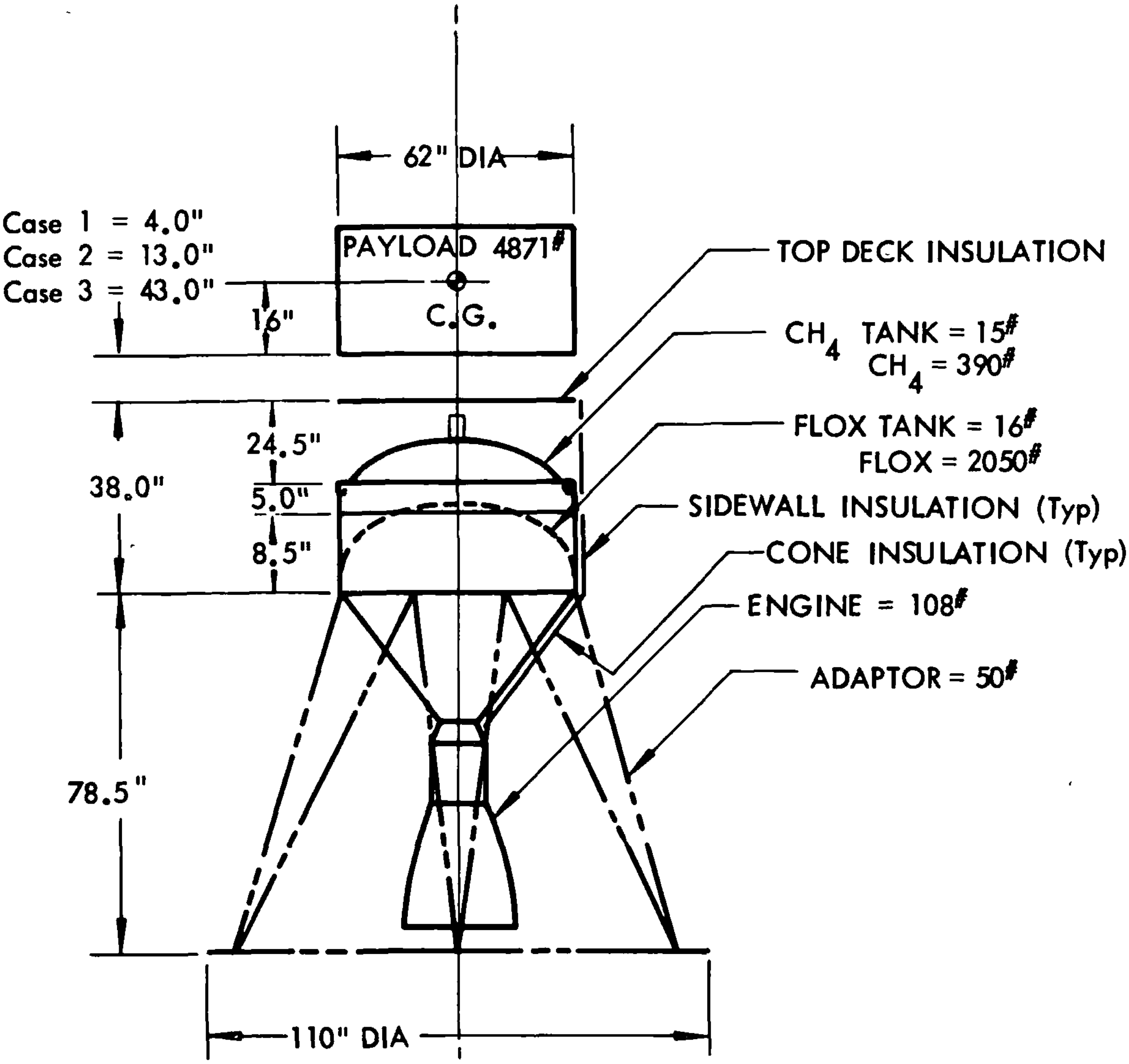


Figure B-10: VEHICLE 2-19

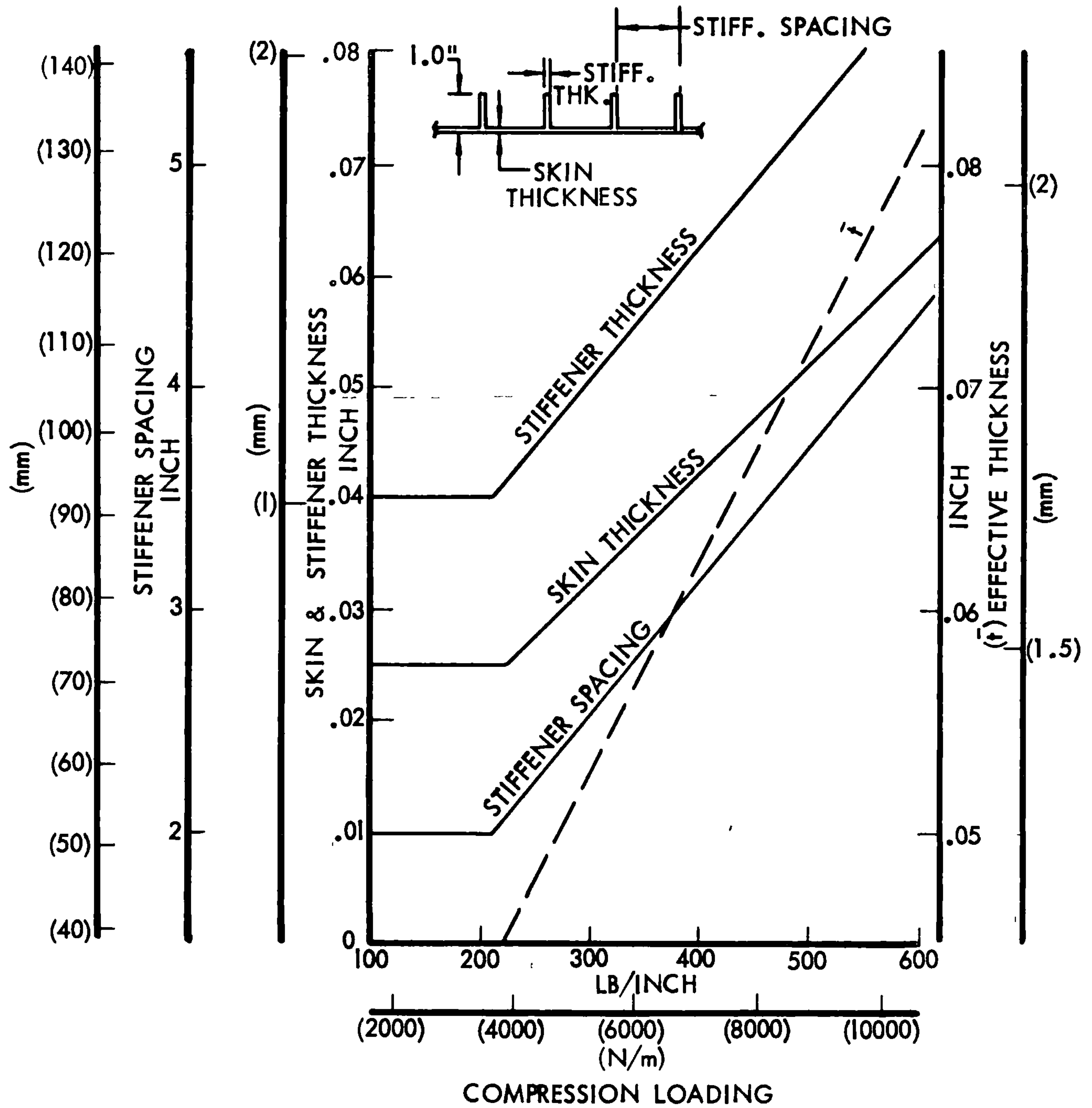


Figure B-11: VEHICLE 2-19 STIFFENER PROPORTIONS

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Table B-1: HONEYCOMB SANDWICH DATA (Cont)

VEHICLE CONFIG	MATERIAL	CASE	SHELL HEIGHT (in)	ULT LOAD N_X (lb/in)	CORE DENSITY (lb/ft^3)*	CORE DEPTH (in.) MAX	MIN	DES	FACE SKIN THICKNESS (in) MAX	MIN	DES	RIBBON THICKNESS (in) MAX	MIN	DES	CELL SIZE (in) MAX	MIN	DES	WEIGHT (lb/ft^2)
VEHICLE 1-14 (UPPER BODY)	ALUMINUM	1	50	287	1.58	0.500	0.250	0.256	0.040	0.020	0.020	0.003	0.001	0.001	0.375	0.250	0.338	0.605
		2		311	1.95			0.250									0.283	0.610
		3		365	1.50			0.262									0.358	0.604
	CARBON/ EPOXY	1		287	1.47			0.250									0.365	0.334
		2		311	1.42			0.257									0.374	0.334
		3		365	1.44			0.251				0.003	0.001	0.001			0.373	0.334
	FIBERGLASS	1		287	3.33			0.252				0.005	0.003	0.003			0.317	0.439
		2		311	2.86			0.254				0.005	0.003	0.003			0.369	0.432
		3	50	365	2.86	0.500		0.253	0.040			0.005	0.003	0.003		0.250	0.372	0.431
VEHICLE 1-14 (LOWER BODY)	ALUMINUM	1	36.5	476	1.41	0.270		0.251	0.021			0.003	0.001	0.001		0.375	0.375	0.601
		2		519	1.41			0.251										0.601
		3		571	1.41			0.251										0.601
	CARBON/ EPOXY	1		476	1.42			0.250										0.332
		2		519	1.42													0.332
		3		571	1.42	0.270						0.003	0.001	0.001				0.332
	FIBERGLASS	1		476	2.81	0.300						0.005	0.003	0.003				0.430
		2		519	2.81	0.300						0.005	0.003	0.003				0.430
		3	36.5	571	2.81	0.300		0.250	0.021			0.005	0.003	0.003		0.375	0.375	0.430
VEHICLE 2-14 (UPPER BODY)	ALUMINUM	1	42.5	298	1.44	0.500		0.251	0.040			0.003	0.001	0.001		0.250	0.371	0.602
		2		322	1.55			0.253									0.344	0.605
		3		377	1.58			0.253									0.338	0.605
	CARBON/ EPOXY	1		298	1.44			0.254									0.374	0.334
		2		322	1.43			0.252									0.372	0.334
		3		377	1.42			0.251				0.003	0.001	0.001			0.373	0.334
	FIBERGLASS	1		298	2.90			0.251				0.005	0.003	0.003			0.366	0.432
		2		322	2.81			0.251				0.005	0.003	0.003			0.374	0.430
		3	42.5	377	2.84			0.251				0.005	0.003	0.003			0.371	0.431
VEHICLE 2-14 (LOWER BODY)	ALUMINUM	1	38.5	437	1.54			0.252				0.003	0.001	0.001			0.349	0.604
		2		462	1.47			0.250				0.003					0.370	0.602
		3		519	1.48			0.251									0.366	0.602
	CARBON/ EPOXY	1		437	1.42			0.250									0.374	0.334
		2		462	1.43			0.250									0.375	0.334
		3		519	1.44			0.250				0.003	0.001	0.001			0.370	0.334
	FIBERGLASS	1		437	2.87			0.252				0.005	0.003	0.003			0.375	0.432
		2		462	2.85			0.251				0.005	0.003	0.003			0.371	0.432
		3	38.5	519	2.81	0.500	0.250	0.256	0.040	0.020	0.020	0.005	0.003	0.003	0.375	0.250	0.374	0.432

*ALUM CORE WITH ALUM & CARBON FACES HRP (F G) CORE WITH F G FACES

Table B-1: HONEYCOMB SANDWICH DATA

VEHICLE CONFIG	MATERIAL	CASE	SHELL HEIGHT (cm)	ULT LOAD N_X (N/m)	CORE DENSITY (Kg/m^3)*	CORE DEPTH (cm) MAX	CORE DEPTH (cm) MIN	CORE DEPTH (cm) DES	FACE SKIN THICKNESS (cm) MAX	FACE SKIN THICKNESS (cm) MIN	FACE SKIN THICKNESS (cm) DES	RIBBON THICKNESS (cm) MAX	RIBBON THICKNESS (cm) MIN	RIBBON THICKNESS (cm) DES	CELL SIZE (cm) MAX	CELL SIZE (cm) MIN	CELL SIZE (cm) DES	WEIGHT (Kg/m^2)
VEHICLE 1-14 (UPPER BODY)	ALUMINUM	1	127	5,023	25.31	1.27	0.635	0.65	0.102	0.051	0.051	0.008	0.003	0.003	0.953	0.635	0.858	2.95
		2		5,443	31.24			0.635									0.718	2.98
		3		6,388	24.03			0.665									0.909	2.948
	CARBON/ EPOXY	1		5,023	23.55			0.635									0.927	1.63
		2		5,443	22.75			0.653									0.95	1.63
		3		6,388	23.07			0.638				0.008	0.003	0.003			0.947	1.63
	FIBERGLASS	1		5,005	53.35			0.64				0.013	0.008	0.008			0.805	2.14
		2		5,443	45.82		0.635	0.645				0.013	0.008	0.008			0.937	2.108
		3	127	6,388	45.82	1.27	0.64	0.643	0.102			0.013	0.008	0.008		0.635	0.945	2.103
VEHICLE 1-14 (LOWER BODY)	ALUMINUM	1	92.7	8,330	22.59	0.69		0.638	0.053			0.008	0.003	0.003		0.953	0.953	2.933
		2		9,083	22.59			0.638										2.933
		3		9,993	22.59			0.638										2.933
	CARBON/ EPOXY	1		8,330	22.75			0.635										1.62
		2		9,083	22.75													1.62
		3		9,993	22.75	0.69						0.008	0.003	0.003				1.62
	FIBERGLASS	1		8,330	45.02	0.76						0.013	0.008	0.008				2.10
		2		9,083	45.02	0.76						0.013	0.008	0.008				2.10
		3	92.7	9,993	45.02	0.76		0.635	0.053			0.013	0.008	0.008		0.953	0.953	2.10
VEHICLE 2-14 (UPPER BODY)	ALUMINUM	1	107.95	5,180	23.07	1.27	0.64	0.638	0.102			0.008	0.003	0.003		0.635	0.942	2.94
		2		5,635	24.83		0.635	0.643									0.874	2.95
		3		6,598	25.31			0.643									0.859	2.95
	CARBON/ EPOXY	1		5,180	23.07			0.645									0.95	1.63
		2		5,635	22.91			0.641									0.945	1.63
		3		6,598	22.75			0.638				0.008	0.003	0.003			0.947	1.63
	FIBERGLASS	1		5,180	46.46			0.638				0.013	0.008	0.008			0.93	2.108
		2		5,635	45.02			0.638				0.013	0.008	0.008			0.95	2.10
		3	107.95	6,598	45.50			0.638				0.013	0.008	0.008			0.942	2.103
VEHICLE 2-14 (LOWER BODY)	ALUMINUM	1	97.79	7,648	24.67			0.664				0.008	0.003	0.003			0.886	2.948
		2		8,085	23.56			0.635									0.94	2.94
		3		9,083	23.71			0.638									0.93	2.94
	CARBON/ EPOXY	1		7,648	22.75			0.635									0.95	1.63
		2		8,085	22.91			0.635									0.953	1.63
		3		9,083	23.07			0.635				0.008	0.003	0.003			0.94	1.63
	FIBERGLASS	1		7,648	45.98			0.641				0.013	0.008	0.008			0.953	2.108
		2		8,085	45.66			0.638				0.013	0.008	0.008			0.942	2.108
		3	97.79	9,083	45.02	1.27	0.635	0.65	0.102	0.051	0.051	0.013	0.008	0.008	0.953	0.635	0.95	2.108

*ALUM CORE WITH ALUM & CARBON FACES   HRP (F G) CORE WITH F G FACES

Table B-2: HONEYCOMB SANDWICH DATA (Cont)

VEHICLE CONFIG	MATERIAL	CASE	SHELL HEIGHT (in.)	ULT LOAD N_x (lb/in)	CORE DENSITY (lb/ft^3) *	CORE DEPTH (in.)			FACE SKIN THICKNESS (in)			RIBBON THICKNESS (in)			CELL SIZE (in)			WEIGHT (lb/ft^2)
						MAX	MIN	DES	MAX	MIN	DES	MAX	MIN	DES	MAX	MIN	DES	
VEHICLE 1-3	ALUMINUM	1	38.5	119	1 52	0 500	0.250	0.251	0.040	0.020	0 020	0 003	0 001	0.001	0.375	0.250	0 354	0 603
		2		136	1 84			0.253									0.293	0 609
		3		165	1 48			0.260									0 361	0 603
	CARBON/ EPOXY	1		119	1 45			0.250									0 366	0 332
		2		136	1 46			0.252									0 365	0.334
		3		165	1 44			0.251				0 003	0 001	0 001			0 373	0 334
	FIBERGLASS	1		119	2.84			0.256				0 005	0 003	0 003			0 369	0 431
		2		136	2.88			0.253				0 005	0 003	0 003			0 372	0 431
		3	38.5	165	2.99			0.250				0.005	0 003	0 003			0 363	0 433
VEHICLE 1-2 (LH_2 ON TOP)	ALUMINUM	1	17 0	142	1 42			0.250				0 003	0 001	0 001			0 349	0 604
		2		159	1 46			0.253									0.367	0 602
		3		188	1 79			0.255									n 299	0 609
	CARBON/ EPOXY	1		142	1 46			0.250									0 368	0 334
		2		159	1 46			0.253									0 370	0 334
		3		188	1 43			0.254				0 003	0 001	0 001			0 372	0 334
	FIBERGLASS	1		142	2.85			0.251				0 005	0 003	0 003			0 372	0 431
		2		159	2.82			0.253				0 005	0.003	0.003			0 372	0 430
		3	17 0	188	2.85			0.261				0.005	0 003	0 003			0 369	0 434
VEHICLE 1-2 (LF_2 ON TOP)	ALUMINUM	1	33.5	113	1 43			0.258				0.003	0 001	0 001			0 371	0 603
		2		129	1.51			0.252									0 357	0 603
		3		159	1.68			0.250									0 321	0 606
	CARBON/ EPOXY	1		113	1 44			0.253									0 369	0 334
		2		129	1 44			0.252									0.373	0 334
		3		159	1 46			0.251				0 003	0 001	0.001			0.366	0 334
	FIBERGLASS	1		113	2.82			0.251				0 005	0.003	0 003			0 373	0 430
		2		129	2.84			0.250				0 006	0 003	0 003			0 371	0 431
		3	33.5	159	2.85			0.250				0.005	0.003	0.003			0.375	0.431
VEHICLE 2-2	ALUMINUM	1	22.0	306	1 45			0.251				0.003	0 001	0 001			0 374	0 603
		2		326	1 57			0.251									0 345	0 604
		3		360	1.82			0.253									0 293	0 609
	CARBON/ EPOXY	1		306	1 42			0.250									0.375	0 333
		2		326	1 44			0.252									0 371	0 334
		3		360	1 48			0.252				0.003	0.001	0.001			0.361	0 334
	FIBERGLASS	1		306	2.82			0.272				0 005	0 003	0 003			0 373	0 436
		2		326	2.92			0.277				0.005	0 003	0.003			0 366	0 438
		3	22.0	360	2.84	0.500	0.250	0.297	0 040	0.020	0 020	0.005	0 003	0.003	0 375	0 250	0 371	0 441

*ALUM CORE WITH ALUM OR CARBON FACES HRP (F G.) CORE WITH F G. FACES

Table B-2: HONEYCOMB SANDWICH DATA

VEHICLE CONFIG	MATERIAL	CASE	SHELL HEIGHT (cm)	ULT LOAD N_X (N/m)	CORE DENSITY (Kg/m^3)*	CORE DEPTH (cm)			FACE SKIN THICKNESS (cm)			RIBBON THICKNESS (cm)			CELL SIZE (cm)			WEIGHT (Kg/m^2)
						MAX	MIN	DES	MAX	MIN	DES	MAX	MIN	DES	MAX	MIN	DES	
VEHICLE 1-3	ALUMINUM	1	97 79	2,083	24.35	1.27	0.635	0.638	0.102	0.051	0 051	0.008	0.003	0.003	0.953	0.635	0 876	2 943
		2		2,380	29 48			0.643									0 744	2.972
		3		2,888	23 71			0.661									0.917	2 943
	CARBON/ EPOXY	1		2,083	23.23			0.635									0 93	1 620
		2		2,380	23.39			0.643									0 927	1 630
		3		2 888	23.07			0.638				0.008	0.003	0.003			0.947	1 630
	FIBERGLASS	1		2 083	45 50			0.650				0.013	0 008	0.008			0 937	2 103
		2		2 380	45.82			0.643				0.013	0 008	0 008			0 945	2.103
		3	97 79	2 888	47 90			0 635				0 013	0 008	0 008			0 922	2 113
VEHICLE 1-2 (LH_2 ON TOP)	ALUMINUM	1	43.18	2,485	22 75			0.635				0.008	0.003	0 003			0 886	2 947
		2		2,783	23.39			0 643									0 932	2 938
		3		3,290	28 76			0.648									0.76	2 972
	CARBON/ EPOXY	1		2 485	23.39			0 635									0 935	1 630
		2		2,783	23.39			0.643									0 94	1 630
		3		3,290	22 91			0.645				0 008	0.003	0 003			0 945	1 630
	FIBERGLASS	1		2 485	45 66			0.638				0.013	0.008	0 008			0 945	2 103
		2		2 783	45 18			0.643				0 013	0.008	0 008			0 945	2 098
		3	43.18	3,290	45 68			0.663				0.013	0.008	0.008			0 937	2 118
VEHICLE 1-2 (LF_2 ON TOP)	ALUMINUM	1	86.08	1,978	22.91			0 655				0 008	0.003	0.003			0 942	2.943
		2		2,258	24 19			0.640									0 907	2 943
		3		2,783	26 91			0 635									0 815	2 957
	CARBON/ EPOXY	1		1,978	23 07			0.643									0 937	1 630
		2		2,258	23.07			0.640									0 947	1 630
		3		2,783	23.39			0.638				0 008	0.003	0 003			0 93	1 630
	FIBERGLASS	1		1,978	45.18			0 638				0 013	0 008	0 008			0 947	2 098
		2		2,258	45 50			0.635				0.013	0.008	0 008			0 942	2 103
		3	86.09	2 783	45.68			0 635				0.013	0.008	0.008			0.953	2 103
VEHICLE 2-2	ALUMINUM	1	56.88	5,365	23.23			0 638				0.008	0.003	0 003			0 95	2 943
		2		5 706	25 15			0 638									0 876	2.947
		3		6 300	29 16			0.643									0.744	2 972
	CARBON/ EPOXY	1		5,366	22.75			0.635									0 953	1 625
		2		5,706	23 07			0.640									0 942	1 630
		3		6,300	23.71			0.640				0.008	0.003	0.003			0 917	1 630
	FIBERGLASS	1		5 365	45 18			0.691				0.013	0.008	0 008			0 947	2.128
		2		5,706	46.78			0.704				0.013	0.008	0 008			0.93	2 137
		3	56.88	6 300	45.60	1.27	0.635	0.754	0.102	0 051	0.051	0.013	0.008	0.008	0 953	0 635	0 942	2.152

*ALUM CORE WITH ALUM OR CARBON FACES HRP (F G.) CORE WITH F G FACES

Table B-3: HONEYCOMB SANDWICH DATA (Cont)

VEHICLE CONFIG	MATERIAL	CASE	SHELL HEIGHT (in)	ULT LOAD N_X (lb/in)	CORE DENSITY (lb/ft^3)*	CORE DEPTH (in.)			FACE SKIN THICKNESS (in.)			RIBBON THICKNESS (in)			CELL SIZE (in.)			WEIGHT (lb/ft^2)
						MAX	MIN	DES	MAX	MIN	DES	MAX	MIN	DES	MAX	MIN	DES	
VEHICLE 2-3	ALUMINUM	1	47	152	1.61	0.500	0.250	0 252	0 040	0 020	0 020	0 003	0.001	0.001	0.375	0.250	0.337	0.605
		2		169	1 86			0.253									0.287	0.610
		3		203	1.53			0.254									0.354	0.604
	CARBON/ EPOXY	1		152	1 46			0.251									0 366	0.334
		2		169	1 42			0.252									0.374	0 334
		3		203	1 43			0.253				0 003	0.001	0.001			0.373	0.334
	FIBERGLASS	1		152	2.85			0.251				0.005	0.003	0.003			0.372	0 431
		2		169	2.81			0.255				0.005	0.003	0.003			0.375	0.431
		3	47	203	2.89			0.252				0.005	0.003	0.003			0.370	0.431
VEHICLE 2-18	ALUMINUM	1	51	379	1 43			0 250				0.003	0.001	0.001			0.373	0.602
		2		405	1.43			0.262									0.373	0.603
		3		458	1 48			0 256									0.375	0.603
	CARBON/ EPOXY	1		379	1 44			0.251									0 373	0.334
		2		405	1 44			0 252									0.373	0.334
		3		458	1 44			0 256				0 003	0.001	0 001			0.371	0 334
	FIBERGLASS	1		379	2.82			0 251				0 005	0.003	0 003			0 374	0 432
		2		405	2 90			0.251				0 005	0 003	0.003			0.375	0.431
		3	51	458	2 97	0.500	0.250	0.251	0.040	0.020	0 020	0 005	0.003	0 003	0.375	0.250	0.371	0 433

*ALUM CORE WITH ALUM AND CARBON FACES
HRP (F G.) CORE WITH F G FACES

Table B-3: HONEYCOMB SANDWICH DATA (Cont)

VEHICLE CONFIG	MATERIAL	CASE	SHELL HEIGHT (cm)	ULT LOAD N_X (N/m)	CORE DENSITY (Kg/m^3)*	CORE DEPTH (cm)			FACE SKIN THICKNESS (cm)			RIBBON THICKNESS (cm)			CELL SIZE (cm)			WEIGHT (Kg/m^2)
						MAX	MIN	DES	MAX	MIN	DES	MAX	MIN	DES	MAX	MIN	DES	
VEHICLE 2-3	ALUMINUM	1	119.38	2,660	25.79	1.27	0.635	0.64	0.102	0.051	0.051	0.008	0.003	0.003	0.953	0 635	0.856	2.953
		2		2,958	29,80			0.643									0.729	2.977
		3		3,553	24.51			0.645									0 899	2.948
	CARBON/ EPOXY	1		2,660	23.39			0.638									0.93	1.630
		2		2,958	22.75			0.64									0.95	1.630
		3		3,553	22.91			0.643				0.008	0.003	0.003			0.948	1.630
	FIBERGLASS	1		2,660	45.66			0.638				0.013	0.008	0 008			0.945	2.103
		2		2,958	45.02			0.648				0.013	0.008	0.008			0.948	2.103
		3	119.38	3,553	46.30			0.643				0.013	0.008	0.008			0.94	2.103
VEHICLE 2-18	ALUMINUM	1	129.54	6,633	22.91			0.635				0.008	0.003	0.003			0.948	2.938
		2		7,088	22.91			0.64									0 948	2.943
		3		8,015	23.71			0.65									0.953	2.943
	CARBON/ EPOXY	1		6,633	23.07			0.638									0.948	1.630
		2		7,088	23.07			0.64									0.948	1 630
		3		8,015	23.07			0.65				0.008	0.003	0.003			0.943	1.630
	FIBERGLASS	1		6,633	45.18			0.638				0.013	0.008	0.008			0.95	2 113
		2		7,088	46.46			0.638				0.013	0.008	0.008			0.953	2.103
		3	129.54	8,015	47.58	1.27	0.635	0.638	0.102	0.051	0.051	0.013	0.008	0.008	0.953	0.635	0.943	2.113

*ALUM CORE WITH ALUM AND CARBON FACES
HRP (F.G) CORE WITH F.G. FACES

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Table B-4: HONEYCOMB SANDWICH DATA (NARROW LIMITS)

		CORE DENSITY LB/FT³*	CORE DEPTH IN (CM)			FACE SKIN THICKNESS IN. (CM)			RIBBON THICKNESS IN. (CM)			CELL SIZE IN. (CM)			WEIGHT LB/FT²
		(kg/m³)	MAX	MIN	DESIGN	MAX	MIN	DESIGN	MAX	MIN	DESIGN	MAX	MIN	DESIGN	(kg/m²)
ALL STUDY VEHICLES AND ALL PAYLOAD HEIGHTS	ALUM	1.41 (24.68)	.270 (.686)	.250 (.635)	.251 (.638)	.021 (.003)	020 (.051)	.020 (.051)	.003 (.008)	001 (.003)	001 (.003)	.375 (.953)	.375 (953)	.375 (.953)	.601 (2.93)
	CARBON EPOXY	1.42 (24.85)	.270 (.686)	.250 (.635)	.250 (.635)	.021 (.053)	.020 (.051)	.020 (051)	.003 (.008)	.001 (.003)	.001 (.003)	.375 (.953)	.375 (.953)	.375 (.953)	.333 (1.625)
	FIBER GLASS	2.81 (49.18)	.300 (.762)	.250 (.635)	250 (.635)	.021 (.053)	.020 (.051)	.020 (.051)	.005 (.013)	.003 (.008)	.003 (.008)	.375 (.953)	.375 (.953)	.375 (.953)	.430 (2.098)

*ALUM CORE WITH ALUM AND CARBON FACES
HRP (F.G.) CORE WITH F.G. FACES

Table B-5: TRUSS STRUCTURE DATA

VEHICLE CONFIG-URATION	MATERIAL	CASE	MEMBER QTY	LENGTH (in.)	LOAD (lb)	TUBE THICKNESS (in.) MAX	TUBE THICKNESS (in.) MIN	TUBE THICKNESS (in.) DES	TUBE RADIUS (in.) MAX	TUBE RADIUS (in.) MIN	TUBE RADIUS (in.) DES	WEIGHT PER MEMBER (lb)
VEHICLE 1-3	ALUMINUM ρ = 0.10 LB/IN.^{3} E = 10 x 10^5 LB/IN.^{2}	1	24	42	3,246	0.200	0.020	0.020	2.50	1.00	1.01	0.526
		2			3,319	0.200	0.020	0.020	2.50	1.00	1.03	0.538
		3			3,520	0.200	0.020	0.021	2.50	1.00	1.00	0.547
	CARBON-EPOXY ρ = 0.055 LB/IN.^{3} E = 28 x 10^6 LB/IN.^{2}	1			3,246	0.070	0.028	0.028	2.25	0.75	0.788	0.317
		2			3,319	0.070	0.028	0.028	2.25	0.75	0.793	0.319
		3			3,520	0.070	0.028	0.028	2.25	0.75	0.809	0.325
	FIBERGLASS ρ = 0.066 LB/IN.^{3} E = 7.5 x 10^6 LB/IN.^{2}	1			3,246	0.054	0.030	0.030	2.50	1.00	1.02	0.526
		2			3,319	0.054	0.030	0.030	2.50	1.00	1.04	0.532
		3		42	3,520	0.054	0.030	0.030	2.50	1.00	1.05	0.541
PAYLOAD SUPPORT: VEHICLE 1-2 UPPER BODY (LH_2 ON TOP)	ALUMINUM	1		56	3,885	0.200	0.020	0.020	2.50	1.00	1.24	0.874
		2			3,954	0.200	0.020	0.020	2.50	1.00	1.24	0.881
		3			4,079	0.200	0.020	0.020	2.50	1.00	1.26	0.890
	CARBON/ EPOXY	1			3,885	0.070	0.028	0.028	2.25	0.75	1.02	0.558
		2			3,954	0.070	0.028	0.028	2.25	0.75	1.03	0.560
		3			4,079	0.070	0.028	0.028	2.25	0.75	1.04	0.566
	FIBERGLASS	1			3,885	0.054	0.030	0.030	2.50	1.00	1.33	0.926
		2			3,954	0.054	0.030	0.030	2.50	1.00	1.33	0.930
		3		56	4,079	0.054	0.030	0.030	2.50	1.00	1.35	0.948
VEHICLE 1-2 LOWER BODY (LH_2 ON TOP)	ALUMINUM	1		23	3,223	0.200	0.020	0.020	2.50	1.00	1.02	0.291 *
		2			3,467	0.200	0.020	0.020	2.50	1.00	1.05	0.301 *
		3			4,046	0.200	0.020	0.020	2.50	1.00	1.00	0.286
	CARBON/ EPOXY	1			3,223	0.070	0.028	0.028	2.25	–	0.532	0.119
		2			3,467	0.070	0.028	0.028	2.25	–	0.544	0.123
		3			4,046	0.070	0.028	0.028	2.25	–	0.614	0.138
	FIBERGLASS	1			3,223	0.054	0.030	0.030	2.50	1.00	1.00	0.288
		2			3,467	0.054	0.030	0.030	2.50	1.00	1.00	0.288
		3		23	4,046	0.054	0.030	0.030	2.50	1.00	1.00	0.288
VEHICLE 1-2 (LF_2 ON TOP)	ALUMINUM	1		37	2,997	0.200	0.020	0.020	2.50	1.00	1.07	0.495 *
		2			3,070	0.200	0.020	0.020	2.50	1.00	1.02	0.472
		3			3,329	0.200	0.020	0.020	2.50	1.00	1.03	0.476
	CARBON/ EPOXY	1			2,997	0.070	0.028	0.028	2.25	–	0.709	0.254
		2			3,070	0.070	0.028	0.028	2.25	–	0.715	0.256
		3			3,329	0.070	0.028	0.028	2.25	–	0.734	0.263
	FIBERGLASS	1			2,997	0.054	0.030	0.030	2.50	1.00	1.00	0.460
		2			3,070	0.054	0.030	0.030	2.50	1.00	1.00	0.461
		3	24	37	3,329	0.054	0.030	0.030	2.50	1.00	1.00	0.462

*NON-OPTIMUM CASE

Table B-5: TRUSS STRUCTURE DATA

VEHICLE CONFIGURATION	MATERIAL	CASE	MEMBER QTY	LENGTH (cm)	LOAD (N)	TUBE THICKNESS (cm) MAX	TUBE THICKNESS (cm) MIN	TUBE THICKNESS (cm) DES	TUBE RADIUS (cm) MAX	TUBE RADIUS (cm) MIN	TUBE RADIUS (cm) DES	WEIGHT PER MEMBER (kg)
VEHICLE 1-3	ALUMINUM ρ = .10 LB/IN ^{3} E = 10 x 10^6 LB/IN 2	1	24	106 68	14,438	0 508	0 051	0 051	6 35	2 54	2 57	0 239
		2			14,763	0 508	0 051	0 051	6 35	2 54	2 62	0 244
		3			15,657	0 508	0 051	0 053	6.35	2.54	2.54	0 248
	CARBON-EPOXY ρ = .055 LB/IN ^{3} E = 28 x 10^6 LB/IN ^{2}	1			14,438	0 179	0 071	0 071	5 72	1.90	2 00	0.144
		2			14,763	0.179	0 071	0 071	5 72	1 90	2 01	0 145
		3			15,657	0 179	0 071	0 071	5 72	1.90	2 05	0 148
	FIBERGLASS ρ = .066 LB/IN ^{3} E = 7.5 x 10^6 LB/IN ^{2}	1			14,438	0 137	0 076	0 076	6 35	2 54	2 59	0 239
		2			14,763	0 137	0 076	0 076			2 64	0 245
		3		106.68	15,657	0 137	0.076	0 076			2.68	0 247
PAYLOAD SUPPORT — VEHICLE 1-2 UPPER BODY (LH_2 ON TOP)	ALUMINUM	1		142 24	17,281	0.508	0 051	0 051			3 15	0 397
		2			17,587	0 508	0 051	0 051			3 15	0 400
		3			18,143	0.508	0 051	0 051	6 35	2 54	3 20	0 404
	CARBON/ EPOXY	1			17,281	0 179	0 071	0 071	5 72	1 90	2 59	0 253
		2			17,587	0 179	0 071	0 071	5 72	1 90	2 62	0 254
		3			18,143	0.179	0 071	0 071	5 72	1 90	2 64	0 257
	FIBERGLASS	1			17,281	0 137	0 076	0 076	6 35	2 54	3 38	0 420
		2			17,587	0 137	0.076	0 076			3 38	0 422
		3		142 24	18,143	0 137	0 076	0 076			3 43	0 431
VEHICLE 1-2 LOWER BODY (LH_2 ON TOP)	ALUMINUM	1		58.40	14,336	0 508	0 051	0 051			2 62	0 132*
		2			15,421	0 508	0.051	0.051			2 68	0 137*
		3			17,997	0 508	0 051	0 051	6 35	2 54	2 54	0 130
	CARBON/ EPOXY	1			14,336	0 178	0 071	0 071	5 72	–	1 35	0 054
		2			15,421	0 178	0 071	0 071	5.72	–	1 38	0 558
		3			17,997	0 178	0 071	0 071	5 72	–	1 56	0 627
	FIBERGLASS	1			14,336	0 137	0 076	0 076	6 35	2 54	2 54	0 131
		2			15,421	0 137	0 076	0 076			2 54	0 131
		3		58 40	17,997	0 137	0 076	0 076			2 54	0 131
VEHICLE 1-2 (LF_2 ON TOP)	ALUMINUM	1		94 00	13,331	0 508	0 051	0 051			2.72	0 225*
		2			13,655	0 508	0 051	0.051			2 59	0 214
		3			14,807	0 508	0 051	0 051	6 35	2 54	2 62	0 216
	CARBON/ EPOXY	1			13,331	0 178	0 071	0 071	5 72	–	1 80	0 115
		2			13,655	0 178	0 071	0 071	5.72	–	1 82	0 116
		3			14,807	0 178	0 071	0 071	5 72	–	1 86	0 119
	FIBERGLASS	1			13,331	0 137	0 076	0 076	6 35	2 54	2 54	0 209
		2			13,655	0 137	0 076	0 076	6 35	2 54	2 54	0 2092
		2	24	94 00	14 807	0 137	0 076	0 076	6 35	2 54	2 54	0 2097

* NON-OPTIMUM CASE

TABLE B-6: TRUSS STRUCTURE DATA (Cont)

VEHICLE CONFIG-URATION	MATERIAL	CASE	MEMBER QTY	LENGTH (in.)	LOAD (lb)	TUBE THICKNESS (in.)			TUBE RADIUS (in.)			WEIGHT PER MEMBER (lb)
						MAX	MIN	DES	MAX	MIN	DES	
VEHICLE 2-2	ALUMINUM	1	24	25	2,698	0.200	0.020	0.020	2.50	1.00	1.02	0.318 *
		2			2,767	0.200	0.020	0.021	2.50	1.00	1.03	0.320 *
		3			3,118	0.200	0.020	0.021	2.50	1.00	1.00	0.312
	CARBON/ EPOXY	1			2,698	0.070	0.028	0.028	2.25	0.75	0.533	0.130
		2			2,767	0.070	0.028	0.028	2.25	0.75	0.536	0.131
		3			3,118	0.070	0.028	0.028	2.25	0.75	0.557	0.137
	FIBERGLASS	1			2,698	0.054	0.030	0.030	2.50	1.00	1.00	0.314
		2			2,767	0.054	0.030	0.030			1.00	0.314
		3	24	25	3,118	0.054	0.030	0.030			1.00	0.315
VEHICLE 1-14 (UPPER BODY)	ALUMINUM	1	12	53	6,656	0.200	0.020	0.021			1.35	0.936
		2			6,656	0.200	0.020	0.021			1.35	0.936
		3			6,679	0.200	0.020	0.020	2.50	1.00	1.43	0.945
	CARBON/ EPOXY	1			6,656	0.070	0.028	0.028	2.25	0.75	1.18	0.606
		2			6,656	0.070	0.028	0.028	2.25	0.75	1.18	0.606
		3			6,679	0.070	0.028	0.028	2.25	0.75	1.18	0.606
	FIBERGLASS	1			6,656	0.054	0.030	0.036	2.50	1.00	1.42	1.132
		2			6,656	0.054	0.030	0.036			1.42	1.132
		3		53	6,679	0.054	0.030	0.036			1.42	1.132
VEHICLE 1-14 (LOWER BODY)	ALUMINUM	1		41	8,824	0.200	0.020	0.021			1.29	0.692
		2			9,077	0.200	0.020	0.021			1.29	0.692
		3			9,582	0.200	0.020	0.022	2.50	1.00	1.30	0.730
	CARBON/ EPOXY	1			8,824	0.070	0.028	0.042	2.25	0.75	0.866	0.512
		2			9,077	0.070	0.028	0.042	2.25	0.75	0.874	0.518
		3			9,582	0.070	0.028	0.042	2.25	0.75	0.890	0.526
	FIBERGLASS	1			8,824	0.054	0.030	0.036	2.50	1.00	1.39	0.845
		2			9,077	0.054	0.030	0.042			1.24	0.882
		3		41	9,582	0.054	0.030	0.042			1.27	0.899
VEHICLE 2-14 (UPPER BODY)	ALUMINUM	1		46	6,119	0.200	0.020	0.020			1.24	0.710
		2			6,119	0.200	0.020	0.020			1.24	0.710
		3			6,220	0.200	0.020	0.021	2.50	1.00	1.24	0.746
	CARBON/ EPOXY	1			6,119	0.070	0.028	0.028	2.25	0.75	1.03	0.456
		2			6,119	0.070	0.028	0.028	2.25	0.75	1.03	0.456
		3			6,220	0.070	0.028	0.028	2.25	0.75	1.04	0.457
	FIBERGLASS	1			6,119	0.054	0.030	0.036	2.50	1.00	1.25	0.848
		2			6,119	0.054	0.030	0.036	2.50	1.00	1.25	0.848
		3	12	46	6,220	0.054	0.030	0.036	2.50	1.00	1.25	0.850

* NON-OPTIMUM CASE

Table B-6: TRUSS STRUCTURE DATA (Cont)

VEHICLE CONFIGURATION	MATERIAL	CASE	MEMBER QTY	LENGTH (cm)	LOAD (N)	TUBE THICKNESS (cm)			TUBE RADIUS (cm)			WEIGHT PER MEMBER (kg)
						MAX	MIN	DES	MAX	MIN	DES	
VEHICLE 2-2	ALUMINUM	1	24	63 5	12,000	0,508	0 051	0 051	6 35	2.54	2 59	0.144*
		2			12,308	0.508	0 051	0 053	6 35	2 54	2 62	0.145*
		3			13,869	0 508	0 051	0.053	6.35	2 54	2 54	0.142
	CARBON/ EPOXY	1			12,000	0 179	0 071	0.071	5 72	1 91	1.35	0.059
		2			12,308	0 179	0 071	0 071	5 72	1.91	1.36	0.0594
		3			13,869	0.179	0 071	0 071	5.72	1 91	1 41	0.062
	FIBERGLASS	1			12,000	0 137	0 076	0.076	6 35	2 54	2.54	0.143
		2			12,308	0.137	0 076	0 076			2 54	0.143
		3	24	63.5	13,869	0 137	0 076	0 076			2 54	0 143
VEHICLE 1-14 (UPPER BODY)	ALUMINUM	1	12	134 62	29,606	0 508	0 051	0 053			3.43	0 425
		2			29,606	0 508	0 051	0 053			3 43	0 425
		3			29,708	0 508	0 051	0 051	6 35	2 54	3 63	0.429
	CARBON/ EPOXY	1			29,606	0 179	0 071	0 071	5 72	1 91	3 00	0 275
		2			29,606	0 179	0 071	0 071	5 72	1 91	3 00	0 275
		3			29,708	0.179	0 071	0 071	5 72	1.91	3.00	0 275
	FIBERGLASS	1			29,606	0 137	0 076	0 091	6 35	2 54	3 61	0 514
		2			29,606	0.137	0 076	0 091			3 61	0.514
		3		134 62	29,708	0.137	0 076	0 091			3.61	0 514
VEHICLE 1-14 (LOWER BODY)	ALUMINUM	1		104 14	39,249	0 508	0,051	0 053			3 28	0.314
		2			40,375	0.508	0 051	0 053			3 28	0 314
		3			42,621	0.508	0 051	0 059	6 35	2 54	3 30	0.331
	CARBON/ EPOXY	1			39,249	0 179	0 071	0 107	5 72	1 91	2 20	0 232
		2			40,375	0 179	0 071	0 107	5 72	1 91	2 22	0 235
		3			42,621	0 179	0 071	0 107	5 72	1.91	2 26	0.239
	FIBERGLASS	1			39,249	0.137	0 076	0 091	6 35	2 54	3 53	0.384
		2			40,375	0 137	0 076	0 107			3.15	0 400
		3		104 14	42,621	0 137	0 076	0 107			3.23	0.408
VEHICLE 2-14 (UPPER BODY)	ALUMINUM	1		116 84	27,217	0 508	0 051	0 051			3.15	0.322
		2			27,217	0 508	0 051	0 051			3.15	0.322
		3			27,667	0 508	0 051	0 053	6 35	2 54	3 15	0 339
	CARBON/ EPOXY	1			27,217	0 179	0 071	0 071	5 72	1 91	2 62	0 207
		2			27,217	0 179	0 071	0 071	5 72	1 91	2 62	0 207
		3			27 667	0 179	0 071	0 071	5 72	1 91	2 64	0 207
	FIBERGLASS	1			27,217	0 137	0 076	0 091	6 35	2 54	3 18	0.385
		2			27,217	0 137	0 076	0 091	6 35	2 54	3 18	0 365
		3	12	116 84	27,667	0 137	0 076	0 091	6 35	2 54	3 18	0 386

* NON OPTIMUM CASE

Table B-7: TRUSS STRUCTURE DATA (Cont)

VEHICLE CONFIG-URATION	MATERIAL	CASE	MEMBER QTY	LENGTH (in.)	LOAD (lb)	TUBE THICKNESS (in.)			TUBE RADIUS (in.)			WEIGHT PER MEMBER (lb)
						MAX	MIN	DES	MAX	MIN	DES	
VEHICLE 2-14 (LOWER BODY)	ALUMINUM	1	12	42	6,947	0.200	0 020	0 020	2 50	1.00	1.23	0 651
		2			7,168	0.200	0.020	0 020	2.50	1 00	1.24	0 662
		3			7,719	0.200	0 020	0 020	2 50	1 00	1 28	0.672
	CARBON/ EPOXY	1			6,947	0.070	0 028	0.028	2 25	0 75	1 05	0 426
		2			7,168	0 070	0.028	0 028	2 25	0 75	1 09	0 440
		3			7,719	0 070	0 028	0 028	2 25	0.75	1 17	0 475
	FIBERGLASS	1			6,947	0 054	0.030	0 036	2.50	1 00	1 31	–
		2			7,168	0.054	0.030	0 036			1.24	0 775
		3	12	42	7,719	0 054	0 030	0 036			1 28	0 794
VEHICLE 2-3	ALUMINUM	1	24	49	3,760	0 200	0 020	0 020			1 11	0 691 *
		2			3,822	0 200	0.020	0 020			1 12	0 689
		3			3,947	0 200	0.020	0 021	2 50	1 00	1 12	0 707
	CARBON/ EPOXY	1			3,760	0 070	0 028	0 028	2 25	0 75	0 921	0 435
		2			3,822	0 070	0 028	0 028	2 25	0 75	0 926	0 437
		3			3,947	0 070	0 028	0 028	2.25	0 75	0 936	0 443
	FIBERGLASS	1			3,760	0 054	0 030	0 030	2 50	1 00	1 19	0 726
		2			3,822	0 054	0 030	0.030			1 20	0.728
		3	24	49	3,947	0 054	0 030	0 030			1.21	0 736
VEHICLE 2-18	ALUMINUM	1	12	53	7,020	0 200	0.020	0.020			1 45	0 981
		2				0.200	0 020	0 020			1 45	0 981
		3				0 200	0 020	0 020	2 50	1 00	1 45	0.981
	CARBON/ EPOXY	1				0 070	0 028	0 028	2 25	0 75	1 20	0.620
		2				0 070	0 028	0 028	2 25	0 75	1 20	0 620
		3				0 070	0.028	0 028	2 25	0 75	1 20	0 620
	FIBERGLASS	1				0.054	0 030	0 036	2 50	1 00	1 45	1 153
		2				0 054	0 030	0 036			1 45	1 153
		3	12	53	7,020	0 054	0 030	0 036			1.45	1 153
VEHICLE 1-7	ALUMINUM MEMBER 1	1	8	37	16,210	0 200	0 020	0 029			1 34	0 908
		2	8	37	17,400			0 031			1 33	0 978
		3	8	37	18,590			0 035			1 32	1.073
	ALUMINUM MEMBER 2	1	4	47	9,100			0 022			1 41	0 911
		2	4	47	10,480			0 023			1 46	0 994
		3	4	47	13,340			0 026			1 52	1.160
	ALUMINUM MEMBER 3	1	4	35	22,700			0 039			1 38	1 190
		2	4	35	25,350			0 048			1.26	1 325
		3	4	35	28,150	0 200	0 020	0 052	2 50	1 00	1 29	1 476

*NON-OPTIMUM CASE

Table B-7: TRUSS STRUCTURE DATA (Cont)

VEHICLE CONFIG-URATION	MATERIAL	CASE	MEM-BER QTY	LENGTH (cm)	LOAD (N)	TUBE THICKNESS (cm)			TUBE RADIUS (cm)			WEIGHT PER MEMBER (Kg)
						MAX	MIN	DES	MAX	MIN	DES	
VEHICLE 2-14 (LOWER BODY)	ALUMINUM	1	12	106.68	30,900	0.508	0.051	0.051	6.35	2.54	3.12	0.297
		2			31,883	0.508	0.051	0.051	6.35	2.54	3.15	0.300
		3			34,334	0.508	0.051	0.051	6.35	2.54	3.25	0.305
	CARBON/ EPOXY	1			30,900	0.178	0.071	0.071	5.72	1.91	2.67	0.193
		2			31,883	0.178	0.071	0.071	5.72	1.91	2.77	0.199
		3			34,334	0.178	0.071	0.071	5.72	1.91	2.97	0.216
	FIBERGLASS	1			30,000	0.137	0.076	0.091	6.35	2.54	3.33	–
		2			31,883	0.137	0.076	0.091			3.15	0.352
		3	12	106.68	34,334	0.137	0.076	0.091			3.25	0.360
VEHICLE 2-3	ALUMINUM	1	24	124.46	16,724	0.508	0.051	0.051			2.82	0.314*
		2			17,000	0.508	0.051	0.051			2.84	0.313
		3			17,556	0.508	0.051	0.051	6.35	2.54	2.84	0.321
	CARBON/ EPOXY	1			16,724	0.178	0.071	0.071	5.72	1.91	2.34	0.197
		2			17,000	0.178	0.071	0.071	5.72	1.91	2.35	0.198
		3			17,556	0.178	0.071	0.071	5.72	1.91	2.38	0.201
	FIBERGLASS	1			16,724	0.137	0.076	0.076	6.35	2.54	3.02	0.329
		2			17,000	0.137	0.076	0.076			3.05	0.330
		3	24	124.46	17,556	0.137	0.076	0.076			3.07	0.334
VEHICLE 2-18	ALUMINUM	1	12	134.62	31,225	0.508	0.051	0.051			3.68	0.445
		2				0.508	0.051	0.051			3.68	0.445
		3				0.508	0.051	0.051	6.35	2.54	3.68	0.445
	CARBON/ EPOXY	1				0.178	0.071	0.071	5.72	1.91	3.05	0.282
		2				0.178	0.071	0.071	5.72	1.91	3.05	0.282
		3				0.178	0.071	0.071	5.72	1.91	3.05	0.282
	FIBERGLASS	1				0.137	0.076	0.091	6.35	2.54	3.68	0.523
		2				0.137	0.076	0.091			3.68	0.523
		3	12	134.62	31,225	0.137	0.076	0.091			3.68	0.523
VEHICLE 1-7	ALUMINUM MEMBER 1	1	8	93.98	72,102	0.508	0.051	0.074			3.40	0.412
		2	8	93.98	77,395			0.079			3.38	0.444
		3	8	93.98	84,290			0.090			3.35	0.487
	ALUMINUM MEMBER 2	1	4	119.38	40,477			0.056			3.58	0.414
		2	4	119.38	46,615			0.058			3.71	0.451
		3	4	119.38	59,336			0.066			3.86	0.527
	ALUMINUM MEMBER 3	1	4	88.90	100,970			0.099			3.51	0.540
		2	4	88.90	112,757			0.122			3.20	0.602
		3	4	88.90	125,211	0.508	0.051	0.132	6.35	2.54	3.28	0.670

* NON OPTIMUM CASE

Table B-8: TRUSS STRUCTURE DATA (Cont)

VEHICLE CONFIG-URATION	MATERIAL		CASE	MEM-BER QTY	LENGTH (in.)	LOAD (lb)	TUBE THICKNESS (in.)			TUBE RADIUS (in)			WEIGHT PER MEMBER (lb)
							MAX	MIN	DES	MAX	MIN	DES	
VEHICLE 1-7	ALUMINUM	MEMBER 4	1	4	48	15,100	0.200	0.020	0.028	2 50	1 00	1 57	1 311
			2	4	48	15,100	0 200	0.020	0 028	2 50	1 00	1 57	1 311
			3	4	48	15,100	0.200	0 020	0 028	2 50	1 00	1 57	1 311
		MEMBER 5	1	4	44	2,350	–	–	0 035	–	–	0 750	0 725
			2	4		2,350						0.750	0 725
			3	4		2,350						0 750	0 725
		MEMBER 6	1	4		2,453						0 813	0 785
			2	4		2,453						0 813	0 785
			3	4		2,453						0 813	0 785
		MEMBER 7	1	8		4,483						0 938	0 905
			2	8		4,483						0 938	0 905
			3	8	44	4,483			0.035			0 938	0 905
		MEMBER 8	1	8	53	5,700			0 049			1 12	0 915
			2	8	53	5,700			0 049			1 12	0 915
			3	8	53	5,700	–	–	0 049	–	–	1 12	0 915
	FIBERGLASS	MEMBER 1	1	8	37	16,210	0 90	0 018	0 054	2 50	1 00	1 29	1 082
			2	8	37	17,400			0 054			1 33	1 109
			3	8	37	18590			0 054			1 36	1 134
		MEMBER 2	1	4	47	9,100			0 042			1 37	1 118
			2	4	47	10,480			0 042			1 43	1 172
			3	4	47	13,340			0 048			1 48	1 383
		MEMBER 3	1	4	35	22,700			0 060			1 33	1.163
			2	4	35	25,350			0 066			1 34	1 281
			3	4	35	28,150			0 066			1 39	1 328
		MEMBER 4	1	4	48	15,100			0 048			1 56	1 490
			2	4	48	15,100			0 048			1 56	1 490
			3	4	48	15,100			0 048			1 56	1 490
		MEMBER 5	1	4	44	2,350			0 024			1 04	0 456
			2	4		2,350						1 04	0 456
			3	4		2,350						1 04	0 456
		MEMBER 6	1	4		2,453						1 06	0 463
			2	4		2,453						1 06	0 463
			3	4		2,453			0 024			1 06	0 463
		MEMBER 7	1	8		4,483			0 030			1 18	0 645
			2	8		4,483			0 030			1 18	0 645
			3	8	44	4,483	0 90	0 018	0 030	2 50	1 00	1 18	0 645

Table B-8: TRUSS STRUCTURE DATA (Cont)

VEHICLE CONFIGURATION	MATERIAL		CASE	MEMBER QTY	LENGTH (cm)	LOAD (N)	TUBE THICKNESS (cm)			TUBE RADIUS (cm)			WEIGHT PER MEMBER (Kg)
							MAX	MIN	DES	MAX	MIN	DES	
VEHICLE 1-7	ALUMINUM	MEMBER 4	1	4	121 92	67,165	0 508	0,051	0 071	6 35	2 54	3 99	0 595
			2	4	121 92	67,165			0 071			3 99	0 595
			3	4	121 92	67,165			0 071			3 99	0 595
		MEMBER 5	1	4	111 76	10,453			0 089			1 91	0 329
			2	4		10,453						1 91	0 329
			3	4		10,453						1 91	0 329
		MEMBER 6	1	4		10,911						2 07	0 356
			2	4		10,911						2 07	0 356
			3	4		10,911						2 07	0 356
		MEMBER 7	1	8		19,940						2 38	0 411
			2	8		19,940						2 38	0 411
			3	8	111 76	19,940			0 089			2 38	0 411
		MEMBER 8	1	8	134 62	25,354			0 124			2 84	0 415
			2	8	134 62	25,354			0 124			2 84	0 415
			3	8	134 62	25,354	0 508	0 051	0 124			2 84	0 415
	FIBERGLASS	MEMBER 1	1	8	93 98	72,102	0 229	0 046	0 137			3 28	0 491
			2	8	93 98	77,395			0 137			3 38	0 503
			3	8	93 98	82,688			0 137			3 45	0 515
		MEMBER 2	1	4	119 38	40,477			0 107			3 48	0 508
			2	4	119 38	46,615			0 107			3 63	0 532
			3	4	119 38	59,336			0 123			3 77	0 628
		MEMBER 3	1	4	88 90	100 969			0 152			3 38	0 528
			2	4	88 90	112,757			0 168			3 40	0 582
			3	4	88 90	125,211			0 168			3 53	0 603
		MEMBER 4	1	4	121 92	67,165			0 122			3 96	0 676
			2	4	121 92	67,165			0 122			3 96	0 676
			3	4	121 92	67,165			0 122			3 96	0 676
		MEMBER 5	1	4	111 76	10,453			0 061			2 64	0 207
			2	4		10,453						2 64	0 207
			3	4		10,453						2 64	0 207
		MEMBER 6	1	4		10,911						2 69	0 210
			2	4		10,911						2 69	0 210
			3	4		10,911			0 061			2 69	0 210
		MEMBER 7	1	8		19,940			0 076			3 00	0 293
			2	8		19,940			0 076			3 00	0 293
			3	8	111 76	19,940	0 229	0 046	0 076	6 35	2 54	3 00	0 293

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Table B-9: TRUSS STRUCTURE DATA (Cont)

VEHICLE CONFIGURATION	MATERIAL		CASE	MEMBER QTY	LENGTH (in.)	LOAD (lb)	TUBE THICKNESS (in)			TUBE RADIUS (in)			WEIGHT PER MEMBER (lb)
							MAX	MIN	DES	MAX	MIN	DES	
VEHICLE 1-7	FIBERGLASS	MEMBER 8	1	8	53	5,700	0.090	0.018	0.030	2.50	1.00	1.44	0.953
			2	8	53	5,700	0.090	0.018	0.030	2.50	1.00	1.44	0.953
			3	8	53	5,700	0.090	0.018	0.030	2.50	1.00	1.44	0.953

Table B-9: TRUSS STRUCTURE DATA (Cont)

VEHICLE CONFIGURATION	MATERIAL		CASE	MEMBER QTY	LENGTH (cm)	LOAD (N)	TUBE THICKNESS (cm)			TUBE RADIUS (cm)			WEIGHT PER MEMBER (Kg)
							MAX	MIN	DES	MAX	MIN	DES	
VEHICLE 1-7	FIBERGLASS	MEMBER 8	1	8	134.62	25,354	0.229	0.046	0.076	6.35	2.54	3.67	0.433
			2	8	134.62	25,354	0.229	0.046	0.076	6.35	2.54	3.67	0.433
			3	8	134.62	25,354	0.229	0.046	0.076	6.35	2.54	3.67	0.433

Table B-10: CORRUGATED SHELL DATA

VEHICLE CONFIG	MATERIAL	CASE	SHELL HEIGHT (in)	ULT LOAD N_X (lb/in)	CORRUGATION DEPTH (in) MAX	DEPTH MIN	DEPTH DES	SKIN THICKNESS (in) MAX	SKIN THICKNESS MIN	SKIN THICKNESS DES	WIDTH (in) MAX	WIDTH MIN	WIDTH DES	ANGLE (deg) MAX	ANGLE MIN	ANGLE DES	RINGS (ALUMINUM**) NO	SPACING (in)	THICKNESS (in)	RING HEIGHT (in) MAX	RING HEIGHT MIN	RING HEIGHT DES	REINFORCEMENT THICKNESS (in) MAX	REINF. THICKNESS MIN	REINF. THICKNESS DES	WIDTH (in)	WEIGHT (lb/ft^2)
VEHICLE 1-3	ALUMINUM $\rho = 0.10\ LB/IN^3$ $E = 10 \times 10^6\ LB/IN^2$	1	38.5	119	2.00	0.500	0.746	0.050	0.020	0.020	2.50	0.500	1.67	80	45	46	0	–	–	–	–	–	–	–	–	–	0.328
		2		138			0.890			0.020			1.54			46											0.330
		3		165			0.922			0.020			1.43			46											0.337
	CARBON EPOXY $\rho = 0.055\ LB/IN^3$ $E = 11.2 \times 10^6\ LB/IN^2$	1		119			0.811			0.020			1.69			52											0.186
		2		138			0.909			0.020			1.59			49											0.187
		3		165			0.971			0.020			1.02			47											0.190
	FIBERGLASS $\rho = 0.068\ LB/IN^3$ $E = 3 \times 10^6\ LB/IN^2$	1		119			1.16			0.026			1.33			60											0.329
		2		138			1.18			0.027			1.38			60											0.342
		3	38.5	165			1.26			0.030			1.45			60											0.380
VEHICLE 1-2 (LH_2 ON TOP)	ALUMINUM	1	17.0	142			0.521			0.020			1.42			47											0.322
		2		159			0.579			0.020			1.43			45											0.324
		3		188			0.514			0.020			1.25			45											0.324
	CARBON EPOXY	1		142			0.549			0.020			1.47			45											0.176
		2		159			0.513			0.020			1.40			46											0.177
		3		188			0.501			0.020			1.36			47											0.177
	FIBERGLASS	1		142			0.707			0.021			0.875			48											0.239
		2		159			0.684			0.020			0.845			64											0.260
		3	17.0	188			0.747			0.021			0.848			58											0.265
VEHICLE 1-2 (LF_2 ON TOP)	ALUMINUM	1	33.5	113			0.898			0.020			1.61			50											0.339 *
		2		129			0.694			0.020			1.59			47											0.328
		3		159			0.847			0.020			1.43			46											0.333
	CARBON EPOXY	1		113			0.608			0.020			1.70			48											0.177
		2		129			0.701			0.020			1.64			47											0.179
		3		159			0.725			0.020			1.52			48											0.182
	FIBERGLASS	1		113			1.05			0.023			1.27			66											0.304
		2		129			1.13			0.024			1.16			59	0										0.312
		3	33.5	159			0.628			0.020			0.813			50	1	16.8	0.030	3.00	1.00	1.09	0.100	0	0.025	½H	0.322
VEHICLE 2-2	ALUMINUM	1	22	306			0.710			0.020			1.05			47	0										0.340
		2		326			0.810			0.020			1.02			49											0.348
		3		360			0.788			0.020			1.00			51											0.353
	CARBON EPOXY	1		306			0.719			0.020			1.09			48											0.187
		2		326			0.761			0.021			1.13			49											0.195
		3	22	360	2.00	0.500	0.773	0.050	0.020	0.021	2.50	0.500	0.914	80	45	48											0.197

** STUDY MAT'L USED FOR RING REINF * NON-OPTIMUM CASE

Table B-10: CORRUGATED SHELL DATA

VEHICLE CONFIG	MATERIAL	CASE	SHELL HEIGHT	ULT LOAD N_X	CORRUGATION: DEPTH (cm)			CORRUGATION: SKIN THICKNESS (cm)			CORRUGATION: WIDTH (cm)			CORRUGATION: ANGLE (rad)			RINGS (ALUMINUM**): NO	RINGS: SPACING	RINGS: THICK-NESS	RINGS: RING HEIGHT (cm)			RINGS: REINFORCEMENT THICKNESS (cm)			RINGS: WIDTH	WEIGHT
			(cm)	(N/m)	MAX	MIN	DES	MAX	MIN	DES	MAX	MIN	DES	MAX	MIN	DES		(cm)	(cm)	MAX	MIN	DES	MAX	MIN	DES	(cm)	(Kg/M^2)
VEHICLE 1-3	ALUMINUM ρ = 0.10 LB/IN^3 E = 10 x 10^6 LB/IN^2	1	97 79	2 083	5 08	1 27	1 89	0 127	0 051	0 051	5 08	1 27	4 24	1 4	0 79	0 81	0										1 600
		2		2 380			2.26						3 91			0 81											1 610
		3		2 888			2 34						3 63			0 81											1 645
	CARBON EPOXY ρ = 0 065 LB/IN^3 E = 11.2 x 10^6 LB/IN^2	1		2 083			2 06						4 29			0 91											0 908
		2		2,380			2 31						4 04			0 86											0 913
		3		2 888			2 47			0 051			2.59			0 82											0 927
	FIBERGLASS ρ = 0.068 LB/IN^3 E = 3 x 10^6 LB/IN^2	1		2 083			2 95			0 066			3 38			1 05											1 606
		2		2 380			3 00			0 069			3 51			1 05											1 669
		3	97 79	2 888			3.20			0 076			3 68			1 05											1 854
VEHICLE 1-2 (LH$_2$ ON TOP)	ALUMINUM	1	43.18	2 485			1 32			0 051			3 61			0 82											1 571
		2		2 696			1 47						3 63			0 79											1 581
		3		3 290			1 31						3 18			0 79											1 581
	CARBON EPOXY	1		2 485			1 39						3 73			0 79											0 8588
		2		2 695			1 30						3 56			0 81											0 8638
		3		3 290			1 27			0 051			3 45			0 82											0 8638
	FIBERGLASS	1		2 485			1 80			0 053			2 22			0 84											1 168
		2		2 695			1 74			0 051			2 15			1 12											1 269
		3	43.18	3 290			1 90			0 053			2 15			1 02											1 293
VEHICLE 1-2 (LF$_2$ ON TOP)	ALUMINUM	1	85 09	1 978			2 28			0 051			4 09			0 88											1 654
		2		2 258			1 76						4 04			0 82											1 600
		3		2 783			2 15						3 63			0 81											1 625
	CARBON EPOXY	1		1 978			1 54						4 32			0 84											0 8638
		2		2 258			1 78						4 17			0 82											0 8735
		3		2 783			1 84			0 051			3 86			0 84											0 8882
	FIBERGLASS	1		1 978			2 67			0.058			3.23			1 16											1 484
		2		2,258			2.87			0 061			2 95			1 03	0										1 523
		3	85 09	2 783			1 60			0.051			2 07			0 88	1	42 67	0 076	7 62	2 54	2.77	0 254	0	0 064	½H	1 571
VEHICLE 2-2	ALUMINUM	1	55.88	5 355			1 80						2 68			0 82	0										1 659
		2		5 706			2 06						2 59			0 86											1 698
		3		6 300			2.00						2 54			0 89											1 723
	CARBON EPOXY	1		5 355			1 83			0.051			2 77			0 84											0 9126
		2		5 705			1 93			0 053			2 87			0 86											0 9516
		3	55.88	6 300	5.08	1 27	1 96	0 127	0 051	0 053	5 08	1 27	2.32	1 4	0 79	0 84	0										0 9614

Table B-11: CORRUGATED SHELL DATA (Cont)

VEHICLE CONFIG	MATERIAL	CASE	SHELL HEIGHT (in)	ULT LOAD N_x (lb/in)	CORRUGATION DEPTH (in) MAX	DEPTH MIN	DEPTH DES	SKIN THICKNESS (in) MAX	SKIN MIN	SKIN DES	WIDTH (in) MAX	WIDTH MIN	WIDTH DES	ANGLE (deg) MAX	ANGLE MIN	ANGLE DES	RINGS NO	SPACING (in)	THICKNESS (in)	RING HEIGHT (in) MAX	RING HEIGHT MIN	RING HEIGHT DES	REINFORCEMENT THICKNESS (in) MAX	REINF. MIN	REINF. DES	WIDTH (in)	WEIGHT (lb/ft^2)
VEHICLE 2-2	FIBERGLASS	1	22	306	2.00	0.500	0.960	0.050	0.020	0.031	2.50	0.500	1.12	80	45	60	0	–	–	–	–	–	–	–	–	–	0.393
		2	22	326			0.980			0.032			1.13			60											0.406
		3	22	360			1.00			0.033			1.16			60											0.418
VEHICLE 1-14 (UPPER BODY)	ALUMINUM	1	50	287			0.644			0.020			1.13			56	1	25	0.030	3.00	1.00	1.00	0.100	0	0.055	½H	0.413
		2		311			0.765			0.022			0.960			49	1	25				1.11			0.037	½H	0.442
		3		365			0.757			0.021			0.983			56	1	25				1.11			0.055	½H	0.448
	CARBON EPOXY	1		287			1.28			0.024			1.45			60											0.253
		2		311			1.29			0.025			1.48														0.263
		3		365			1.33			0.027			1.55														0.285
	FIBERGLASS	1		287			0.620			0.023			0.720				3	12.5				1.09			0.032	½H	0.412
		2		311			0.630			0.024			0.730				3	12.5				1.09			0.032		0.424
		3	50	365			0.660			0.026			0.760			60	3	12.5				1.09			0.032		0.449
VEHICLE 1-14 (LOWER BODY)	ALUMINUM	1	38.5	476			0.644			0.021			0.908			47	1	18.3				1.01			0.027		0.440
		2		519			0.683			0.021			0.794			48	1	18.3				1.05			0.075		0.459
		3		571			0.730			0.021			0.779			51	1	18.3				1.07			0.044	½H	0.471
	CARBON EPOXY	1		476			1.13			0.026			1.30			60	0										0.273
		2		519			1.15			0.027			1.33			60											0.284
		3		571			1.20			0.028			1.39			60											0.295
	FIBERGLASS	1		476			0.546			0.023			0.626			66	3	9.1				1.00			0.044	½H	0.467
		2		519			0.596			0.029			0.685			45	3	9.1				1.06			0.006	½H	0.475
		3	38.5	571			0.888			0.034			1.02			66	3	9.1				1.01			0.025	½H	0.538
VEHICLE 2-14 (UPPER BODY)	ALUMINUM	1	42.5	296			1.18			0.023			1.37			60	0										0.440
		2		322			1.21			0.024			1.40														0.460
		3		377			1.26			0.026			1.45														0.498
	CARBON EPOXY	1		296			1.13			0.022			1.30														0.231
		2		322			1.15			0.023			1.33														0.242
		3		377			1.19			0.025			1.37			60											0.263
	FIBERGLASS	1		296			0.644			0.022			0.672			67	2	14.2				1.05			0.063	½H	0.407
		2		322			0.612			0.021			0.634			66	3	10.6				1.06			0.003	½H	0.407
		3	42.5	377			0.568			0.021			0.560			65	3	10.6	0.030	3.00	1.00	1.02	0.100	0	0.028	½H	0.416
VEHICLE 2-14 (LOWER BODY)	ALUMINUM	1	38.5	437			1.21			0.026			1.40			60	0										0.498
		2	38.5	462			1.23			0.027			1.42			60											0.517
		3	38.5	519	2.00	0.500	1.26	0.050	0.020	0.029	2.50	0.500	1.46	80	45	60											0.557

Table B-11: CORRUGATED SHELL DATA (Cont)

VEHICLE CONFIG	MATERIAL	CASE	SHELL HEIGHT (cm)	ULT LOAD N_X (N/m)	CORRUGATION DEPTH (cm) MAX	DEPTH MIN	DEPTH DES	SKIN THICKNESS (cm) MAX	SKIN THICKNESS MIN	SKIN THICKNESS DES	WIDTH (cm) MAX	WIDTH MIN	WIDTH DES	ANGLE (rad) MAX	ANGLE MIN	ANGLE DES	RINGS NO	SPACING (cm)	THICKNESS (cm)	RING HEIGHT (cm) MAX	RING HEIGHT MIN	RING HEIGHT DES	REINFORCEMENT THICKNESS (cm) MAX	REINFORCEMENT THICKNESS MIN	REINFORCEMENT THICKNESS DES	WIDTH (cm)	WEIGHT (Kg/M²)
VEHICLE 2-2	FIBERGLASS	1	55.88	5,356	5 08	1.27	2.44	0.127	0.061	0.079	6 35	1.27	2.84	1 4	0.79	1 06											1 918
		2	55 88	5 706			2.49			0.081			2 87			1 05											1 881
		3	55.88	6 300			2.54			0.084			2.95			1 06											2 039
VEHICLE 1-14 (UPPER BODY)	ALUMINUM	1	127 0	5 023			1 64			0.061			2 87			0.98		63 5	0 076	7 62	2 54	2 54	0.254	0	0 140		2 015
		2		5 443			1 94			0.066			2.44			0 86		63.5				2 82			0 094		2.157
		3		6,388			1 92			0.063			2.50			0.98		63 5				2.82			0 140		2 186
	CARBON EPOXY	1		5 023			3.20			0.061			3.68			1 06											1 235
		2		5 443			3.28			0 064			3.76														1 283
		3		6,388			3.38			0.069			3.94														1 391
	FIBERGLASS	1		5 023			1 57			0.058			1.83					31 7'				2.77			0 082		2 016
		2		5,443			1 60			0.061			1 85					31 75				2.77			0 082		2 069
		3	127 0	6 388			1 68			0.066			1 93			1 06		31 75				2 77			0 082		2 191
VEHICLE 1-14 (LOWER BODY)	ALUMINUM	1	92.71	8 330			1 64			0 053			2 31			0.82		46 48				2.57			0 069		2 147
		2		9 083			1 73			0.053			2.02			0.84		46 48				2.67			0 191		2 240
		3		9 993			1.85			0 053			1 98			0.89		46 48				2.72			0 112		2 298
	CARBON EPOXY	1		8,330			2.87			0.068			3.30			1 05											1 332
		2		9,083			2.92			0.069			3.38			1 06											1 386
		3		9 993			3.06			0.071			3.53			1 06											1 440
	FIBERGLASS	1		8 330			1.39			0.058			1 59			1 16		23 11				2.54			0 112		2 279
		2		9 083			1 51			0 074			1 74			0 78		23 11				2 69			0 15		2.318
		3	92.71	9 993			2.51			0.066			2.59			1 16		23.11				2.57			0 064		2 616
VEHICLE 2-14 (UPPER BODY)	ALUMINUM	1	107 95	5 180			3.00			0.058			3 48			1 05											2.147
		2		5 635			3.07			0.061			3.56														2.245
		3		6 598			3.20			0.066			3 68														2.430
	CARBON EPOXY	1		5 180			2.87			0.056			3.30														1 127
		2		5,635			2.92			0 058			3.38														1 181
		3		6,598			3.02			0.064			3.53			1 06											1 283
	FIBERGLASS	1		5,180			1 64			0.056			1 71			1 17		37 08				2 67			0 160		1 986
		2		5,635			1.56			0.053			1 61			1 16		26 92				2.69			0 008		1 988
		3	107.95	6,598			1 44			0.053			1 42			1 14		26 92	0.076	7 62	2.54	2.59	0.254	0	0 071		2.030
VEHICLE 2-14 (LOWER BODY)	ALUMINUM	1	97 79	7 648			3.07			0.066			3.56			1 06											2 430
		2	97 79	8 086			3.12			0.069			3.61			1 05											2 523
		3	97 79	9 083	5.08	1.27	3.20	0.127	0.061	0.074	6.35	1 27	3.71	1 4	0 79	1 06											2 718

Table B-12: CORRUGATED SHELL DATA (Cont)

VEHICLE CONFIG	MATERIAL	CASE	SHELL HEIGHT (in.)	ULT LOAD N_x (lb/in.)	CORRUGATION DEPTH (in.)			CORRUGATION SKIN THICKNESS (in.)			CORRUGATION WIDTH (in.)			CORRUGATION ANGLE (deg)			RINGS NO	RINGS SPACING (in.)	RINGS THICKNESS (in.)	RING HEIGHT (in.)			REINFORCEMENT THICKNESS (in.)			WIDTH (in.)	WEIGHT (lb/ft²)
					MAX	MIN	DES	MAX	MIN	DES	MAX	MIN	DES	MAX	MIN	DES				MAX	MIN	DES	MAX	MIN	DES		
VEHICLE 2-14 (LOWER BODY)	CARBON EPOXY	1	38.5	437	2.00	0.500	1.16	0.050	0.020	0.025	2.50	0.500	1.32	80	45	60	0	–	–	–	–	–	–	–	–	–	0.263
		2		462			1.17			0.026			1.34			60											0.274
		3		519			1.20			0.028			1.39			60											0.295
	FIBERGLASS	1		437			0.556			0.022			0.598			60	3	9.6	0.030	3.00	1.00	1.04	0.100	0	0.009	½H	0.435
		2		462			0.559			0.023			0.561			67	3	9.6				1.05			0.016	½H	0.461
		3	38.5	519			0.710			0.024			0.696			78	3	9.6				1.08			0.043	½H	0.501
VEHICLE 2-3	ALUMINUM	1	47	152			1.06			0.020			1.55			46	0										0.342
		2		169			1.13			0.020			1.47			49											0.350
		3		203			1.20			0.021			1.40			50											0.379
	CARBON EPOXY	1		152			1.01			0.020			1.59			45											0.187
		2		169			1.06			0.020			1.45			52											0.197
		3		203			1.22			0.020			1.37			55											0.205
	FIBERGLASS	1		152			0.617			0.022			0.880			45	2	15.7				1.05			0.070	½H	0.349
		2		169			0.630			0.023			0.890				2	15.7				1.05			0.070		0.360
		3	47	203			0.650			0.024			0.920				2	15.7				1.05			0.070		0.371
VEHICLE 2-18	ALUMINUM	1	51	379			0.830			0.022			1.17				1	25.5				1.04			0.092		0.447
		2		405			0.700			0.024			0.990				2	17				1.02			0.043		0.498
		3		458			0.720			0.026			1.02			45	2	17				1.05			0.012	½H	0.520
	CARBON EPOXY	1		379			1.38			0.027			1.58			60	0										0.285
		2		405			1.40			0.028			1.61			60											0.295
		3		458			1.44			0.030			1.67			60											0.316
	FIBERGLASS	1		379			0.591			0.022			0.520			61	4	10.2				1.02			0.011	½H	0.417
		2		405			0.632			0.025			0.708			54	4	10.2				1.02			0.011	½H	0.427
		3	51	458	2.00	0.500	0.580	0.050	0.020	0.028	2.50	0.500	0.621	80	45	49	4	10.2	0.030	3.00	1.00	1.01	0.100	0	0.021	½H	0.453
VEHICLE 1-7	ALUMINUM	1	83	544	–	–	2.08	–	–	0.041	–	–	2.40	–	–	60	0	–	–	–	–	–	–	–	–	–	0.780
		2		601			2.14			0.043			2.47														0.820
		3		658			2.20			0.045			2.53														0.860
	CARBON EPOXY	1		544			2.02			0.038			2.33														0.400
		2		601			2.08			0.040			2.39														0.420
		3		658			2.13			0.042			2.45														0.440
	FIBERGLASS	1		544			2.83			0.073			3.25														0.930
		2		601			2.90			0.077			3.33														0.980
		3	83	658			2.95			0.081			3.40			60											1.03

Table B-12 CORRUGATED SHELL DATA (Cont)

VEHICLE CONFIG	MATERIAL	CASE	SHELL HEIGHT (cm)	ULT LOAD N_X (N/m)	CORRUGATION DEPTH (cm) MAX	DEPTH MIN	DEPTH DES	SKIN THICKNESS (cm) MAX	SKIN THICKNESS MIN	SKIN THICKNESS DES	WIDTH (cm) MAX	WIDTH MIN	WIDTH DES	ANGLE (rad) MAX	ANGLE MIN	ANGLE DES	RINGS NO	SPACING (cm)	THICKNESS (cm)	RING HEIGHT (cm) MAX	RING HEIGHT MIN	RING HEIGHT DES	REINFORCEMENT THICKNESS (cm) MAX	REINFORCEMENT THICKNESS MIN	REINFORCEMENT THICKNESS DES	WIDTH (cm)	WEIGHT (Kg m^2)
VEHICLE 2-14 (LOWER BODY)	CARBON EPOXY	1	97 79	7 648	5 08	1.27	2 92	0 127	0 051	0 064	6 35	1 27	3 35	1 4	0 79	1 05	0	–	–	–	–	–	–	–	–	–	1 283
		2		8 085			2 97			0 066			3 40			1 05											1 337
		3		9 083			3 05			0 071			3.53			1 05											1 440
	FIBERGLASS	1		7 648			1 41			0 056			1 52			1 05	3	24 38	0 076	7 62	2 54	2 64	0 254	0	0 023	1/2 H	2 123
		2		8 085			1 42			0 058			1 42			1 17	3	24 38				2 68			0 041	1/2 H	2 250
		3	97 79	9 083			1 80			0 061			1 77			1 37	3	24 38				2 74			0 109	1/2 H	2 445
VEHICLE 2-3	ALUMINUM	1	119 38	2 660			2 69			0 051			3.94			0 81											1 669
		2		2 958			2 87			0 051			3.73			0 86											1 708
		3		3 553			3.05			0 053			3.56			0 88											1 850
	CARBON EPOXY	1		2 660			2.56			0 051			4 04			0 79											0 9125
		2		2 958			2 69			0.051			3 04			0 91											0 9614
		3		3 553			3.10			0 051			3 48			0 96											1 000
	FIBERGLASS	1		2 660			1 57			0 056			2 24			0 79	2	39 88				2 68			0 178	1/2 H	1 703
		2		2 958			1 60			0 058			2 26				2	39 88				2 68			0 178		1 757
		3	119.38	3 553			1 65			0.061			2 34				2	39 88				2 68			0 178		1 810
VEHICLE 2-18	ALUMINUM	1	129.54	6 633			2 11			0 056			2 97				1	64 77				2 64			0 234		2 181
		2		7 088			1 78			0.061			2.52				2	43 18				2 59			0 109		2 430
		3		8 015			1,83			0 066			2 59			0 79	2	43.18				2 68			0 031	1/2 H	2 440
	CARBON EPOXY	1		6 633			3.51			0.069			4 01			1 05											1 391
		2		7 088			3.56			0 071			4 09			1 05											1 440
		3		8 015			3.67			0 076			4 24			1 05											1 542
	FIBERGLASS	1		6 633			1 50			0 056			1 32			1 07	4	25 91				2 59			0 028	1/2 H	2.035
		2		*7 088*			*1 61*			*0 064*			*1 80*			*0 95*	*4*	*25 91*				*2 59*			*0 028*	*1/2 H*	*2 084*
		3	129 54	8 015	5 08	1.27	1 47	0.127	0 051	0 071	6.35	1 27	1 58	1 4	0 79	0 86	4	25 91	0 076	7 62	2 54	2 56	0 254	0	0 053	1/2 H	2 211
VEHICLE 1-7	ALUMINUM	1	210.82	9 520			5.28			0 104			6.10			1 05		–	–	–	–	–	–	–	–	–	3 806
		2		10 518			5 44			0 109			6.27														4 002
		3		11 515			5 60			0.114			.643														4 197
	CARBON EPOXY	1		9 520			5 13			0 097			5 92														1 952
		2		10 518			5.28			0.102			6 07														2 049
		3		11 515			5 43			0.107			6 22														2 147
	FIBERGLASS	1		9 520			7 19			0.185			8.26														4 538
		2		10 518			7 37			0 196			8 46														4 782
		3	210.82	11 515			7 49			0.206			8 64			1 05											5 026

Table B-13: ADAPTER TRUSS DATA

VEHICLE CONFIGURATION	MATERIAL	CASE	MEMBER QTY	LENGTH (in)	LOAD (lb)	TUBE THICKNESS (in)			TUBE RADIUS (in)			WEIGHT PER MEMBER (lb)
						MAX	MIN	DES	MAX	MIN	DES	
VEHICLE 1-3	CARBON EPOXY	1	24	43	5,404	0.070	0.028	0.028	2.25	0.750	0.953	0.396
	ρ = 0.055 LB/IN^3	2		43	5,604						0.965	0.402
	E = 28 x 10^6 PSI	3		43	5,963						0.985	0.408
VEHICLE 1-2 (LH$_2$ ON TOP)		1		54	6,434						1.18	0.620
		2		54	6,633						1.20	0.627
		3		54	6,977			0.028			1.22	0.638
VEHICLE 1-2 (LF$_2$ ON TOP)		1		103	9,490			0.042			1.65	2.47
		2		103	9,675			0.042			1.66	2.48
		3		103	10,010			0.042			1.68	2.51
VEHICLE 2-2		1		38	5,748			0.028			0.899	0.331
		2		38	5,923			0.028			0.906	0.333
		3	24	38	6,260			0.028			0.949	0.347
VEHICLE 1-14		1	12	73	13,520			0.042			1.47	1.57
		2		73	14,280			0.042			1.50	1.60
		3		73	15,140			0.042			1.53	1.63
VEHICLE 2-14		1		70	13,350			0.056			1.25	1.70
		2		70	13,740			0.056			1.44	1.95
		3	12	70	14,660			0.056			1.48	2.01
VEHICLE 2-3		1	24	31	4,686			0.028			0.750	0.225
		2	24	31	4,868			0.028			0.750	0.225
		3	24	31	5,231			0.028			0.760	0.227
VEHICLE 2-18		1	12	75	12,260			0.042			1.45	1.57
		2		75	12,660						1.46	1.58
		3		75	13,610						1.50	1.63
VEHICLE 2-19		1		86	12,386						1.59	1.99
		2		86	12,732						1.61	2.01
		3	12	86	13,613			0.042			1.65	2.06
VEHICLE 1-7		1	24	35.4	7,447			0.028			0.934	0.320
	CARBON EPOXY	2	24	35.4	7,995			0.028			0.956	0.327
		3	24	35.4	8,542	0.070	0.028	0.028	2.25	0.750	0.978	0.335

Table B-13: ADAPTER TRUSS DATA

VEHICLE CONFIG-URATION	MATERIAL	CASE	MEMBER QTY	LENGTH (cm)	LOAD (N)	TUBE THICKNESS (cm)			TUBE RADIUS (cm)			WEIGHT PER MEMBER (Kg)
						MAX	MIN	DES	MAX	MIN	DES	
VEHICLE 1-3	CARBON EPOXY ρ = 0 055 LB/IN^3 E = 28 x 10^6 PSI	1	24	109 22	24,037	0 178	0 071	0 071	5 72	1 91	2 42	0 180
		2		109 22	24,927						2 45	0 182
		3		109 22	26,528						2 50	0 185
VEHICLE 1-2 (LH$_2$ ON TOP)		1		137 16	28,618						3 00	0 281
		2		137 16	29,504						3 04	0 285
		3		137 16	31,034			0 071			3 10	0 290
VEHICLE 1-2 (LF$_2$ ON TOP)		1		261 62	42,212			0 107			4 19	1 121
		2		261 62	43,034			0 107			4 22	1 126
		3		261 62	44,524			0 107			4 27	1 140
VEHICLE 2-2		1		96 52	25 567			0 071			2 28	0 150
		2		96 52	26,346			0 071			2 30	0 151
		3	24	96 52	27,844			0 071			2 41	0 158
VEHICLE 1-14		1	12	185 42	60,137			0 107			3 73	0 713
		2		185 42	63,517			0 107			3 80	0 726
		3		185 42	67,343			0 107			3 90	0 740
VEHICLE 2-14		1		177 80	59,381			0 142			3 18	0 772
		2		177 80	61,115			0 142			3 67	0 885
		3	12	177 80	65,208			0 142			3 76	0 913
VEHICLE 2-3		1	24	78 74	20,843			0 071			1 905	0 102
		2	24	78 74	21,653			0 071			1 905	0 102
		3	24	78 74	23,267			0 071			1 93	0 103
VEHICLE 2-18		1	12	190 50	54,532			0 107			3 68	0 713
		2		190 50	54,532						3 71	0 717
		3		190 50	60,537						1 50	0 740
VEHICLE 2-19		1		218 44	55,092						4 04	0 903
		2		218 44	56,632						4 09	0 913
		3	12	218 44	60,551			0 107			4 19	0 935
VEHICLE 1-7	CARBON EPOXY	1	24	89 92	33,124			0 071			2 37	0 145
		2	24	89 92	35,562			0 071			2 43	0 148
		3	24	89 92	37,995	0 178	0 071	0 071	5 72	1 91	2 49	0 152

Table B-14: STRUCTURAL WEIGHT SUMMARY

			MATERIAL	WEIGHT (lb/ft²)	WT/MEM (lb)	AREA (ft²)	MEMBER QTY	BODY WT (lb)	ADJUSTED WT (lb)**	TOTAL WEIGHT (lb) †
VEHICLE 1-3	VEHICLE BODY (CASE 1)*	CORRUG.	ALUM	0.328	–	101		33.1	41.8	65.8
			CARBON EPOXY	0.186	–			18.8	35.2	59 2
			FIBERGLASS	0.304	–			30.7	47.1	71.1
		H C SANDWICH	ALUM	0.601	–			60.6	79.9	103.9
			CARBON EPOXY	0.333	–			33.6	48.5	72.5
			FIBERGLASS	0.430	–			43.4	58.3	82.3
		TRUSS	ALUM	–	0.526		24	12.6	25.3	49.3
			CARBON EPOXY	–	0.317		24	7.6	19 7	43.7
			FIBERGLASS	–	0.526		24	12 6	25.3	49.3
	ADAPTER	TRUSS	CARBON EPOXY	–	0.396		24	9.5	24.0	–
	VEHICLE BODY (CASE 2)*	CORRUG	ALUM	0.330	–			33.3	43.2	67 5
			CARBON EPOXY	0.187	–			18.9	37.6	61.9
			FIBERGLASS	0.316	–			31.9	50.6	74.9
		H C. SANDWICH	ALUM	0.601	–			60.6	82.7	107.0
			CARBON EPOXY	0.333	–			33.6	50.7	75.0
			FIBERGLASS	0.430	–			43.4	60.5	84.8
		TRUSS	ALUM	–	0.538		24	12.9	25.7	50.0
			CARBON EPOXY	–	0.319		24	7.7	19.9	44.2
			FIBERGLASS	–	0.532		24	12.8	25 6	49.9
	ADAPTER	TRUSS	CARBON EPOXY	–	0.402		24	9.7	24.3	–
	VEHICLE BODY (CASE 3)*	CORRUG.	ALUM	0.337	–			34.0	46.0	70.7
			CARBON EPOXY	0.190	–			19.2	41.9	66.6
			FIBERGLASS	0.322	–			32.5	55.2	79.9
		H.C. SANDWICH	ALUM	0.601	–			60.6	87.4	112.1
			CARBON EPOXY	0.333	–			33.6	54 3	79.0
			FIBERGLASS	0.430	–	101		43.4	64.1	88.8

* CASE 1 – LOW PAYLOAD – 4"
CASE 2 – MED PAYLOAD – L/D = 0.2
CASE 3 – HIGH PAYLOAD – L/D = 0.5
** INCLUDING END FTG'S AND ATTACHMENTS

† BODY PLUS ADAPTER

Table B-14: STRUCTURAL WEIGHT SUMMARY

			MATERIAL	WEIGHT (Kg/m²)	WT/MEM (Kg)	AREA (m²)	MEMBER QTY	BODY WT (Kg)	ADJUSTED WT (Kg) **	TOTAL WEIGHT (Kg) †
VEHICLE 1-3	VEHICLE BODY (CASE 1)*	CORRUG	ALUM	1.60	–	9.38		15.1	19.0	29.9
			CARBON EPOXY	0 91	–			8.54	16 0	26.8
			FIBERGLASS	1.48	–			13.8	21 4	32.3
		H C. SANDWICH	ALUM	2.93	–			27.5	35.3	46.7
			CARBON EPOXY	1.65	–			15.5	21 8	32 9
			FIBERGLASS	2.10	–			19.8	26 4	37.4
		TRUSS	ALUM	–	0.24		24	5 7	11.5	22.4
			CARBON EPOXY	–	0.144		24	3 4	8 8	19.7
			FIBERGLASS	–	0.24		24	5 7	11.5	22 3
	ADAPTER	TRUSS	CARBON EPOXY	–	0 18		24	4.3	10.9	–
	VEHICLE BODY (CASE 2)*	CORRUG.	ALUM	1.62	–			15.2	19 6	30 7
			CARBON EPOXY	0.91	–			8 54	17.2	28 1
			FIBERGLASS	1.54	–			14 5	22 8	33.0
		H.C SANDWICH	ALUM	2.92	–			27 5	37 6	48 6
			CARBON EPOXY	1 65	–			15 5	22.8	33.1
			FIBERGLASS	2.10	–			19 3	27.5	38 6
		TRUSS	ALUM	–	0.245		24	5 8	11 7	22 7
			CARBON EPOXY	–	0 145		24	3 4	8.9	20 3
			FIBERGLASS	–	0.245		24	5.77	11.6	22 6
	ADAPTER	TRUSS	CARBON EPOXY	–	0.185		24	4 4	11.05	–
	VEHICLE BODY (CASE 3)*	CORRUG	ALUM	1.65	–			15 6	20.9	32 1
			CARBON EPOXY	0.93	–			8 7	19.1	30.2
			FIBERGLASS	1.57	–			14.7	25 2	36 3
		H. C. SANDWICH	ALUM	2.92	–			27.5	39 8	51.1
			CARBON EPOXY	1.65	–			15 5	24.7	35 9
			FIBERGLASS	2.10	–	9.38		19.3	29.2	40 7

* CASE 1 – LOW PAYLOAD – 4"
CASE 2 – MED PAYLOAD – L/D = 0.2
CASE 3 – HIGH PAYLOAD – L/D = 0.5
** INCLUDING END FTG'S AND ATTACHMENTS

† BODY PLUS ADAPTER

Table B-15: WEIGHT SUMMARY (Cont)

			MATERIAL	WEIGHT (lb/ft^2)	WT/MEM (lb)	AREA (ft^2)	MEMBER QTY	BODY WT (lb)	AD-JUSTED WT (lb) *	TOTAL WEIGHT (lb) †
VEHICLE 1-3	VEHICLE BODY (CASE 3)	TRUSS	ALUM	–	0 547		24	13 1	26 2	50 9
			CARBON EPOXY	–	0 325		24	7 8	20 3	45 0
			FIBERGLASS	–	0 541		24	13 0	26 1	50 8
	ADAPTER	TRUSS	CARBON EPOXY	–	0.408		24	9 8	24 7	–
VEHICLE 1-14	VEHICLE BODY (CASE 1)	CORRUG.	ALUM	0.440		132 2		58.2	78 5	108 4
			CARBON EPOXY	0.273				36 1	74 4	104 3
			FIBERGLASS	0 467				61 8	100 1	130 0
		H C. SANDWICH	ALUM	0.601				79 5	124 5	154 4
			CARBON EPOXY	0.333				44 0	78.8	108 7
			FIBERGLASS	0 430		132 2		56 9	91 7	121 6
		TRUSS	ALUM		0 936 0.692	–	12 12	19 6	37 0	66 9
			CARBON EPOXY		0 606 0 512		12 12	13 4	29.0	58 9
			FIBERGLASS		1.132 0 845		12 12	23 8	42 0	71 9
	ADAPTER	TRUSS	CARBON EPOXY		1 57		12	18 9	29 9	–
	VEHICLE BODY (CASE 2)	CORRUG	ALUM	0.459		132.2		60 5	82 6	113 1
			CARBON EPOXY	0 284				37.6	79 3	109 8
			FIBERGLASS	0.475				62.8	104 5	135 0
		H.C SANDWICH	ALUM	0.601				79 5	128.5	159 0
			CARBON EPOXY	0.333				44 0	81 9	112 4
			FIBERGLASS	0.430		132 2		56 9	94 8	125 3
		TRUSS	ALUM		0.936 0.692		12 12	19.6	37 2	67 7
			CARBON EPOXY		0.606 0.518		12 12	13 5	29 4	59 9
			FIBERGLASS		1.132 0 882		12 12	24 2	41 4	71 9
	ADAPTER	TRUSS	CARBON EPOXY		1 60		12	19 2	30 5	–
	VEHICLE BODY (CASE 3)	CORRUG.	ALUM	0.471		132 2		62 4	86 8	118.0
			CARBON EPOXY	0.295		132 2		39 0	85 0	116 2
			FIBERGLASS	0.536		132.2		71 0	117 0	148 2

* CASE 1 – LOW PAYLOAD – 4″
CASE 2 – MED PAYLOAD – L/D = 0 2
CASE 3 – HIGH PAYLOAD – L/D = 0 5

† BODY PLUS ADAPTER

Table B-15: WEIGHT SUMMARY (Cont)

			MATERIAL	WEIGHT (Kg/m^2)	WT/MEM (Kg)	AREA (m^2)	MEMBER QTY	BODY WT (Kg)	AD-JUSTED WT (Kg)*	TOTAL WEIGHT (Kg)†
VEHICLE 1-3	VEHICLE BODY (CASE 3)	TRUSS	ALUM	–	0 248		24	5 9	11 8	23 8
			CARBON EPOXY	–	0 148		24	3 5	9 2	20 4
			FIBERGLASS	–	0.246		24	5.8	11 75	23 8
	ADAPTER	TRUSS	CARBON EPOXY	–	0 185		24	4 5	11 2	–
VEHICLE 1-14	VEHICLE BODY (CASE 1)	CORRUG	ALUM	2.15		12.3		26 3	36 7	49.1
			CARBON EPOXY	1 34				16 4	33 9	47 2
			FIBERGLASS	2 33				28 1	45 5	59 0
		H C SANDWICH	ALUM	2 94				36 2	56 6	70 0
			CARBON EPOXY	1 62				20 0	35 8	49 0
			FIBERGLASS	2 10		12.3		25 8	41 6	55 0
		TRUSS	ALUM		0.425 0 315		12 12	8 9	16 8	30 8
			CARBON EPOXY		0 273 0 232		12 12	6 1	13 2	26 7
			FIBERGLASS		0.514 0 374		12 12	10 9	19 1	32 7
	ADAPTER	TRUSS	CARBON EPOXY		0 708		12	8 6	13 6	–
	VEHICLE BODY (CASE 2)	CORRUG	ALUM	2.24		12.3		27 5	37 5	51 4
			CARBON EPOXY	1.39				17 2	36 0	49 5
			FIBERGLASS	2 32				28 5	47.3	61 4
		H C SANDWICH	ALUM	2.94				36 2	58 1	72 3
			CARBON EPOXY	1 62				20 0	37 2	51 0
			FIBERGLASS	2 15		12.3		25 8	43.0	56 8
		TRUSS	ALUM		0 425 0.315		12 12	8 9	16 8	30 8
			CARBON EPOXY		0 273 0 235		12 12	6 2	13 3	27 2
			FIBERGLASS		0 514 0 402		12 12	11 0	18 8	32 3
	ADAPTER	TRUSS	CARBON EPOXY		0 726		12	8 7	13 8	–
	VEHICLE BODY (CASE 3)	CORRUG	ALUM	2.35		12.3		28.3	39 5	53 7
			CARBON EPOXY	1.44		12 3		17 7	38 6	52.3
			FIBERGLASS	2.62		12.3		32.2	53 2	67 3

* CASE 1 – LOW PAYLOAD – 4"
CASE 2 – MED PAYLOAD – L/D = 0.2
CASE 3 – HIGH PAYLOAD – L/D = 0 5

† BODY PLUS ADAPTER

Table B-16: WEIGHT SUMMARY (Cont)

			MATERIAL	WEIGHT (lb/ft²)	WT/MEM (lb)	AREA (ft²)	MEMBER QTY	BODY WT (lb)	ADJUSTED WT (lb) *	TOTAL WEIGHT (lb) †
VEHICLE 1-14	VEHICLE BODY (CASE 3)	H C SANDWICH	ALUM	0.601		132 2		79 5	133 5	164 7
			CARBON EPOXY	0 333		132.2		44 0	85 7	116 9
			FIBERGLASS	0.430		132 2		56 9	98 6	129 8
		TRUSS	ALUM		0.945 0 730		12 12	20 1	38 5	69 7
			CARBON EPOXY		0 606 0 526		12 12	13 6	29 6	60 8
			FIBERGLASS		1 132 0 899		12 12	24 4	41 8	73 0
	ADAPTER	TRUSS	CARBON EPOXY		1 63		12	19 6	31 2	–
VEHICLE 1-2 (LH_2 ON TOP)	VEHICLE BODY (CASE 1)	CORRUG	ALUM	0 322		44 5		14 3	24 7	56 0
			CARBON EPOXY	0 176				7 8	27 4	58 7
			FIBERGLASS	0 239				10.7	30 3	61 6
		H C SANDWICH	ALUM	0 601				26 8	49 8	81 1
			CARBON EPOXY	0 333				14 8	32 6	63.9
			FIBERGLASS	0 430		44 5		19 2	37 0	68 3
		TRUSS	ALUM		0.286		24	6.9	20 0	51 3
			CARBON EPOXY		0 119		24	2 9	13 9	45 2
			FIBERGLASS		0.288		24	6 9	20 1	51 4
	ADAPTER	TRUSS	CARBON EPOXY		0 620		24	14.9	31 3	–
	VEHICLE BODY (CASE 2)	CORRUG	ALUM	0.324		44 5		14 4	26 0	58 2
			CARBON EPOXY	0 177				7 9	29 9	62 1
			FIBERGLASS	0 260				11 6	33 6	65 8
		H C SANDWICH	ALUM	0 601				26 8	52 6	84 8
			CARBON EPOXY	0.333				14 8	34 7	66.9
			FIBERGLASS	0 430		44.5		19.2	39 1	71 3
		TRUSS	ALUM		0.286		24	6 9	20 2	52 4
			CARBON EPOXY		0 123		24	3 0	14 2	46 4
			FIBERGLASS		0 288		24	6 9	20 3	52 5
	ADAPTER	TRUSS	CARBON EPOXY		0.627		24	15 1	32 2	–

* CASE 1 – LOW PAYLOAD – 4"
CASE 2 – MED PAYLOAD – L/D = 0 2
CASE 3 – HIGH PAYLOAD – L/D = 0 5

† BODY PLUS ADAPTER

Table B-16: WEIGHT SUMMARY (Cont)

VEHICLE	COMPONENT	CONSTRUCTION	MATERIAL	WEIGHT (Kg/m^2)	WT/MEM (Kg)	AREA (m^2)	MEMBER QTY	BODY WT (Kg)	AD-JUSTED WT (kg)*	TOTAL WEIGHT (Kg) †
VEHICLE 1-14	VEHICLE BODY (CASE 3)	H.C SANDWICH	ALUM	2 94		12 3		36 1	60 5	74 5
VEHICLE 1-14	VEHICLE BODY (CASE 3)	H.C SANDWICH	CARBON EPOXY	1 63		12 3		20 0	39.0	53 0
VEHICLE 1-14	VEHICLE BODY (CASE 3)	H.C SANDWICH	FIBERGLASS	2 15		12 3		25 8	44 8	58 6
VEHICLE 1-14	VEHICLE BODY (CASE 3)	TRUSS	ALUM		0 430 0 332		12 12	9 2	17 5	31 7
VEHICLE 1-14	VEHICLE BODY (CASE 3)	TRUSS	CARBON EPOXY		0 273 0.238		12 12	6.17	13.4	27 4
VEHICLE 1-14	VEHICLE BODY (CASE 3)	TRUSS	FIBERGLASS		0 514 0 407		12 12	11 2	19 0	33 2
VEHICLE 1-14	ADAPTER	TRUSS	CARBON EPOXY		0 741		12	8 9	14 3	–
VEHICLE 1-2 (LH_2 ON TOP)	VEHICLE BODY (CASE 1)	CORRUG	ALUM	1 57		0.42		6 5	11 2	25 4
VEHICLE 1-2 (LH_2 ON TOP)	VEHICLE BODY (CASE 1)	CORRUG	CARBON EPOXY	0 865				3 5	12 4	26 7
VEHICLE 1-2 (LH_2 ON TOP)	VEHICLE BODY (CASE 1)	CORRUG	FIBERGLASS	1 17				4 9	13 9	27 8
VEHICLE 1-2 (LH_2 ON TOP)	VEHICLE BODY (CASE 1)	H.C SANDWICH	ALUM	2 94				12.3	22.6	36 9
VEHICLE 1-2 (LH_2 ON TOP)	VEHICLE BODY (CASE 1)	H.C SANDWICH	CARBON EPOXY	1 63				6 7	14.8	29 0
VEHICLE 1-2 (LH_2 ON TOP)	VEHICLE BODY (CASE 1)	H.C SANDWICH	FIBERGLASS	2 15		0.42		8 7	16 8	30 9
VEHICLE 1-2 (LH_2 ON TOP)	VEHICLE BODY (CASE 1)	TRUSS	ALUM		0.130		24	3.2	9 1	23 3
VEHICLE 1-2 (LH_2 ON TOP)	VEHICLE BODY (CASE 1)	TRUSS	CARBON EPOXY		0 054		24	1 3	6.3	20 5
VEHICLE 1-2 (LH_2 ON TOP)	VEHICLE BODY (CASE 1)	TRUSS	FIBERGLASS		0.132		24	3 2	9.12	23 4
VEHICLE 1-2 (LH_2 ON TOP)	ADAPTER	TRUSS	CARBON EPOXY		0.282		24	6 8	14 4	–
VEHICLE 1-2 (LH_2 ON TOP)	VEHICLE BODY (CASE 2)	CORRUG	ALUM	1 58		0 42		6 7	11 8	26 4
VEHICLE 1-2 (LH_2 ON TOP)	VEHICLE BODY (CASE 2)	CORRUG	CARBON EPOXY	0 865				3 6	13 6	28.2
VEHICLE 1-2 (LH_2 ON TOP)	VEHICLE BODY (CASE 2)	CORRUG	FIBERGLASS	1 27				5 3	15 3	29 9
VEHICLE 1-2 (LH_2 ON TOP)	VEHICLE BODY (CASE 2)	H.C. SANDWICH	ALUM	2 94				12 3	23 9	38 5
VEHICLE 1-2 (LH_2 ON TOP)	VEHICLE BODY (CASE 2)	H.C. SANDWICH	CARBON EPOXY	1 63				6 7	15 7	30 4
VEHICLE 1-2 (LH_2 ON TOP)	VEHICLE BODY (CASE 2)	H.C. SANDWICH	FIBERGLASS	2 15		0 42		8 7	17 8	32 3
VEHICLE 1-2 (LH_2 ON TOP)	VEHICLE BODY (CASE 2)	TRUSS	ALUM		0.130		24	3 13	9 2	23 8
VEHICLE 1-2 (LH_2 ON TOP)	VEHICLE BODY (CASE 2)	TRUSS	CARBON EPOXY		0 056		24	1 36	6 45	21 1
VEHICLE 1-2 (LH_2 ON TOP)	VEHICLE BODY (CASE 2)	TRUSS	FIBERGLASS		0.132		24	3 13	9 2	23 9
VEHICLE 1-2 (LH_2 ON TOP)	ADAPTER	TRUSS	CARBON EPOXY		0 285		24	6 75	14 6	–

* CASE 1 – LOW PAYLOAD – 4"
CASE 2 – MED PAYLOAD – L/D = 0.2
CASE 3 – HIGH PAYLOAD – L/D = 0 5

† BODY PLUS ADAPTER

Table B-17: WEIGHT SUMMARY (Cont)

			MATERIAL	WEIGHT (lb/ft^2)	WT/MEM (lb)	AREA (ft^2)	MEMBER QTY	BODY WT (lb)	ADJUSTED WT (lb)	TOTAL WEIGHT (lb) †
VEHICLE 1-2 (LH_2 ON TOP)	VEHICLE BODY (CASE 3)	CORRUG	ALUM	0 324		44 5		14 4	28 1	60 7
			CARBON EPOXY	0 177				7.9	33 9	66 5
			FIBERGLASS	0 265				11 8	37 8	70 4
		H C SANDWICH	ALUM	0.601				26 8	57 3	89 9
			CARBON EPOXY	0.333				14 8	38 4	71 0
			FIBERGLASS	0 430		44 5		19.2	42 8	75 4
		TRUSS	ALUM		0 286		24	6 9	20 7	53 3
			CARBON EPOXY		0 138		24	3 3	15 4	48 0
			FIBERGLASS		0 288		24	6 9	20 8	53 4
	ADAPTER	TRUSS	CARBON EPOXY		0.638		24	15 3	32.6	–
VEHICLE 1-2 (LF_2 ON TOP)	VEHICLE BODY (CASE 1)	CORRUG	ALUM	0 328		87.5		28 7	36 9	67 8
			CARBON EPOXY	0 177				15.5	31 1	62 0
			FIBERGLASS	0.304				26 6	42 2	73 1
		H C SANDWICH	ALUM	0.601				52 5	70.9	101.8
			CARBON EPOXY	0.333				29 1	43 3	74 2
			FIBERGLASS	0 430		87.5		37 6	51 8	82 7
		TRUSS	ALUM		0 472		24	11 4	23 8	54 7
			CARBON EPOXY		0 254		24	6 1	17 7	48.6
			FIBERGLASS		0 460		24	11 0	23 5	54 4
	ADAPTER	TRUSS	CARBON EPOXY		2 47		24	5 9	30.9	–
	VEHICLE BODY (CASE 2)	CORRUG	ALUM	0.328		87 5		28 7	38 1	69.8
			CARBON EPOXY	0.179				15.7	33 5	65 2
			FIBERGLASS	0 312				27.3	45 1	76.8
		H C. SANDWICH	ALUM	0.601				52 5	73 5	105 2
			CARBON EPOXY	0 333				29 1	45 3	77.0
			FIBERGLASS	0 430		87.5		37 6	53 8	85 5

† BODY PLUS ADAPTER

Table B-17: WEIGHT SUMMARY (Cont)

			MATERIAL	WEIGHT (Kg/m^2)	WT/MEM (Kg)	AREA (m^2)	MEMBER QTY	BODY WT (Kg)	AD-JUSTED WT (Kg)	TOTAL WEIGHT (Kg) †
VEHICLE 1-2 (LH_2 ON TOP)	VEHICLE BODY (CASE 3)	CORRUG	ALUM	1.58		0 42		6 5	12 7	27 7
			CARBON EPOXY	0.87				3.6	15 4	30 2
			FIBERGLASS	1.29				5 45	16.8	32.0
		H C SANDWICH	ALUM	2.94				12 4	27.0	40 8
			CARBON EPOXY	1.63				6 72	17.4	32 3
			FIBERGLASS	2.15		0 42		8.72	19.5	34 3
		TRUSS	ALUM		0 130		24	3.2	9 4	24 2
			CARBON EPOXY		0.063		24	1 5	7.0	21 8
			FIBERGLASS		0 132		24	3.2	9.38	24 3
	ADAPTER	TRUSS	CARBON EPOXY		0.290		24	6.95	14 8	–
VEHICLE 1-2 (LF_2 ON TOP)	VEHICLE BODY (CASE 1)	CORRUG	ALUM	1 61		0 813		13 1	16 7	30 9
			CARBON EPOXY	0.865				7 04	14 3	28 2
			FIBERGLASS	0.148				12.2	19 4	33 3
		H C SANDWICH	ALUM	2.94				23.8	32.2	46 2
			CARBON EPOXY	1 63				13 2	19.7	33 7
			FIBERGLASS	2.15		0.813		17 2	23 6	37 7
		TRUSS	ALUM		0 214		24	5.18	10 8	24 8
			CARBON EPOXY		0 116		24	2 7	8 04	22 1
			FIBERGLASS		0 208		24	5 0	10 7	24 7
	ADAPTER	TRUSS	CARBON EPOXY		1 13		24	2 7	14 1	–
	VEHICLE BODY (CASE 2)	CORRUG	ALUM	1.61		0.813		13 1	17 6	31 7
			CARBON EPOXY	0.87				7 14	15.3	29 6
			FIBERGLASS	1 53				12 5	20.4	34.9
		H C. SANDWICH	ALUM	2.94				23.8	33 4	47 8
			CARBON EPOXY	1.63				13 4	20 6	36 0
			FIBERGLASS	2.15		0.813		17 2	24.4	38 8

† BODY PLUS ADAPTER

Table B-18: WEIGHT SUMMARY (Cont)

			MATERIAL	WEIGHT (lb/ft^2)	WT/MEM (lb)	AREA (ft^2)	MEMBER QTY	BODY WT (lb)	ADJUSTED WT (lb)	TOTAL WEIGHT (lb) †
VEHICLE 1-2 (LF$_2$ ON TOP)	VEHICLE BODY (CASE 2)	TRUSS	ALUM		0.472		24	11 3	23.8	55 5
			CARBON EPOXY		0 256		24	6.2	17 7	49 4
			FIBERGLASS		0.461		24	11 1	23.6	55 3
	ADAPTER	TRUSS	CARBON EPOXY		2 48		24	6 0	31 7	–
	VEHICLE BODY (CASE 3)	CORRUG	ALUM	0.333		87 5		29.1	40 7	72 7
			CARBON EPOXY	0 182				15 9	37 8	69 8
			FIBERGLASS	0 322				28 2	50 1	82 1
		H C SANDWICH	ALUM	0 601				52 5	78 3	110 3
			CARBON EPOXY	0.333				29 1	49 1	81 1
			FIBERGLASS	0.430		87 5		37 6	57 6	89 6
		TRUSS	ALUM		0 476		24	11 4	24 2	56 2
			CARBON EPOXY		0 263		24	6 3	18 2	50 2
			FIBERGLASS		0 462		24	11 1	24 0	56 0
	ADAPTER	TRUSS	CARBON EPOXY		2 51		24	6.0	32 0	–
VEHICLE 2-2	VEHICLE BODY (CASE 1)	CORRUG	ALUM	0 340		45 5		15 5	33 1	55 2
			CARBON EPOXY	0 187				8 5	41 9	64.0
			FIBERGLASS	0.393				17 9	51 3	73 4
		H C SANDWICH	ALUM	0 601				27 4	66.6	88.7
			CARBON EPOXY	0 333				15 2	45.5	67 6
			FIBERGLASS	0.430		45 5		19 6	49.9	72.0
		TRUSS	ALUM		0 312		24	7 5	19 5	41 6
			CARBON EPOXY		0 130		24	3 1	13 5	35 6
			FIBERGLASS		0 314		24	7 5	19 5	41 6
	ADAPTER	TRUSS	CARBON EPOXY		0 331		24	7 9	22 1	–
	VEHICLE BODY (CASE 2)	CORRUG	ALUM	0 348		45 5		15 8	34 5	56 7
			CARBON EPOXY	0 195		45.5		8 9	44 4	66 6
			FIBERGLASS	0 406		45 5		18 5	54 0	76 2

† BODY PLUS ADAPTER

Table B-18: WEIGHT SUMMARY (Cont)

			MATERIAL	WEIGHT (Kg/m^2)	WT/MEM (Kg)	AREA (m^2)	MEMBER QTY	BODY WT (Kg)	AD-JUSTED WT (Kg)	TOTAL WEIGHT (Kg) †
VEHICLE 1-2 (LF$_2$ ON TOP)	VEHICLE BODY (CASE 2)	TRUSS	ALUM		0 215		24	5.1	10.8	25.2
			CARBON EPOXY		0 116		24	2.7	8.05	22 4
			FIBERGLASS		0 209		24	5 0	10 7	25 1
	ADAPTER	TRUSS	CARBON EPOXY		1.13		24	2 7	14 8	–
	VEHICLE BODY (CASE 3)	CORRUG	ALUM	1 63		0 813		13 4	18 3	33 0
			CARBON EPOXY	0 89				7.2	17 3	31 7
			FIBERGLASS	1.57				12 8	22 8	37 3
		H C SANDWICH	ALUM	2 94				24.8	35 5	50.0
			CARBON EPOXY	1 63				13 2	22 3	37 9
			FIBERGLASS	2 15		0 813		16 6	26 1	40 6
		TRUSS	ALUM		0.216		24	5.2	11 0	25 5
			CARBON EPOXY		0 119		24	2 7	8.3	22 8
			FIBERGLASS		0.209		24	5.0	10 8	25 4
	ADAPTER	TRUSS	CARBON EPOXY		1 14		24	2.7	14 5	–
VEHICLE 2-2	VEHICLE BODY (CASE 1)	CORRUG	ALUM	1 66		0.42		7.0	15.0	25 3
			CARBON EPOXY	0.914				3.9	19 0	29 1
			FIBERGLASS	1.92				8 1	23.2	33 3
		H.C SANDWICH	ALUM	2.94				12 4	30 8	40 4
			CARBON EPOXY	1 63				6 9	20.7	30.6
			FIBERGLASS	2.10		0.42		8 9	22.6	32.7
		TRUSS	ALUM		0.143		24	3 4	8 85	18.8
			CARBON EPOXY		0.059		24	1 4	6 1	16 6
			FIBERGLASS		0 144		24	3 4	8.85	18.8
	ADAPTER	TRUSS	CARBON EPOXY		0 151		24	3 6	10 1	–
	VEHICLE BODY (CASE 2)	CORRUG	ALUM	0.170		0.42		7 2	15.7	25.7
			CARBON EPOXY	0.952		0 42		4 1	20.1	30 8
			FIBERGLASS	1 97		0.42		8 4	24 5	34.6

† BODY PLUS ADAPTER

Table B-19: WEIGHT SUMMARY (Cont)

			MATERIAL	WEIGHT (lb/ft^2)	WT/MEM (lb)	AREA (ft^2)	MEMBER QTY	BODY WT (lb)	ADJUSTED WT (lb)	TOTAL WEIGHT (lb) †
VEHICLE 2-2	VEHICLE BODY (CASE 2)	H C. SANDWICH	ALUM	0.601		45.5		27.4	69.1	91 3
			CARBON EPOXY	0.333		45.5		15.2	47.4	69 6
			FIBERGLASS	0 430		45.5		19.6	51 8	74 0
		TRUSS	ALUM		0.312		24	7 5	19.7	41 9
			CARBON EPOXY		0 131		24	3 1	13.7	35 9
			FIBERGLASS		0 314		24	7.5	19 7	41 9
	ADAPTER	TRUSS	CARBON EPOXY		0 333		24	8 0	22 2	–
	VEHICLE BODY (CASE 3)	CORRUG	ALUM	0 353		45.5		16 1	36.8	60 6
			CARBON EPOXY	0 197				9 0	48.3	72.1
			FIBERGLASS	0 418				19.0	58.3	82 1
		H.C SANDWICH	ALUM	0 601				27 4	73 4	97 2
			CARBON EPOXY	0.333				15 2	50 9	74 7
			FIBERGLASS	0.430		45.5		19.6	55.3	79 1
		TRUSS	ALUM		0 312		24	7 5	20.2	44.0
			CARBON EPOXY		0.137		24	3 3	14 8	38.6
			FIBERGLASS		0 315		24	7 6	20.2	44.0
	ADAPTER	TRUSS	CARBON EPOXY		0 347		24	8 3	23.8	–
VEHICLE 2-14	VEHICLE BODY (CASE 1)	CORRUG	ALUM	0.498		112.4		56 0	73.0	102.6
			CARBON EPOXY	0.263				29.5	61 7	91.3
			FIBERGLASS	0 435				48.9	81 1	110.7
		H C. SANDWICH	ALUM	0.601				67.5	105 4	135 0
			CARBON EPOXY	0 333				37 4	66 7	96.3
			FIBERGLASS	0 430		112.4		48 4	77 7	107.3
		TRUSS	ALUM		0.710 0 651		12 12	16 3	33 0	62.6
			CARBON EPOXY		0 456 0 426		12 12	10 6	25 9	55 5
			FIBERGLASS		0.848 0 775		12 12	19 5	35 8	65 4
	ADAPTER	TRUSS	CARBON EPOXY		1.70		12	20.4	29 6	–

† BODY PLUS ADAPTER

Table B-19. WEIGHT SUMMARY (Cont)

			MATERIAL	WEIGHT (Kg/m^2)	WT/MEM (Kg)	AREA (m^2)	MEMBER QTY	BODY WT (Kg)	AD-JUSTED WT (kg)	TOTAL WEIGHT (kg) †
VEHICLE 2-2	VEHICLE BODY (CASE 2)	H C SANDWICH	ALUM	2 94		0.42		12.8	31 4	41 4
			CARBON EPOXY	1.63		0 42		6.9	21 5	31 6
			FIBERGLASS	2 10		0.42		8 9	23 5	33.6
		TRUSS	ALUM		0.142		24	3 4	8 94	19 0
			CARBON EPOXY		0 059		24	1.4	6 3	16 6
			FIBERGLASS		0 143		24	3 4	8 95	19 0
	ADAPTER	TRUSS	CARBON EPOXY		0.152		24	3.6	10.1	–
	VEHICLE BODY (CASE 3)	CORRUG	ALUM	1 73		0 42		7.3	16 8	27 3
			CARBON EPOXY	0 963				4.1	21 9	32 7
			FIBERGLASS	1 99				8 6	26 4	37 3
		H C SANDWICH	ALUM	2.94				12.5	33 3	44 1
			CARBON EPOXY	1 63				6.9	23 1	33.9
			FIBERGLASS	2 10		0 42		8 9	25 1	36 0
		TRUSS	ALUM		0 142		24	3 4	9 17	19 9
			CARBON EPOXY		0 059		24	1.5	6.7	17 5
			FIBERGLASS		0 143		24	3 4	9 17	19 9
	ADAPTER	TRUSS	CARBON EPOXY		0 157		24	3 7	10 8	–
VEHICLE 2-14	VEHICLE BODY (CASE 1)	CORRUG	ALUM	2 43		11 5		25 4	34 1	46.5
			CARBON EPOXY	1 28				13 4	28 1	41.3
			FIBERGLASS	2 12				22 1	36 8	50 2
		H C SANDWICH	ALUM	2.94				30.6	47 8	61 3
			CARBON EPOXY	1.63				16 9	30.8	43.7
			FIBERGLASS	2 10		11 5		21.9	34 3	48 6
		TRUSS	ALUM		0.322 0 296		12 12	7.4	14 9	28.4
			CARBON EPOXY		0.207 0 194		12 12	4 8	13 6	25 5
			FIBERGLASS		0 385 0 352		12 12	8.85	16 3	29.3
	ADAPTER	TRUSS	CARBON EPOXY		0.771		12	9 25	13 4	–

† BODY PLUS ADAPTER

Table B-20: WEIGHT SUMMARY (Cont)

			MATERIAL	WEIGHT (lb/ft²)	WT/MEM (lb)	AREA (ft²)	MEMBER QTY	BODY WT (lb)	AD-JUSTED WT (lb)	TOTAL WEIGHT (lb) †
VEHICLE 2-14	VEHICLE BODY (CASE 2)	CORRUG	ALUM	0 517		112.4		58 1	76 1	109 6
			CARBON EPOXY	0 274				30 8	64 9	98 4
			FIBERGLASS	0 461				51 8	85 9	119 4
		H C SANDWICH	ALUM	0 601				67 5	107 6	141 1
			CARBON EPOXY	0 333				37 4	68 4	101 9
			FIBERGLASS	0 430		112 4		48 4	79 4	112 9
		TRUSS	ALUM		0 710 0 662		12 12	16 4	33.1	66 6
			CARBON EPOXY		0 456 0 440		12 12	10 8	26 3	59 8
			FIBERGLASS		0 848 0 775		12 12	19 5	35 8	69 3
	ADAPTER	TRUSS	CARBON EPOXY		1 95		12	23 4	33 5	–
	VEHICLE BODY (CASE 3)	CORRUG	ALUM	0 557		112 4		62 5	82 7	117 4
			CARBON EPOXY	0 295				33 2	71 4	106 1
			FIBERGLASS	0 501				56 4	94 6	129 3
		H C SANDWICH	ALUM	0 601				67 5	112 5	147 2
			CARBON EPOXY	0 333				37 4	72 2	106 9
			FIBERGLASS	0 430		112.4		48 4	83 2	117 9
		TRUSS	ALUM		0 746 0 672		12 12	17 0	33 9	68 6
			CARBON EPOXY		0 457 0 475		12 12	11 2	26 9	61 6
			FIBERGLASS		0 850 0 794		12 12	19 7	35.9	70 6
	ADAPTER	TRUSS	CARBON EPOXY		2 01		12	24 1	34 7	–
VEHICLE 2-3	VEHICLE BODY (CASE 1)	CORRUG	ALUM	0.342		104 5		35 7	45 1	63 8
			CARBON EPOXY	0 187				19 5	37 3	56 0
			FIBERGLASS	0 349				36 4	54 2	72 9
		H C SANDWICH	ALUM	0.601				62 7	83 7	102 4
			CARBON EPOXY	0 333				34 8	51 0	69 7
			FIBERGLASS	0.430		104.5		45 0	61 2	79 9

† BODY PLUS ADAPTER

Table B-20: WEIGHT SUMMARY (Cont)

			MATERIAL	WEIGHT (Kg/m^2)	WT/MEM (Kg)	AREA (m^2)	MEMBER QTY	BODY WT (Kg)	ADJUSTED WT (Kg)	TOTAL WEIGHT (Kg) †
VEHICLE 2-14	VEHICLE BODY (CASE 2)	CORRUG	ALUM	2.57		11 5		26.4	34 5	49 8
			CARBON EPOXY	1 34				14 0	29 5	44 7
			FIBERGLASS	2.25				23 5	39 0	54 2
		H C SANDWICH	ALUM	2 94				30.6	48 9	64 1
			CARBON EPOXY	1 63				17 0	31 1	46 3
			FIBERGLASS	2 10		11 5		22 0	36 1	51 2
		TRUSS	ALUM		0 322 0 300		12 12	7 5	15 0	30 2
			CARBON EPOXY		0 206 0 199		12 12	4 9	11 9	27 2
			FIBERGLASS		0 385 0 352		12 12	8 9	16 3	31 5
	ADAPTER	TRUSS	CARBON EPOXY		0 885		12	10 6	15 2	–
	VEHICLE BODY (CASE 3)	CORRUG	ALUM	2 72		11 5		28 4	37 5	53 3
			CARBON EPOXY	1 44				15 1	32 4	48 2
			FIBERGLASS	2 45				25 6	43 0	58 7
		H C SANDWICH	ALUM	2 94				30 6	51 1	66 8
			CARBON EPOXY	1 63				17 0	32 8	48 5
			FIBERGLASS	2 10		11 5		22 0	37 8	53 5
		TRUSS	ALUM		0 339 0 305		12 12	7.7	15 4	31 1
			CARBON EPOXY		0 207 0 216		12 12	5 1	12 2	28 0
			FIBERGLASS		0 386 0 360		12 12	8 9	16 3	32 1
	ADAPTER	TRUSS	CARBON EPOXY		0 913		12	10 9	15 8	–
VEHICLE 2-3	VEHICLE BODY (CASE 1)	CORRUG	ALUM	1 67		9 65		16 2	20.5	29 0
			CARBON EPOXY	0.915				8 9	17 0	25 4
			FIBERGLASS	1 70				16.5	24 6	33 1
		H C SANDWICH	ALUM	2.94				28 5	38 0	46 5
			CARBON EPOXY	1 63				15.8	23 2	31 6
			FIBERGLASS	2 10		9.65		20 4	27 8	36.3

† BODY PLUS ADAPTER

Table B-21: WEIGHT SUMMARY (Cont)

			MATERIAL	WEIGHT (lb/ft^2)	WT/MEM (lb)	AREA (ft^2)	MEMBER QTY	BODY WT (lb)	ADJUSTED WT (lb)	TOTAL WEIGHT (lb) †
VEHICLE 2-3	VEHICLE BODY (CASE 1)	TRUSS	ALUM		0 689		24	16.5	30 4	49 1
			CARBON EPOXY		0 435		24	10 5	23 8	42 5
			FIBERGLASS		0 726		24	17 4	32 1	50 8
	ADAPTER	TRUSS	CARBON EPOXY		0.225		24	5 4	18 7	–
	VEHICLE BODY (CASE 2)	CORRUG	ALUM	0 350		104.5		36 6	47 1	66 1
			CARBON EPOXY	0 197				20 6	40 4	59 4
			FIBERGLASS	0.360				37 6	57 4	76 4
		H C SANDWICH	ALUM	0.601				62 7	86 0	105 0
			CARBON EPOXY	0 333				34 8	52 8	71 8
			FIBERGLASS	0.430		104 5		45 0	63 0	82 0
		TRUSS	ALUM		0 689		24	16 5	30 4	49 4
			CARBON EPOXY		0 437		24	10 5	23 8	42 8
			FIBERGLASS		0 728		24	17 5	32 1	51 1
	ADAPTER	TRUSS	CARBON EPOXY		0 225		24	5 4	19 0	–
	VEHICLE BODY (CASE 3)	CORRUG	ALUM	0 379		104.5		39 6	52 2	71 5
			CARBON EPOXY	0 205				21 4	45 2	64 5
			FIBERGLASS	0.371				38 8	62 6	81 9
		H C SANDWICH	ALUM	0.601				62.7	90 7	110.0
			CARBON EPOXY	0 333				34 8	56 4	75 7
			FIBERGLASS	0.430		104 5		45 0	66 6	85.9
		TRUSS	ALUM		0 707		24	17.0	31 0	50 3
			CARBON EPOXY		0 443		24	10 6	24.6	43 9
			FIBERGLASS		0.736		24	17.7	32 5	51 8
	ADAPTER	TRUSS	CARBON EPOXY		0 227		24	5 5	19 3	–
VEHICLE 2-18	VEHICLE BODY (CASE 1)	CORRUG	ALUM	0.447		66 8		29 9	43 7	73.2
			CARBON EPOXY	0.285		66 8		19 1	45 3	74 8
			FIBERGLASS	0.417		66 8		27 8	54 0	83 5

† BODY PLUS ADAPTER

Table B-21: WEIGHT SUMMARY (Cont)

			MATERIAL	WEIGHT (Kg/m²)	WT/MEM (Kg)	AREA (m²)	MEMBER QTY	BODY WT (Kg)	AD-JUSTED WT (Kg)	TOTAL WEIGHT (Kg) †
VEHICLE 2-3	VEHICLE BODY (CASE 1)	TRUSS	ALUM		0 313		24	7 5	13 8	22 3
			CARBON EPOXY		0 198		24	4 8	10 8	19 3
			FIBERGLASS		0 330		24	7 9	14 6	23 1
	ADAPTER	TRUSS	CARBON EPOXY		0 102		24	2 5	8 5	–
	VEHICLE BODY (CASE 2)	CORRUG	ALUM	1 70		9 65		16 6	21 4	30 0
			CARBON EPOXY	0 096				9 4	18 3	27 0
			FIBERGLASS	1 76				17 1	26 1	34 7
		H C SANDWICH	ALUM	2 93				28 5	39 0	47 7
			CARBON EPOXY	1 63				15 8	24 0	32 6
			FIBERGLASS	2 09		9 65		20 4	28 6	37 2
		TRUSS	ALUM		0 313		24	7 5	13 8	22.4
			CARBON EPOXY		0 198		24	4 8	10 8	19 4
			FIBERGLASS		0 330		24	7 9	14 6	23 2
	ADAPTER	TRUSS	CARBON EPOXY		0 102		24	2.6	8 6	–
	VEHICLE BODY (CASE 3)	CORRUG	ALUM	1 85		9 65		18 0	23 7	32 5
			CARBON EPOXY	1.00				9.7	20 5	29 3
			FIBERGLASS	1 81				17.6	28 4	37 2
		H C SANDWICH	ALUM	2 93				28.5	41 2	49.9
			CARBON EPOXY	1 63				15 8	25 6	34.4
			FIBERGLASS	2 10		9.65		20 4	30 2	39 0
		TRUSS	ALUM		0 321		24	7 7	14.1	22 8
			CARBON EPOXY		0 201		24	4 8	11 2	20 0
			FIBERGLASS		0 334		24	8.0	14 8	23 5
	ADAPTER	TRUSS	CARBON EPOXY		0 103		24	2 5	8 8	–
VEHICLE 2-18	VEHICLE BODY (CASE 1)	CORRUG	ALUM	2.18		0 62		13 6	19 8	33 2
			CARBON EPOXY	1 39		0 62		8 7	20 6	34 0
			FIBERGLASS	2 03		0 62		12 6	24 5	37 9

† BODY PLUS ADAPTER

Table B-22: WEIGHT SUMMARY (Cont)

			MATERIAL	WEIGHT (lb/ft^2)	WT/MEM (lb)	AREA (ft^2)	MEMBER QTY	BODY WT (lb)	AD-JUSTED WT (lb)	TOTAL WEIGHT (lb) †
VEHICLE 2-18	VEHICLE BODY (CASE 1)	H C SANDWICH	ALUM	0.601		66.8		40.2	71.0	100.5
			CARBON EPOXY	0.333		66.8		22.3	46.1	75.6
			FIBERGLASS	0.430		66.8		28.7	52.5	82.0
		TRUSS	ALUM		0.981		12	11.8	21.4	50.9
			CARBON EPOXY		0.620		12	7.5	16.0	45.5
			FIBERGLASS		1.15		12	13.8	23.1	52.6
	ADAPTER	TRUSS	CARBON EPOXY	-	1.57		12	18.8	29.5	–
	VEHICLE BODY (CASE 2)	CORRUG	ALUM	0.498		66.8		33.2	47.9	77.6
			CARBON EPOXY	0.295				19.7	47.7	77.4
			FIBERGLASS	0.427				28.5	56.5	86.2
		H C SANDWICH	ALUM	0.601				40.2	73.2	102.9
			CARBON EPOXY	0.333				22.3	47.7	77.4
			FIBERGLASS	0.430		66.8		28.7	54.1	83.8
		TRUSS	ALUM		0.981		12	11.8	21.4	51.1
			CARBON EPOXY		0.620		12	7.5	16.0	45.7
			FIBERGLASS		1.15		12	13.8	23.1	52.8
	ADAPTER	TRUSS	CARBON EPOXY		1.58		12	19.0	29.7	–
	VEHICLE BODY (CASE 3)	CORRUG	ALUM	0.520		66.8		34.7	51.5	82.3
			CARBON EPOXY	0.316				21.1	52.8	83.6
			FIBERGLASS	0.453				30.3	62.0	92.8
		H.C SANDWICH	ALUM	0.601				40.2	77.4	108.2
			CARBON EPOXY	0.333				22.3	51.0	81.8
			FIBERGLASS	0.430		66.8		28.7	57.4	88.2
		TRUSS	ALUM		0.981		12	11.8	21.4	52.2
			CARBON EPOXY		0.620		12	7.5	16.0	46.8
			FIBERGLASS		1.15		12	13.8	23.1	53.9
	ADAPTER	TRUSS	CARBON EPOXY		1.63		12	19.6	30.8	–

† BODY PLUS ADAPTER

Table B-22: WEIGHT SUMMARY (Cont)

			MATERIAL	WEIGHT (Kg/m^2)	WT/MEM (Kg)	AREA (m^2)	MEMBER QTY	BODY WT (Kg)	AD-JUSTED WT (Kg)	TOTAL WEIGHT (Kg) †
VEHICLE 2-18	VEHICLE BODY (CASE 1)	H C SANDWICH	ALUM	2 93		0 62		18 3	32 2	45 7
			CARBON EPOXY	1.63		0 62		10 1	20 9	34 3
			FIBERGLASS	2 10		0 62		13.0	23 8	37 2
		TRUSS	ALUM		0 445		12	5 4	9 7	23 1
			CARBON EPOXY		0 282		12	3 4	7 3	20 6
			FIBERGLASS		0 522		12	6 3	10.5	23 9
	ADAPTER	TRUSS	CARBON EPOXY		0 713		12	8 5	13 4	–
	VEHICLE BODY (CASE 2)	CORRUG	ALUM	2 43		0 62		15 1	21 7	35 2
			CARBON EPOXY	1 44				8 9	21 7	35 1
			FIBERGLASS	2 08				12.9	25 7	39 1
		H C SANDWICH	ALUM	2 93				18 3	33 2	46 7
			CARBON EPOXY	1 63				10 1	21 7	35 1
			FIBERGLASS	2 10		0.62		13 0	24 6	38 0
		TRUSS	ALUM		0 445		12	5 4	9 7	23 2
			CARBON EPOXY		0 282		12	3 4	7 3	20 7
			FIBERGLASS		0 522		12	6 3	10 5	24 0
	ADAPTER	TRUSS	CARBON EPOXY		0.717		12	8 6	13 5	–
	VEHICLE BODY (CASE 3)	CORRUG	ALUM	2.54		0 62		15 8	23 4	37 4
			CARBON EPOXY	1 54				9.6	24 0	38 0
			FIBERGLASS	2 21				13 8	28 2	42 1
		H C SANDWICH	ALUM	2.93				18 3	35 2	49 4
			CARBON EPOXY	1 63				10.1	23 1	37 1
			FIBERGLASS	2 10		0.62		13.0	26 1	40 0
		TRUSS	ALUM		0.445		12	5 4	9 7	23 7
			CARBON EPOXY		0 281		12	3.4	7 3	21 2
			FIBERGLASS		0 522		12	6.3	10 5	24 5
	ADAPTER	TRUSS	CARBON EPOXY		0 740		12	8.9	14 0	

† BODY PLUS ADAPTER

Table B-23: WEIGHT SUMMARY (Cont)

			MATERIAL	WEIGHT (lb/ft²)	WT/MEM (lb)	AREA (ft²)	MEMBER QTY	BODY WT (lb)	AD-JUSTED WT (lb)	[illegible] (lb) †
VEHICLE 1-7	VEHICLE BODY (CASE 1)	CORRUG	ALUM	0 780		113 0		88.0	108 6	131 7
			CARBON EPOXY	0 400		113.0		45.2	84 2	107 3
			FIBERGLASS	0 930		113 0		105 0	144 0	167 1
		TRUSS	ALUM		–		44	41 5	71 0	94 1
			FIBERGLASS		–		44	40 2	72 3	95 4
	ADAPTER	TRUSS	CARBON EPOXY		0.320		24	7 7	23 1	–
	VEHICLE BODY (CASE 2)	CORRUG	ALUM	0 820		113.0		92.6	115 4	139 5
			CARBON EPOXY	0.420		113.0		47.4	90 4	114 5
			FIBERGLASS	0.980		113.0		111 0	154 0	178 1
		TRUSS	ALUM		–		44	43 0	72 8	96 9
			FIBERGLASS		–		44	41 1	73 6	97 7
	ADAPTER	TRUSS	CARBON EPOXY		0 327		24	7 9	24.1	–
	VEHICLE BODY (CASE 3)	CORRUG	ALUM	0.860		113.0		97 0	122 0	147 1
			CARBON EPOXY	0.440		113.0		49 6	96.6	121 7
			FIBERGLASS	1.03		113 0		116 2	163 2	188 3
		TRUSS	ALUM		–		44	45 0	75 1	100.2
			FIBERGLASS		–		44	42 3	75.8	100 9
	ADAPTER	TRUSS	CARBON EPOXY		0.335		24	8 0	25 1	–

† BODY PLUS ADAPTER

Table B-23: WEIGHT SUMMARY (Cont)

			MATERIAL	WEIGHT (Kg/m^2)	WT/MEM (Kg)	AREA (m^2)	MEMBER QTY	BODY WT (Kg)	AD-JUSTED WT (Kg)	TOTAL WEIGHT (Kg) †
VEHICLE 1-7	VEHICLE BODY (CASE 1)	CORRUG	ALUM	3 80		10 5		40 0	49 3	59 8
			CARBON EPOXY	1 95		10 5		20 5	38 2	48 7
			FIBERGLASS	4 54		10 5		47 7	65 4	75 9
		TRUSS	ALUM		–		44	18 8	32 2	42 7
			FIBERGLASS				44	18 3	32 8	43 3
	ADAPTER	TRUSS	CARBON EPOXY		0 145		24	3 5	10 5	–
	VEHICLE BODY (CASE 2)	CORRUG	ALUM	4 00		10 5		42 0	52 4	63 3
			CARBON EPOXY	2.05		10 5		21 5	41 1	52 0
			FIBERGLASS	4 78		10 5		50 4	70 0	80 9
		TRUSS	ALUM				44	19 5	33.1	44 0
			FIBERGLASS				44	18 7	33 4	44 4
	ADAPTER	TRUSS	CARBON EPOXY		0 148		24	3 6	10 9	–
	VEHICLE BODY (CASE 3)	CORRUG	ALUM	4.20		10 5		44 0	55 4	66.8
			CARBON EPOXY	2.15		10 5		22 5	43 9	55 3
			FIBERGLASS	5 03		10.5		52 8	74.1	85 5
		TRUSS	ALUM				44	20 4	34 1	45 5
			FIBERGLASS				44	19 2	34 4	45.8
	ADAPTER	TRUSS	CARBON EPOXY		0 152		24	3 6	11 4	–

† BODY PLUS ADAPTER

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APPENDIX C

METEOROID PROTECTION

This appendix discusses the meteoroid environment and the method of laboratory simulation, derivation of the Earth-Mars trajectory for the study vehicles, the design meteoroid sizes for the study, a tabulation of weights for the materials used in the tests, and the design curves developed in the course of the study.

METEOROID ENVIRONMENT

Meteoroid experimental information comes from two primary sources: meteors in the Earth's upper atmosphere and satellite impact records. None of the sources of the information provide meteoroid mass directly except meteorite finds which are of no interest here.

The most important sources of information on meteors are the photographic observations. This covers a mass range down to about 0.01 grams. Figure C-1 is a cumulative distribution of a sample of sporadic photographic meteors as a function of brightness, using the stellar magnitude scale (Reference C-1). Since the total collecting rate of the cameras is known, the cumulative flux as a function of magnitude can be approximated (Reference C-2) as

$$\log N = 0.537\ M_p - 4.34 \quad (km^{-2} hr^{-1})$$

The equations of meteor physics and an average meteor velocity (variously taken as 16.5, 20, 35, 40 km/sec) can be used to obtain a mass flux curve. These average values are usually obtained from the raw data: 35 km/sec from photographic data, 40 km/sec from radar data, and the other values resulting from various data weighting schemes.

A derivation of the velocity distribution (Reference C-3) was considered here. From Figure C-1 note that the sample appeared to be complete only to magnitude one. The roll-off was not a real effect. Rather, it was caused by the limiting sensitivity of the photographic system.

If the sensitivity were independent of velocity, the raw data would provide a velocity distribution at constant brightness. However, slow meteors are easier to see, and the limiting magnitude extends to much fainter meteors for low velocities than for high velocities. The sensitivity dependence is essentially inversely as the velocity, as would be expected. To eliminate those observational biases, the total sample of Figure C-1 is divided into small velocity intervals with distributions of the same form in each. The velocity distribution of the raw data was obtained from the total number in each velocity interval. This is called the observed distribution in Figure C-2. Next, the portion of the distribution where the data was complete was fitted by a straight line in each interval with the same slope as in Figure C-1. From these straight lines the constants in equations of the form shown in Figure C-1 are obtained, but now for each velocity interval. From the theory of meteor physics (Reference C-4) a relationship among magnitude M_p, velocity V, and mass m is obtained. By this means the number per unit velocity interval at constant mass is then obtained with the observational bias removed. The average velocity of meteors in the earth's atmosphere is computed to be 16.5 km/sec. The average velocity for impact on a near earth satelliteis 17.8 km/sec.

The velocity distribution in the absence of the Earth's field is also shown in Figure C-2. The average of this distribution is 14.1 km/sec, however, the average for impact is 17.0 km/sec. Meteoroid velocities relative to a spacecraft can range from 0 to 70 km/sec; however, 90 percent of the population is in the range 0 to 20 km/sec.

Taking the appropriate average over the velocity distribution, the luminous flux of Figure C-1 is converted to a mass flux, given by

$$\log N = -1.21 \log m - 13.85 \; (M^{-2} \; sec^{-1})$$

where m was in grams. When the influence of the Earth's field on the flux is removed:

$$\log N = -1.21 \log m - 14.20$$

which is shown as the straight line portion of Figure C-3. This is the flux encountered by a spacecraft at Earth's distance from the sun, but not near Earth itself.

The meteoroid satellites such as Explorer 16 and 23, Pegasus 1, 2, and 3, and also the Lunar Orbiters provide flux rates by recording the number of perforations in thin metal sheets of several thicknesses. These measurements automatically give the cumulative penetration flux, since particles larger than the threshold size also penetrated. The sensors on Lunar Orbiter were the same as the .001 inch (.0025 cm) be-cu pressure cans on Explorer 16. The penetration rate of Explorer 16 was 2.0 times that recorded by the Lunar Orbiter (44 penetrations on Explorer 16 and 22 on Lunar Orbiter with almost the same effective exposure). This result was due to the increase in the meteor flux by the Earth's field and, to a lesser extent, the greater velocity of the near Earth satellites. Since this effect is velocity dependent, something can be inferred about the average speed from the experimental result.

To analyze this problem, the meteor flux is taken to be effectively isotropic. The meteoroids are in hyperbolic orbits and the satellites were in elliptic orbits. The penetrated thickness is given by the empirical formula:

$$p = km^{1/3} \, (V \cos\lambda)^{\beta}$$

The satellite penetrating flux is approximately of the form:

$$\log F = -\delta \log p + \log F_1 \tag{1}$$

The penetration rate of a satellite is given by Reference C-5

$$\Delta F = \frac{N_1 k^{\delta} p^{-\delta}}{2+\beta\delta} \; V\beta\delta \left[1 + \frac{V_e^{\,2}}{V^2}\left(\frac{2R}{r} - \frac{R}{2a} - 1\right)\right]^{\frac{1+\beta\delta}{2}} \times$$

$$\left[\left(1 - \frac{V_e^{\,2}}{V^2}\left(1 - \frac{R}{r}\right)\right)^{1/2} + \left(1 - \frac{R^2}{r^2} - \frac{V_e^{\,2}}{V^2}\left(1 - \frac{R}{r}\right)\right)^{1/2}\right] F(V)\,\Delta V \tag{2}$$

Integrating over V using the bias free velocity distribution (the near-Earth curve) in Figure C-2 and averaging over the orbits of Lunar Orbiter and over Explorer 16 and computing the ratio F_{exp}/F_{lo} the function of $\beta\delta$ shown in Figure C-4 is obtained. The best value of $\beta\delta$ is 0.64 ($\beta = 2/3$ from impact data, $\delta = 0.96$ from satellite data) which checks the experimental result exactly. However, the extreme range of possible values ($0.43 \leq \beta\delta \leq 0.96$) gives good comparison. The dashed curves were computed using unique values for the velocity rather than a distribution in Equation 2. These curves illustrate the velocity dependence. It can be seen that the bias free velocity distribution obtained from the photographic range is confirmed by the comparison of Lunar Orbiter and Explorer 16 data.

The satellite data is available in the form of Equation 1. From the integral of Equation 2 the parameter N_1 can be evaluated and hence the mass flux results in the form:

$$\log N = -1/3 \;\; \delta \log m + \log N_1 \tag{3}$$

The curve for the satellite range in Figure C-3 was obtained by using Equation 3 over short intervals of mass.

The mass range of importance in spacecraft design is from about 10^{-6} grams to one gram. The flux curve was established on the satellite and the photographic data; an interpolation was used between these ranges. Radar data appears to be improperly corrected, especially for low velocity meteors. Radar meteors appear to have velocities which are too high and flux rates which are too low.

Meteors of the photographic and radar range, because of their behavior in the atmosphere, appear to be fragile and of very low density, ranging from less than 0.25 gm/cc at one gram to around 0.8 gm/cc at 10^{-4} grams. They crumble and burn up in the 80 to 120 km altitude region. They are believed to be cometary debris; the association of some meteor streams with comets bears this out.

Annual meteor streams do not appear to be a significant hazard to spacecraft (Reference C-6). Although some streams have very high visual rates, this is primarily because of the high luminosity of even the very small particles in those streams which have large velocities relative to Earth.

EXPERIMENTAL SIMULATION

The Boeing Company Meteoroid Protection Laboratory was developed for the primary purpose of generating data suitable for design of meteoroid protection systems. Little emphasis was placed on the study of the physics of hypervelocity impact as such. Within the physical limitations, meteoroid impact was simulated as closely as possible.

As shown in the previous section, most meteoroids have velocities ranging up to 20 km/sec, densities from 0.25 to 0.8 gm/cc, and very little strength. These conditions could not be simulated in the laboratory. Although speeds up to 10 km/sec were occasionally reported, a practical upper limit for routine testing is about 8.5 km/sec. The minimum density projectile that can be routinely launched is polyethylene (sp. gr. = 0.95), although inlyte (sp. gr. = 0.7) has been launched with some success in other laboratories (Reference C-7).

Most laboratories used spherical projectiles because they gave symmetrical and repeatable damage patterns. This was necessary for the study of hypervelocity impact phenomena. However, there is no reason to believe that meteoroids are spheres. Indeed, the current theory that they are cometary fragments would preclude this possibility except for those few which come close enough to the sun to be melted but not vaporized. Cylindrical projectiles with random attitudes at impact give random damage patterns, which should be more representative of meteoroid damage. Reference C-8 concluded that cylindrical projectiles caused greater damage than spherical projectiles, thus the use of the latter projectiles could yield non-conservative results. Since cylindrical polyethylene projectiles were easy to launch, these were selected by Boeing as the best projectiles to simulate meteoroid impact.

A family of small light-gas guns, which were simple and economical to operate, were available. With polyethylene and Lexan projectiles, velocities up to 9 km/sec were achieved. The 1/16 and 3/32-inch (.16 and .24cm) projectiles were launched with basically the same gun. It was powered by a .375 magnum case loaded with Bullseye powder. The guns were shock compression types using hydrogen gas. The most important factor in their economical operation was the disposable launch tube consisting of commercial tubing.

Velocity Dependence - Meteor speeds relative to a spacecraft have a wide range. From Figure C-2 it was seen that velocities up to 20 km/sec must be considered to include 90 percent of the meteoroid population. Since the test data effectively ends at 8.5 km/sec an extrapolation is required. In Reference C-9 a theoretical treatment based on blast loading of the second sheet was given. This resulted in a linear increase of the threshold thickness of the second wall with velocity. However, this approach did not determine the constant. This linear dependence is included in an empirical relation in Reference C-10, resulting in a very conservative penetration threshold at approximately 20 km/sec. This is a consequence of the fact that in the test range, the blast loading contributes only a small part of the damage to the second sheet. A more realistic treatment is given in Reference C-11 where experimental thresholds, using glass spheres, were determined with sufficient accuracy so that extrapolation was possible. Here the second wall thickness was found to vary with velocity as:

$$\frac{T_2}{D} \sim V^{0.278}$$

This weak dependence on velocity was in keeping with Boeing test results. Since the Boeing data was valid up to about 8 km/sec, the following expression could be written:

$$\frac{T_2}{D} = f_1\left(\frac{T_1}{D}, \frac{S}{D}\right) f_2(\rho) \qquad 4 < V < 8 \text{ km/sec}$$

$$\frac{T_2}{D} = f_1\left(\frac{T_1}{D}, \frac{S}{D}\right) f_2(\rho) \left(\frac{V}{8}\right)^{0.278} \qquad V > 8 \text{ km/sec}$$

Density Dependence - Very little accurate work has been done on the density dependence of low density projectiles. This is because low density (sp. gr. < 1) materials have little strength and testing is difficult. Reference C-7 compared Inlyte (sp. gr. = 0.7) with aluminum projectiles (sp. gr. = 2.8). Several configurations were considered, and it was found that total thickness varied as

$$(T_1 + T_2) / D \approx \rho^{0.6}$$

for very small mass and low density projectiles. This was a somewhat stronger dependence on density than would have been the case if damage depended only on the projectile mass; i.e., $\rho^{1/3}$. The second sheet thickness was not given separately as a function of density.

However, in spite of the value of this work, there was insufficient supporting test data to include this density dependence in the penetration equation of this study. It did demonstrate, though, that a threshold dependence on projectile mass is conservative. Consequently, the penetration equation is:

$$\frac{T_2}{D} = f_1\left(\frac{T_1}{D}, \frac{S}{D}\right)\left(\frac{\rho}{0.95}\right)^{1/3} \qquad 4 < V < 8 \quad \text{km/sec}$$

$$\frac{T_2}{D} = f_1\left(\frac{T_1}{D}, \frac{S}{D}\right)\left(\frac{\rho}{0.95}\right)^{1/3}\left(\frac{V}{8}\right)^{0.278} \qquad V > 8 \quad \text{km/sec}$$

since test data was obtained with polyethylene (sp. gr. = 0.95) projectiles.

DETERMINATION OF THE METEOROID ENVIRONMENT FOR EARTH TO MARS TRAJECTORY

The meteoroid flux varies in the solar system as a function of distance from the sun. The reliability requirement for this study was stated for the total mission. Therefore, an average flux was used in the meteoroid protection analysis. This average was not very sensitive to the particular mission, but specifically the computation was based on a feasible 208-day trajectory starting on Earth on October 7, 1975. This trajectory was not necessarily a practical one, but served the purposes of computing the average meteoroid flux for the study.

The desired trajectory was an ellipse satisfying the two end conditions. Earth distance from the sun would be very close to one A.U. on October 7. Mars distance from the sun on May 2, 1976 was computed. The equation for the mean anomaly was

$$M = nt + \varepsilon - \tilde{\omega}$$

For epoch January 15, 1960, this was

$$M = .524033\,t - 76.5554$$

for Mars' orbit. On May 2, 1976, $M = 169.535^{\circ}$.

Other data for Mars' orbit were:

semi-major axis,	$a = 1.523691$
eccentricity,	$e = .093368$

Mars distance was computed from

$$r = a(1 - e \cos E_M)$$

where E_M was the eccentric anomaly which was determined from Kepler's equation

$$M = E_M - e \sin E_M$$

which was solved by iteration. The result was $r = 1.664$ A.U. on May 2, 1976.

The trajectory, that is a and e, of the spacecraft was next computed. It was assumed that perihelion of this trajectory was at Earth; hence was

$$1 = a(1 - e)$$

At intercept

$$1.664 = a(1 - e \cos E_S)$$

where E_S was the eccentric anomaly of the spacecraft trajectory at intercept. It was related to time by

$$t = 208 = \frac{365}{2\pi} a^{3/2} (E_S - e \sin E_S) \text{ days.}$$

These three equations were solved for a, e, and E_S by iteration. Starting with $E_S = \pi$, the solutions converged in four steps to:

$$E_S = 2.389 \text{ rad } (136.8^\circ)$$
$$a = 1.383 \text{ A.U.}$$
$$e = .275$$

The orbits of Earth, Mars, and the spacecraft are shown in Figure C-5. A plot of the equations

$$R = 1.383\ (1 - .275 \cos E) \quad \text{A.U.} \quad (1)$$

$$t = 94.5\ (E - .275 \sin E) \quad \text{Days} \quad (2)$$

giving R as a function of t is shown in Figure C-6.

The model of the cumulative meteoroid flux in interplanetary space was assumed to have the functional form

$$N = f\,(m)\ \ f\,(R) \qquad (3)$$

where N was the total rate on a surface of unit area by meteoroids of mass m and larger at a distance R from the sun. This implied that the mass distribution was independent of the distance R. Hence, the near Earth flux model gave f(m). Strictly speaking, this was the flux relative to an object in a direct circular orbit such as Earth; however, the spacecraft's elliptic trajectory would produce only a very small deviation in the relative flux. This model also assumed that the flux was isotropic relative to the spacecraft. Meteoroids are primarily in direct orbits. However, most of the orbits are very eccentric and the relative flux is approximately isotropic.

The total number of hits per unit area during the mission was

$$\int f(m)\, f(R)\, dt$$

hence the average rate was

$$\langle N \rangle = \frac{f(m)}{\tau} \int_0^{\tau} f(R)\, dt \qquad (4)$$

Over the relatively small distance from Earth to Mars the space dependence could be approximated as

$$f(R) = R^{\gamma}$$

where R was in A.U. From Equation 1

$$f(R) = \left[1.383\ (1 - .275 \cos E)\right]^{\gamma} \qquad (5)$$

and from Equation 2

$$dt = 94.5\ (1 - .275 \cos E)\ dE$$

Substituting in Equation 4

$$\langle N \rangle = f(m)\ F(\gamma)/F(0) \qquad (6)$$

where

$$F(\gamma) = (1.383)^{\gamma} \int_0^{E_S} (1 - .275 \cos E)\ dE$$

and E_S = 2.389 rad. For the purpose of computation, the integrand could be expanded in a series and integrated term by term as

$$\int_0^{E_S} (1 - .275 \cos E)^{1+\gamma}\ dE =$$

$$2.389 - .1879\ (\gamma+1) + .03574\ (\gamma+1)\ \gamma - .002\ (\gamma+1)(\gamma-1)\gamma$$

$$+\ .0001848\ (\gamma+1)(\gamma-1)(\gamma-2)\gamma\ .$$

The quantity $F(\gamma)/F(0)$ is plotted in Figure C-7.

The average of the relative meteoroid velicity over the trajectory was next calculated. An approximation suitable for the purpose was that the relative meteoroid speed depended on distance from the sun as

$$V = V_1 \ R^{-1/2} \tag{7}$$

This result was exact for a particular (fictitious) distribution of meteoroid orbital elements. The velocity relative to an object in a circular orbit varied as

$$V = R^{-1/2} \left[3 - R/a - 2\sqrt{(1-e^2)\ a/R}\ \cos i \right]^{1/2}$$

If the distribution was such that the average semi-major axis "a" was proportional to the distance R at each point in space, then Equation 7 was exact.

The average over the trajectory was defined as

$$\langle V \rangle = \frac{\int NV\ dt}{\int N\ dt}$$

From (3), (4) and (7) this became

$$\langle V \rangle = \frac{V_1 \int R^{\gamma\ -1/2} dt}{\int R^{\gamma}\ dt}$$

and by means of Equation (6) this was represented by

$$\langle V \rangle = V_1 \ F(\gamma - 1/2)/F(\gamma)$$

which is plotted in Figure C-7.

The curves of Figure C-7 were used to determine the sensitivity of the meteoroid protection requirement to variations in the model of the environment as described in Section 1.3.4 of the Volume I document.

For instance, various published models of the environment corresponded to a range of γ from -2 (Reference C-12) to an unrealistic extreme of +5 (Reference C-13). A nominal value of γ was selected, and the flux from the near-Earth model multiplied by $F(\gamma)/F(0)$ to give the average flux over the trajectory (the nominal value of γ was most likely between 0 and -2). This was used to determine the design meteoroid mass. The average velocity for penetration based on the near-Earth flux was multiplied by $F(\gamma - 1/2)/F(\gamma)$ to give the average velocity over the trajectory. The amount of meteoroid protection required was computed from these values. Another value, $\gamma = 3$ for instance, would then be used for a similar calculation. A comparison of the two results gave a measure of the sensitivity of the weight to the model used.

DESIGN METEOROID SIZES

Section 1.3.4 of the Volume I document described how the spherical diameter of the polyethylene design projectile was computed. The nominal values of the meteoroid environment and velocity dependence, β and γ , were used to derive design meteoroids for all study vehicles with varying payload heights. These values were $\beta = 0.182$, $\gamma = -2$, and the design probability of no failure was 0.999. The resulting design meteoroid diameters are listed in Table C-1.

METEOROID PROTECTION MATERIALS

The meteoroid protection design curves presented in this Appendix were developed from a wide range of materials. The weights and description of materials are listed in Table C-2.

DESIGN CURVES

Figures C-8 through C-12 present meteoroid protection design curves for the various MLI materials of the program. The 3 σ curve and the arithmetic mean curves are shown as well as the individual data points. The experimental results were developed in terms of an equivalent thickness of aluminum protection system (T_1) necessary to protect a certain aluminum tank wall thickness (T_2). Both thicknesses (T_1 and T_2) were normalized to meteoroid diameter (D) so the data could be used to evaluate protection systems for various vehicles and probabilities of mission success. The normalized penetration depth is also shown on the ordinate.

The aluminized mylar/nylon net curve, Figure C-8, had a very steep slope, indicating a substantial increase in protection efficiency with a slight increase in thickness. Figure C-12 shows the arithmetic mean curve for multiple discrete shields of 1/2 mil aluminized mylar with 1/4 inch (0.64 cm) spacing. This concept was very weight efficient; however, it would be difficult to maintain the spacing in a vehicle installation.

Figures C-13, C-14 and C-15 are the curves for single sheet materials. The characteristic decrease in protection efficiency as aluminum sheet thickness was increased is evident in Figure C-14. Figures C-16 and C-17 represent fiberglass honeycomb sandwich with different thickness face skins. Figure C-18 is for aluminum honeycomb sandwich. Fiberglass honeycomb sandwich provided considerably more protection than an equivalent weight of aluminum honeycomb sandwich. Fiberglass sandwich approximately 1/7 the weight of the aluminum sandwich shown in the curve provided equal protection. Continuous shell concepts were not tested in more detail because of prohibitive structural weight.

Figures C-19 through C-22 present the test data for combinations of Beta fiber cloth in front of MLI. The curves show a reduction in protection system efficiency with initial additions of MLI, moving from left to right on the curves. As more MLI was added there was a corresponding increase in efficiency. There was no apparent explanation for this. Figures C-23 through C-31 present data for combinations of aluminum skin in front of MLI, and Figures C-32 through C-42 for fiberglass laminate skin in front of MLI.

Figures C-43 through C-48 show the data for combined honeycomb sandwich and MLI. The honeycomb sandwich was in front of the MLI and was impacted first. Fiberglass honeycomb shows greater efficiency in combination with MLI than aluminum honeycomb.

Figure C-49 shows data for one thickness of carbon composite bidirectional laminate.

Figures C-50 and C-51 show data for MLI in front of an aluminum skin. This configuration was representative of vehicles with MLI on the outside of the structural shell. Figure C-52 is for vehicles with MLI on the outside of a fiberglass laminate structural shell.

Figures C-53 and C-54 show data for MLI in front of aluminum and fiberglass honeycomb sandwich. The results were about the same as for MLI located behind the honeycomb sandwich shell.

Figures C-55 through C-57 represent a combination of metallic bumpers in front of MLI, located on the outside of an aluminum vehicle shell. The curves show the trend towards less efficiency as an aluminum bumper is added, except for Figure C-57. In this case, the downward turn of the curve could have been due to an increased effectiveness of MLI. Figures C-58 through C-60 show similar data for fiberglass laminate structural shells. In this configuration, improved efficiency was experienced because spallation consisted of low mass particles.

Figures C-61 through C-66 represent vehicles constructed with honeycomb sandwich shells and incorporating a metallic bumper and MLI on the outside. Observations made previously for fiberglass and aluminum honeycomb sandwich are also applicable for these configurations.

Figures C-67 through C-78 present final design curves for material combinations where the thickness of MLI and bumper material were varied. The curves identified as T_β/D or T_{FG}/D represent constant Beta fiber cloth or fiberglass laminate thickness with varying amounts of MLI. The interpolation formula used to derive these curves was described in Section 2.1.2 of the Volume I document. The curves were constructed with 3σ values.

Figures C-79 through C-81 are the final design curves for MLI and bumper combinations located in front of fiberglass laminate structural shells. The curves labeled T_S/D represent a fixed laminate skin thickness with varying thickness of MLI.

Figure C-82 is the design curve for MLI located outside of an aluminum structural shell.

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C-11 Nysmith, C.R.; "An Experimental Investigation of Aluminum Double-Sheet Structures", 69-375, AIAA Hypervelocity Impact Conference, 1969.

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C-13 Wall, J.K.; "The Meteoroid Environment Near the Ecliptic", NASA SP-150, p. 343, 1967.

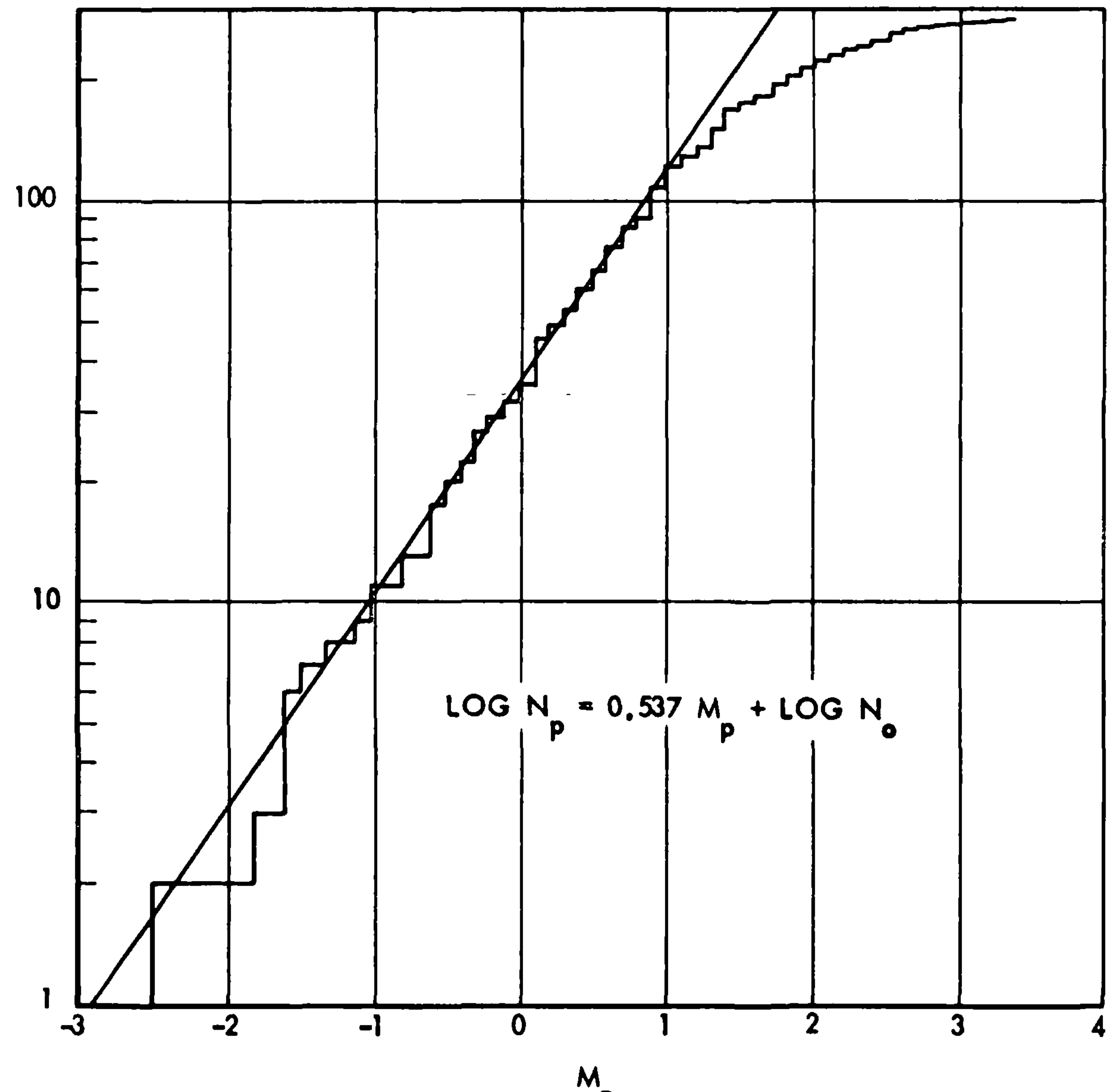


FIGURE C-1: CUMULATIVE DISTRIBUTION OF METEORS AS A FUNCTION OF MAGNITUDE

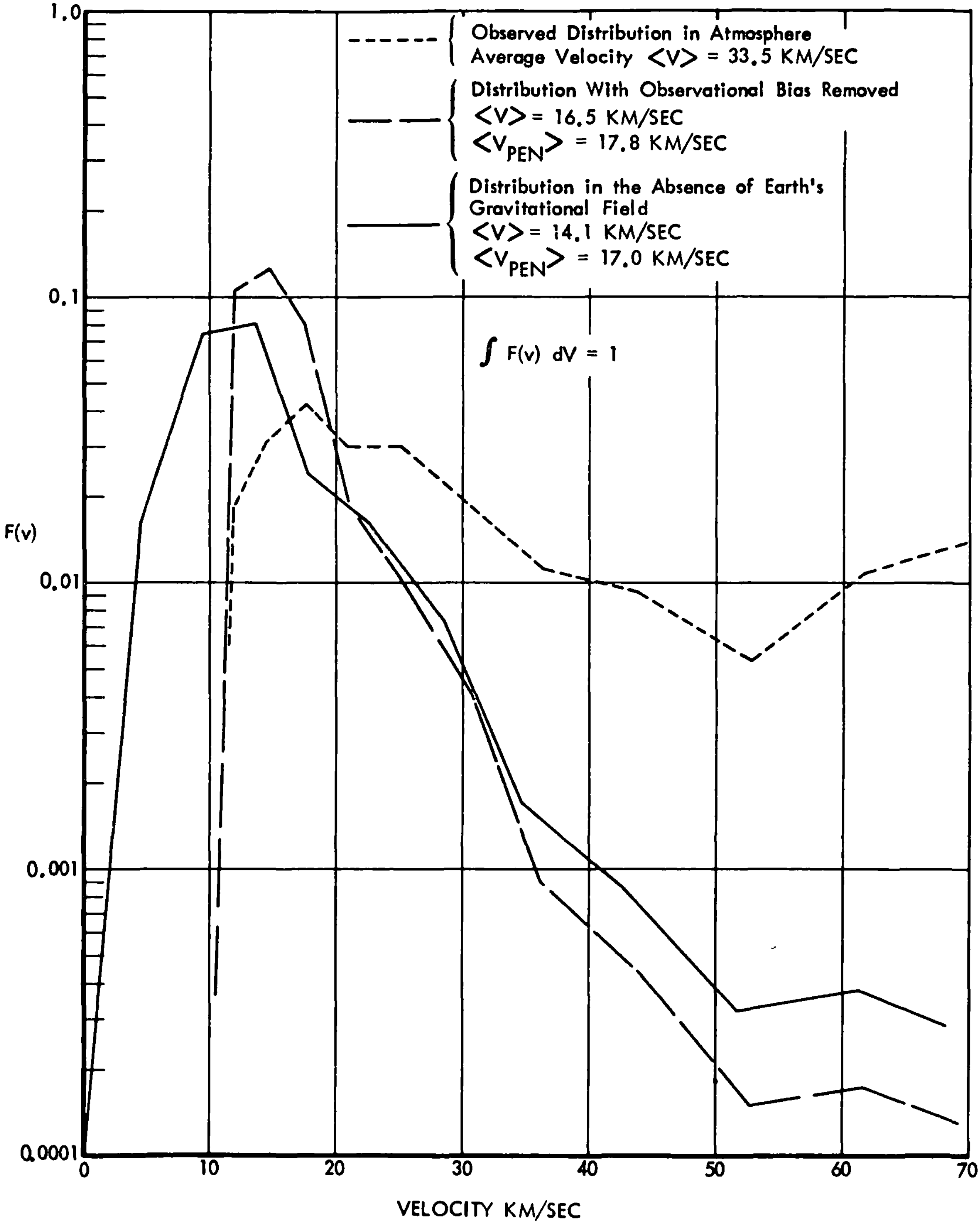


FIGURE C-2: METEOROID VELOCITY DISTRIBUTIONS

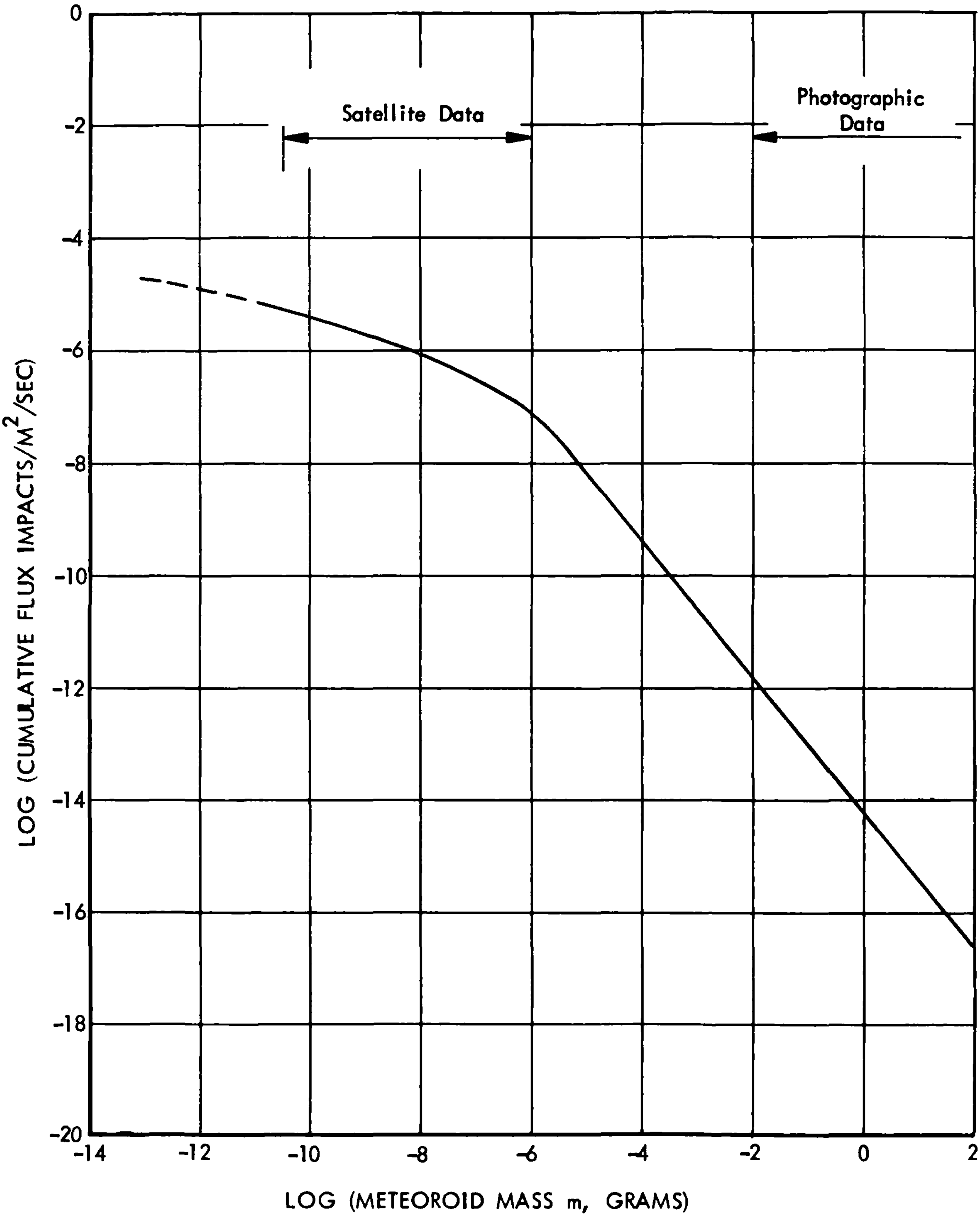


FIGURE C-3: METEOROID ENVIRONMENT NEAR EARTH, BUT IN THE ABSENCE OF EARTH'S GRAVITATIONAL FIELD

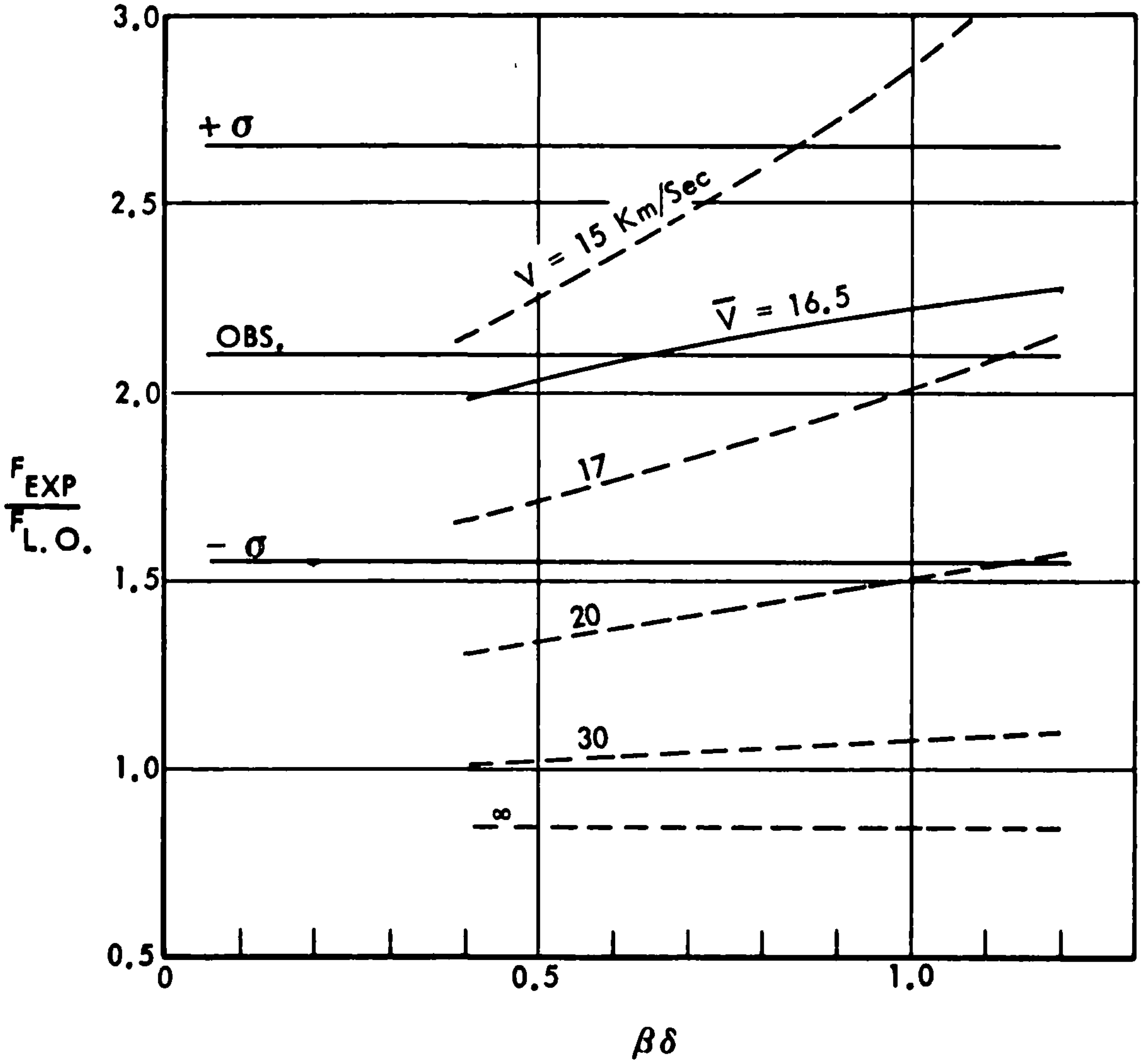


FIGURE C-4: COMPUTED EXPLORER 16 METEOROID FLUX/LUNAR ORBITER FLUX

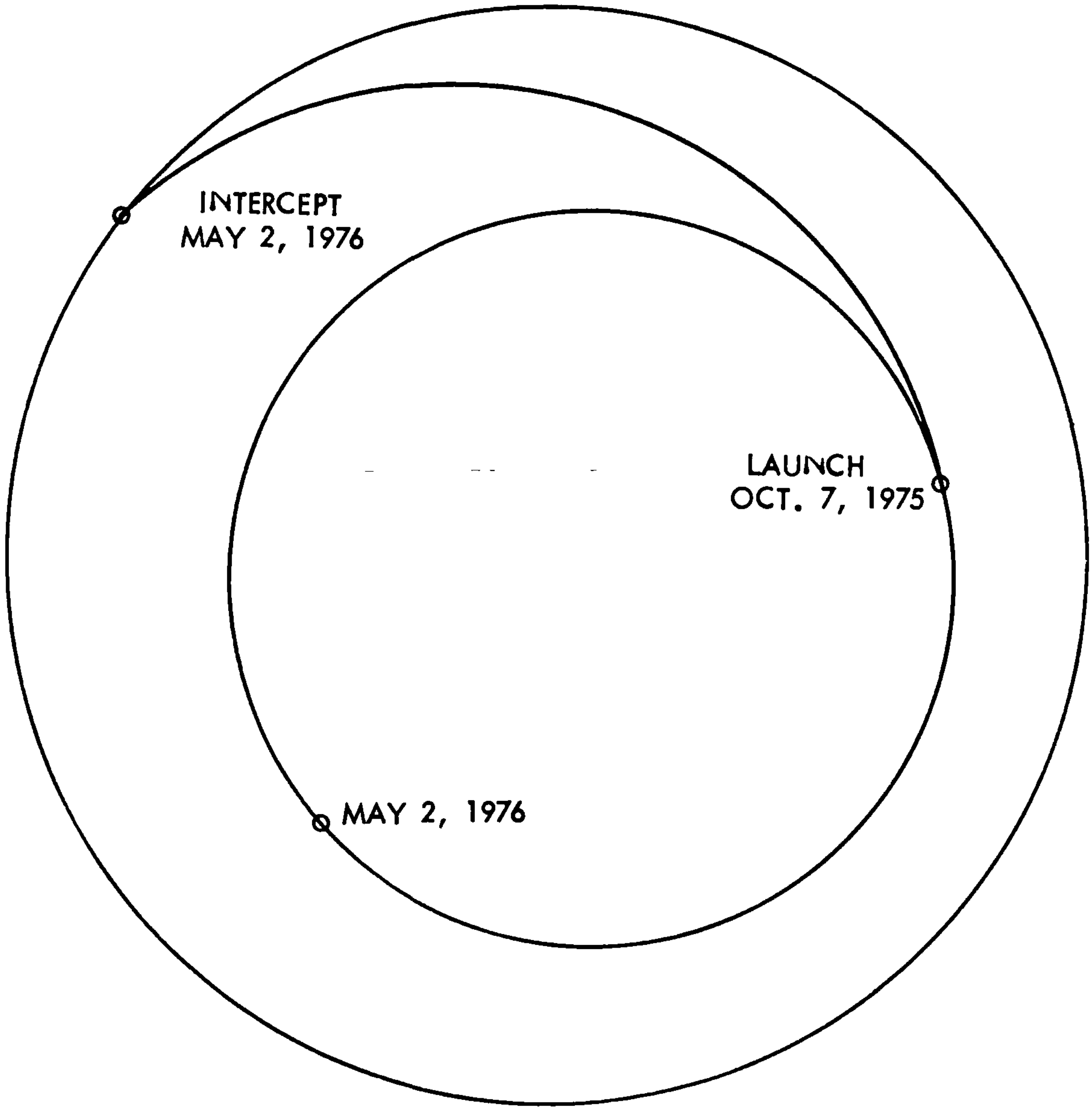


FIGURE C-5: SPACECRAFT TRAJECTORY

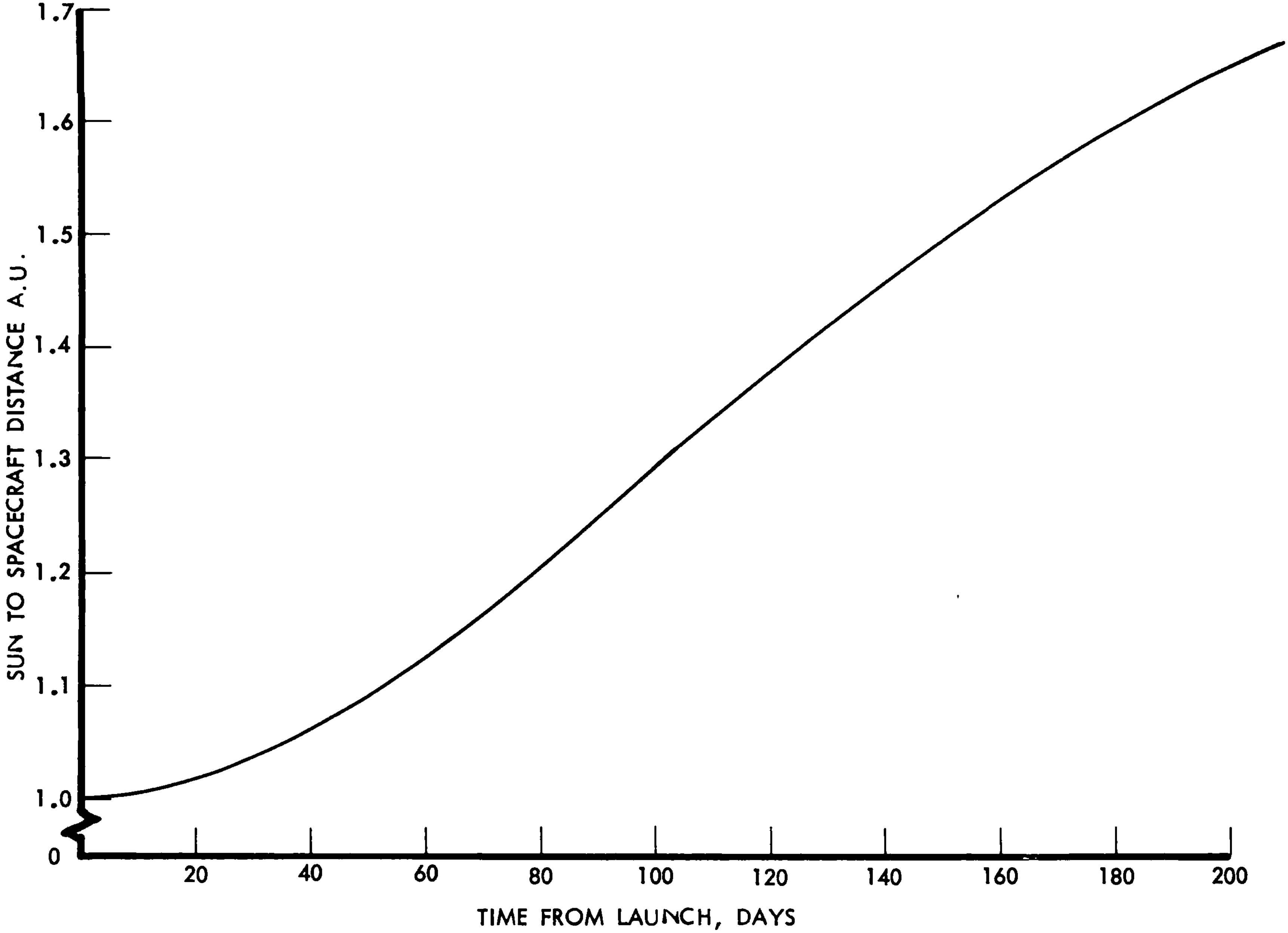


FIGURE C-6 : SPACECRAFT TRAJECTORY DATA

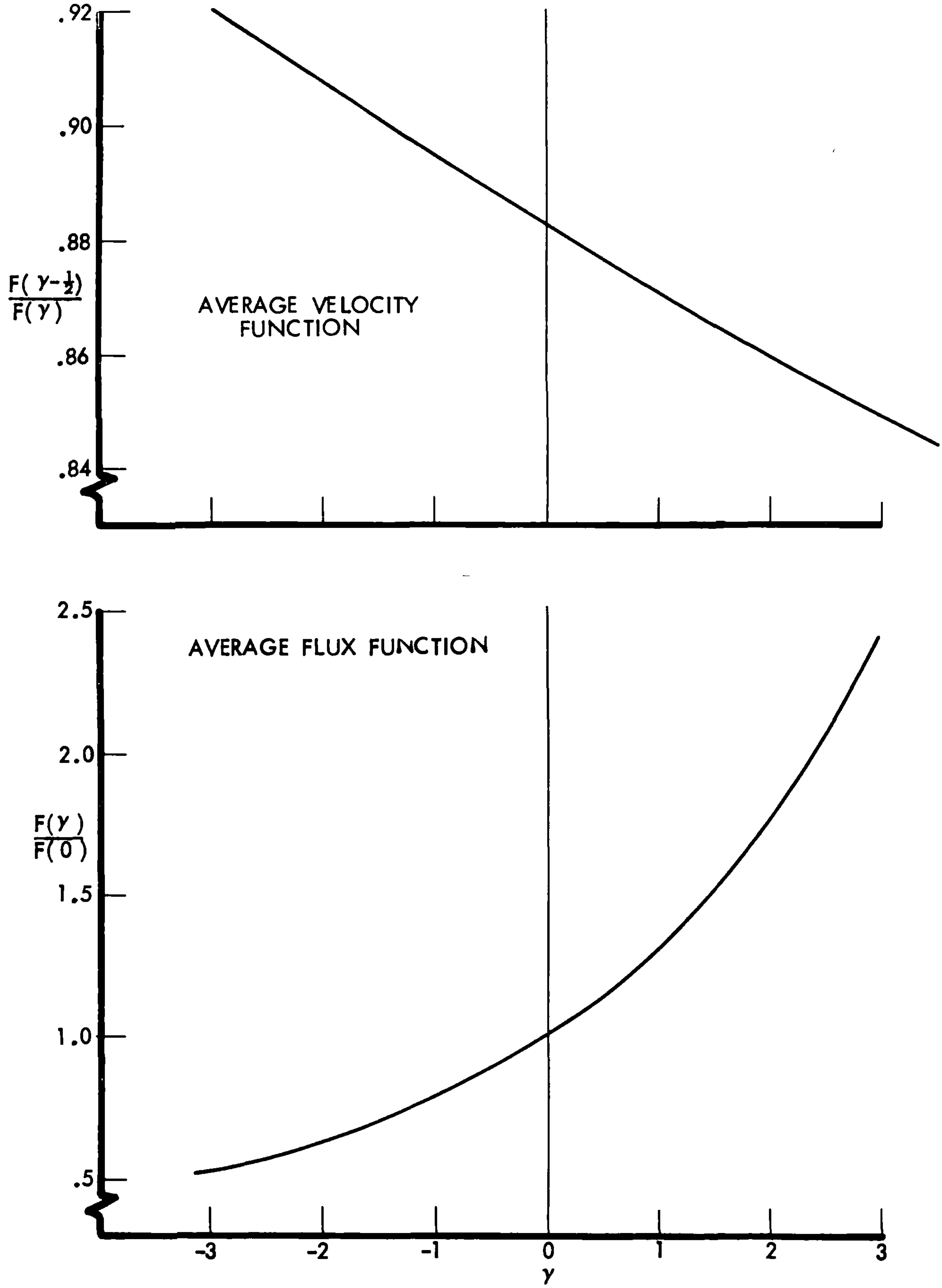


FIGURE C-7 DEPENDENCE OF THE AVERAGE FLUX ON THE METEOROID ENVIRONMENT PARAMETER, γ

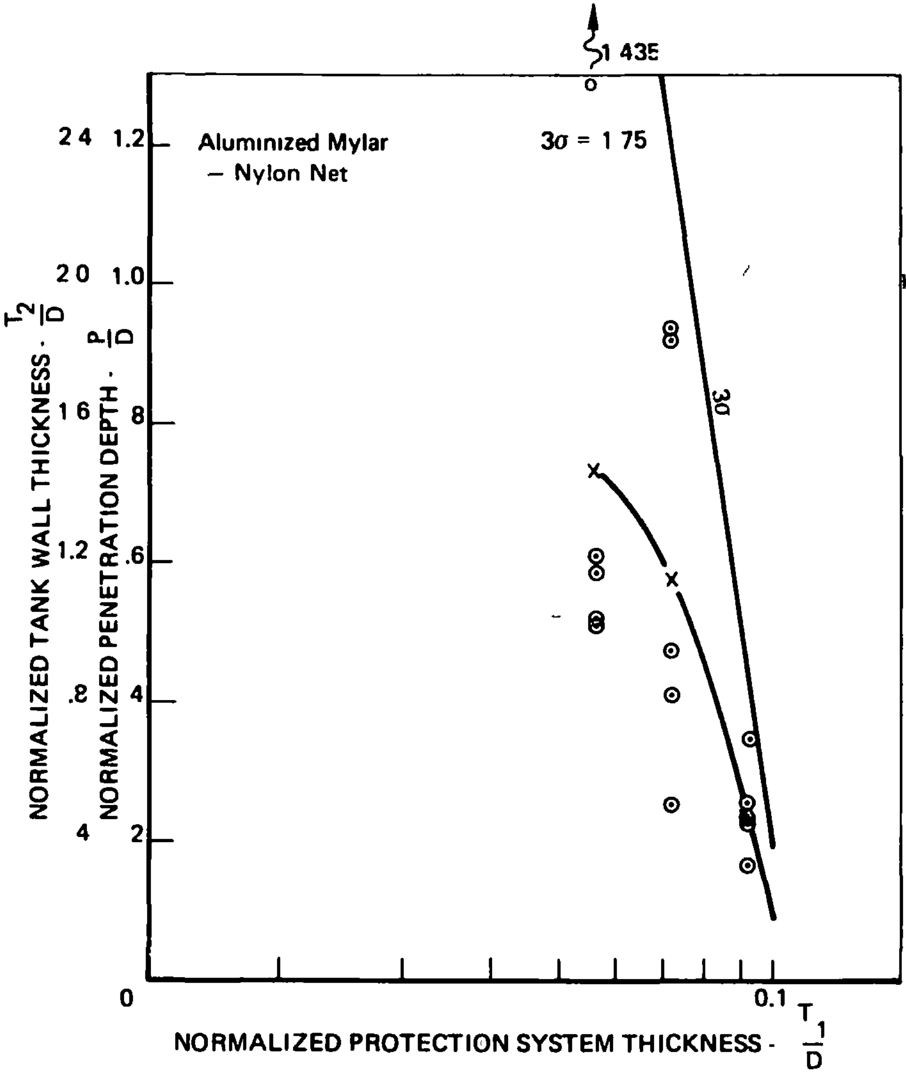


FIGURE C-8: METEOROID PROTECTION DESIGN DATA - MLI

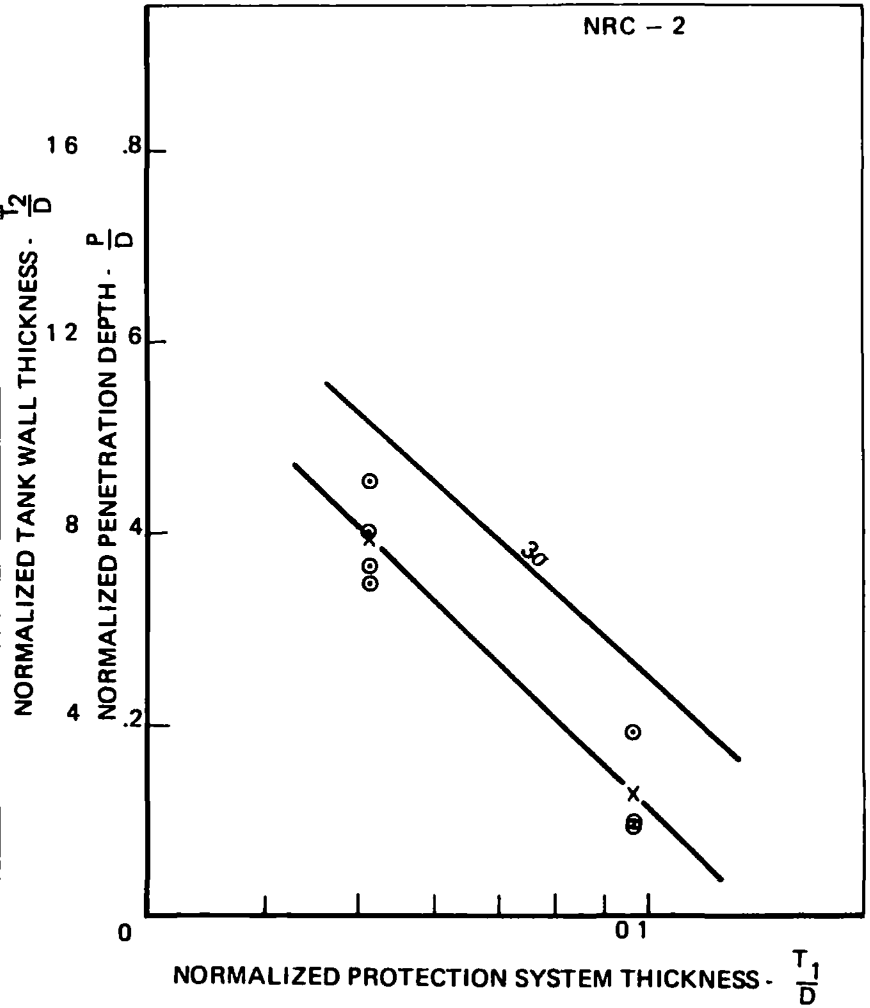
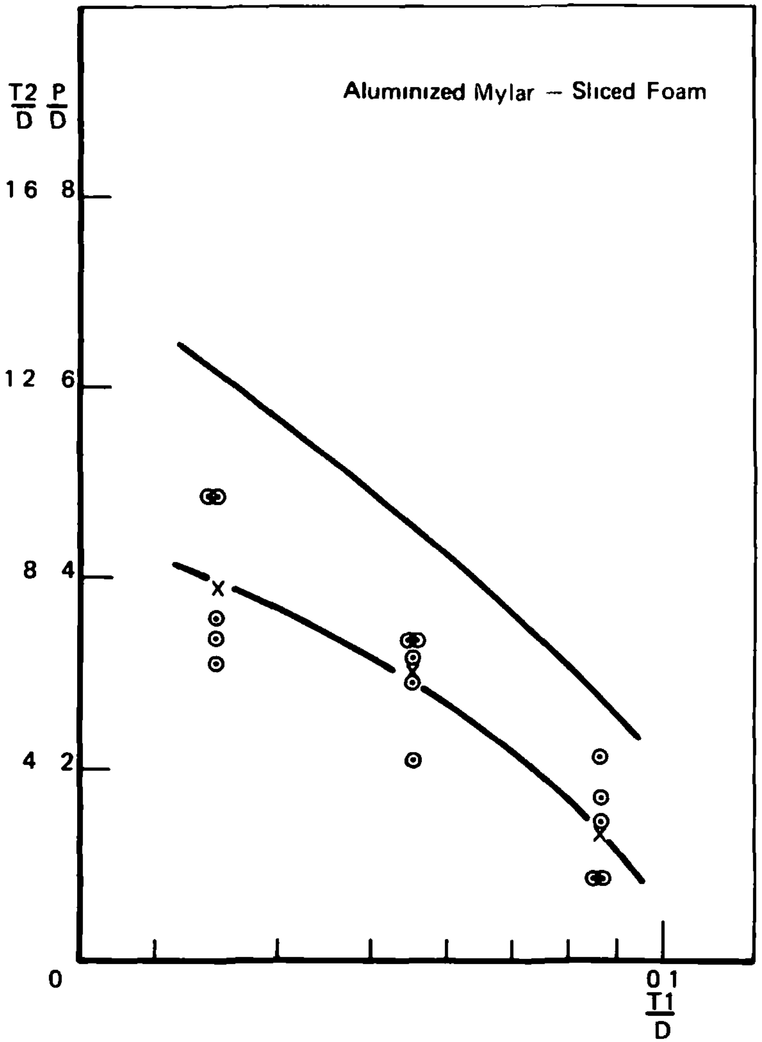


FIGURE C-9: METEOROID PROTECTION DESIGN DATA - MLI



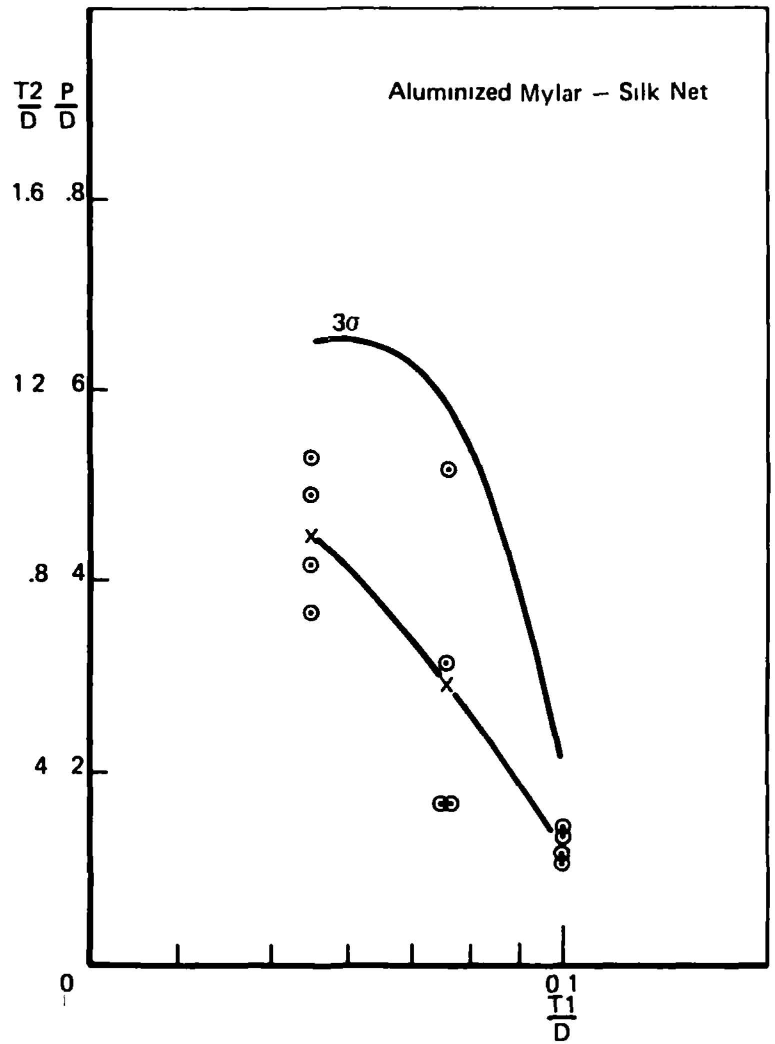


FIGURE C-10: METEOROID PROTECTION DESIGN DATA - MLI

FIGURE C-11: METEOROID PROTECTION DESIGN DATA - ML

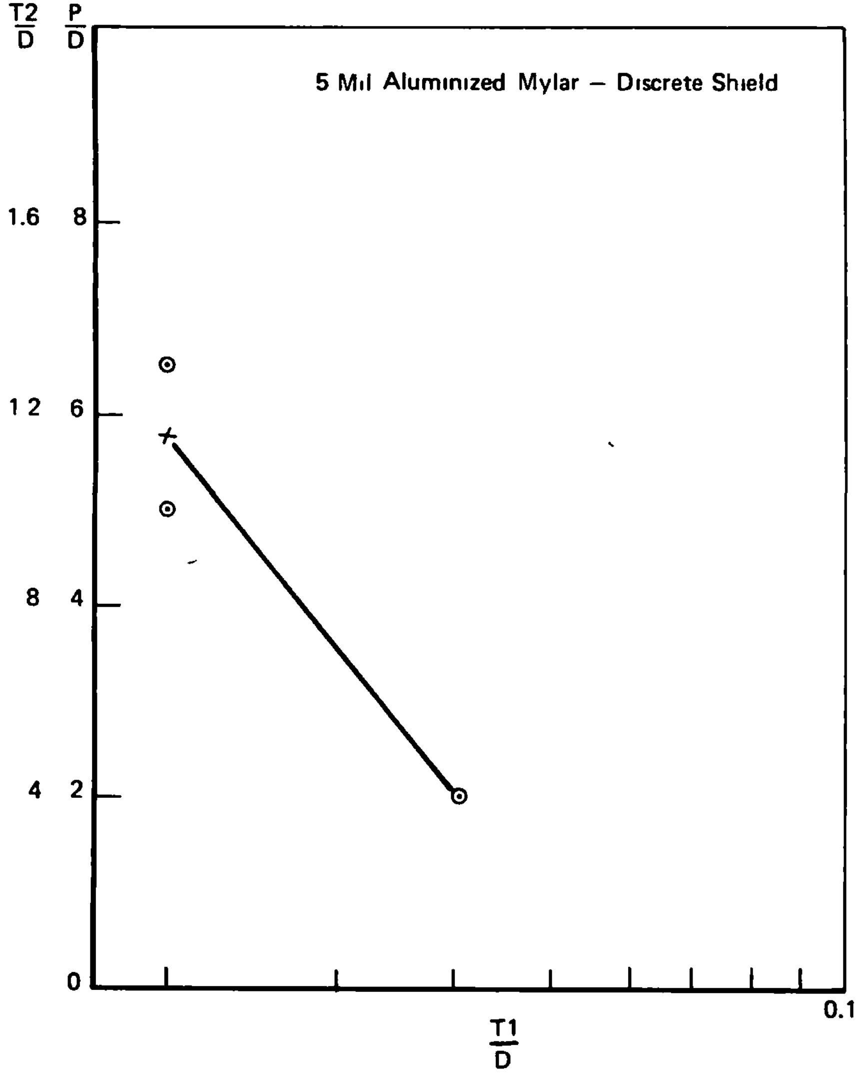


FIGURE C-12: METEOROID PROTECTION DESIGN DATA - MLI

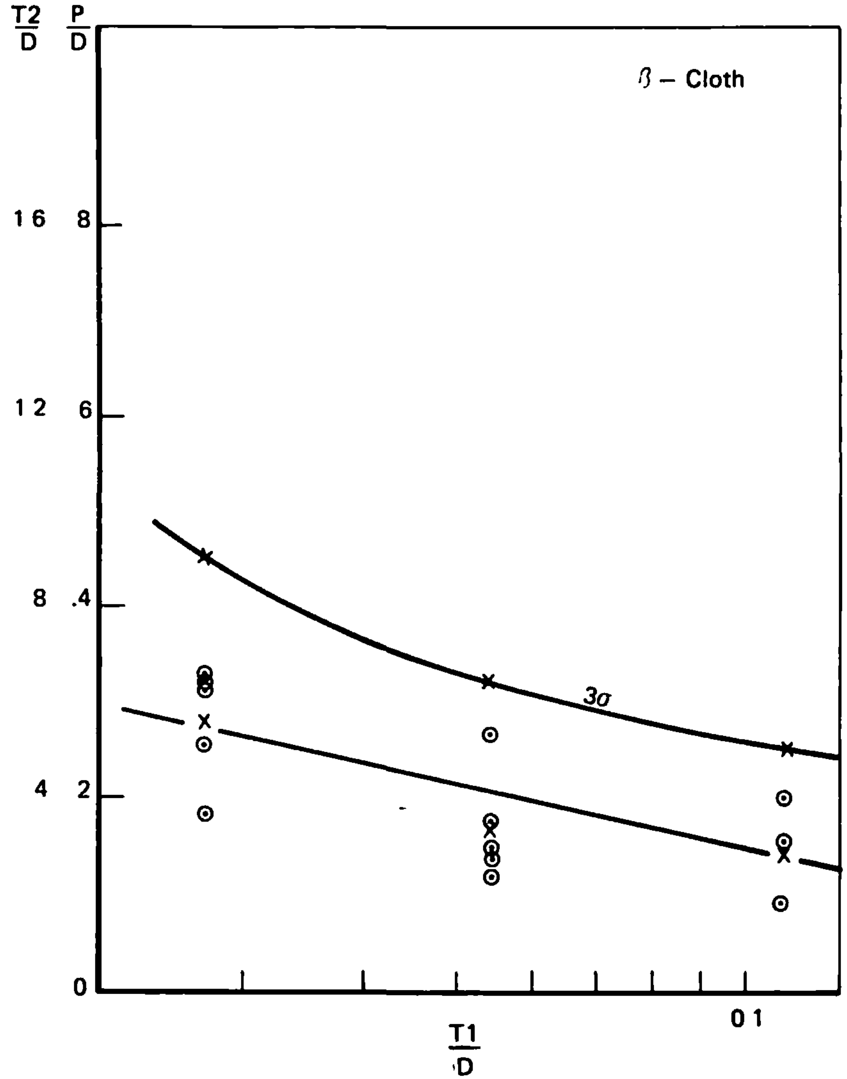


FIGURE C-13: METEOROID PROTECTION DESIGN DATA - SINGLE SHEETS

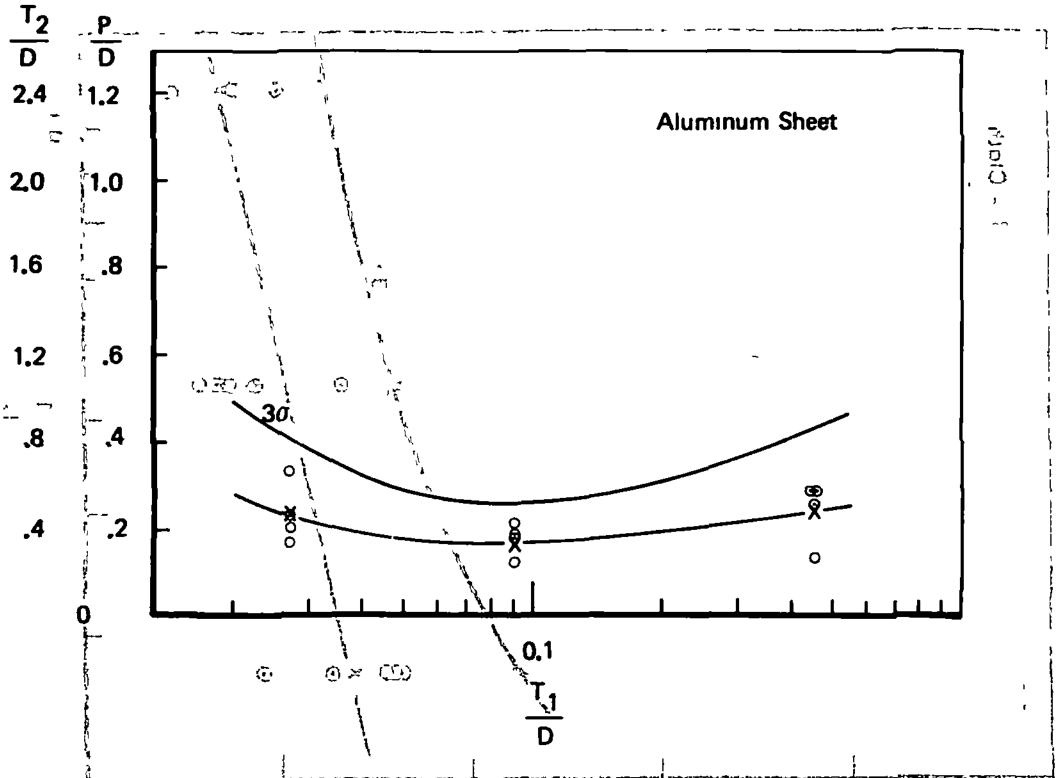
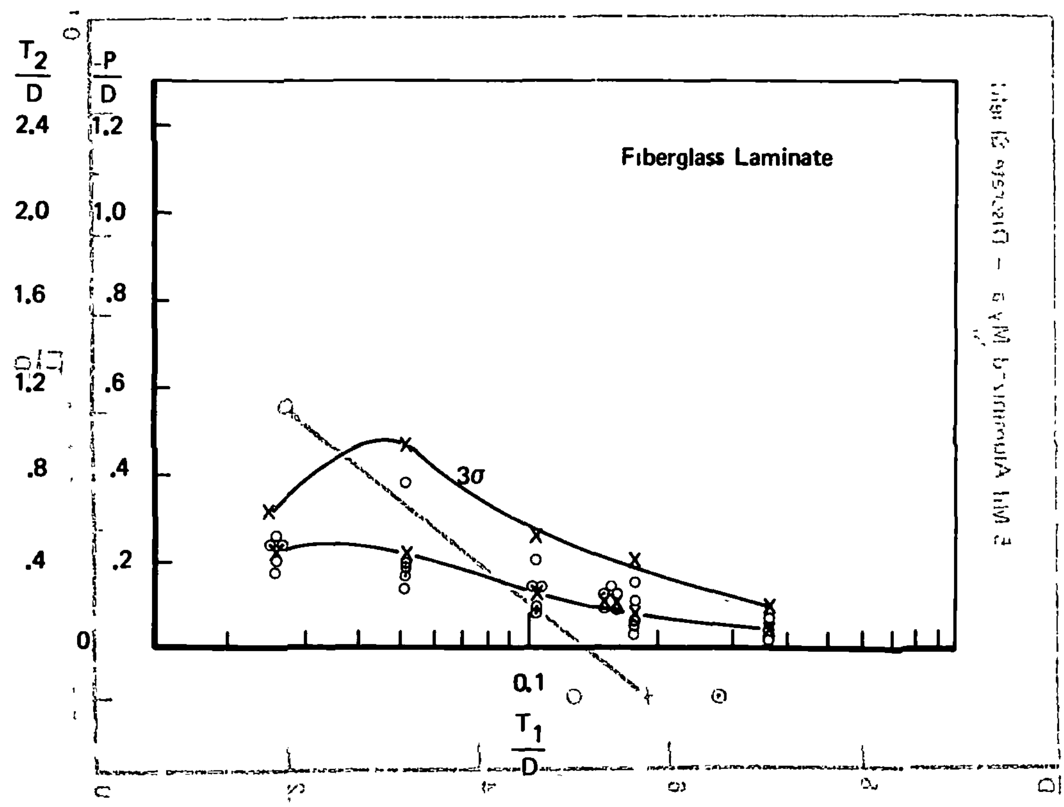


FIGURE C-14: METEOROID PROTECTION DESIGN DATA - SINGLE SHEETS



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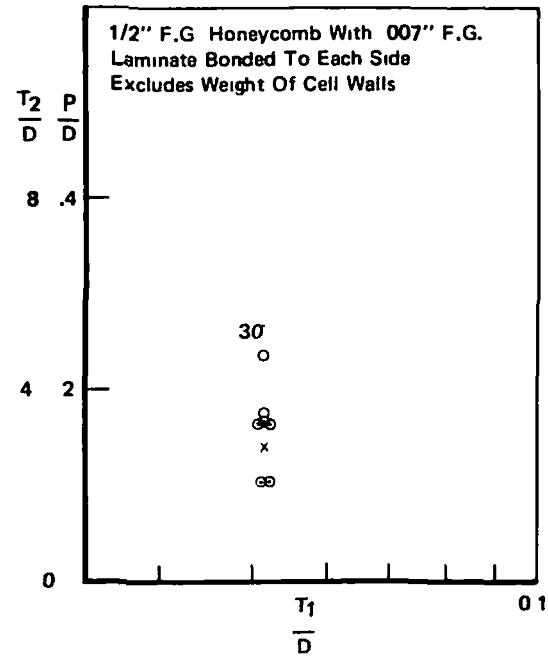


FIGURE C-16: METEOROID PROTECTION DESIGN DATA-SANDWICH

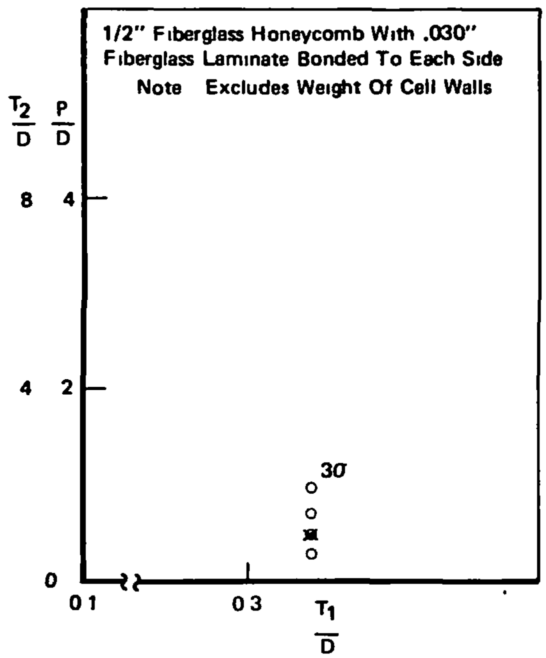


FIGURE C-17: METEOROID PROTECTION DESIGN DATA-SANDWICH

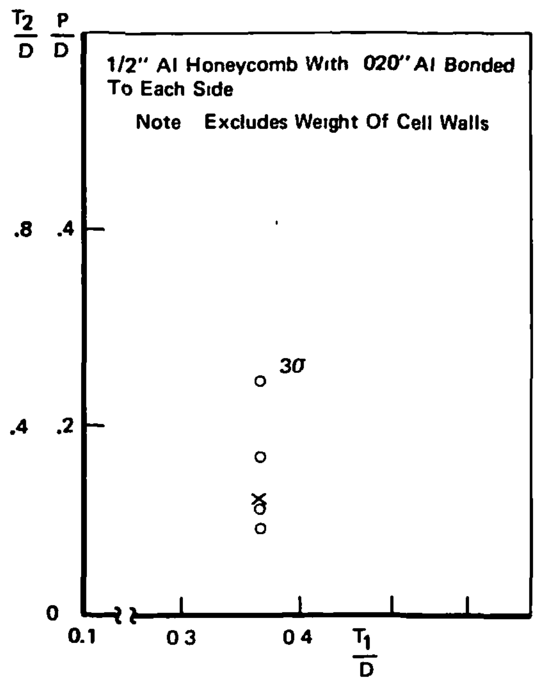


FIGURE C-18: METEOROID PROTECTION DESIGN DATA-SANDWICH

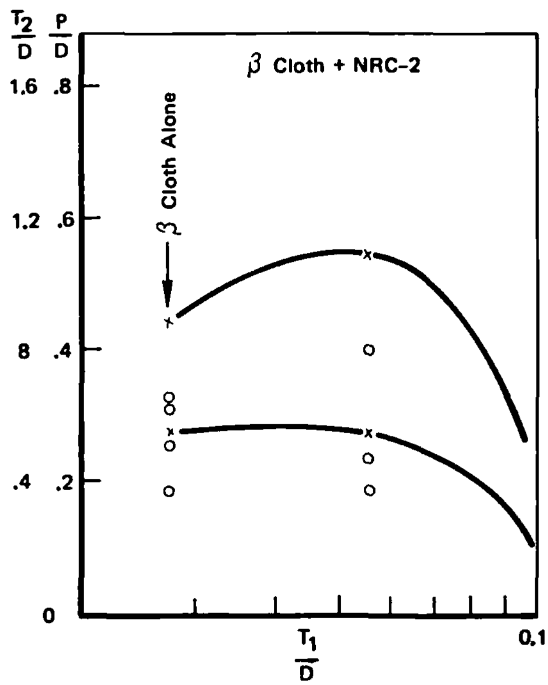
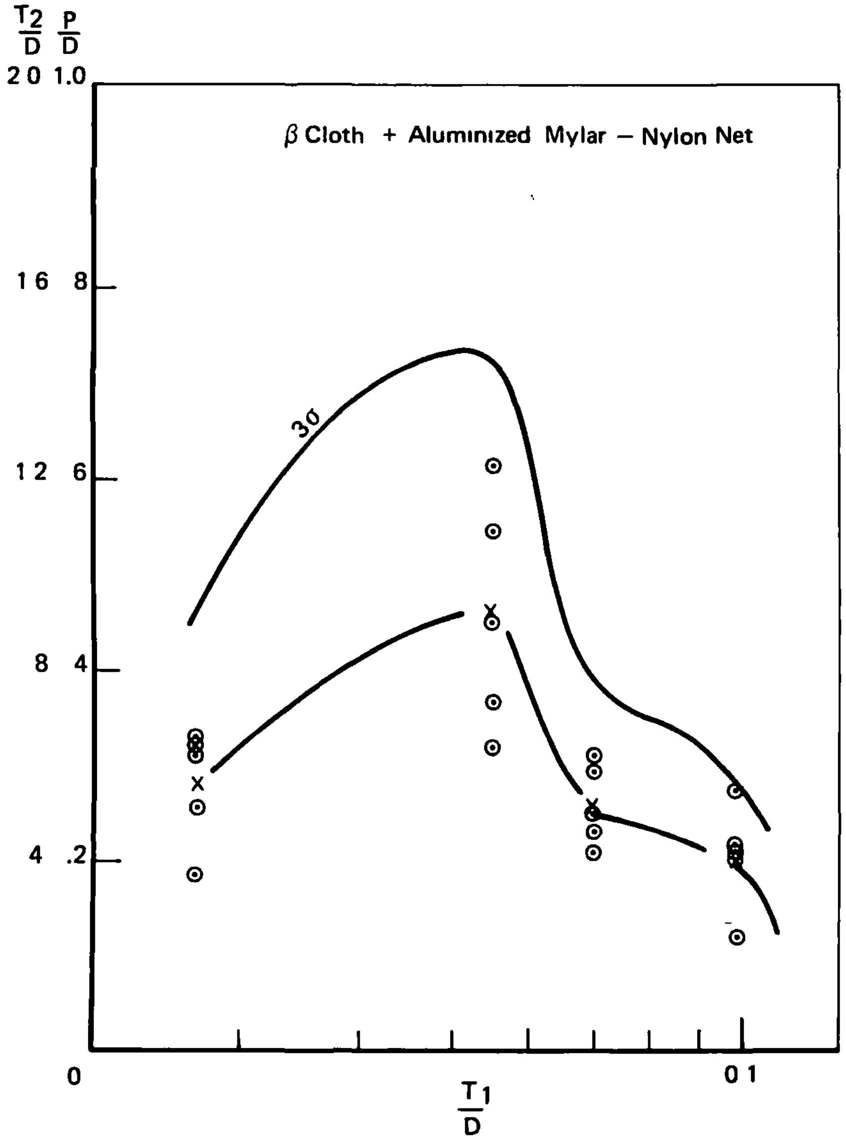


FIGURE C-19: METEOROID PROTECTION DESIGN DATA-SINGLE SHEET AND MLI



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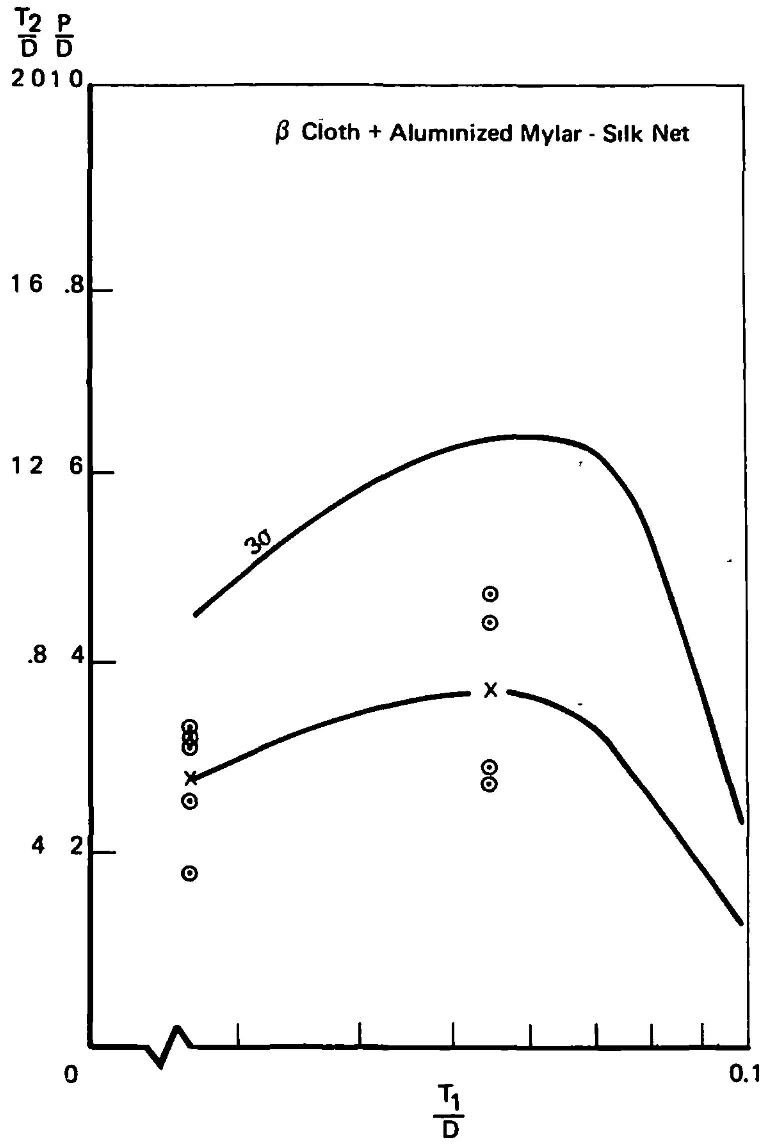

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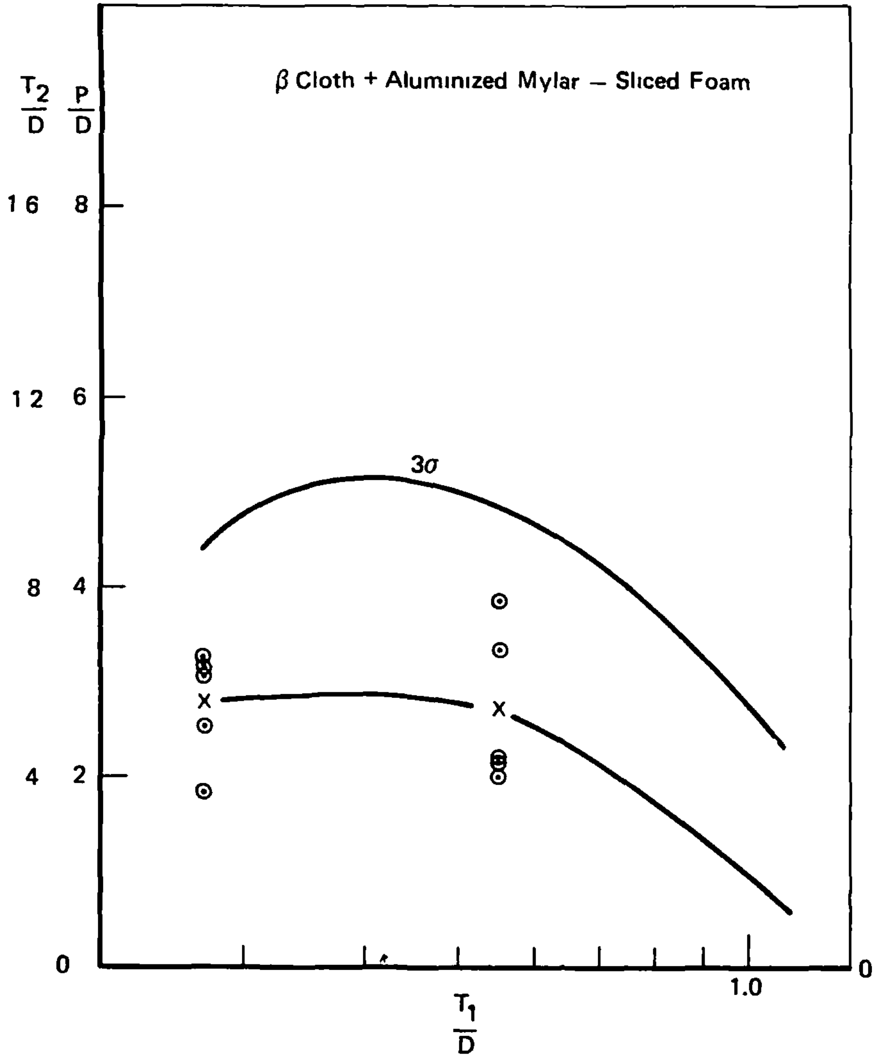

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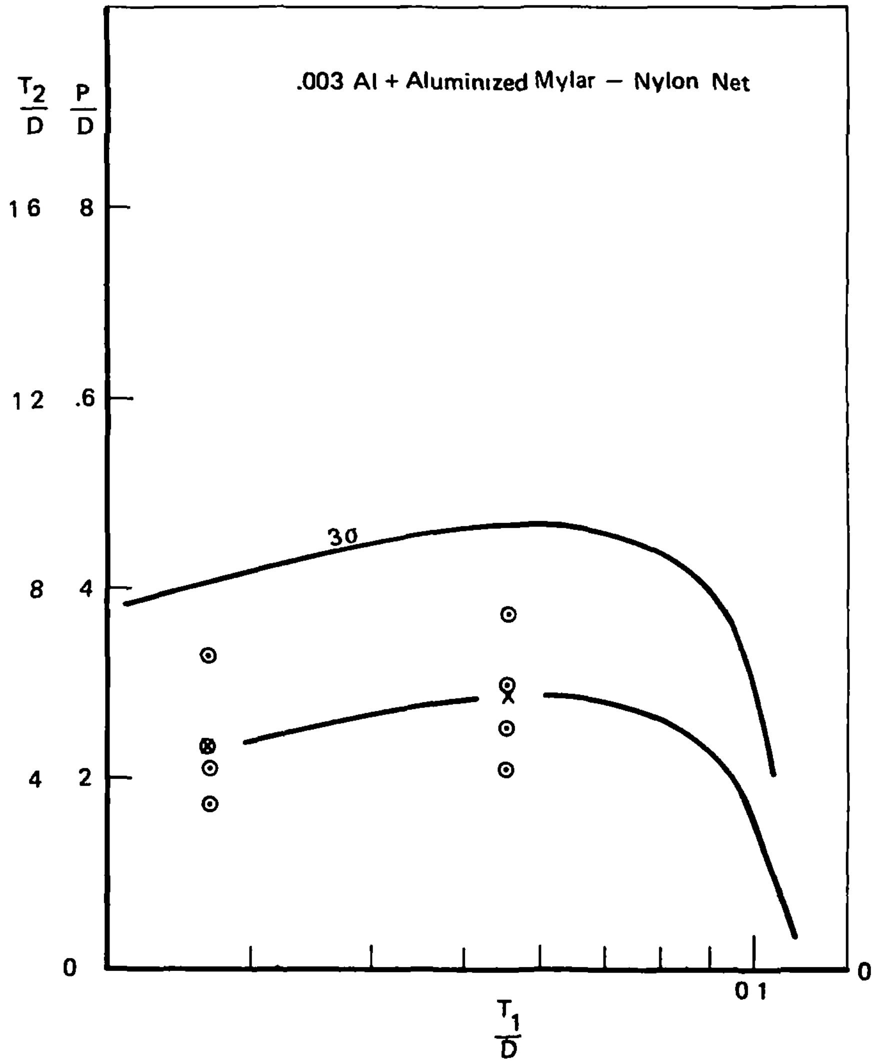

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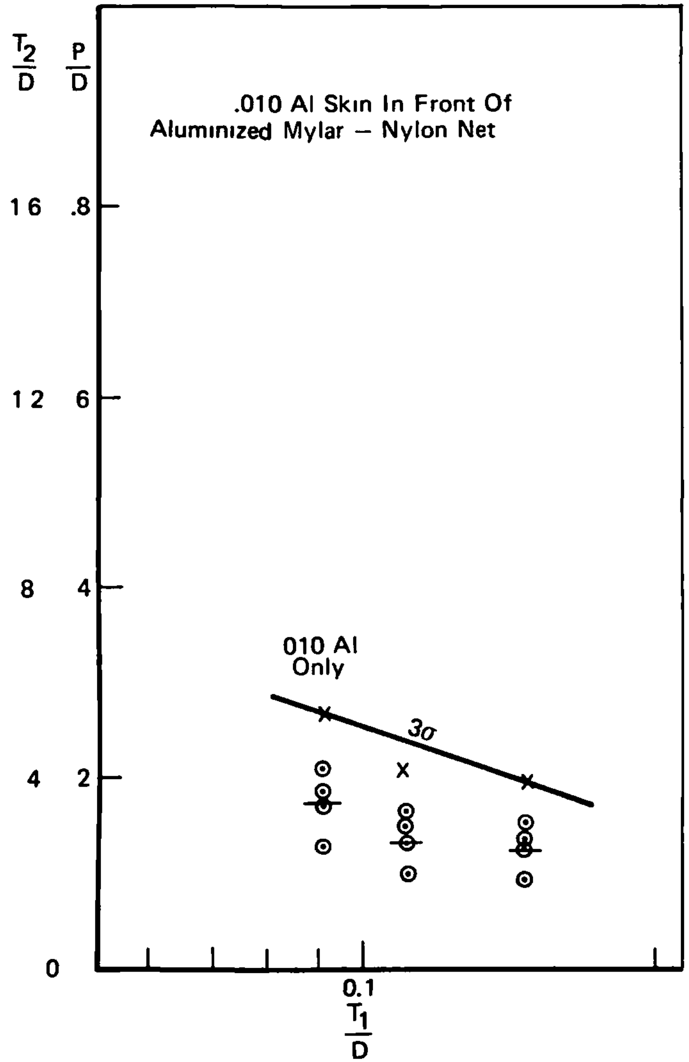

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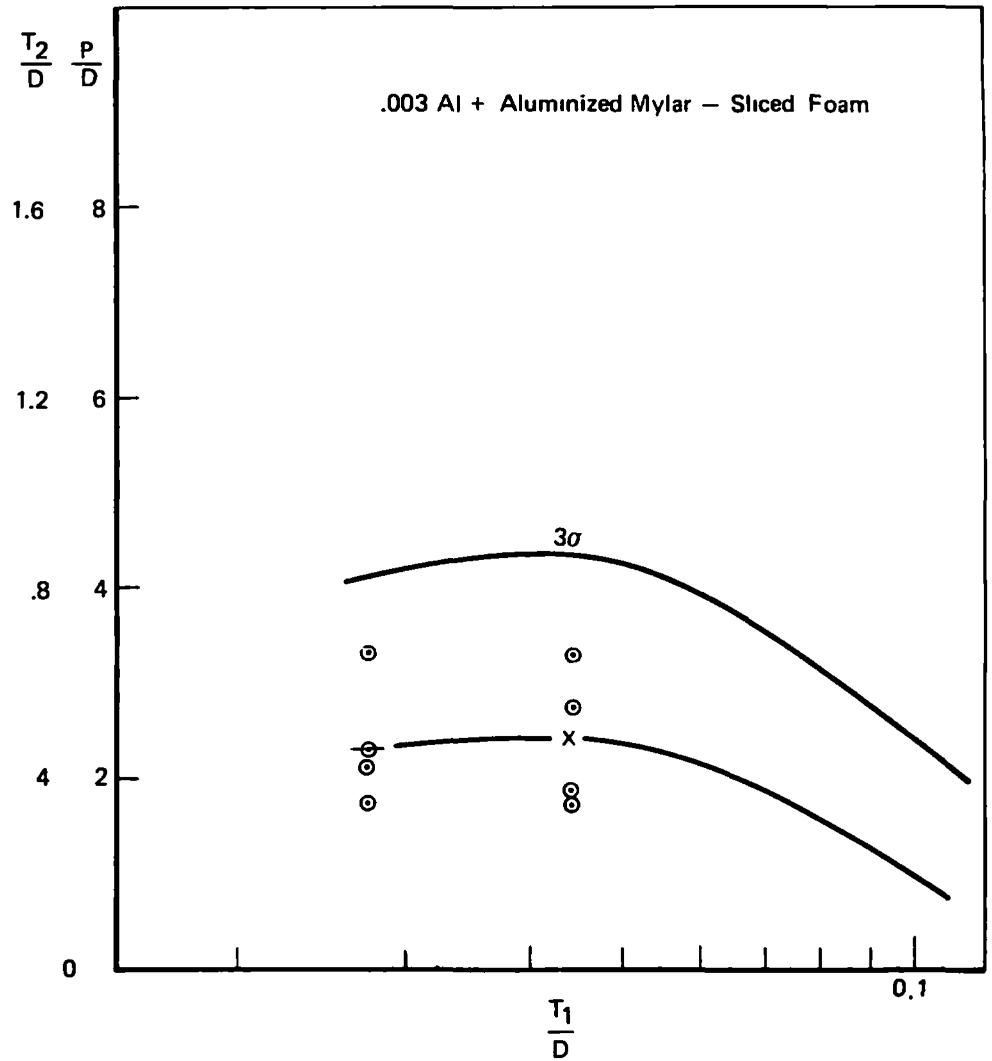

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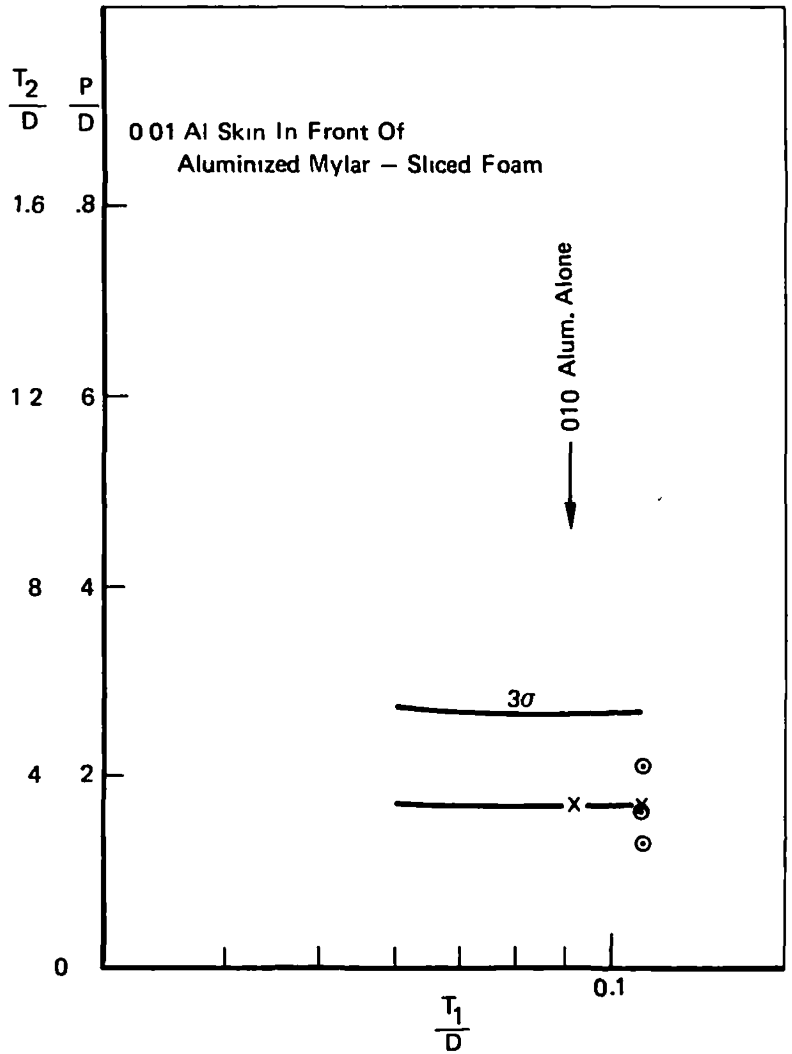
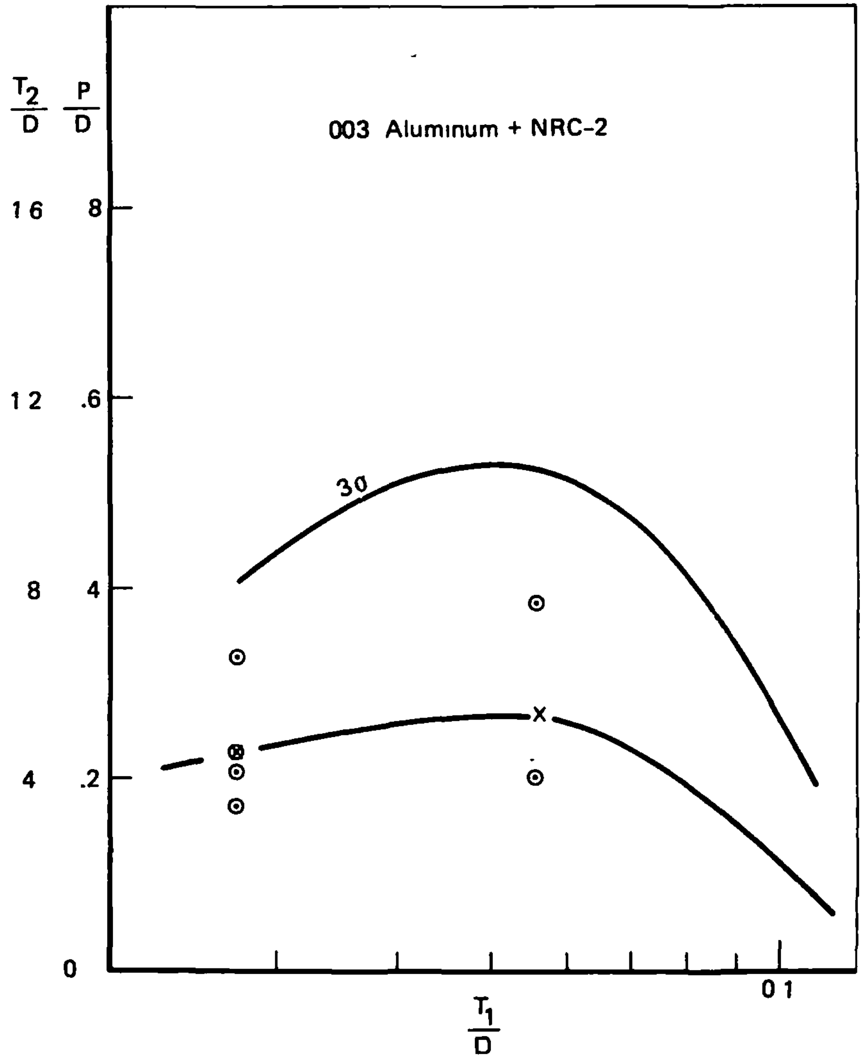


FIGURE C-26: METEOROID PROTECTION DESIGN DATA - SINGLE SHEET AND MLI



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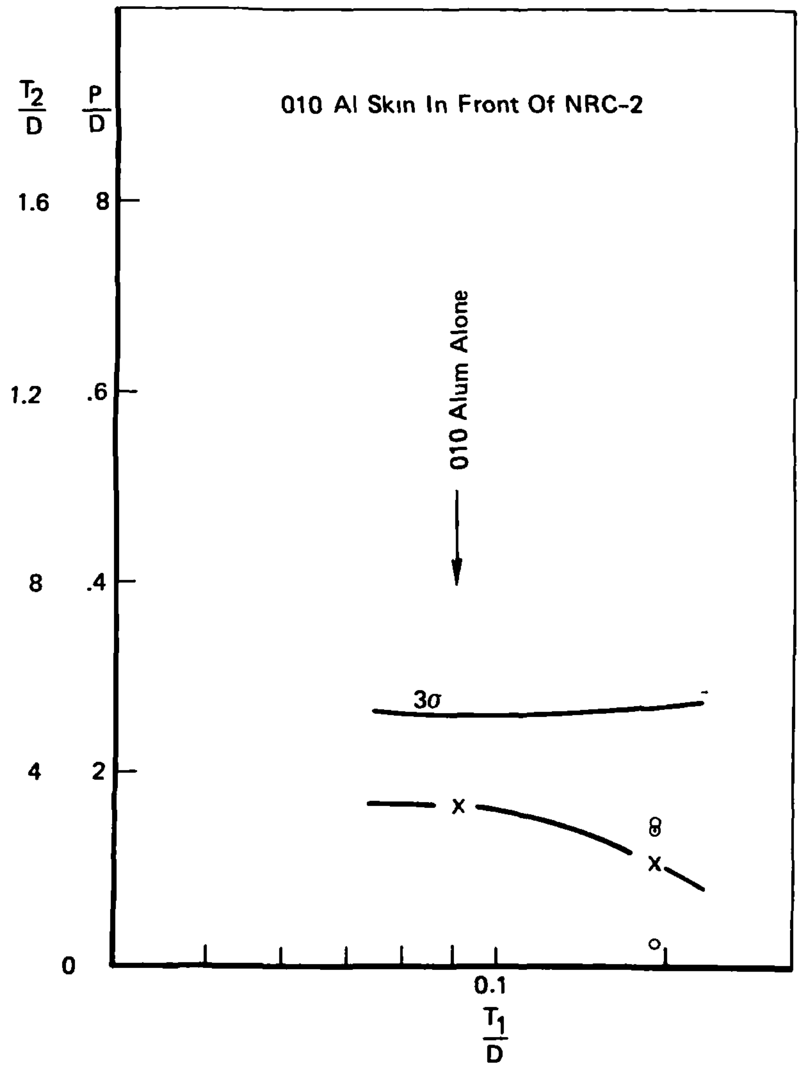

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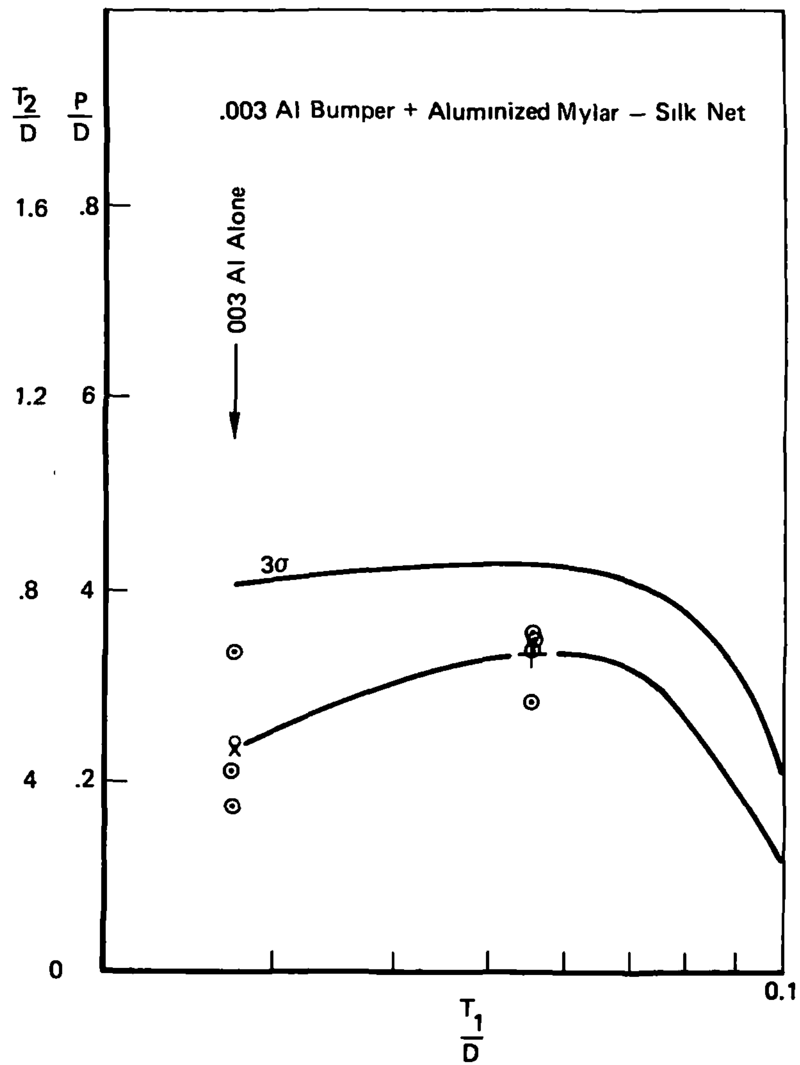

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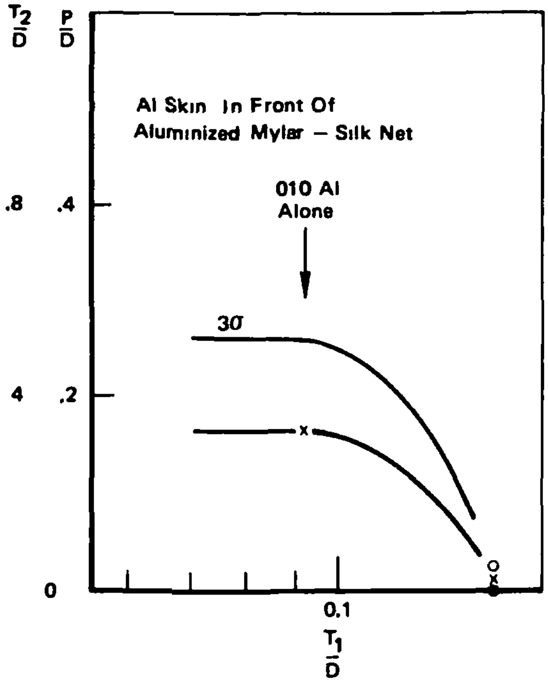

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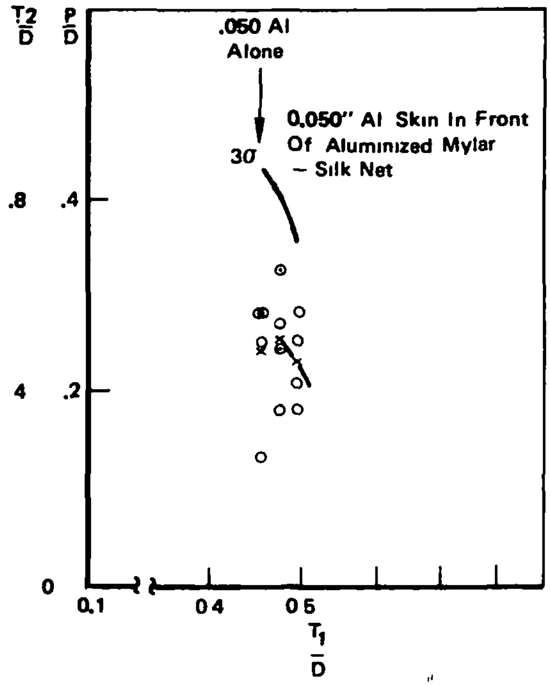

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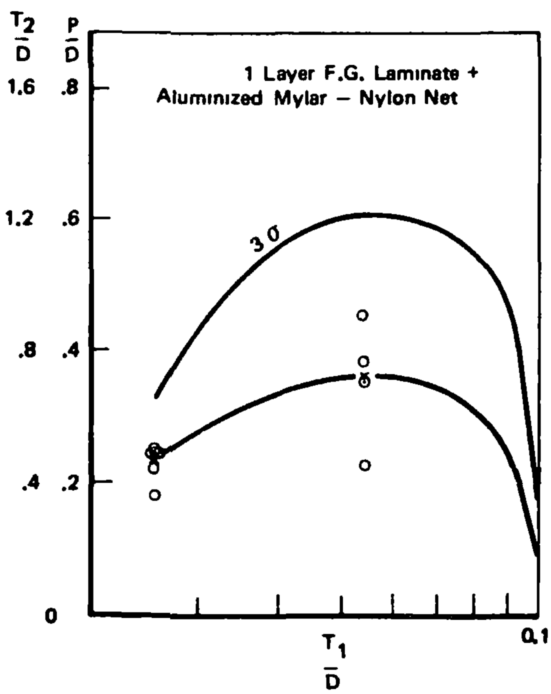

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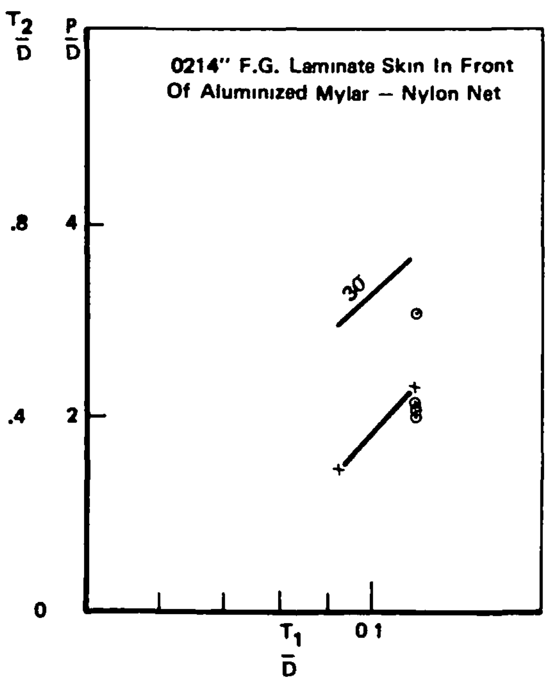

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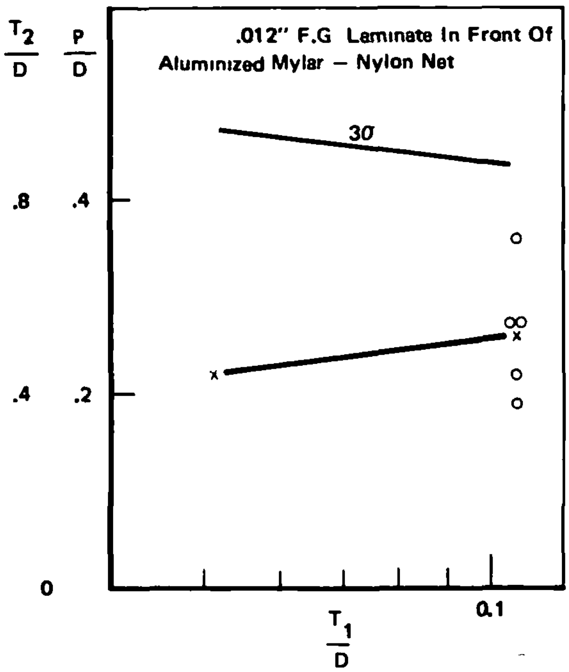

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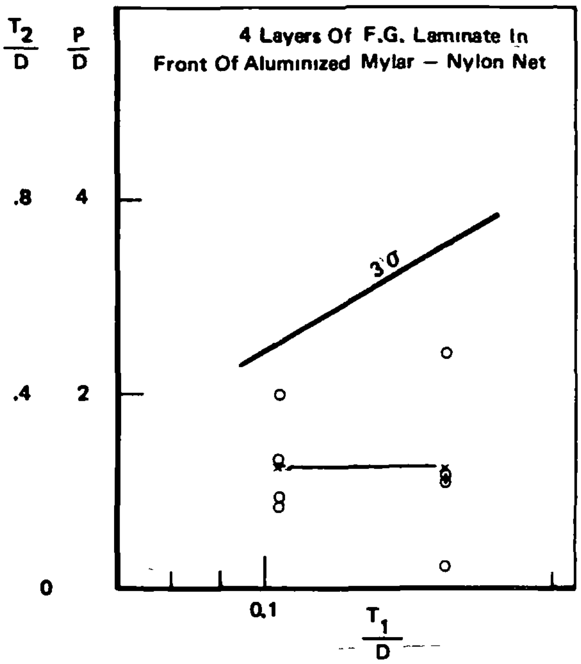

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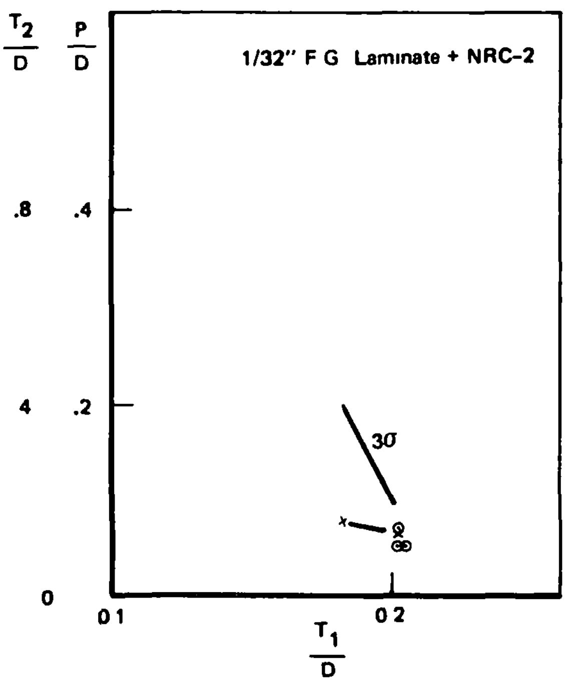

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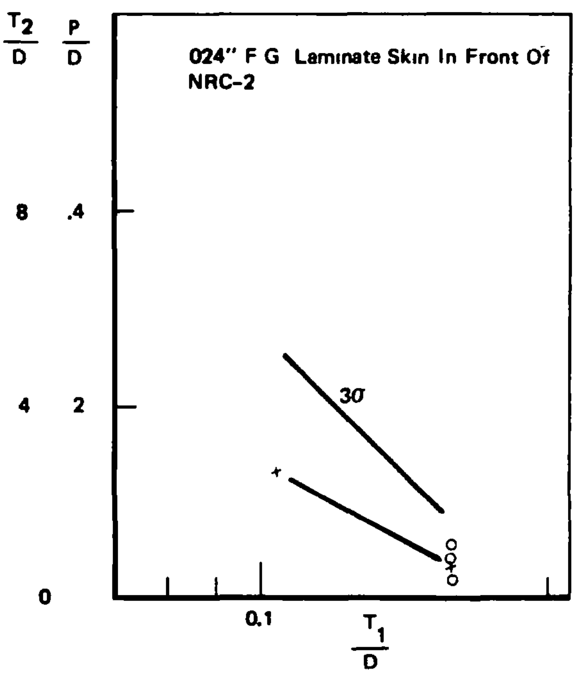

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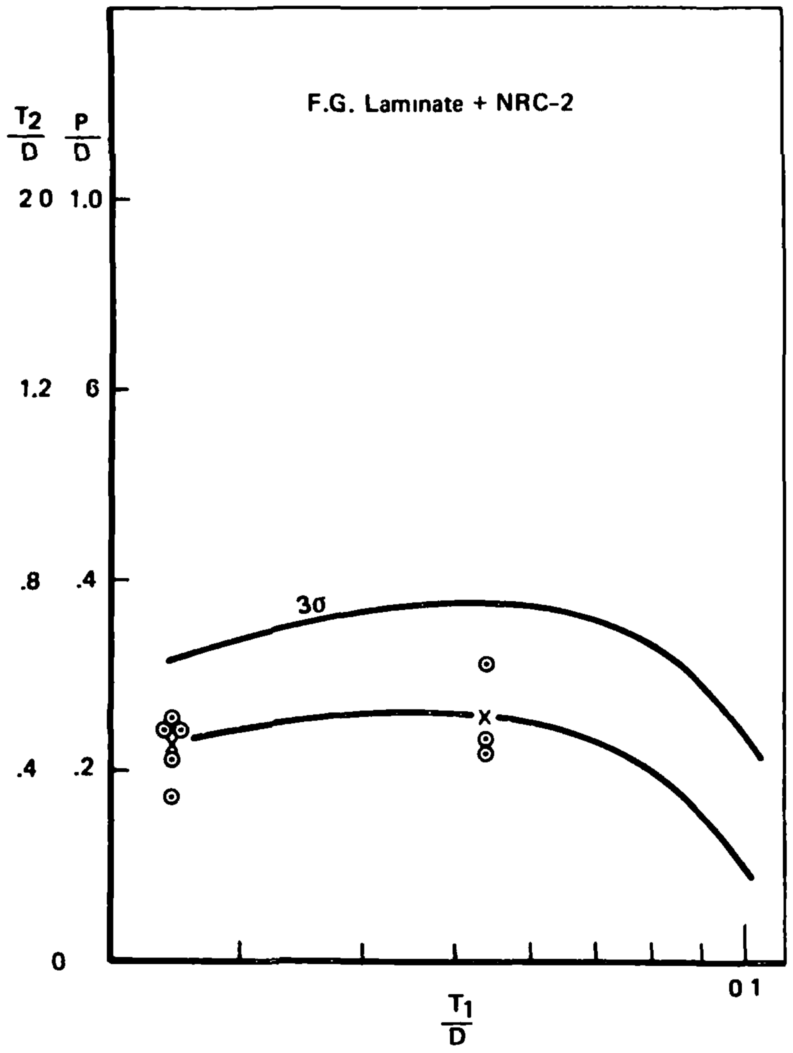

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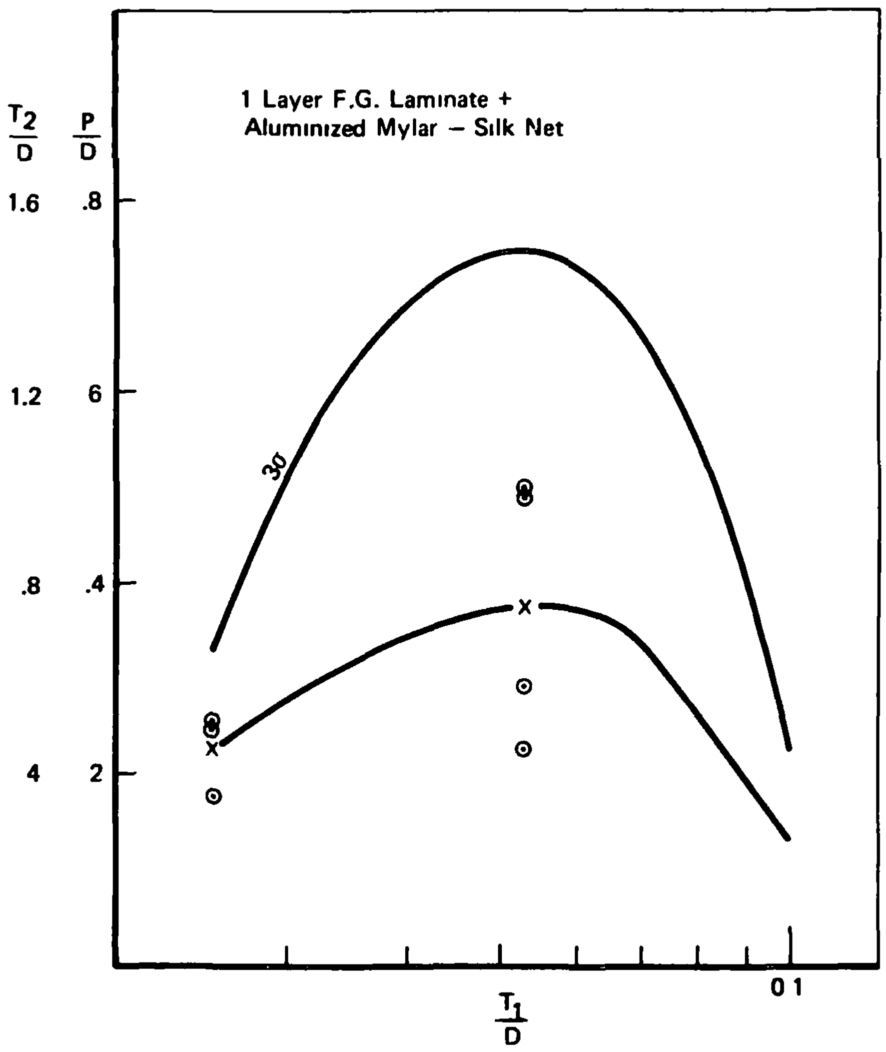

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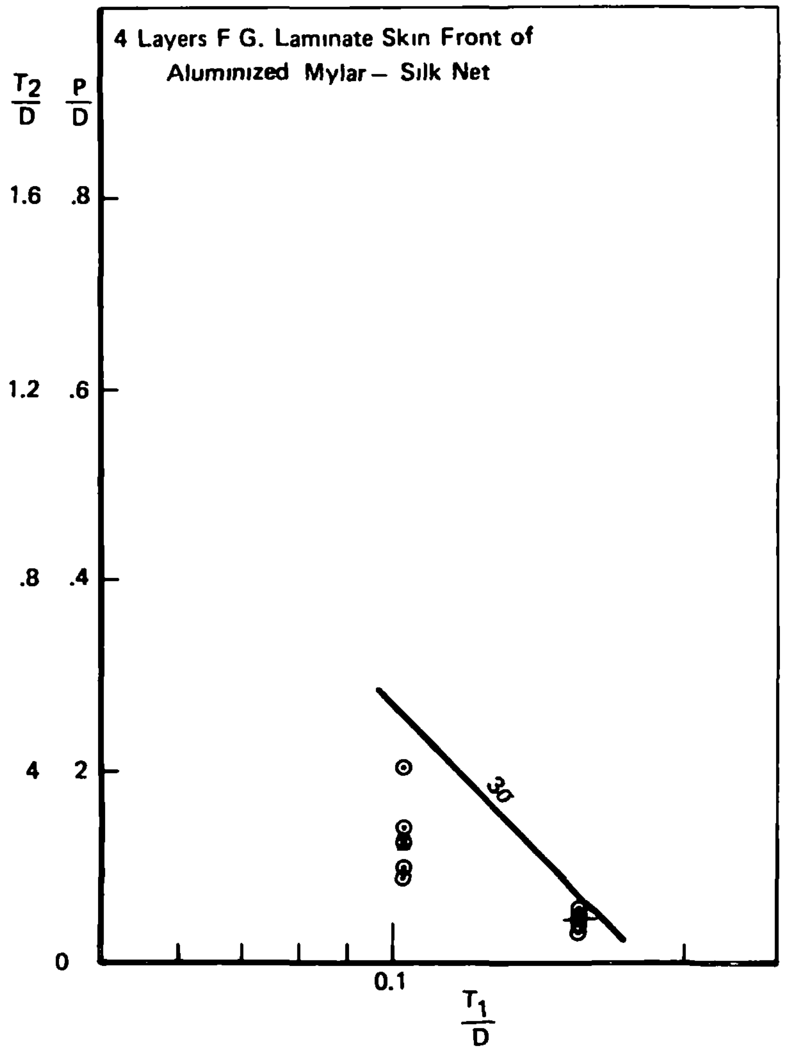

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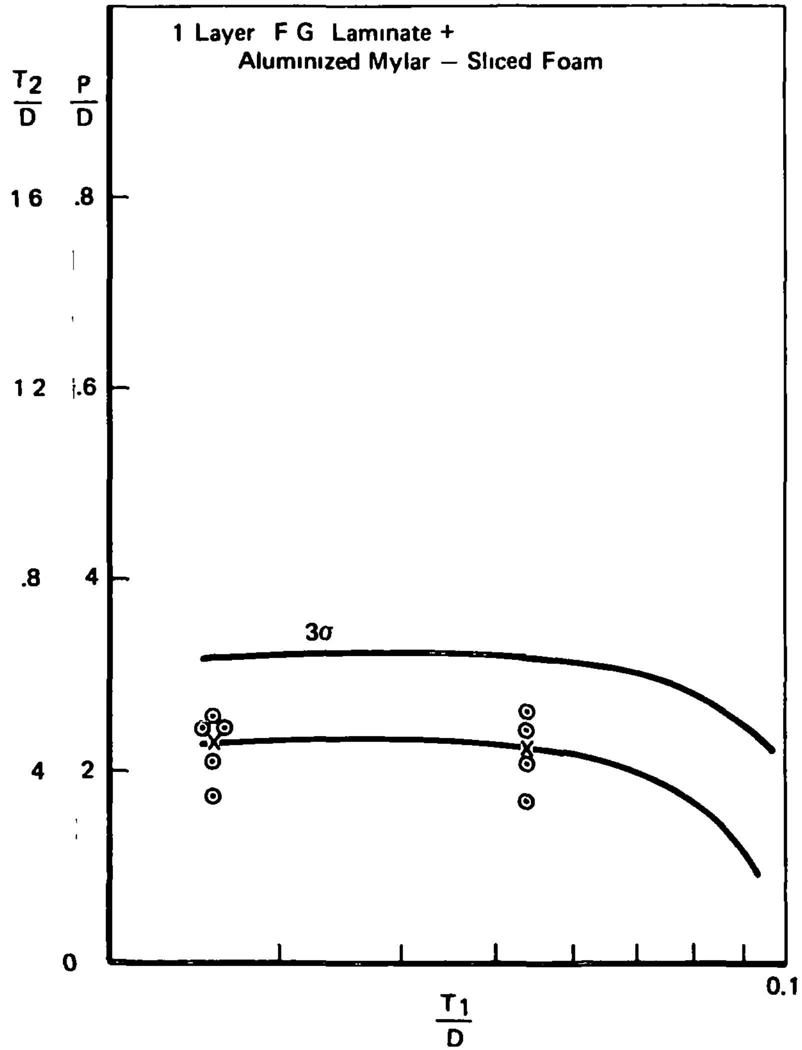


FIGURE C-41: METEOROID PROTECTION DESIGN DATA - SINGLE SHEET AND MLI

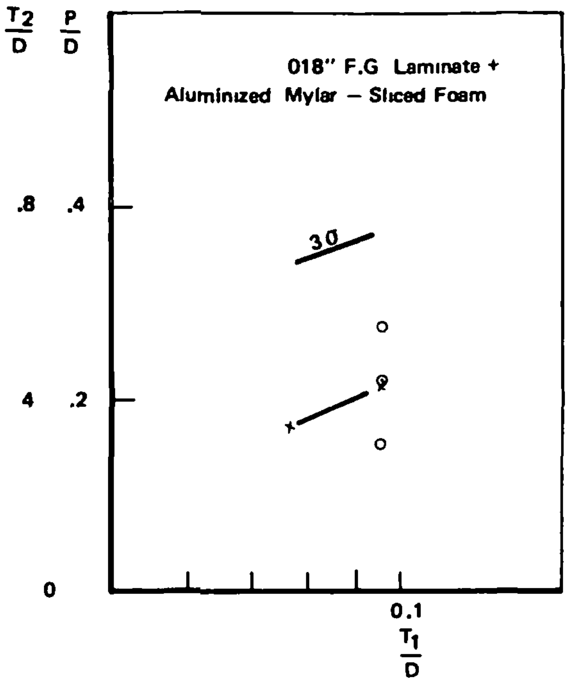


FIGURE C-42: METEOROID PROTECTION DESIGN DATA - SINGLE SHEET AND MLI

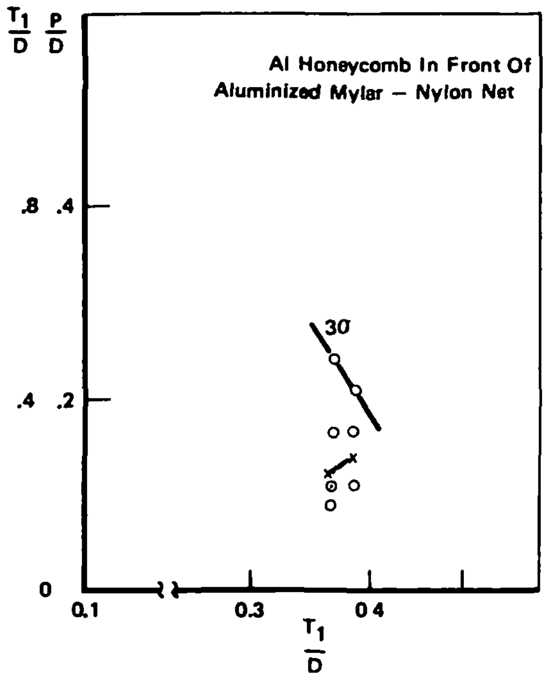


FIGURE C-43: METEOROID PROTECTION DESIGN DATA - SANDWICH AND MLI

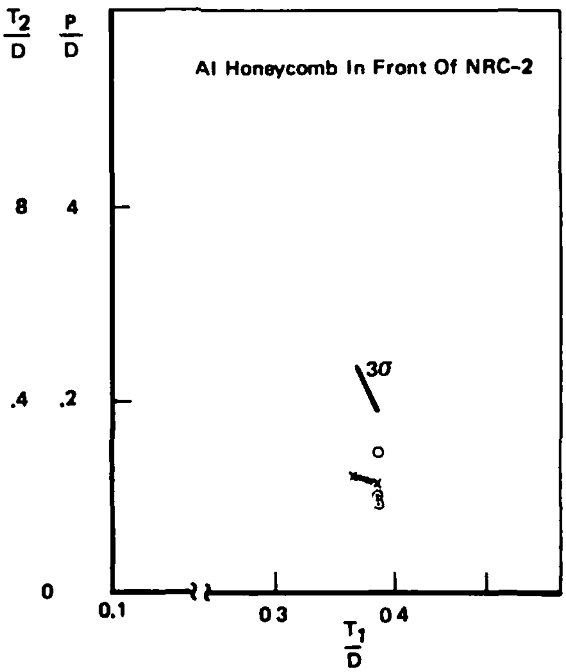


FIGURE C-44: METEOROID PROTECTION DESIGN DATA - SANDWICH AND MLI

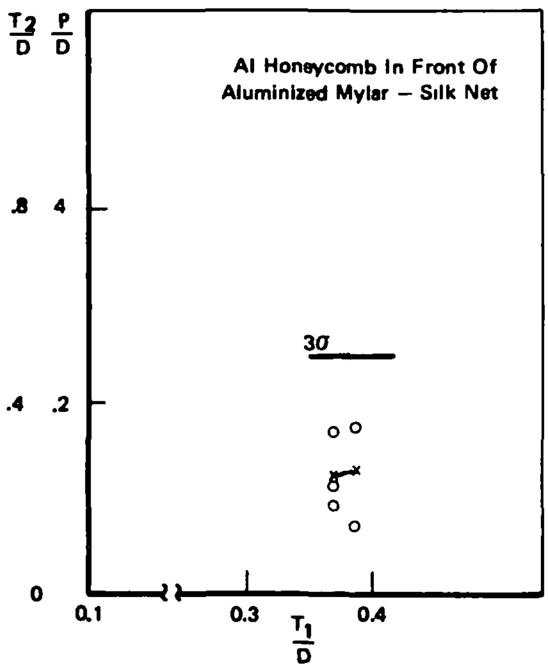


FIGURE C-45: METEOROID PROTECTION DESIGN DATA - SANDWICH AND MLI

Al

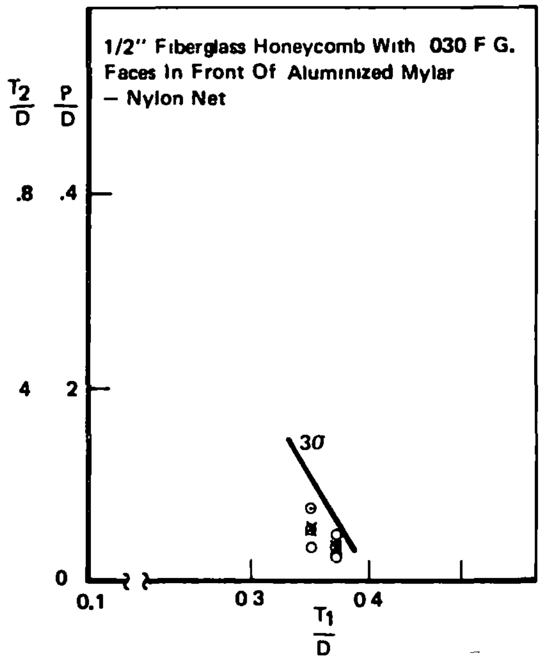


FIGURE C-46: METEOROID PROTECTION DESIGN DATA-SANDWICH AND MLI

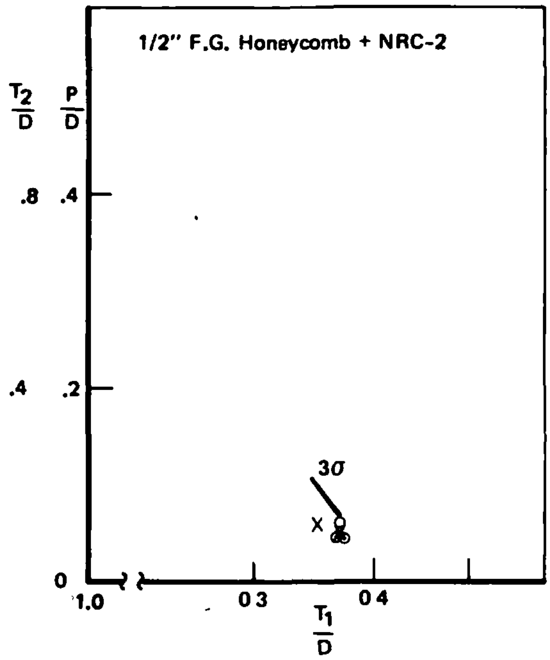


FIGURE C-47: METEOROID PROTECTION DESIGN DATA-SANDWICH AND MLI

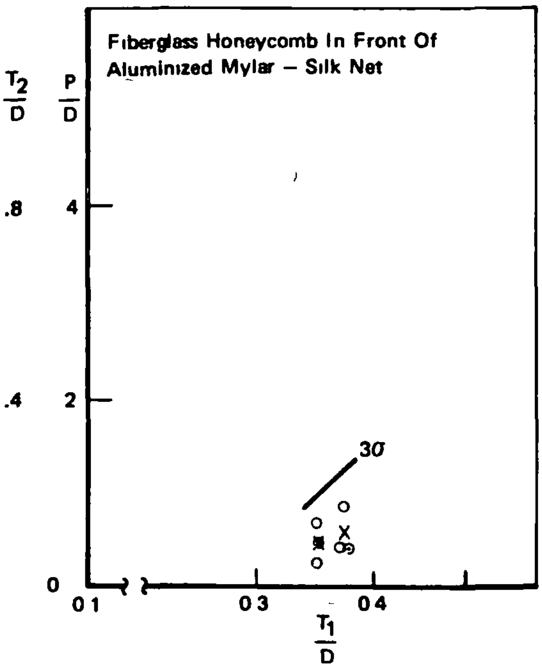


FIGURE C-48: METEOROID PROTECTION DESIGN DATA-SANDWICH AND MLI

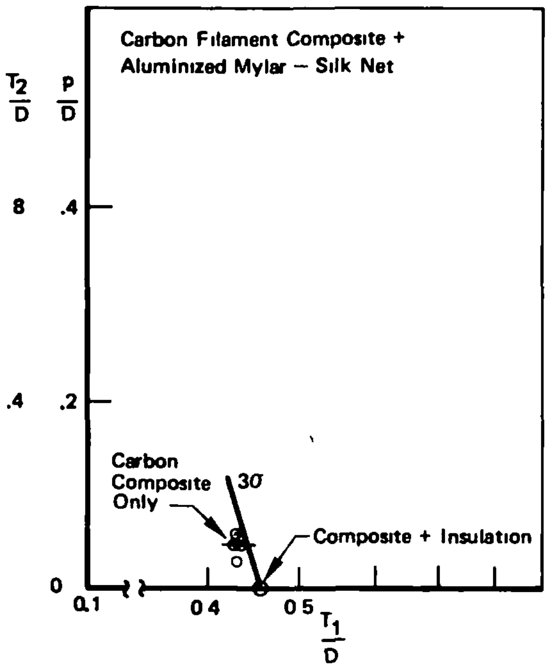


FIGURE C-49: METEOROID PROTECTION DESIGN DATA-SANDWICH SINGLE SHEET AND MLI

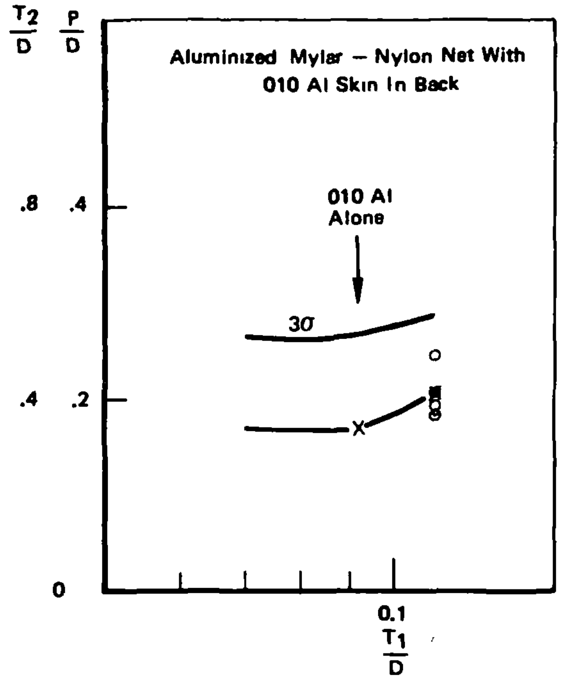


FIGURE C-50: METEOROID PROTECTION DESIGN DATA - MLI AND SINGLE SHEET

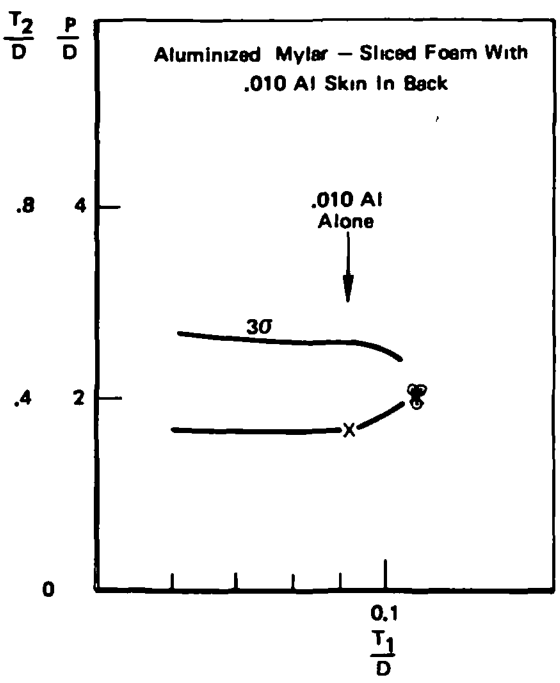


FIGURE C-51: METEOROID PROTECTION DESIGN DATA - MLI AND SINGLE SHEET

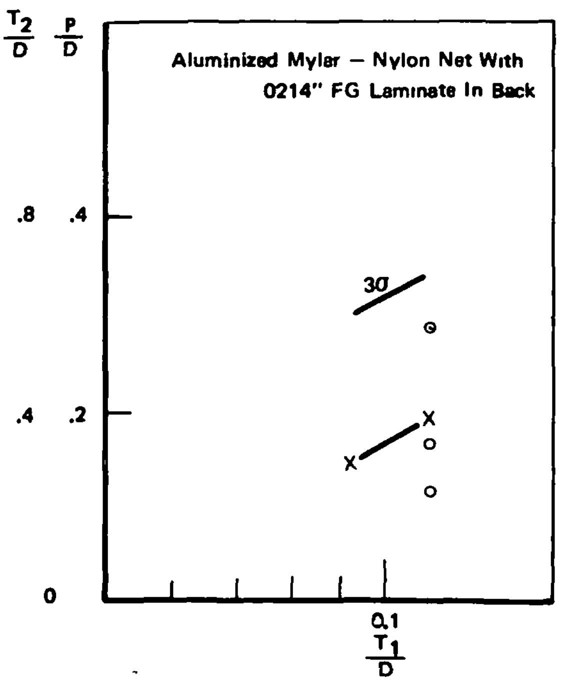


FIGURE C-52: METEOROID PROTECTION DESIGN DATA - MLI AND SINGLE SHEET

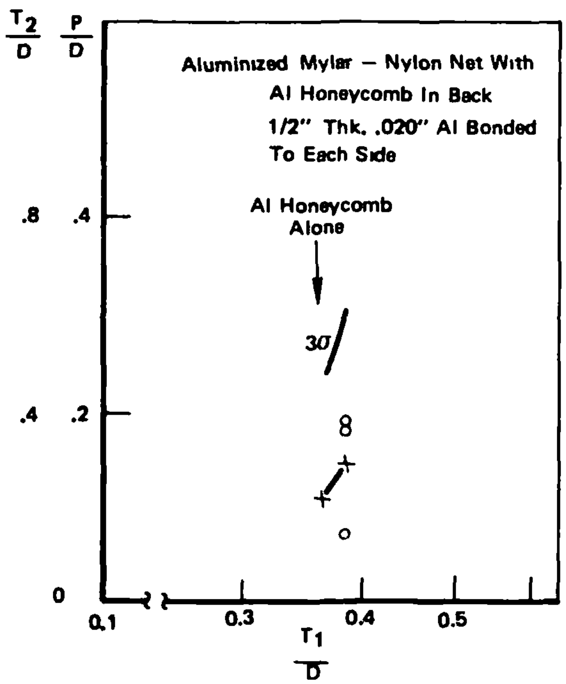


FIGURE C-53: METEOROID PROTECTION DESIGN DATA - MLI AND SANDWICH

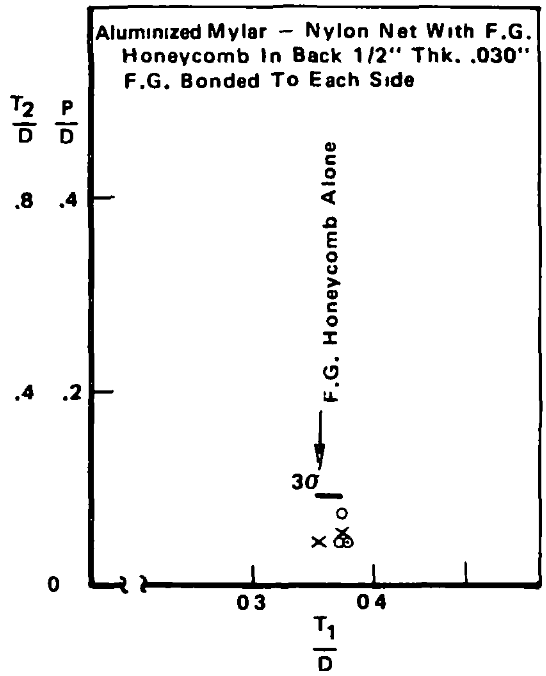


FIGURE C-54: METEOROID PROTECTION DESIGN DATA-MLI AND SANDWICH

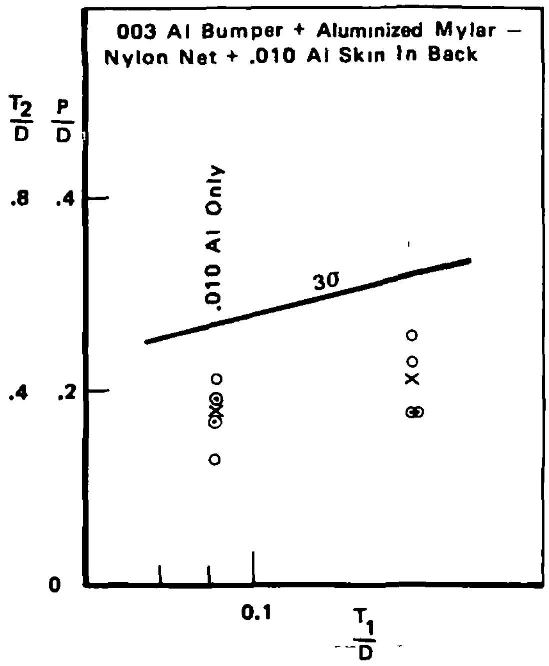


FIGURE C-55: METEOROID PROTECTION DESIGN DATA-SINGLE SHEETS AND MLI

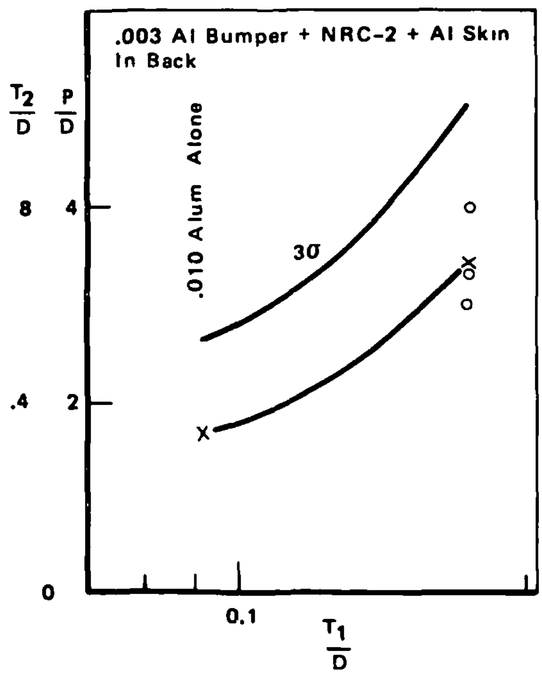


FIGURE C-56: METEOROID PROTECTION DESIGN DATA-SINGLE SHEETS AND MLI

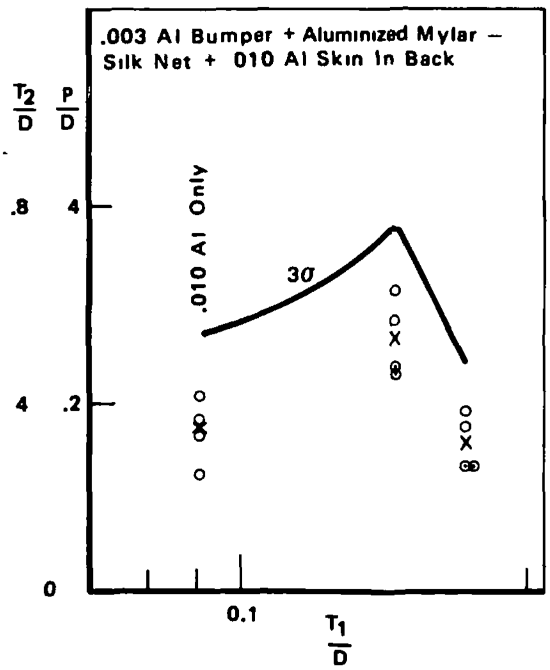


FIGURE C-57: METEOROID PROTECTION DESIGN DATA-SINGLE SHEETS AND MLI

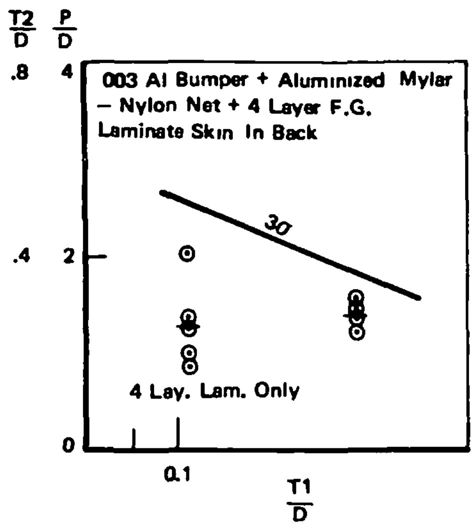


FIGURE C-58: METEOROID PROTECTION DESIGN DATA - SINGLE SHEETS AND MLI

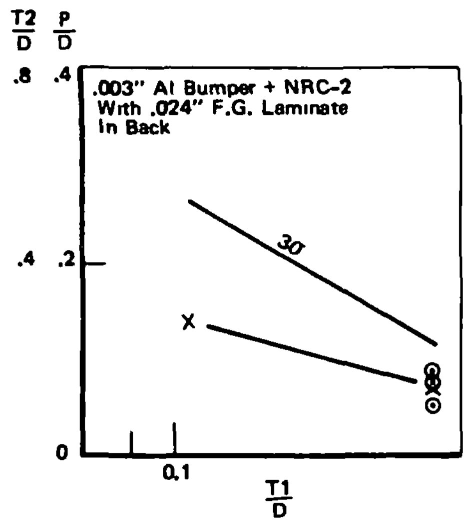


FIGURE C-59: METEOROID PROTECTION DESIGN DATA - SINGLE SHEETS AND MLI

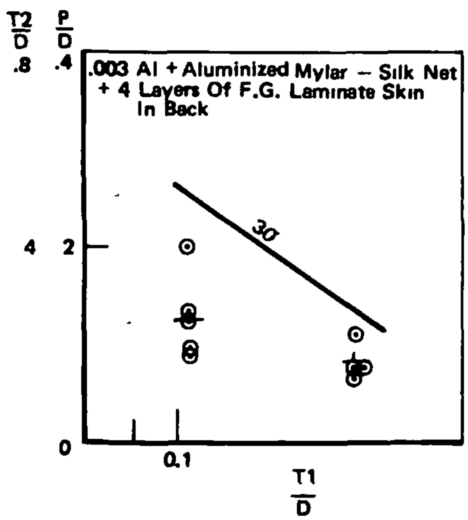


FIGURE C-60: METEOROID PROTECTION DESIGN DATA-SINGLE SHEETS AND MLI

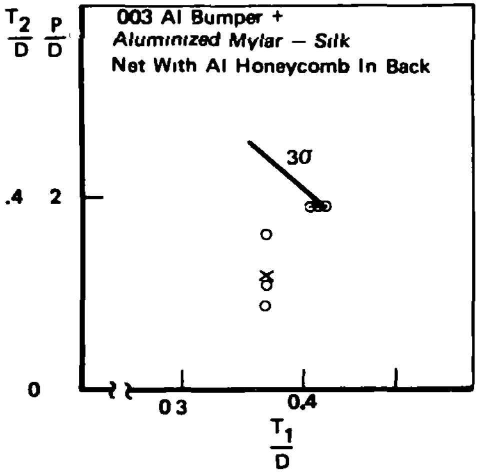


FIGURE C-61: METEOROID PROTECTION DESIGN DATA - SINGLE SHEET, MLI AND SANDWICH

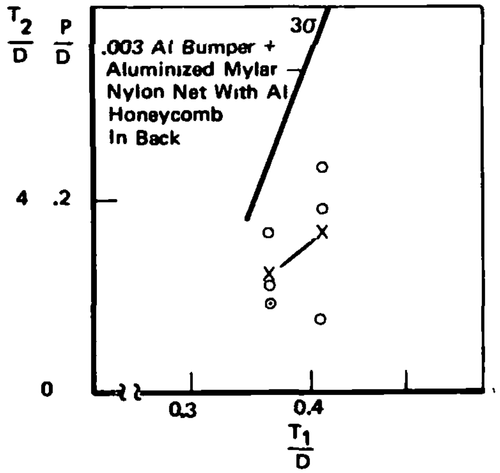


FIGURE C-62: METEOROID PROTECTION DESIGN DATA - SINGLE SHEET, MLI AND SANDWICH

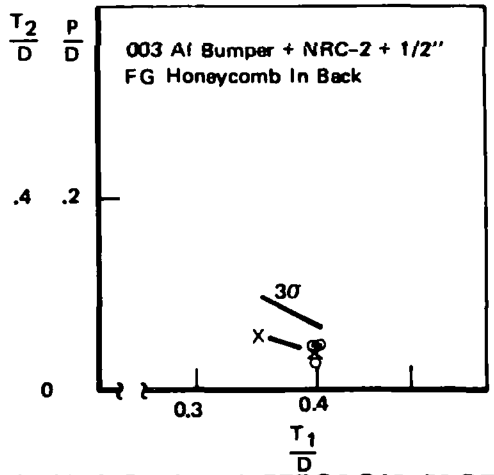


FIGURE C-63: METEOROID PROTECTION DESIGN DATA - SINGLE SHEET, MLI AND SANDWICH

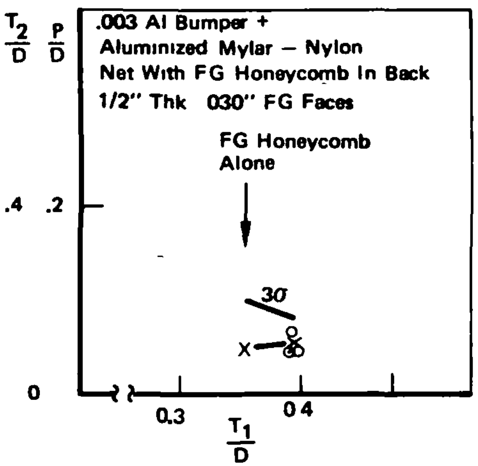


FIGURE C-64: METEOROID PROTECTION DESIGN DATA - SINGLE SHEET, MLI AND SANDWICH

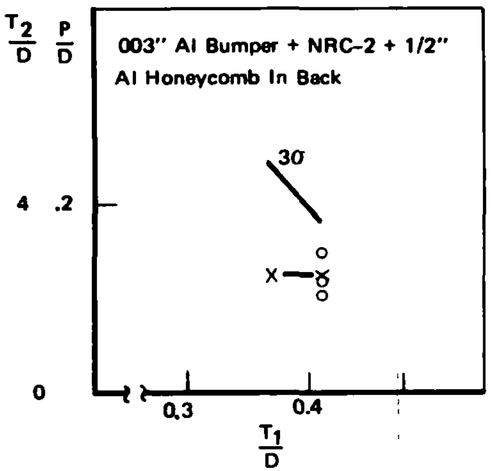


FIGURE C-65: METEOROID PROTECTION DESIGN DATA - SINGLE SHEET, MLI AND SANDWICH

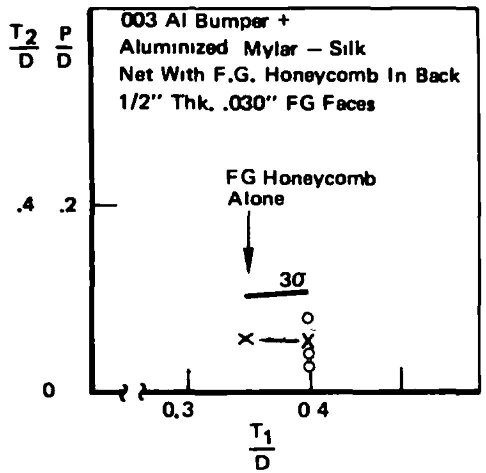


FIGURE C-66: METEOROID PROTECTION DESIGN DATA - SINGLE SHEET, MLI AND SANDWICH

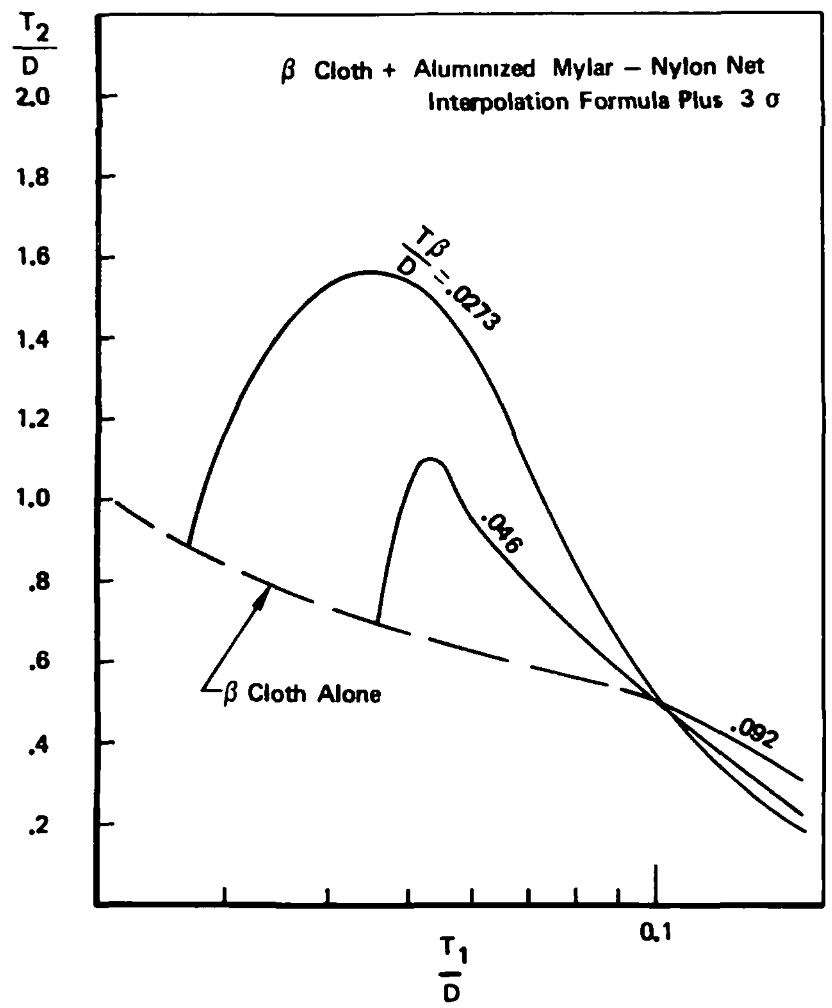


FIGURE C-67: METEOROID PROTECTION DESIGN DATA - MATERIAL COMBINATIONS

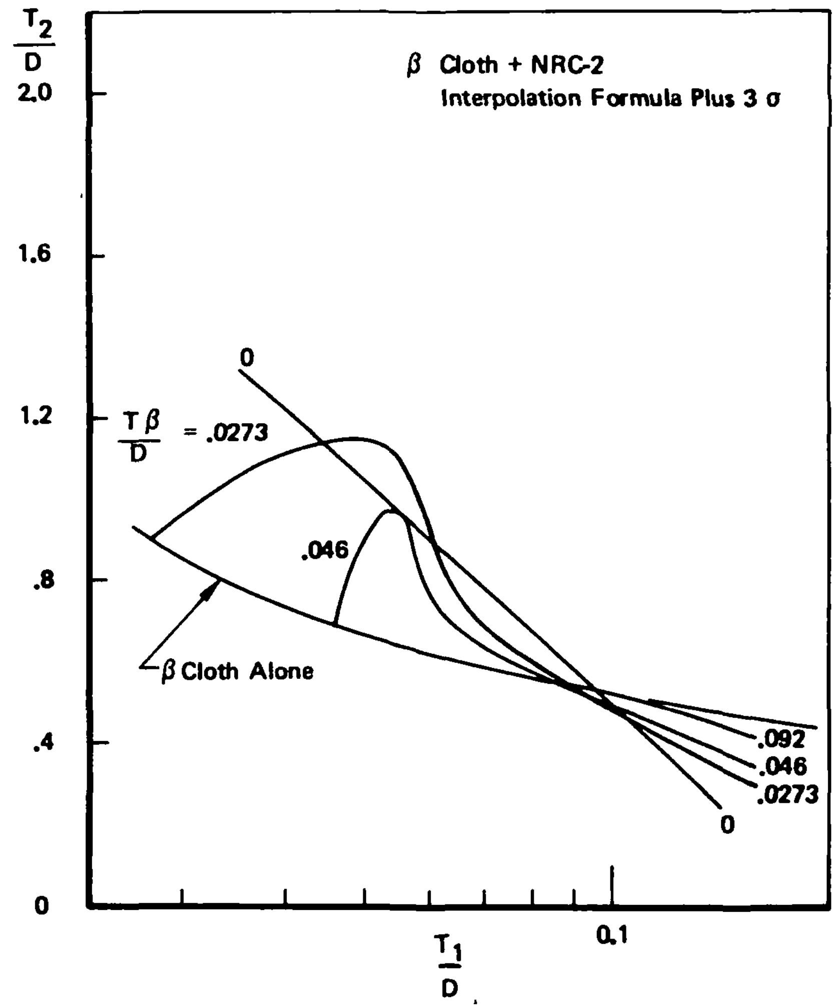


FIGURE C-68: METEOROID PROTECTION DESIGN DATA - MATERIAL COMBINATIONS

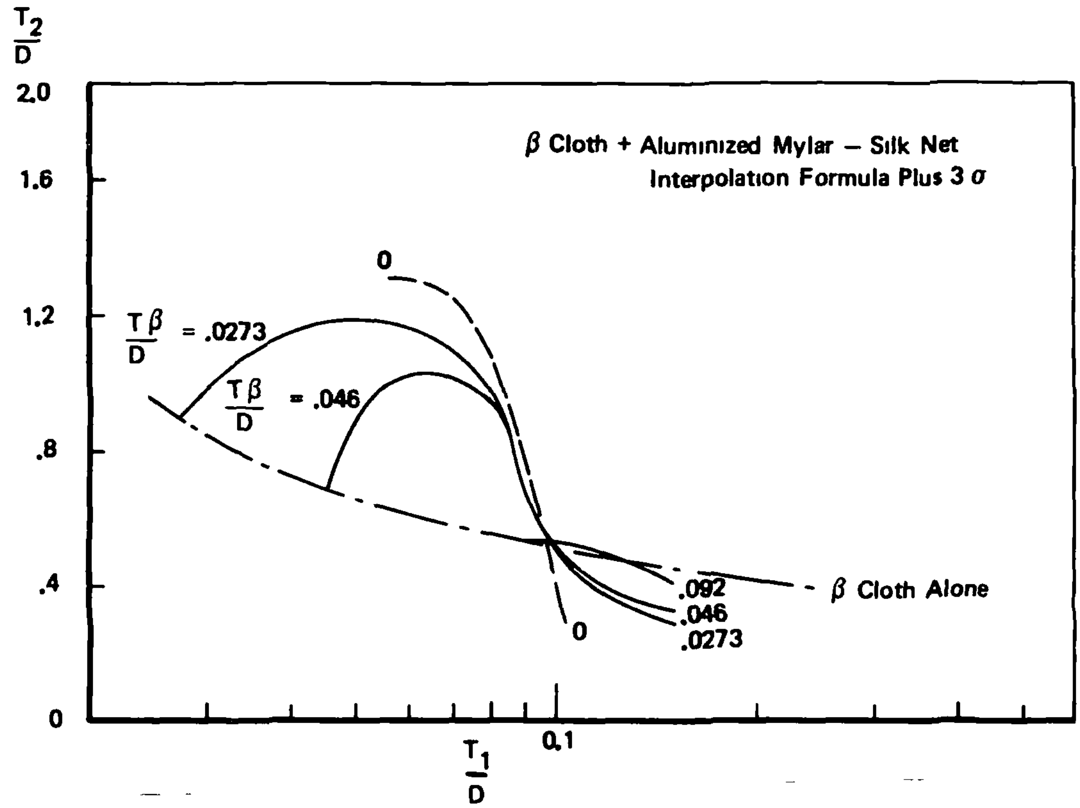


FIGURE C-69: METEOROID PROTECTION DESIGN DATA - MATERIAL COMBINATIONS

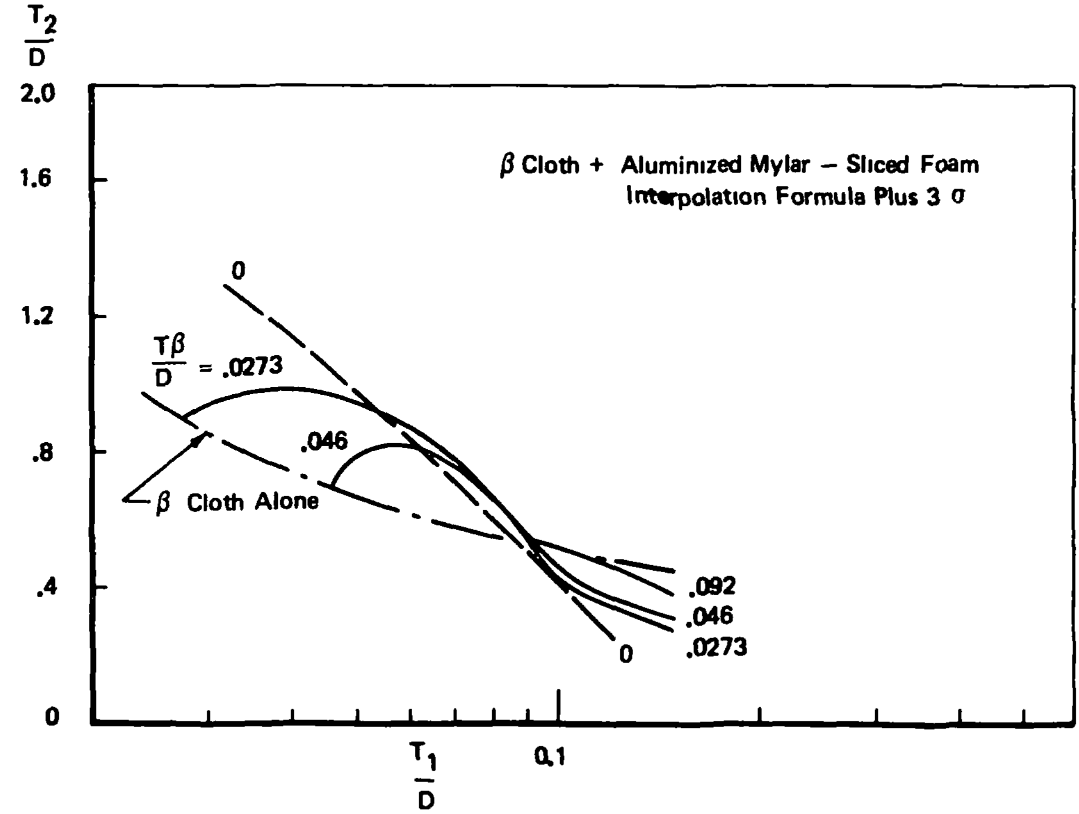


FIGURE C-70: METEOROID PROTECTION DESIGN DATA - MATERIAL COMBINATIONS

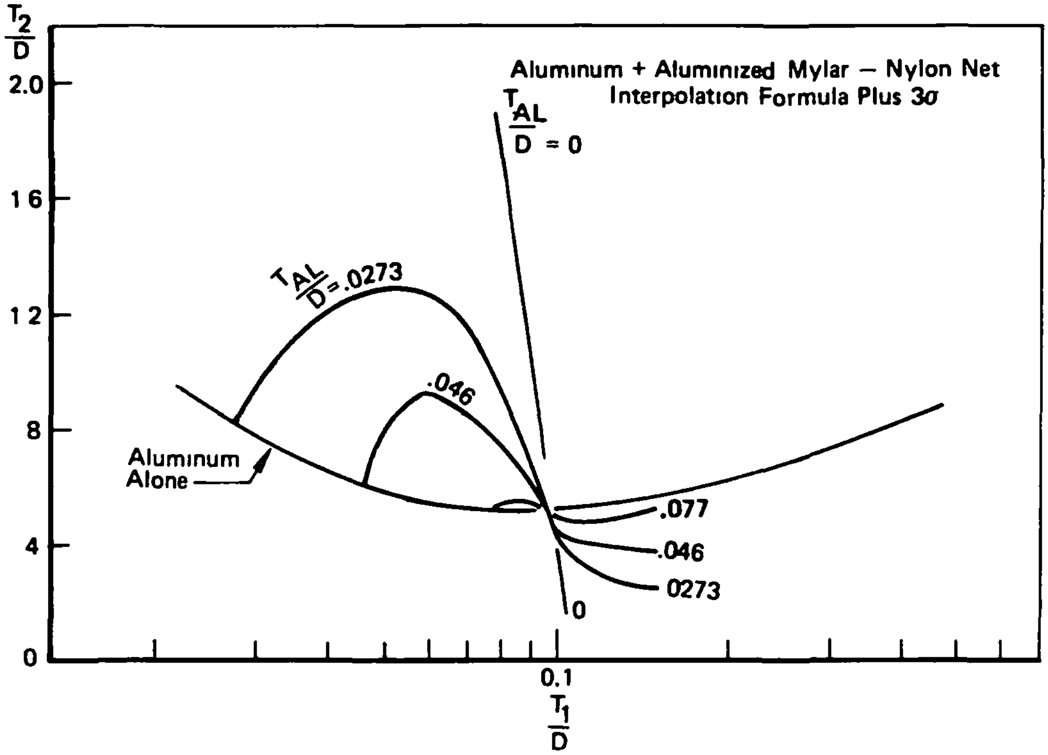


FIGURE C-71: METEOROID PROTECTION DESIGN DATA - MATERIAL COMBINATIONS

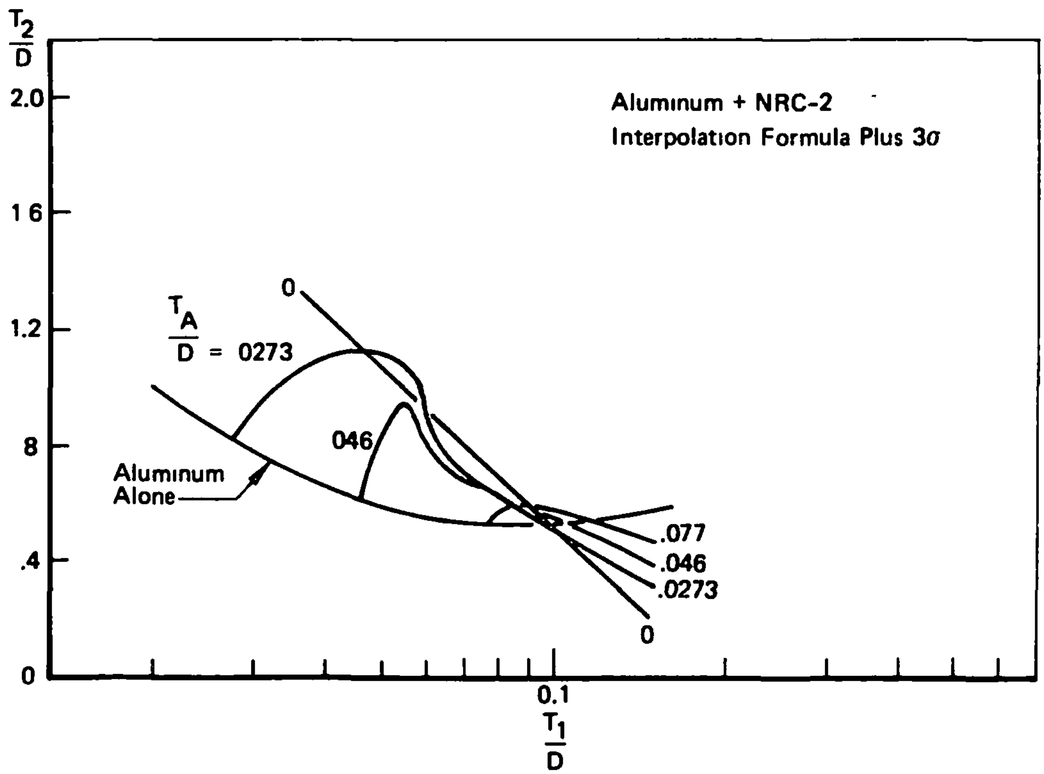


FIGURE C-72: METEOROID PROTECTION DESIGN DATA - MATERIAL COMBINATIONS

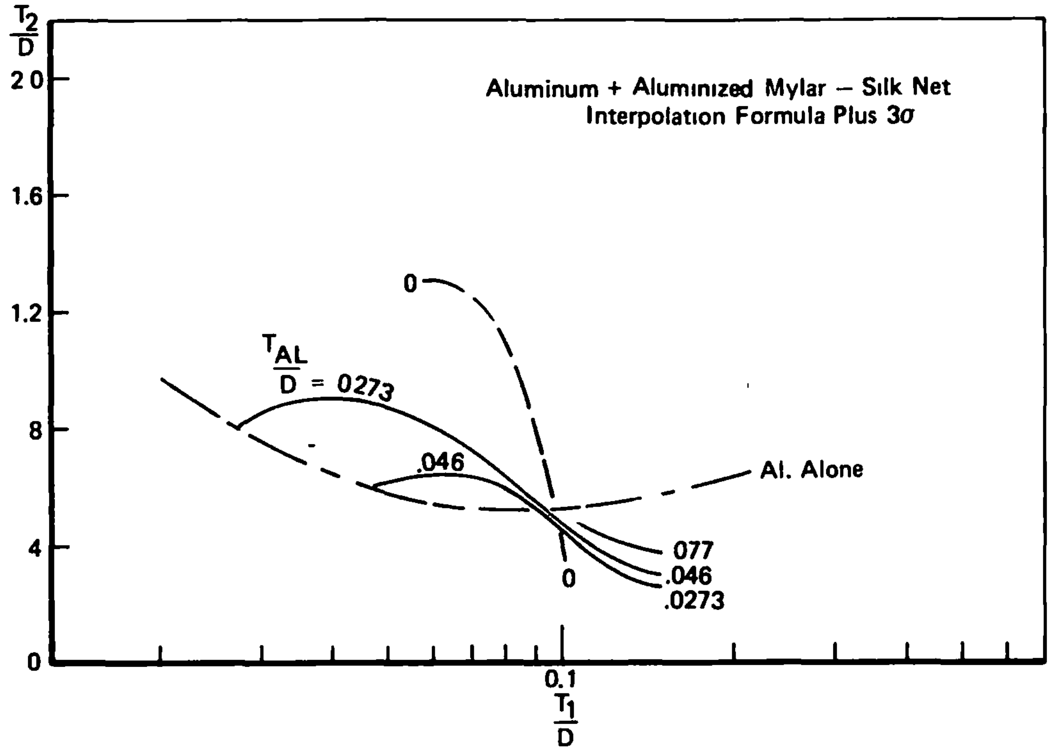


FIGURE C-73: METEOROID PROTECTION DESIGN DATA-MATERIAL COMBINATIONS

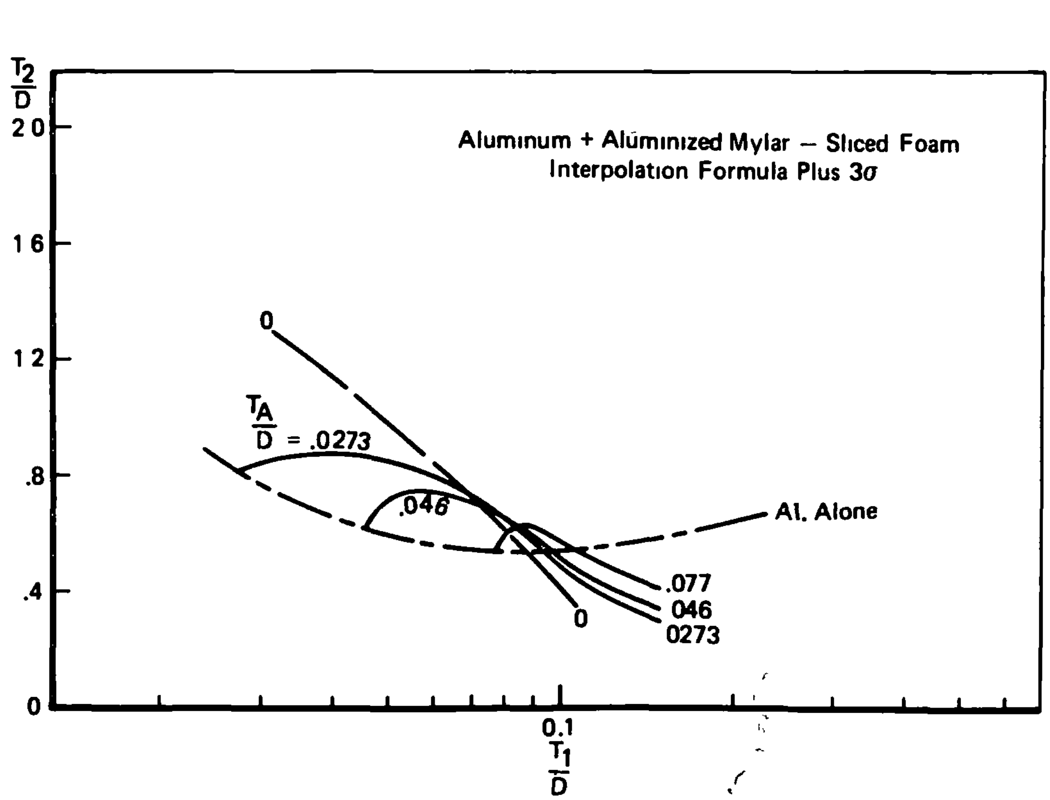


FIGURE C-74: METEOROID PROTECTION DESIGN DATA -MATERIAL COMBINATIONS

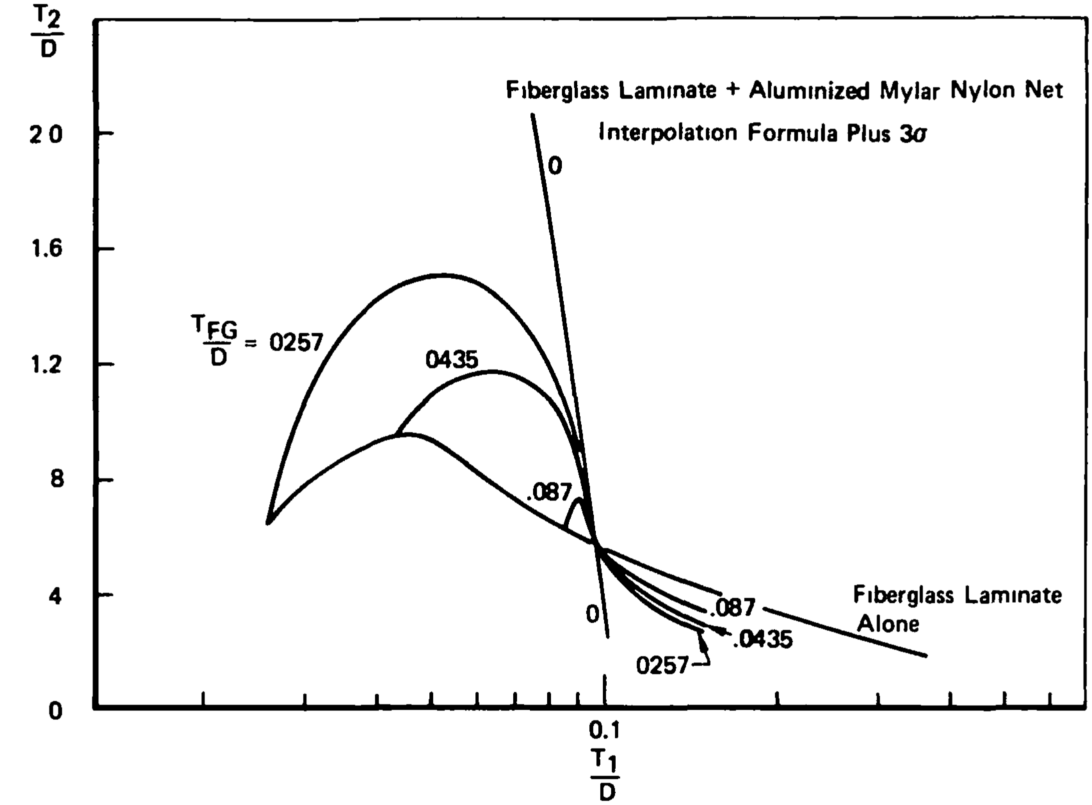


FIGURE C-75: METEOROID PROTECTION DESIGN DATA - MATERIAL COMBINATIONS

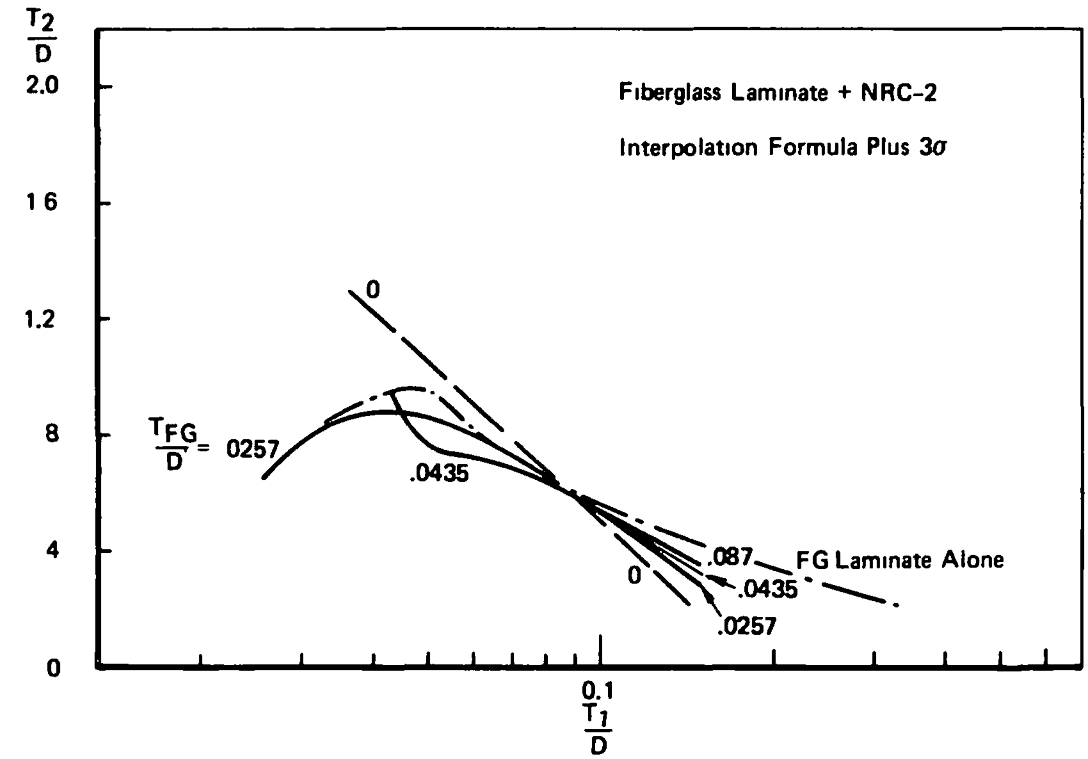


FIGURE C-76: METEOROID PROTECTION DESIGN DATA - MATERIAL COMBINATIONS

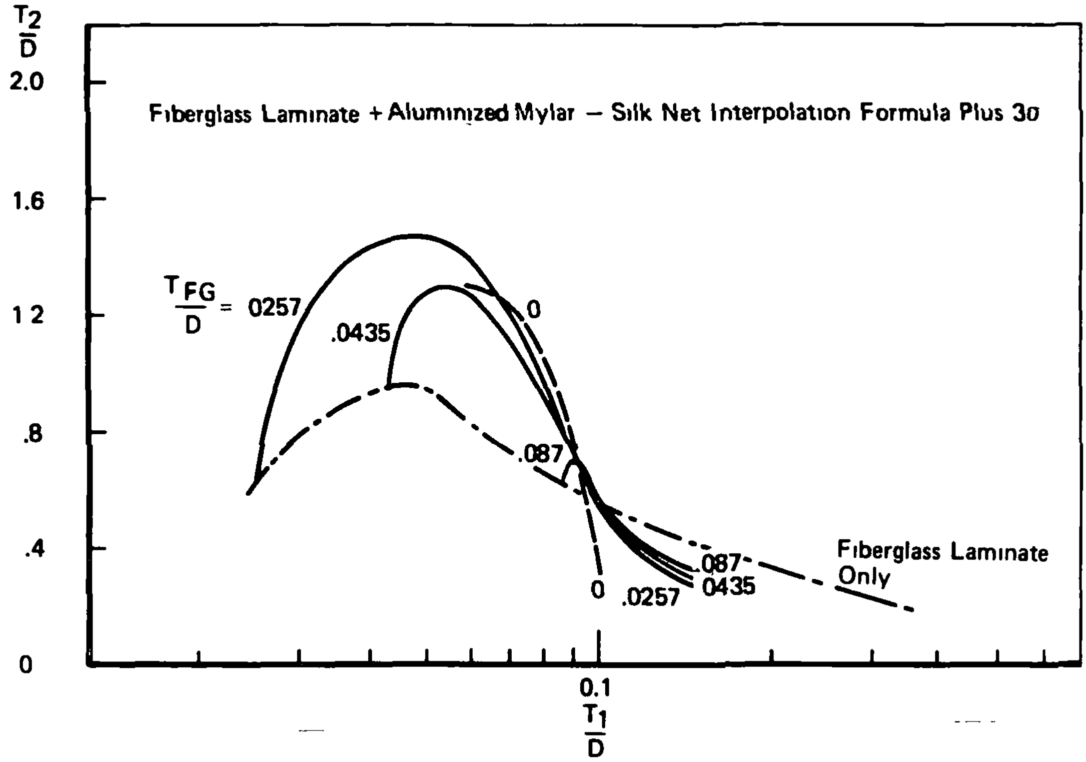


FIGURE C-77: METEOROID PROTECTION DESIGN DATA - MATERIAL COMBINATIONS

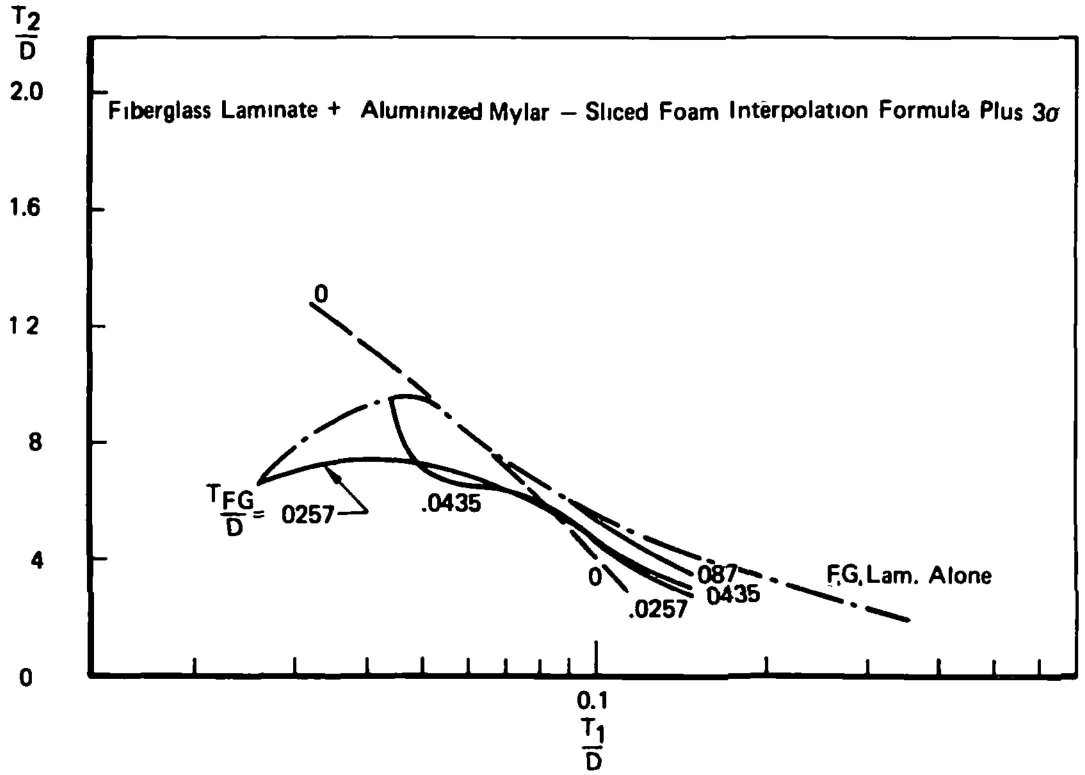


FIGURE C-78: METEOROID PROTECTION DESIGN DATA - MATERIAL COMBINATIONS

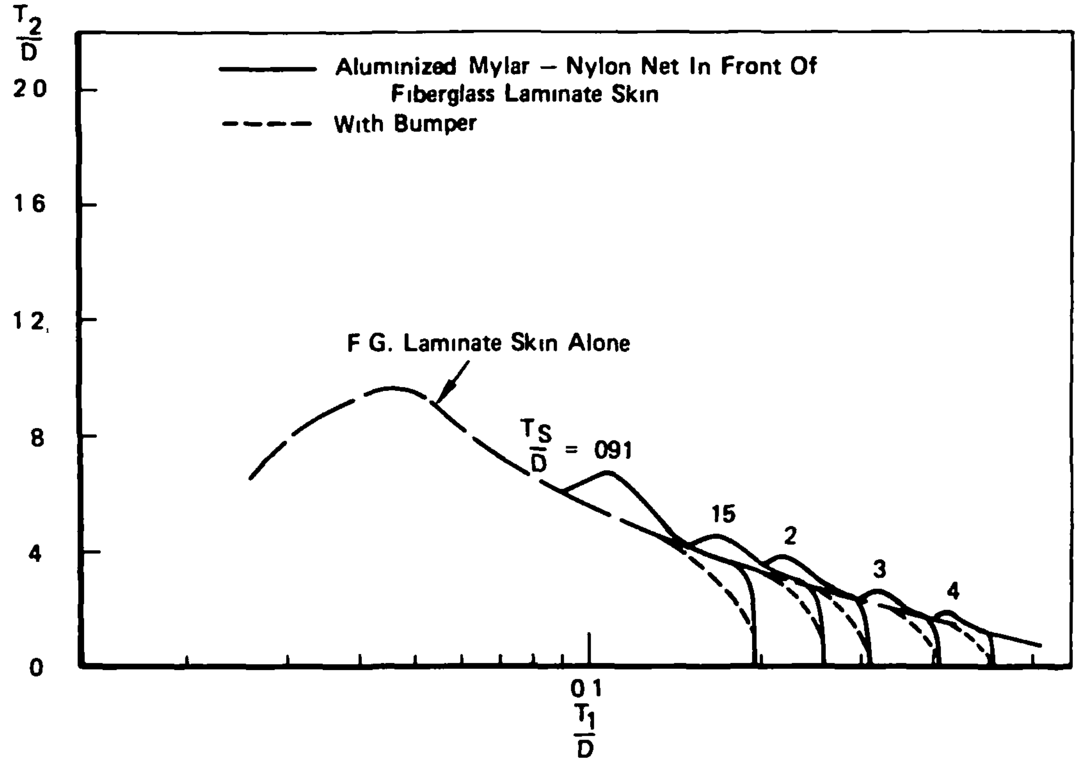


FIGURE C-79: METEOROID PROTECTION DESIGN DATA - MATERIAL COMBINATIONS

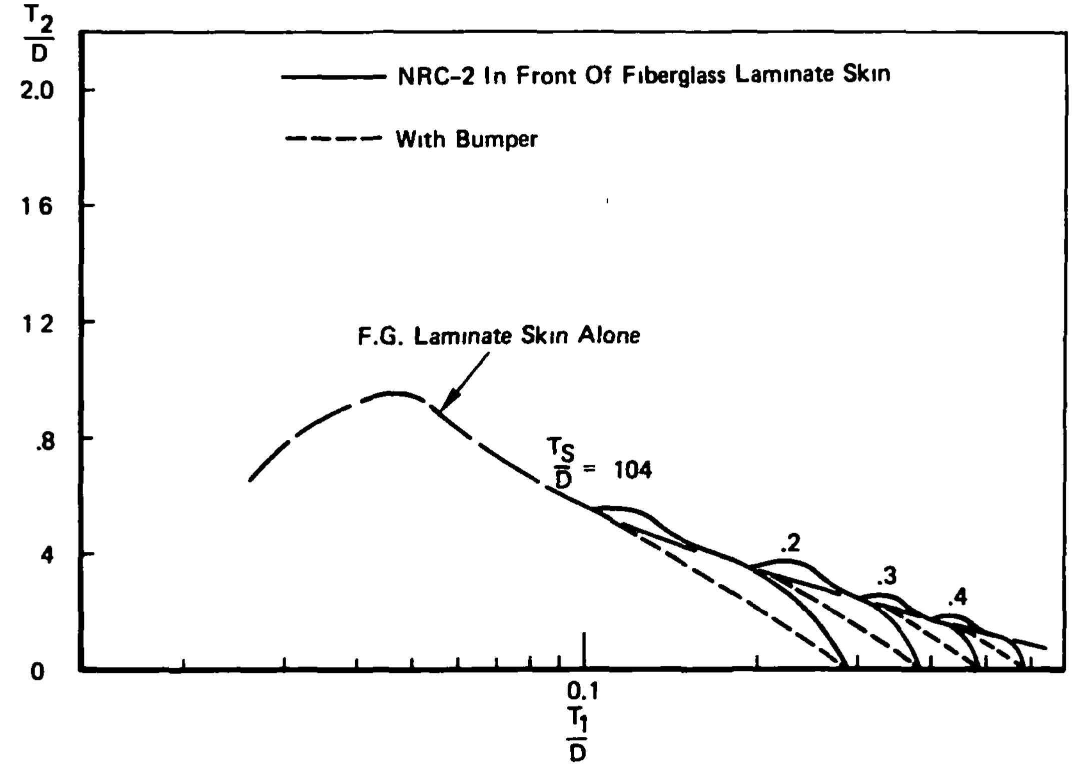


FIGURE C-80: METEOROID PROTECTION DESIGN DATA - MATERIAL COMBINATIONS

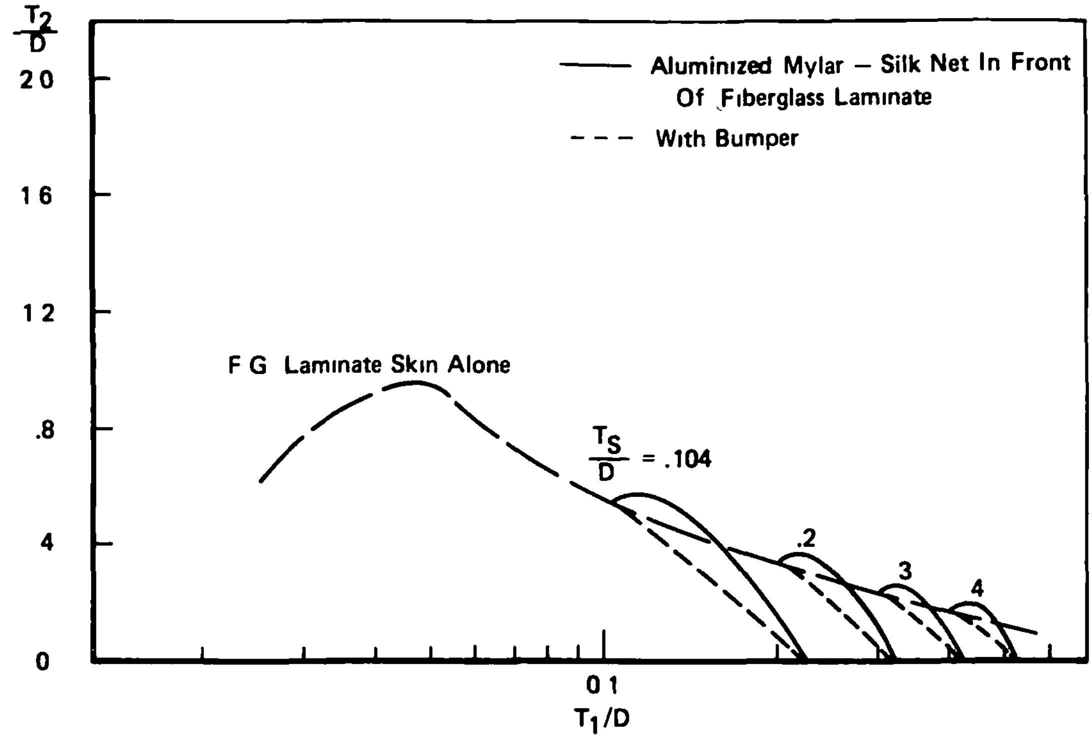


FIGURE C-81: METEOROID PROTECTION DESIGN DATA - MATERIAL COMBINATIONS

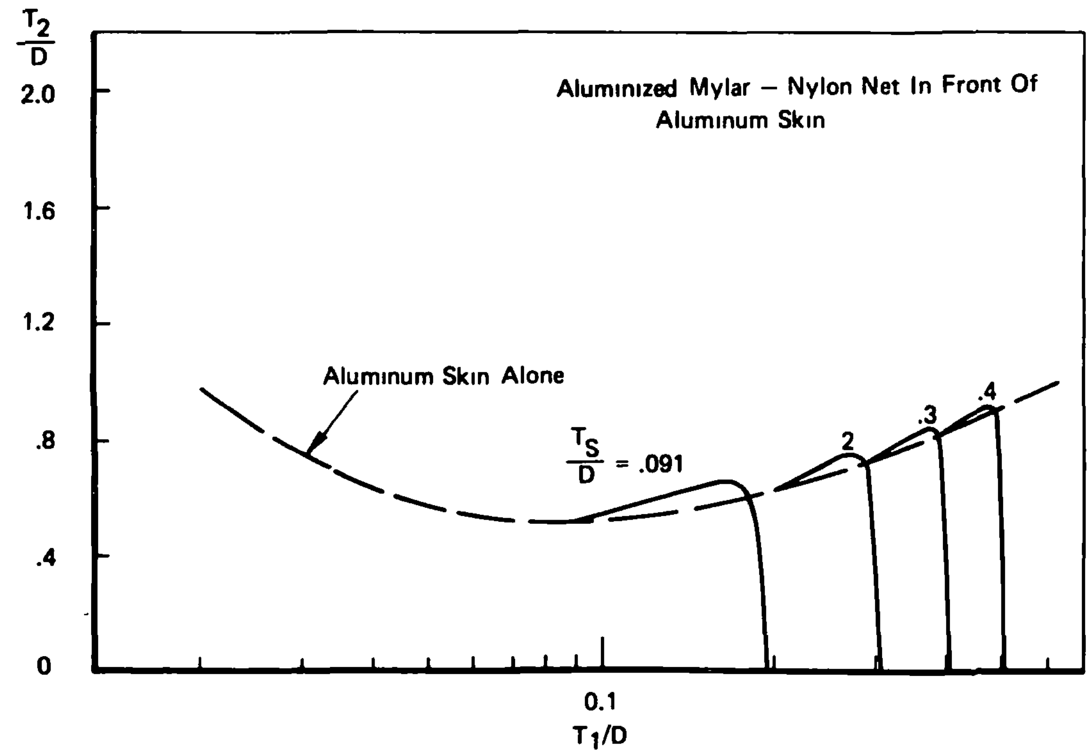


FIGURE C-82: METEOROID PROTECTION DESIGN DATA - MATERIAL COMBINATIONS

TABLE C-1

DESIGN METEOROID SIZES

VEHICLE	PAYLOAD HEIGHT		METEOROID DIA	
	in	cm	in	cm
1-14	4	10	.0644	.1636
	14	36	.0648	.1646
	35	89	.0655	.1664
1-2B	4	10	.0615	.1562
	24	61	.0626	.1590
	60	152	.0638	.1621
1-2A	4	10	.0626	.1590
	24	61	.0637	.1618
	60	152	.0648	.1646
1-3	4	10	.0588	.1494
	24	61	.0602	.1529
	60	152	.0619	.1572
1-7	4	10	.0610	.1549
	24	61	.0612	.1554
	35	89	.0616	.1565

VEHICLE	PAYLOAD HEIGHT		METEOROID DIA	
	in	cm	in	cm
2-14	4	10	.0605	.1537
	13	33	.0609	.1547
	32	81	.0615	.1562
2-3	4	10	.0538	.1367
	20	51	.0541	.1374
	50	127	.0548	.1392
2-18	4	10	.0539	.1369
	12	30	.0543	.1379
	32	81	.0555	.1410
2-2	4	10	.0577	.1466
	9	23	.0586	.1488
	48	122	.0598	.1519
2-19	4	10	.0539	.1369
	13	33	.0544	.1382
	43	109	.0559	.1420

TABLE C-2: METEOROID PROTECTION MATERIALS

MATERIAL	WEIGHT oz/in^2	WEIGHT kg/m^2	SOURCE	DESCRIPTION
Nylon net	3.186×10^{-4}	1.400×10^{-2}	Sears Catalog #36P1000	Bridal Veil - 0.41 oz/yd^2 0.007 inch (.178 mm) Nominal Thickness
15 gage double aluminized mylar	1.320×10^{-4}	5.800×10^{-3}	National Metallizing Spec. 1003	48" (1.219 m) roll stock
Sliced foam	4.802×10^{-4}	2.110×10^{-2}	Industrial Rubber and Supply Co.	1/32 inch (.159 cm) polyester foam 48" Roll Stock
Silk net	6.860×10^{-5}	3.014×10^{-3}	Boeing Stores	
NRC-2	2.253×10^{-4}	9.900×10^{-3}	Boeing Stores	25 gage crinkled aluminized mylar 48" wide roll
50 gage aluminized mylar	4.415×10^{-4}	1.940×10^{-2}	Boeing Stores	48" (1.219 m) roll stock
Beta fiber cloth	4.916×10^{-3}	2.160×10^{-1}	J. P. Stevens	Style 15035 fabric, 6.3 oz/yd^2 10 yd sample
Fiberglass/epoxy laminate	2.464×10^{-2}	1.083	Boeing Stores	Fiberglass cloth layup
Aluminum	1.607×10^{-3}	7.061×10^{-2}		0.001 inch (.0254 mm) thick sheet
Aluminum Honeycomb	2.060×10^{-2}	9.052×10^{-1}		Hexcell - 3/16" (.476 cm) cell size
Fiberglass Honeycomb	3.640×10^{-2}	1.599	Boeing Stores	Hexcell - 3/16" (.476 cm) cell size
One layer nylon net + one layer 15 gage Alm.	4.506×10^{-4}	1.980×10^{-2}		
2 layers silk net + one layer 15 gage Alm.	2.700×10^{-4}	1.186×10^{-2}		
One layer sliced foam + one layer 15 gage Alm.	6.122×10^{-4}	2.690×10^{-2}		

APPENDIX D

VEHICLE PRELIMINARY DESIGNS

Section 1.2.3 of Volume I, "Final Report" NASA CR-121103, summarized the weight data for ten vehicle preliminary designs. This appendix presents the design drawings, discusses some of the main features and includes a detailed weight statement for each vehicle configuration.

LH_2-LF_2 Propellants

Vehicle 1-14 - Figure D-1 shows the vehicle structural arrangement and fluid line details. A median height payload position was selected for design. A possible design improvement was the elimination of upper ring and payload supports. The payload supports would then originate at the mid-body ring and would be constructed of fiberglass. This feature was incorporated in the final designs discussed in Section 1.3.1 of Volume I. The ring weight saved by this change would be offset to some extent by the addition of a MLI support ring between the payload and the LF_2 tank. It was estimated that the net effect was a weight reduction of 7 lbs (3.2 kg).

Figure D-2 shows insulating details. Internal MLI was selected and the meteoroid protection was provided by the MLI. The top deck, compartment separation and bottom blankets were supported by X-850 film laminate. A fiberglass laminate ring was added at the mid-body point to support the compartment separation blanket. This ring was totally enclosed within the MLI blanket, thus there were no bracket penetrations through the multilayer. The ring rested on a pair of fluid line support beams which spanned the vehicle at the mid-body location. The innermost radiation shields were joined at this location, shown in Detail I, to provide thermal continuity around the corner and to act as a purge seal.

A 90° corner and blanket overlap was provided at the intersection of top deck and sidewall MLI. It was necessary to add strips of fiberglass laminate to the upper ring to produce this type of joint.

Vehicle 1-2A - The structural arrangement is shown in Figure D-3. It was necessary to provide secondary structure in the form of an insulation support framework over and under the LH_2 tank. The vehicle body was only 17 in. (0.43 m) high, with a 52 in. (1.32 m) centaur adaptor below and a 58 in. (1.48 m) payload support bay above. A six-truss member structure supported the engine and some of the tank load. The LF_2 tanks were manifolded together for engine feed and venting functions.

Figure D-4 shows the insulation design. The conical surface above the LH_2 tank was insulated with six large panels and six filler panels. The smaller panels were necessary due to material width limitations and the arrangement of MLI support members. A more efficient design could be possible by splicing aluminized mylar roll stock to greater widths and by relocating some MLI support structure; however, a minimum of six panels still appeared necessary.

This insulation design located the MLI on the outside of the vehicle structure, therefore, it is necessary to provide penetrations for the payload supports and for the adaptor. Hand-fitting at these penetrations would be necessary to produce a thermally efficient joint. Access to the LH_2 tank would necessitate removal of several panels with the attendant problems of replacement to produce a thermally efficient joint.

Vehicle 1-2B - The structural arrangement of this vehicle eliminated the internal truss construction of its counterpart, Vehicle 1-2A. Instead, the tanks were suspended from the main body rings, and engine loads were applied through a conical framework. It was necessary, however, to provide secondary structural support for the MLI blanket separating the two propellants. Figure D-5 shows these details. As in the case of the previous vehicle, there was a considerable amount of unused volume between the LF_2 tanks.

Figure D-6 shows insulation details. External MLI was used and meteoroid protection was provided by the addition of MLI with non-aluminized radiation shields. That portion of the blanket using clear mylar films was used as a structural support for the remainder of the MLI. The compartment separation blanket utilized X-850 film laminate for support. This blanket would be applied in two pieces. The top deck blanket was also supported by X-850 film and would be applied as one piece. It would be necessary to splice the mylar to produce this panel.

Vehicle 1-3 - Figure D-7 shows the structural arrangement. The vehicle was divided into four bays by trusses. The tanks were supported partially on the trusses and partially on the external ring. A manifold system connected pairs of oxidizer and fuel tanks. The manifold system was located above the tanks for simplicity, however, this necessitated some additional MLI support structure.

Figure D-8 shows the insulating details for this vehicle. External MLI was chosen and non-aluminized mylar was used in the MLI added for meteoroid protection. The top deck blanket thicknesses were different for the fuel and oxidizer compartments, therefore, foam block shims were used along abutting edges to maintain panel alignment. A fiberglass laminate support structure was devised to elevate the MLI above the plumbing lines. The sidewall blankets were all the same thickness for meteoroid protection, however, the number of radiation shields varied between oxidizer and fuel compartments. This necessitated four panels to insulate the sidewall. Compartment separation blankets within the vehicle were located inside the LH_2 tank enclosure. The intersection of these blankets at the center, and the joints with top and bottom panels, would present severe insulating problems.

Vehicle 1-7 - The structure of this vehicle is arranged in a square configuration, with four corner posts supporting tank and engine loads. Fiberglass tubular struts were selected for the design because the structural trades indicated this was the least weight approach. The two LH_2 tanks were suspended externally by a system of fiberglass struts and tension straps. Figure D-9 shows the structural arrangement.

Figure D-10 shows the insulation details for this vehicle. It was necessary to add fiberglass laminate structure to support the MLI blankets around the perimeter of the LH_2 tanks. It appeared that this configuration could be efficiently insulated with tank mounted MLI, at least for the LH_2 tanks. Producing thermally efficient MLI joints at sidewall, top deck and the intersection of compartment separation blankets would be very difficult.

FLOX-CH_4 PROPELLANTS

Vehicle 2-19 - The structure is shown in Figure D-11. This configuration was unique in that tank mounted insulation appeared to be more adaptable to all the surfaces except possibly the upper deck. Primary boost loads would be carried through the cylindrical portion of the tank which necessitated a tank gage increase and the integral stiffening ribs shown on the drawing. There were obvious pressure vessel weight penalties associated with this approach, however, such items as structural members, MLI supports, tank support and engine thrust structure were minimized, thus offsetting the tank weight increases. The structure was relatively simple, consisting of a tank shell extension (skirt), payload supports and an adaptor. A design review revealed that the skirt shown on the drawing was 5 in. (12.7 cm) longer than necessary. Shortening the skirt and lengthening the payload support struts resulted in a weight reduction of 4 lbs (1.82 kg). The weights of Table D-1 do not reflect this reduction. The reduction was included in the weight summary, Figure 1.2-42, of the Volume I report.

Figure D-12 shows insulation details. External MLI was selected. The MLI blanket on the sidewall and cone consisted partly of aluminized shields for thermal protection and non-aluminized shields for meteoroid protection. The non-aluminized shield portion of the blanket was used to support the thermal protection portions and incorporated a zipper joint to aid installation and obtain a close fitting joint.

The top deck blanket was supported by an aluminized laminate film, Schjedahl X-850. The film was reinforced around the perimeter with fiberglass laminate and riveted to an insulation mounting ring. The MLI blanket was attached to the laminate with nylon retainers. A 90° corner was incorporated in the top deck blanket. This comer was formed during construction by cutting and taping the edges of shields and spacers. The insulation extension along the sidewall was held in place with hollow nylon studs and the edges restrained by sewing several net spacers to the sidewall blanket. Aluminized mylar roll stock was not wide enough to make a complete radiation shield. It would be necessary to splice this material for the top deck of all vehicles. The splice would be made by overlapping and taping sheets of aluminized mylar. The overlapped joints would be staggered to avoid excessive thickness.

Payload support members penetrated the top deck blanket and were wrapped with MLI. The external plumbing lines and those within the insulation enclosure were also wrapped with MLI.

Venting of the purge gas used during prelaunch operations would be accomplished along the edges of the blankets. The mylar films (but not the radiation shields) would be perforated in the zipper area to aid in evacuation.

Vehicle 2-18 - Figure D-13 shows the structural arrangement for this vehicle. Payload supports and the adaptor attached to a common ring. The tanks, as well as the engine thrust structure, were also connected to the same ring.

Figure D-14 shows insulation details. Internal MLI was used. A fiberglass mounting ring was added to support the top deck and sidewall blankets. X-850 film was used to support the top deck blanket and a group of mylar films and net spacers were used for sidewall blanket suspension. The sidewall blanket was separated at the top so that the top deck blanket could be overlapped outside of the radiation shields and spacers. The sidewall meteoroid protection (mylar films and net spacers) was on the outside so a zipper could be used for closing the longitudinal joint. The MLI on the inside, above the separation point, was held in place with hollow nylon studs and washers.

The conical base MLI blanket was envisioned as two pieces, with appropriate cuts and taped joints in the aluminized mylar to produce the correct shape. The net spacers could be cut and sewn, or formed to the desired contour. The mylar films and spacers which were added for meteoroid protection were also used here to support the blanket. Structural members were external to the MLI blanket, therefore, they were uninsulated. This simplified fabrication as compared to Vehicles 2-2 and 2-3.

Vehicle 2-14 - Figure D-15 shows the structural arrangement. The vehicle is divided into two bays with rings enclosing each bay. Further structural weight reductions appeared possible by omission of the uppermost ring, changing the upper bay truss members to fiberglass and connecting them directly to the payload. It was not expected that these changes would improve the ranking of this vehicle significantly, based on similar changes to Vehicle 1-14.

Figure D-16 shows insulation blanket and mounting details. The multilayer was located inside the structure and the entire blanket incorporated aluminized shields. The top deck blanket was suspended from an X-850 film and was held in place at the corners with velcro tape. The sidewall blanket was suspended at the top from hollow nylon studs. A blanket joint was necessary at the mid-body ring because of aluminized mylar roll stock width limitations. Velcro tape was used for suspending the lower sidewall blanket and restraining the bottom of both upper and lower sidewall blankets. A lacing joint was used on the sidewall. The outer and inner net layers were reinforced with X-850 in this area to support the nylon retainers.

The bottom insulation panel employed X-850 film for support since it was nearly perpendicular to the direction of maximum acceleration forces. Velcro patches attached the panel to the engine thrust members.

Vehicle 2-3 - The body structure of this vehicle (Figure D-17) consisted of two rings separated by aluminum truss members. A crossed truss arrangement supported the tanks and engine thrust loads.

Figure D-18 shows the insulation arrangement. External MLI was used which made it necessary to insulate all of the structural members. This task was complicated because of the numerous joints, and because external portions of the members had to be left exposed to permit attachment of sidewall and bottom blankets to velcro patches. Sidewall and top blankets were both suspended from the upper vehicle ring, thus additional MLI support structure was unnecessary in this area. A fiberglass ring was added in the engine recess to hold the blanket clear of the engine. The engine recess MLI joints would require considerable hand work to obtain thermally efficient joints.

Vehicle 2-2 - A six beam structural arrangement was employed to support tank and engine thrust loads of this vehicle. An insulation cage covered the FLOX tank and also supported the fluid lines. The details are shown in Figure D-19. The payload height of this vehicle was found to be excessive and a reduction of 27.1 lbs (12.3 kg) was possible with shorter payload support members. This change was incorporated in the weight summary, Figure 1.2-42 of Volume I, but not in Table D-1 of this appendix.

Figure D-20 shows MLI and meteoroid protection details. External MLI was used, therefore the difficulties of insulating structural members described for Vehicle 2-3 were encountered for this vehicle also. The top deck blanket was penetrated diagonally by the twelve payload support members. This resulted in a large cut, which would need to be prepared carefully to avoid heat shorts. The conical blankets were supported by X-850 film and were assembled in six units. A scarf joint, attached by velcro tape, was employed at the longitudinal edges of these panels. The scarf joint was held together on the outside by sewing adjacent panels. Sidewall, bottom and engine recess panels were supported by the non-aluminized mylar films and net spacers added for meteoroid protection.

Weight Statement

The weight data for the ten vehicle preliminary designs is summarized in Table D-1. The weights breakdown is confined to major systems in this table. Tables D-2, D-3, D-4 and D-5 show secondary structure and MLI weights. The latter item consists of additions to the basic MLI panel weights derived by the TATE program discussed in Appendix A. Tables D-6 through D-8, and D-9 through D-11 show FLOX-CH_4 and LH_2-LF_2 vehicle plumbing weights.

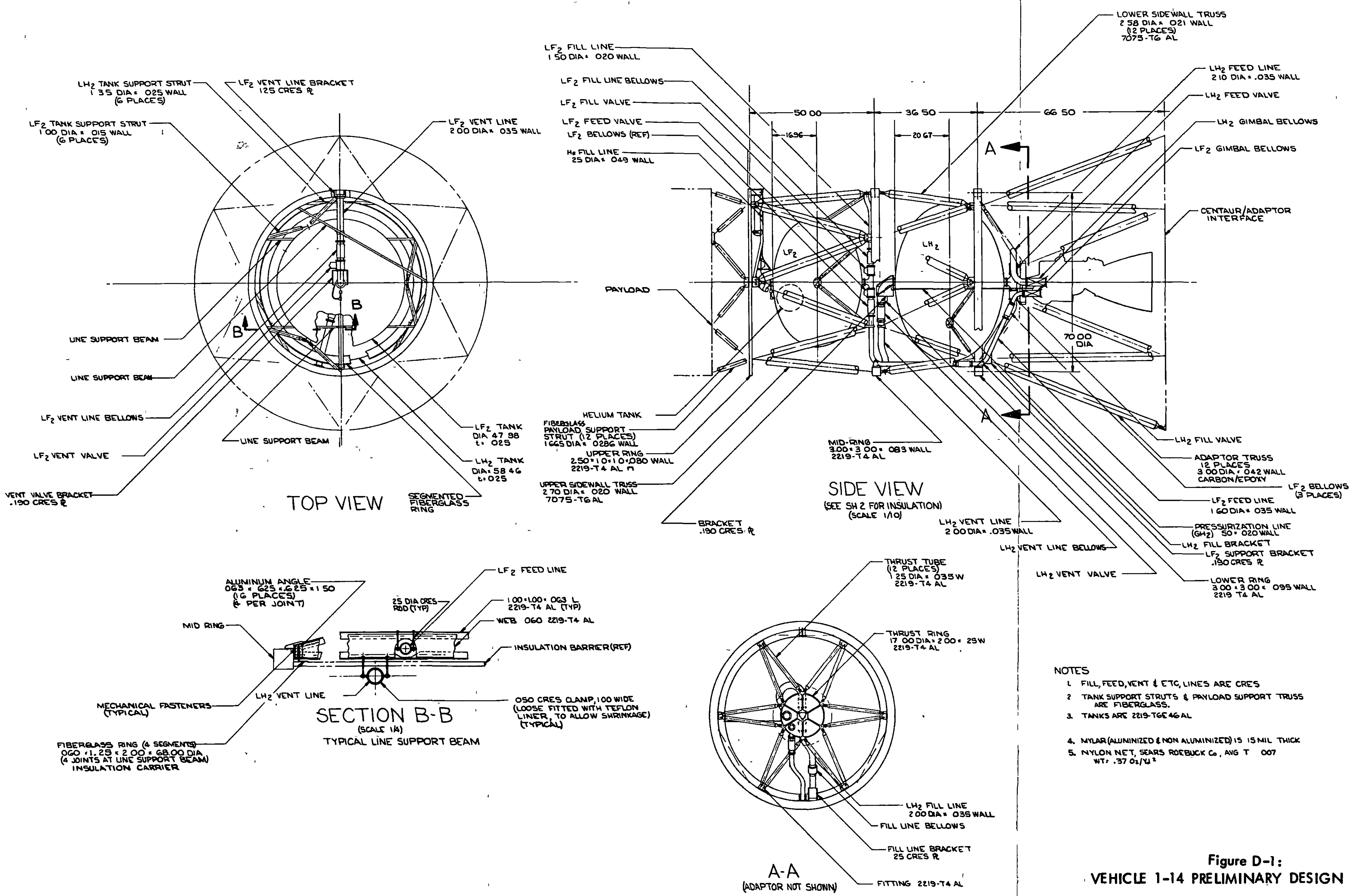


Figure D-1: VEHICLE 1-14 PRELIMINARY DESIGN

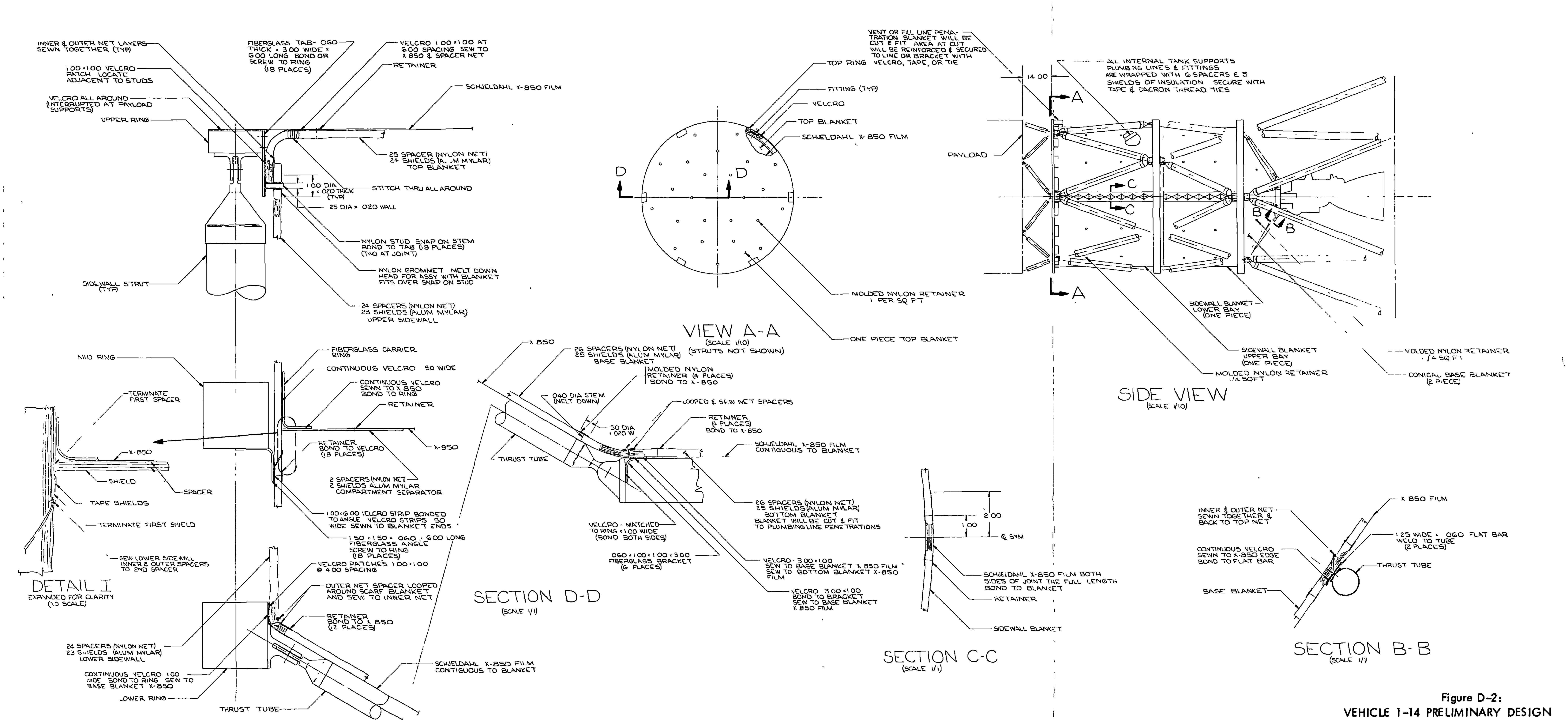


Figure D-2: VEHICLE 1-14 PRELIMINARY DESIGN

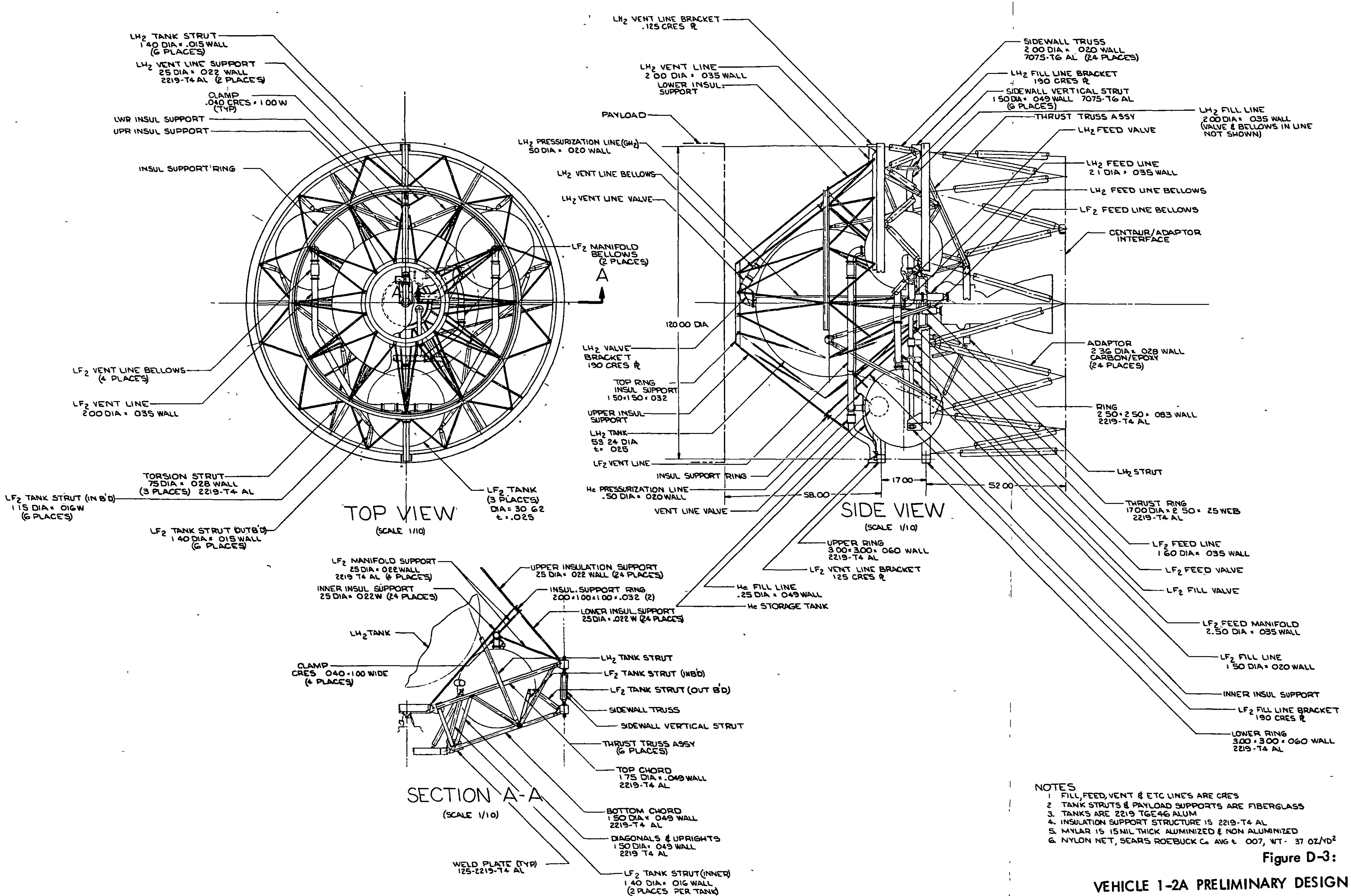


Figure D-3:

VEHICLE 1-2A PRELIMINARY DESIGN

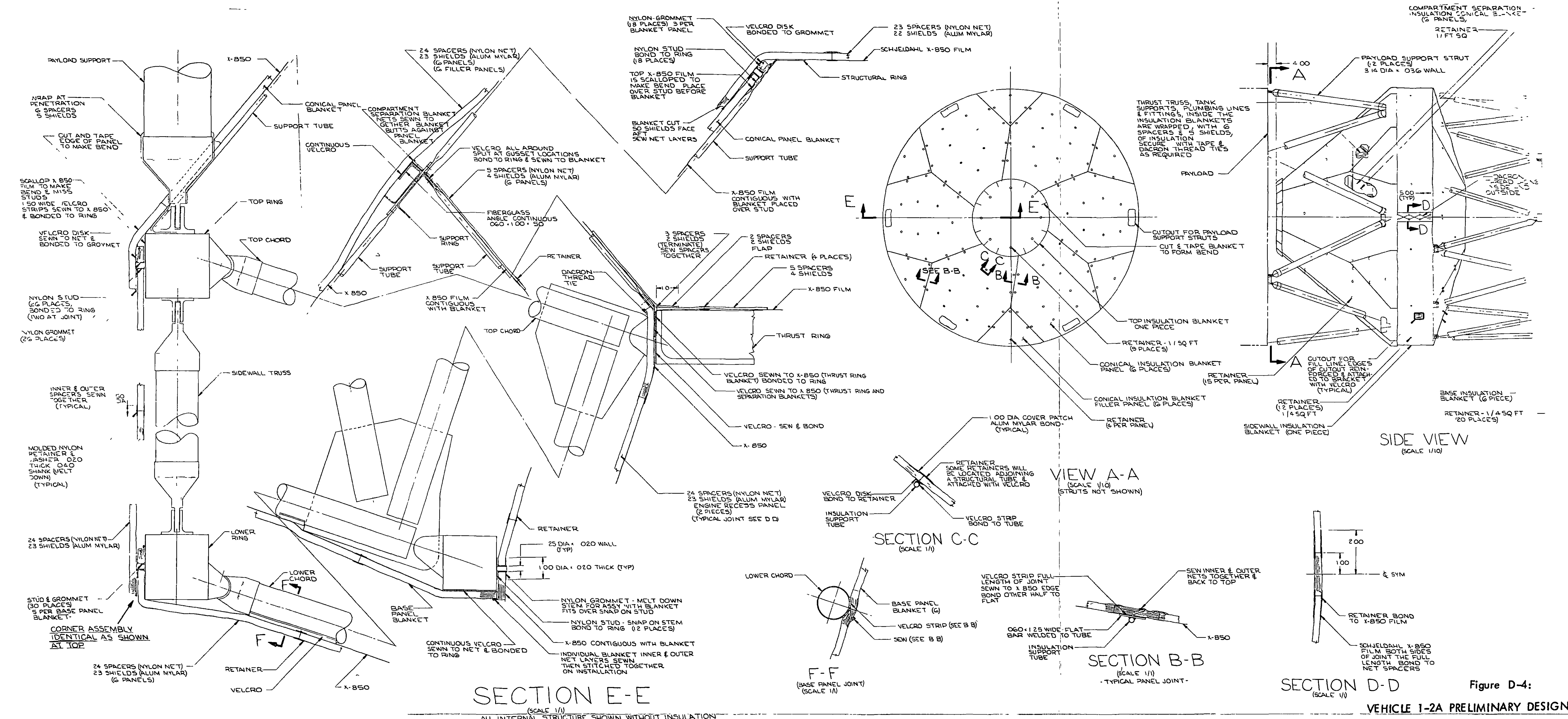


Figure D-4: VEHICLE 1-2A PRELIMINARY DESIGN

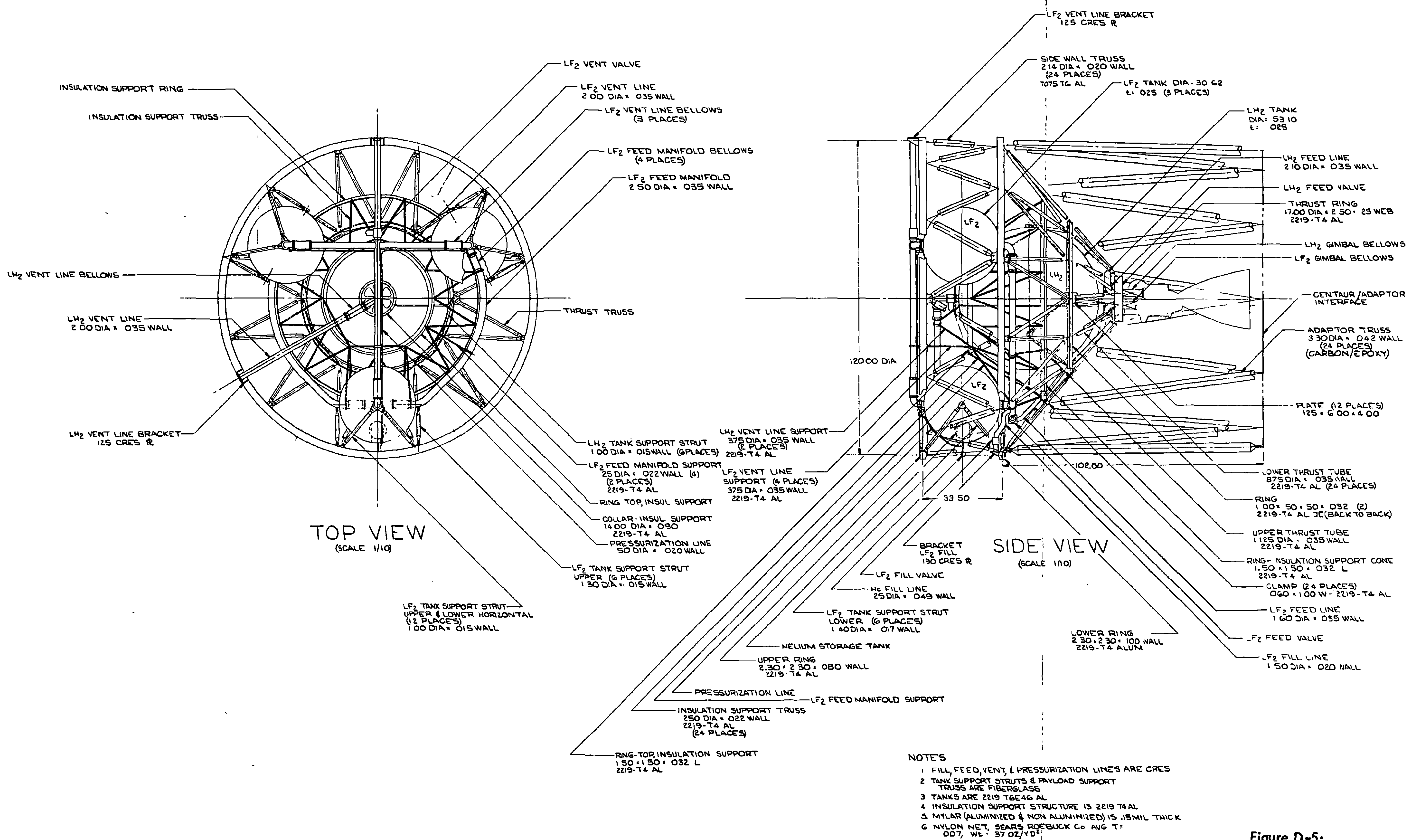


Figure D-5: VEHICLE 1-2B PRELIMINARY DESIGN

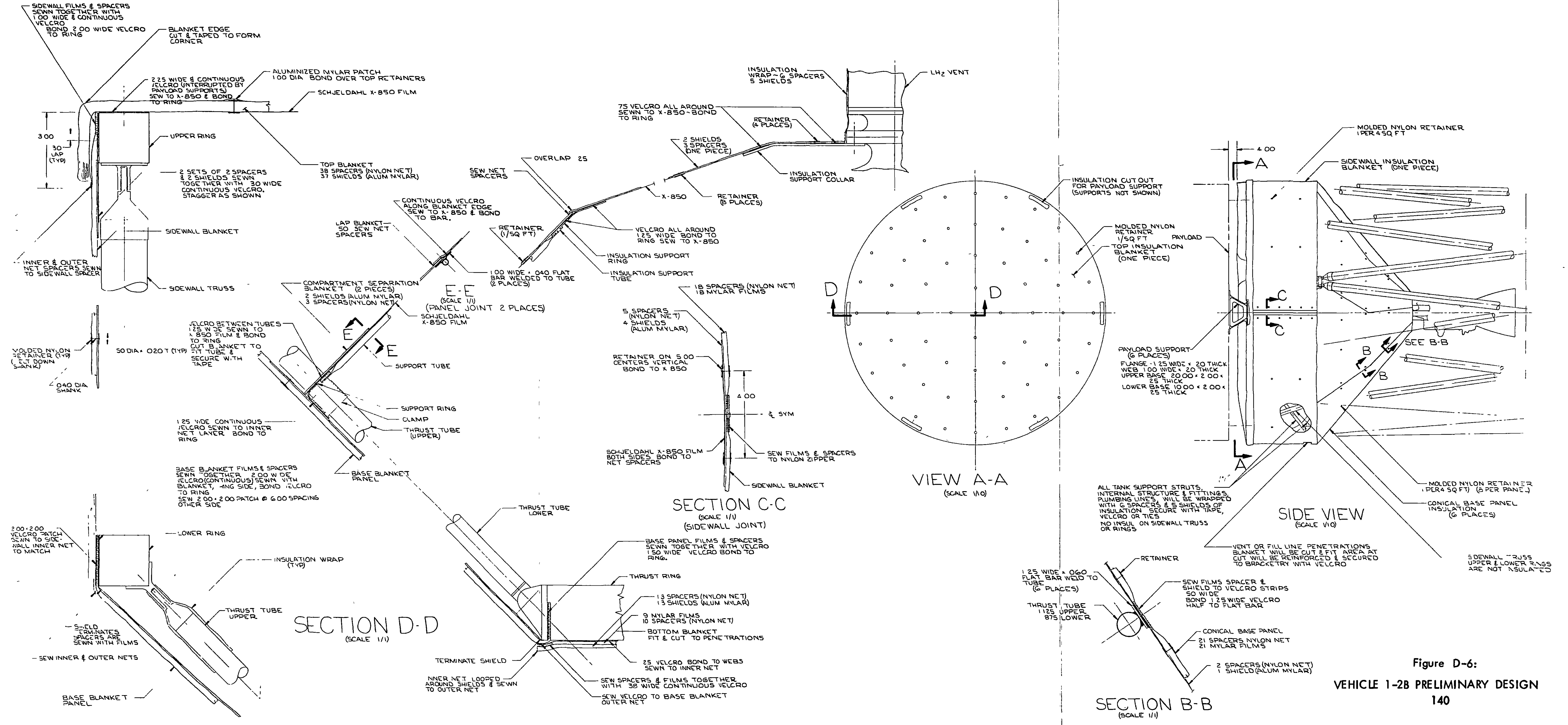
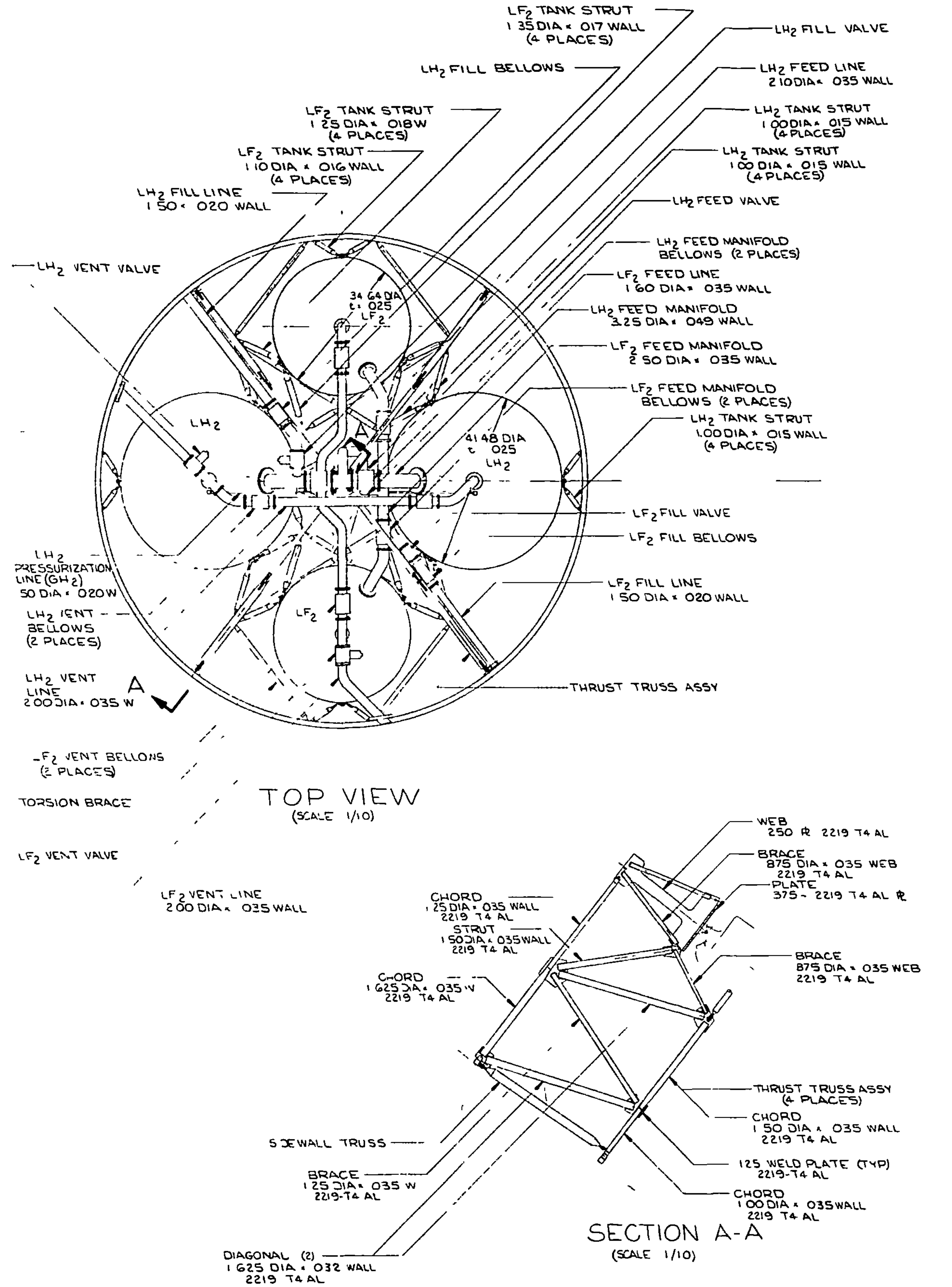
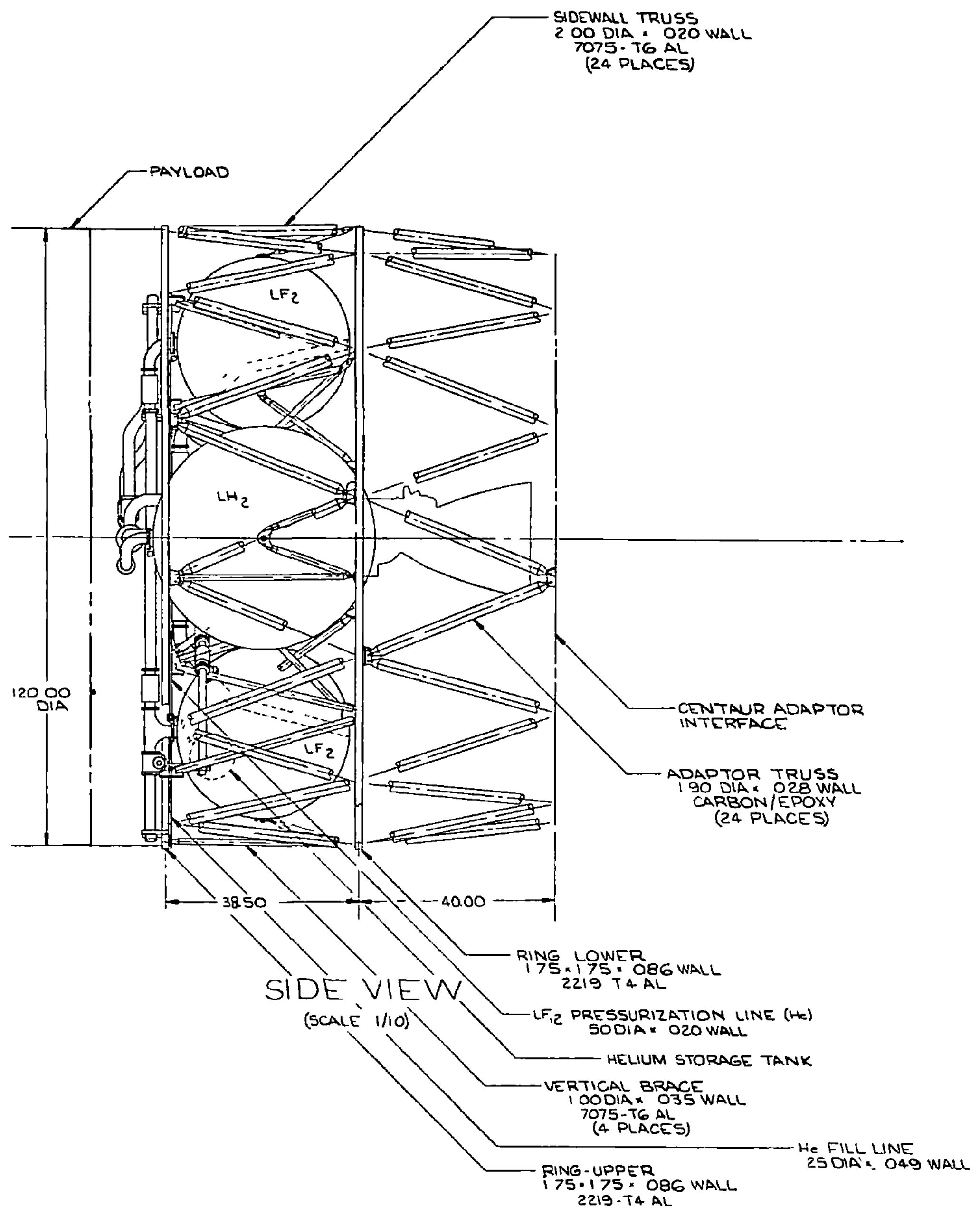
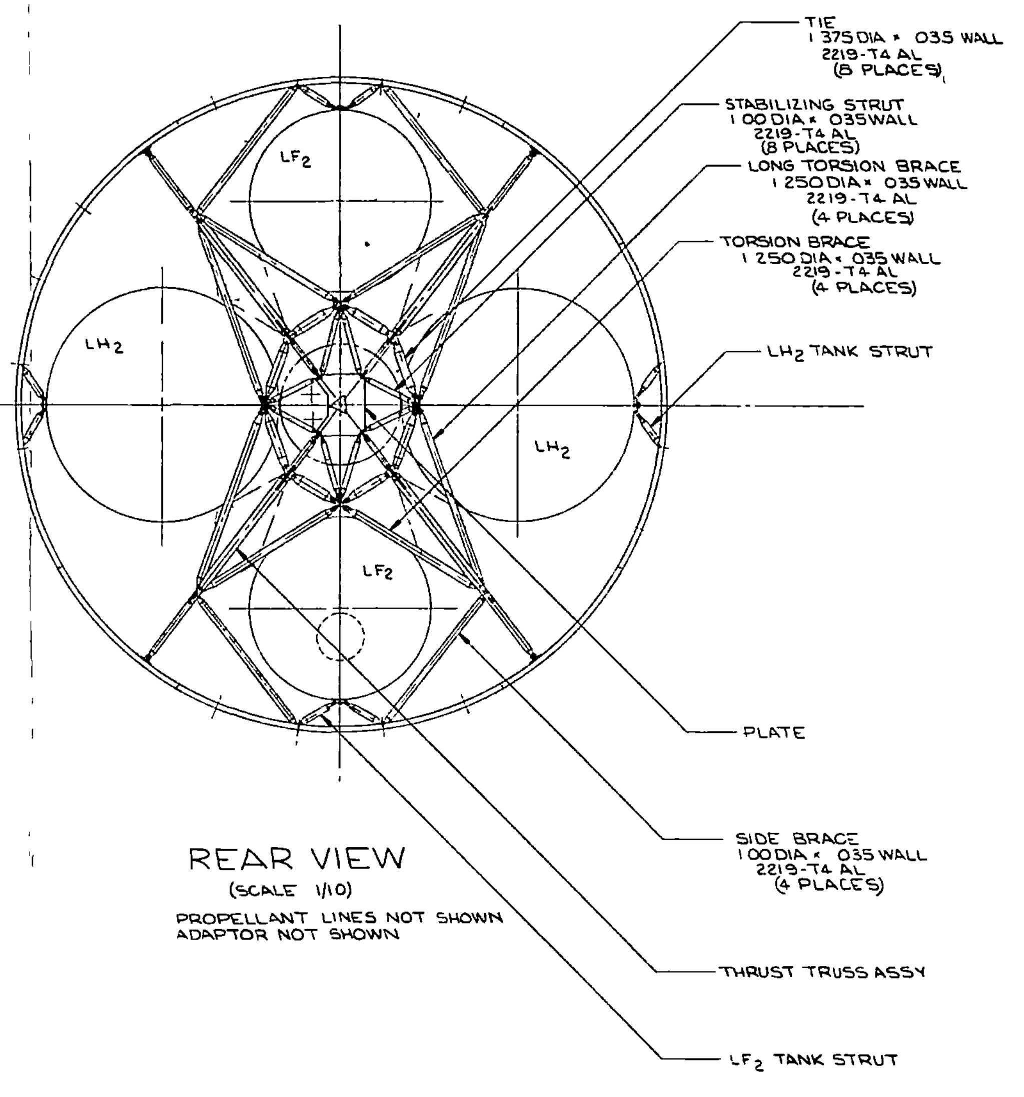


Figure D-6: VEHICLE 1-2B PRELIMINARY DESIGN



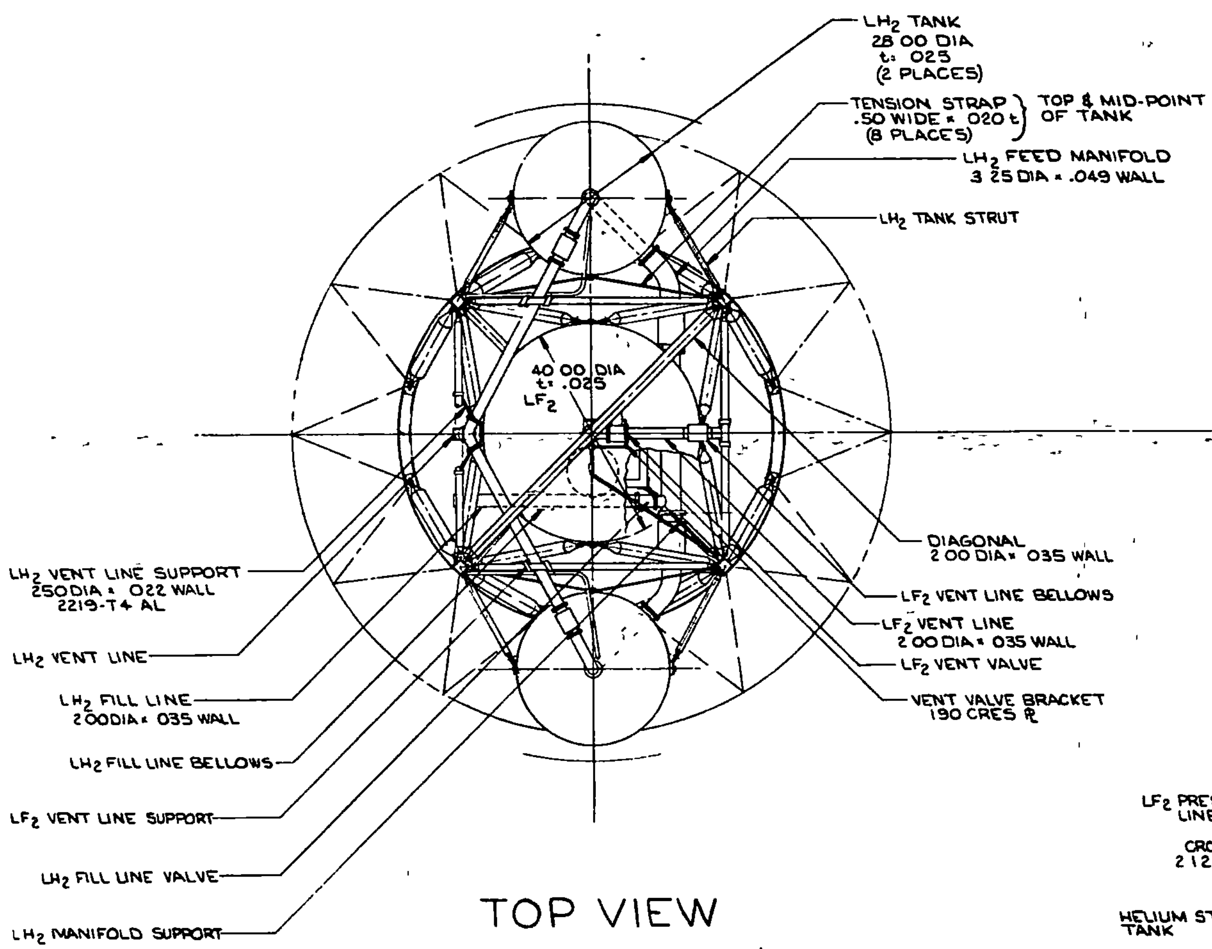




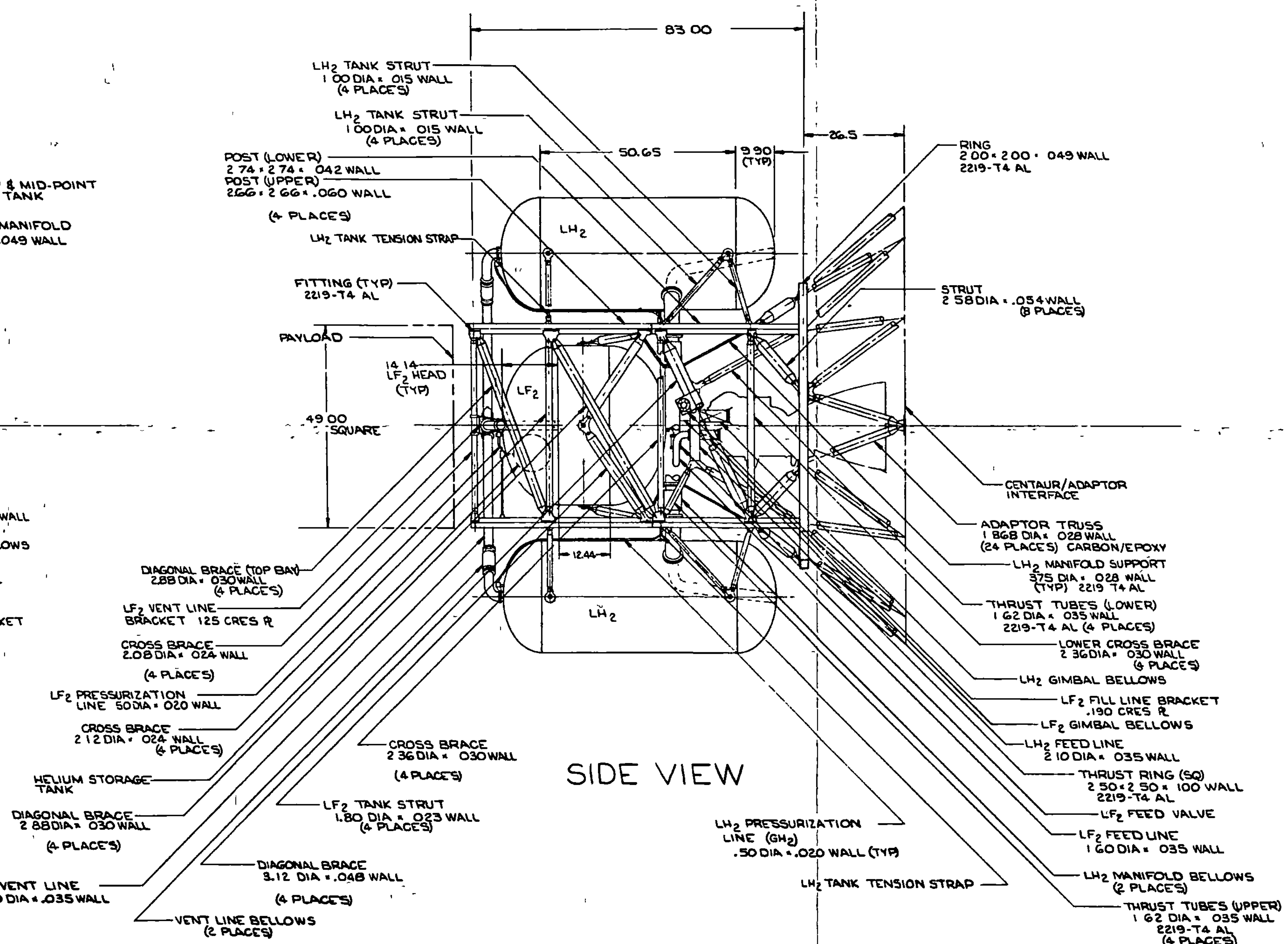
NOTES
1. FILL FEED VENT & ETC LINES ARE CRES
2. TANK STRUTS & PAYLOAD SUPPORTS ARE FIBERGLASS
3. TANKS ARE 2219-T6E46 AL.
4. MYLAR, ALUMINIZED & NON ALUMINIZED, IS .15 MIL THICK
5. NYLON NET, SEARS ROEBUCK & CO, WT: .37 oz/yd², .007 AVG THICKNESS

Figure D-7: VEHICLE 1-3 PRELIMINARY DESIGN

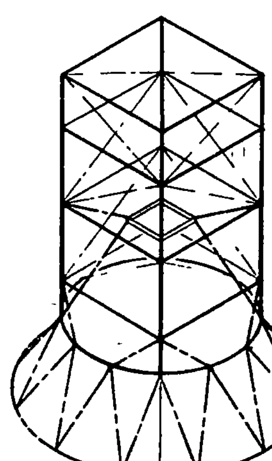
Figure D-8:
VEHICLE 1-3 PRELIMINARY DESIGN



TOP VIEW



SIDE VIEW



ISOMETRIC-CENTER LINE DIAGRAM
(NO SCALE)

NOTES:
1. FILL, FEED, VENT & ETC LINES ARE CRES.
2. TANK SUPPORT STRUTS & STRAPS ARE FIBERGLASS
3. TANKS ARE 2219-T6E46 AL
4. STRUCTURE IS FIBERGLASS EXCEPT AS NOTED
5. ALUMINIZED MYLAR IS .15 MIL THICK
6. NYLON NET, SEARS ROEBUCK Co, .37 OZ/SQ YD, .007 AVG THICKNESS

Figure D-9:

VEHICLE 1-7 PRELIMINARY DESIGN

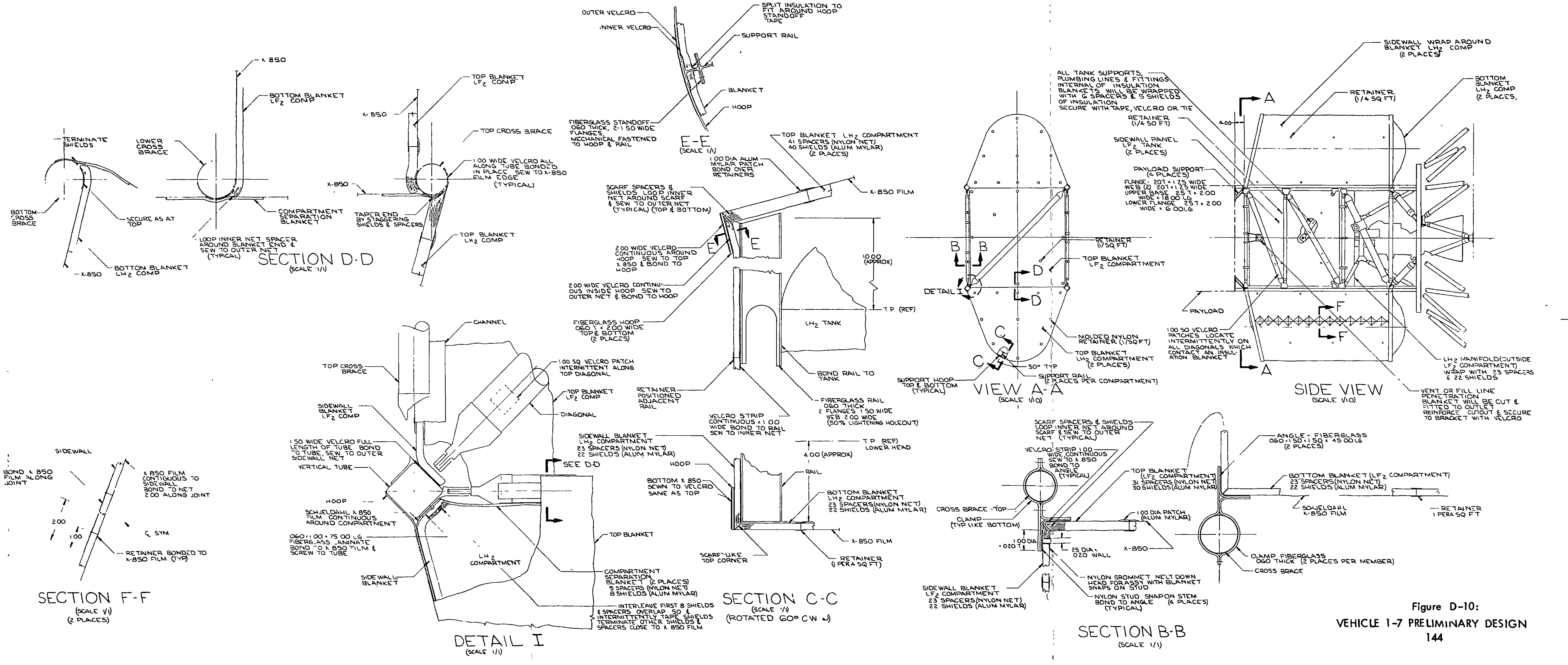


Figure D-10: VEHICLE 1-7 PRELIMINARY DESIGN

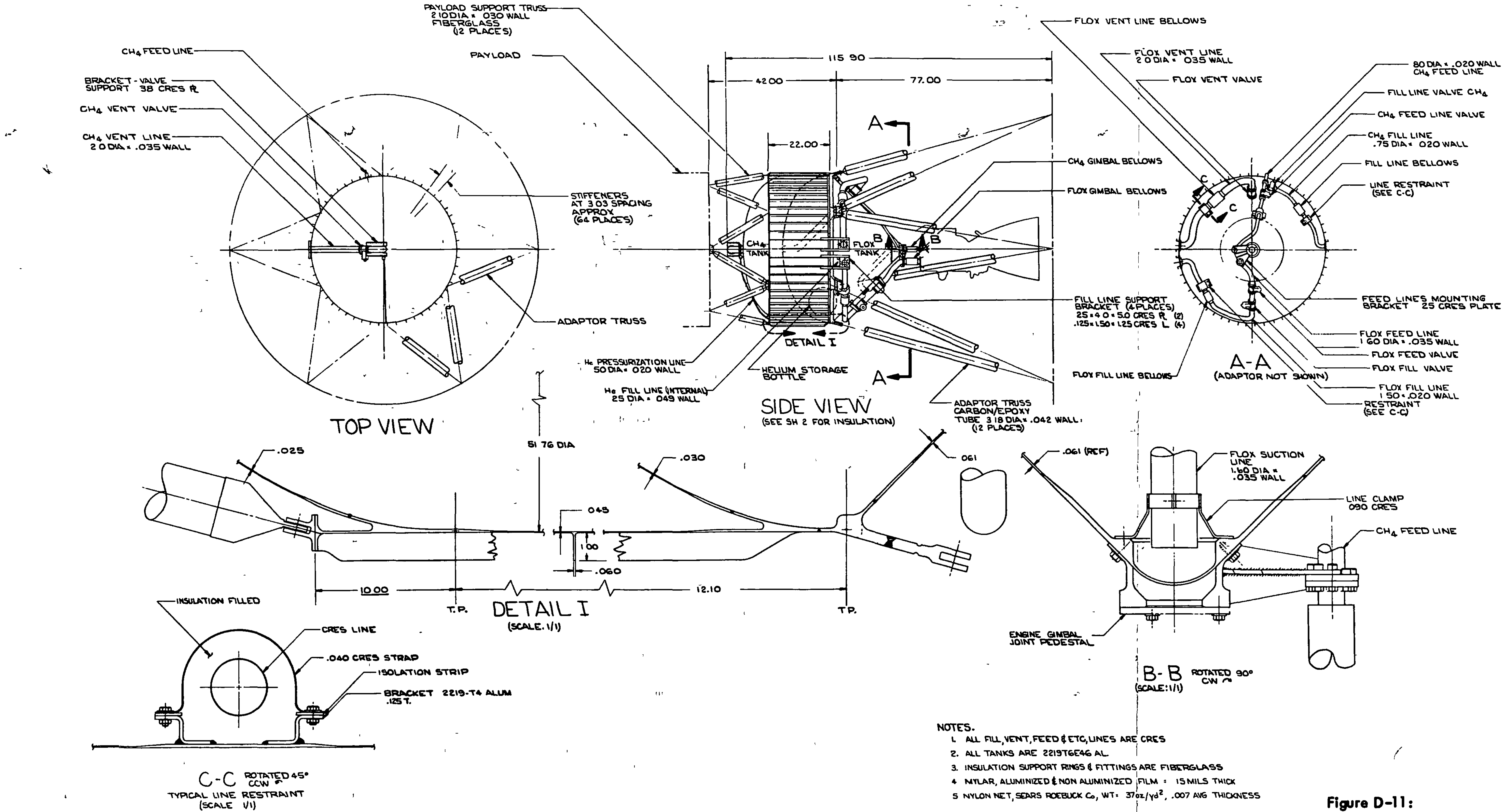


Figure D-11: VEHICLE 2-19 PRELIMINARY DESIGN

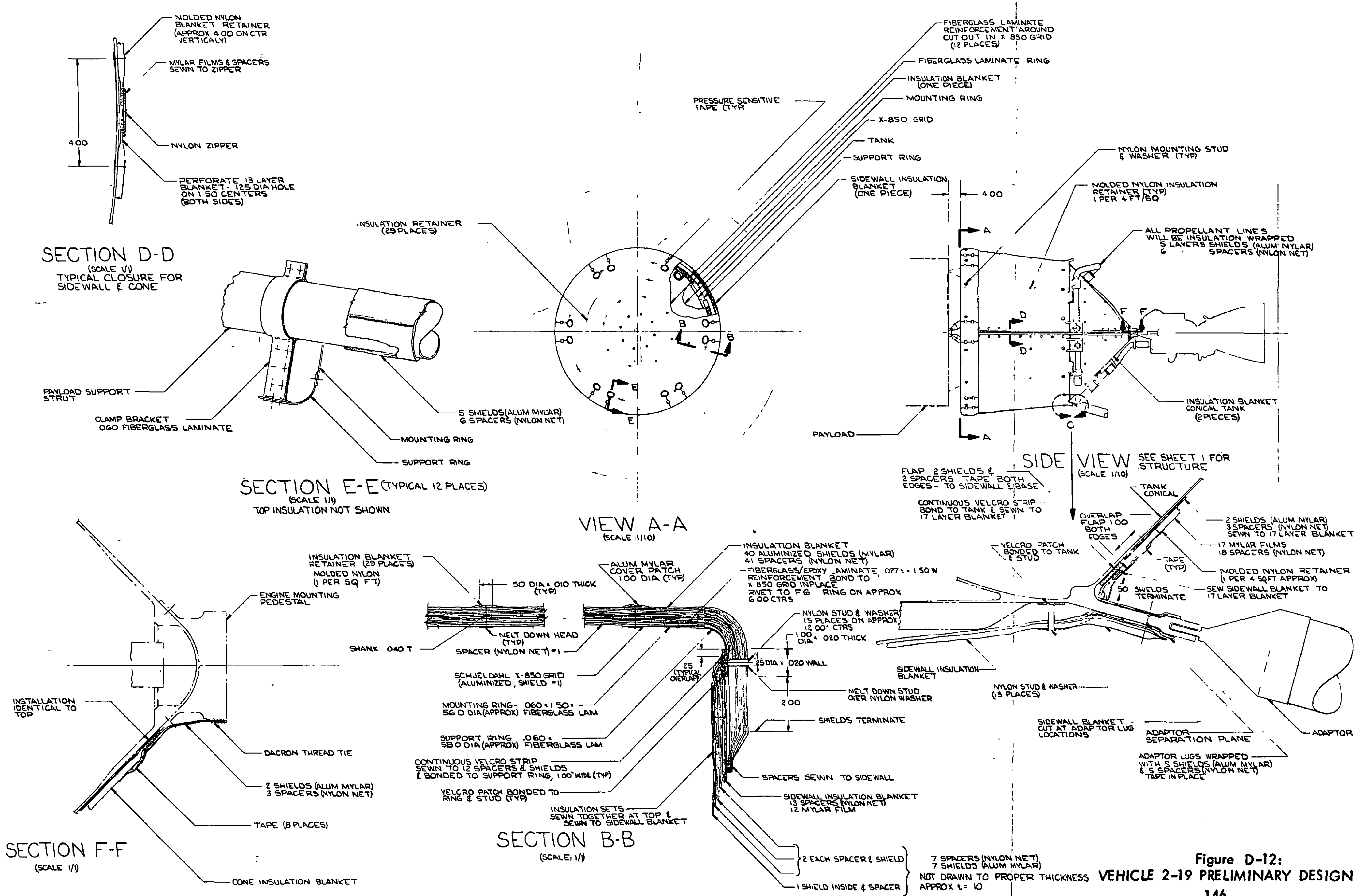
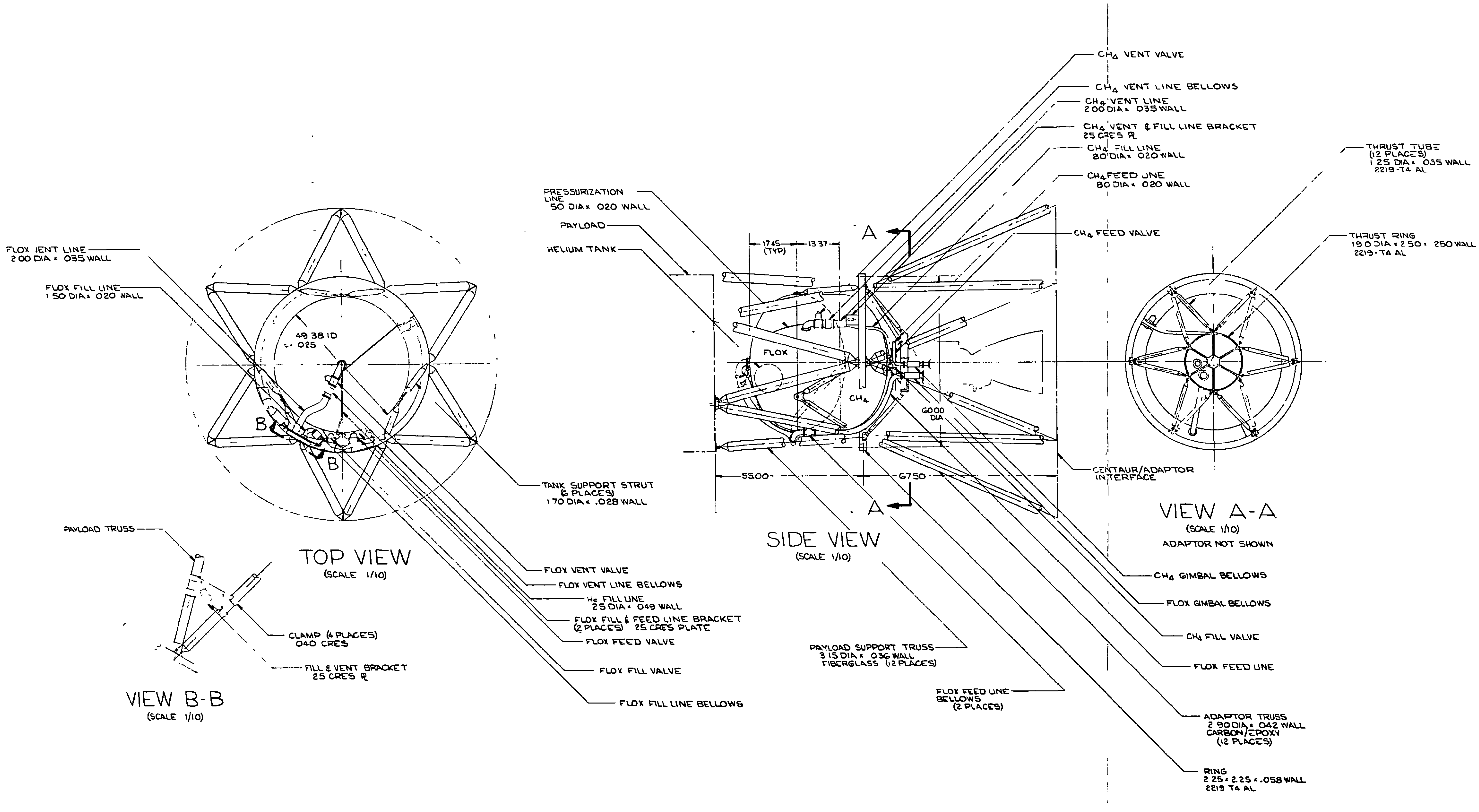


Figure D-12: VEHICLE 2-19 PRELIMINARY DESIGN



NOTES.
1. TANKS ARE 2219 T6E46 AL t=.025
2. FILL FEED, VENT & ETC, LINES ARE CRES
3. TANK SUPPORT STRUTS ARE FIBERGLASS
4. MYLAR, ALUMINIZED & NON-ALUMINIZED = .15 MIL THICK
5. NYLON NET, SEARS ROEBUCK Co, WT = .37 oz/yd², .007 AVG THICKNESS

Figure D-13: VEHICLE 2-18 PRELIMINARY DESIGN

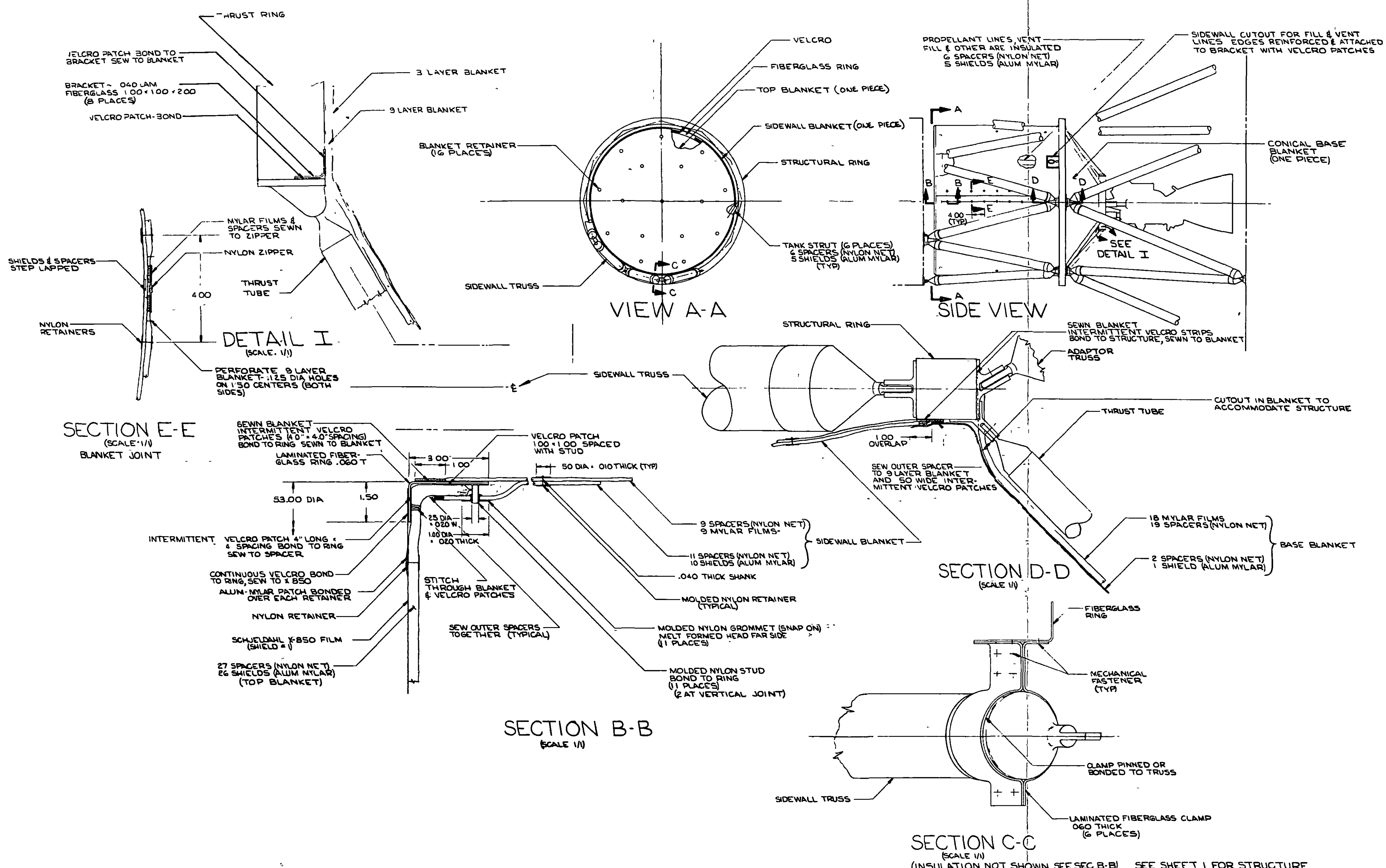


Figure D-14: VEHICLE 2-18 PRELIMINARY DESIGN

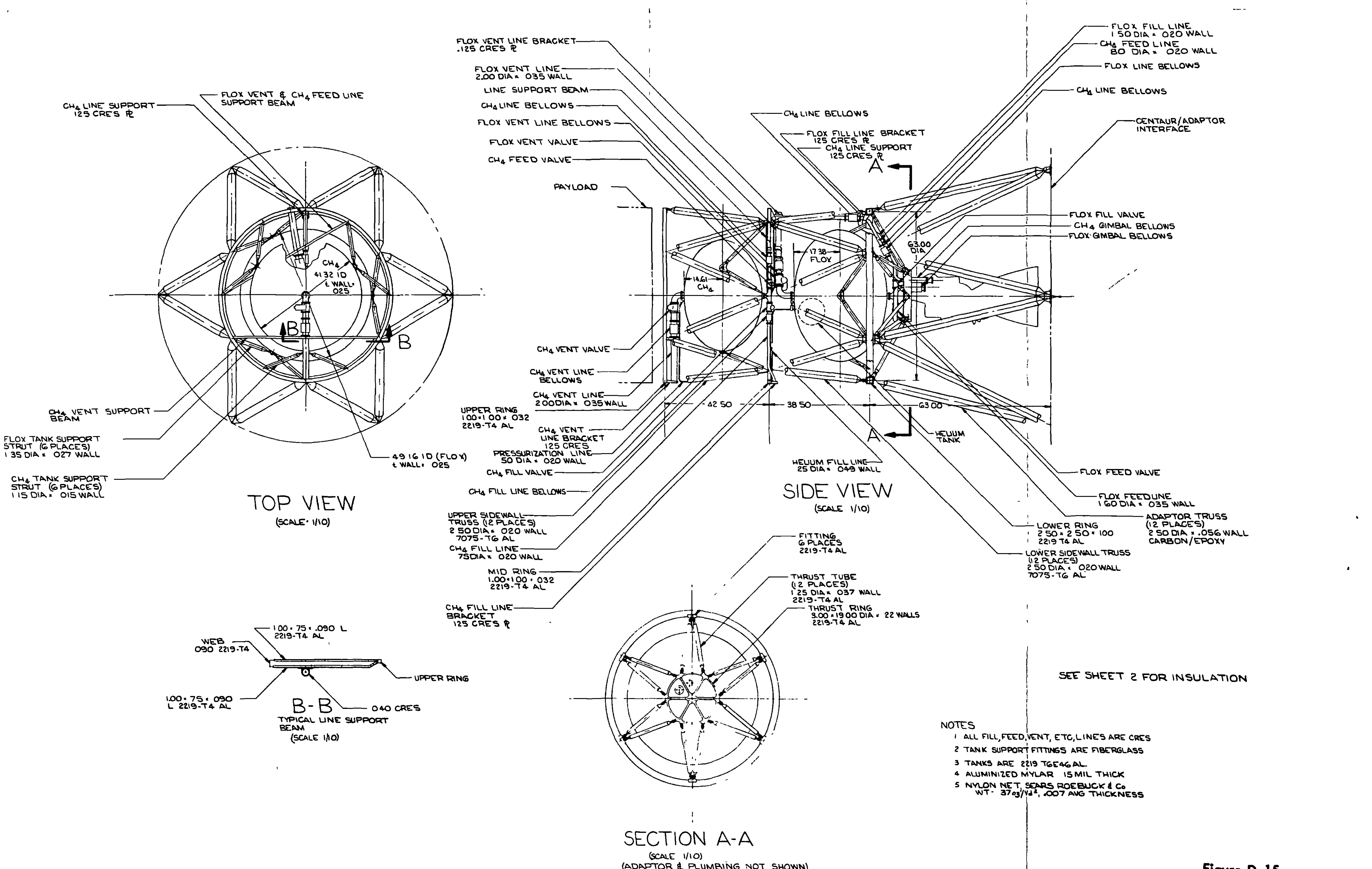


Figure D-15: VEHICLE 2-14 PRELIMINARY DESIGN

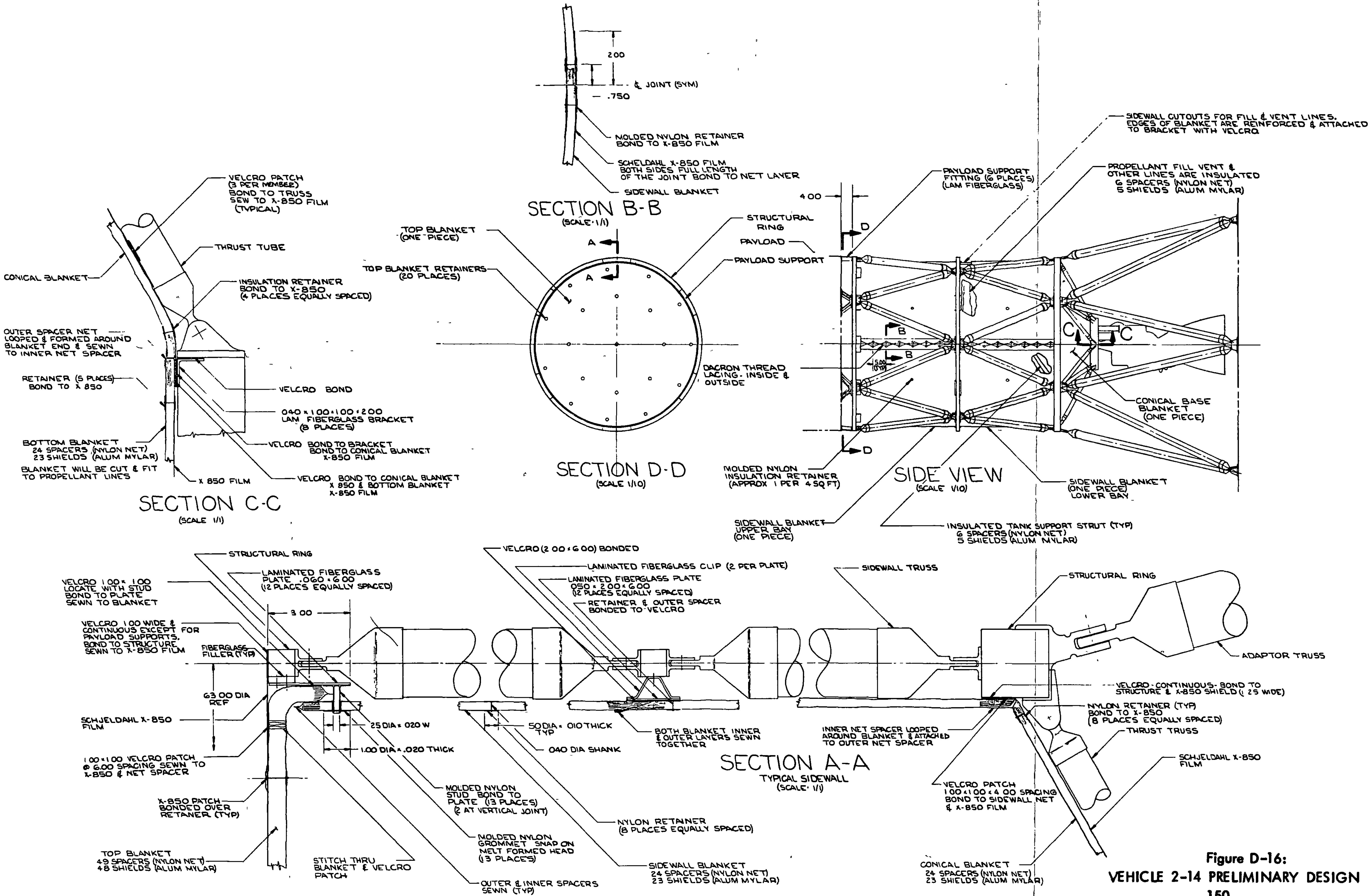


Figure D-16: VEHICLE 2-14 PRELIMINARY DESIGN

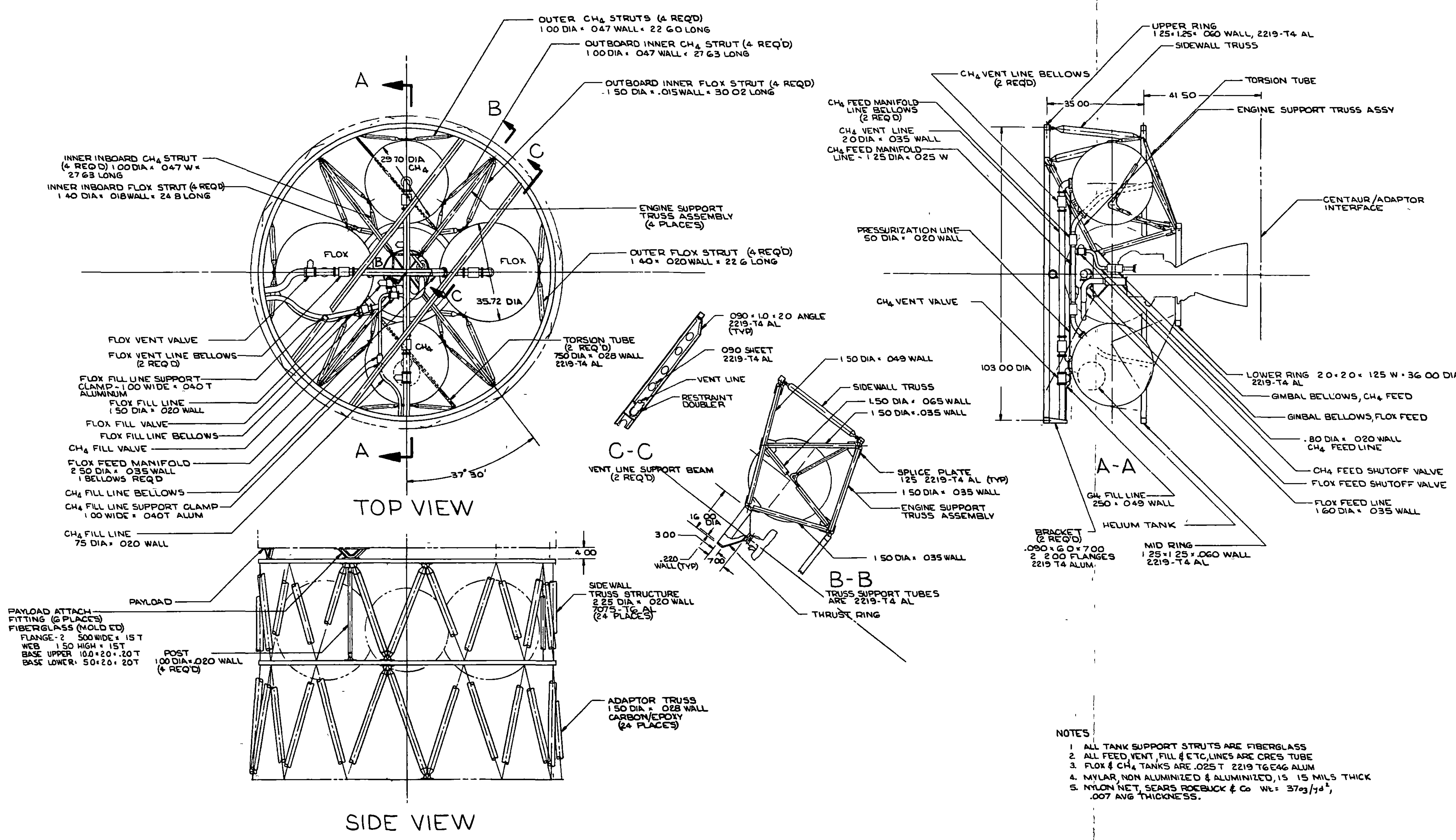


Figure D-17:

VEHICLE 2-3 PRELIMINARY DESIGN

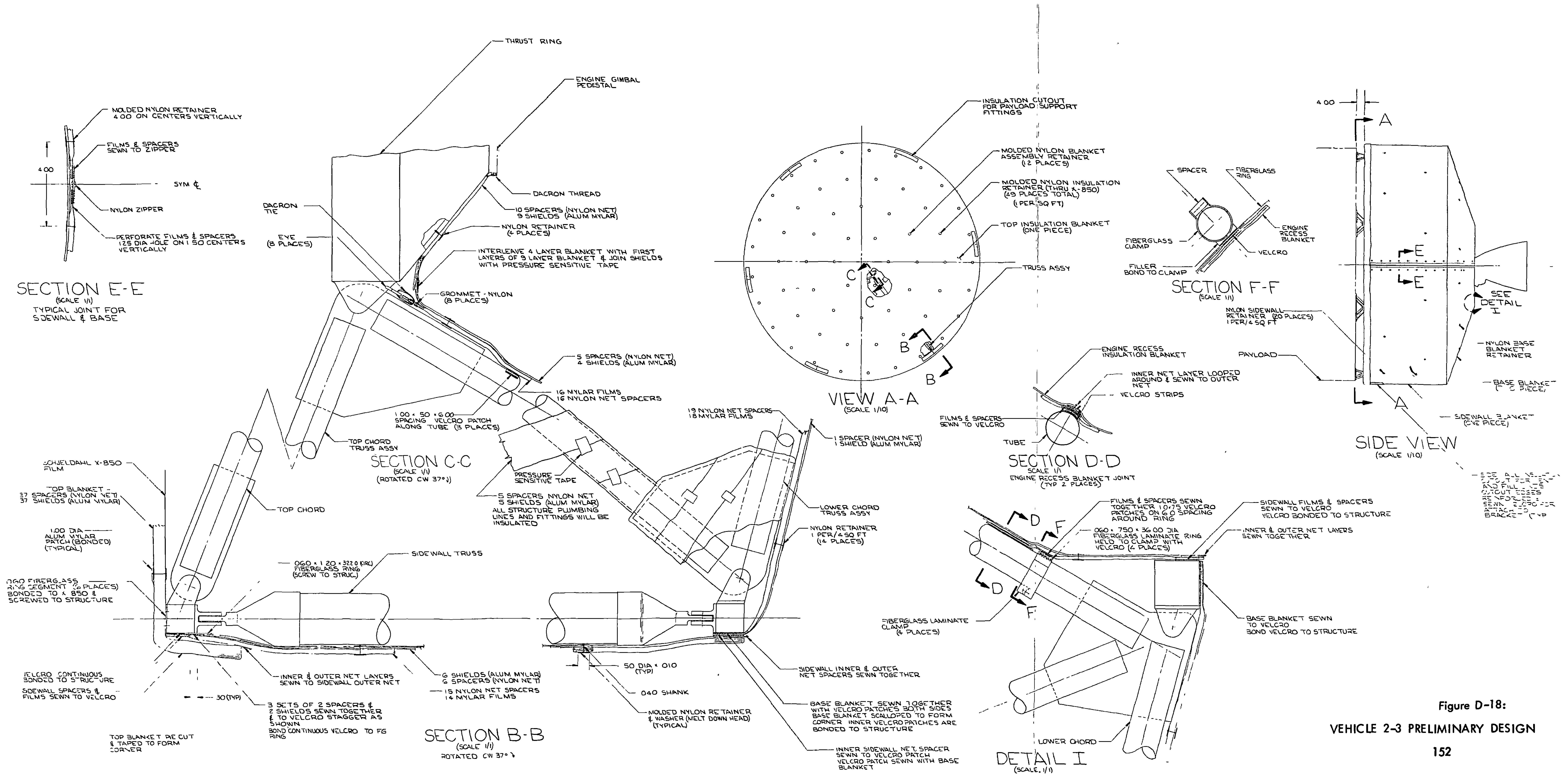


Figure D-18:

VEHICLE 2-3 PRELIMINARY DESIGN

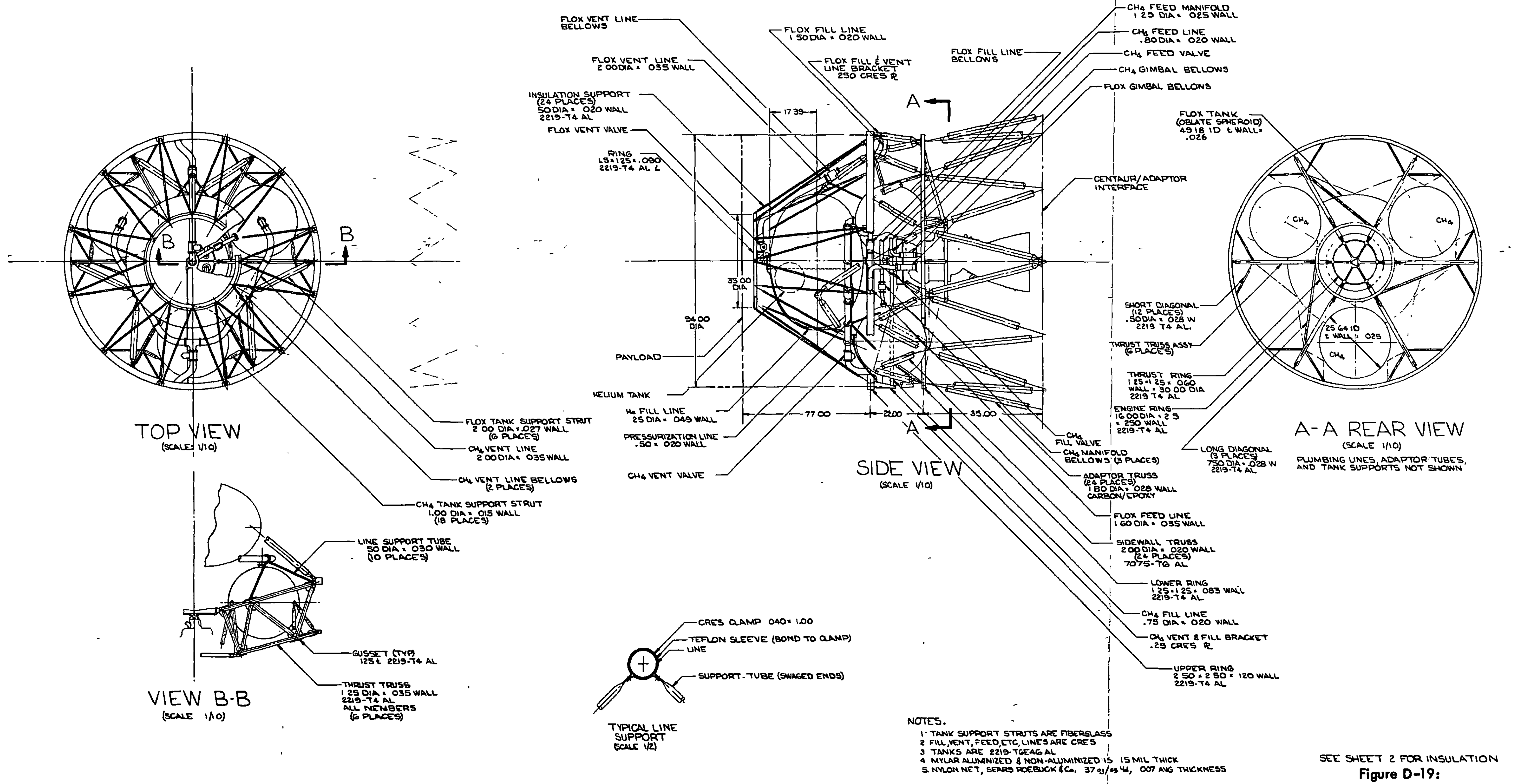


Figure D-19:

VEHICLE 2-2 PRELIMINARY DESIGN

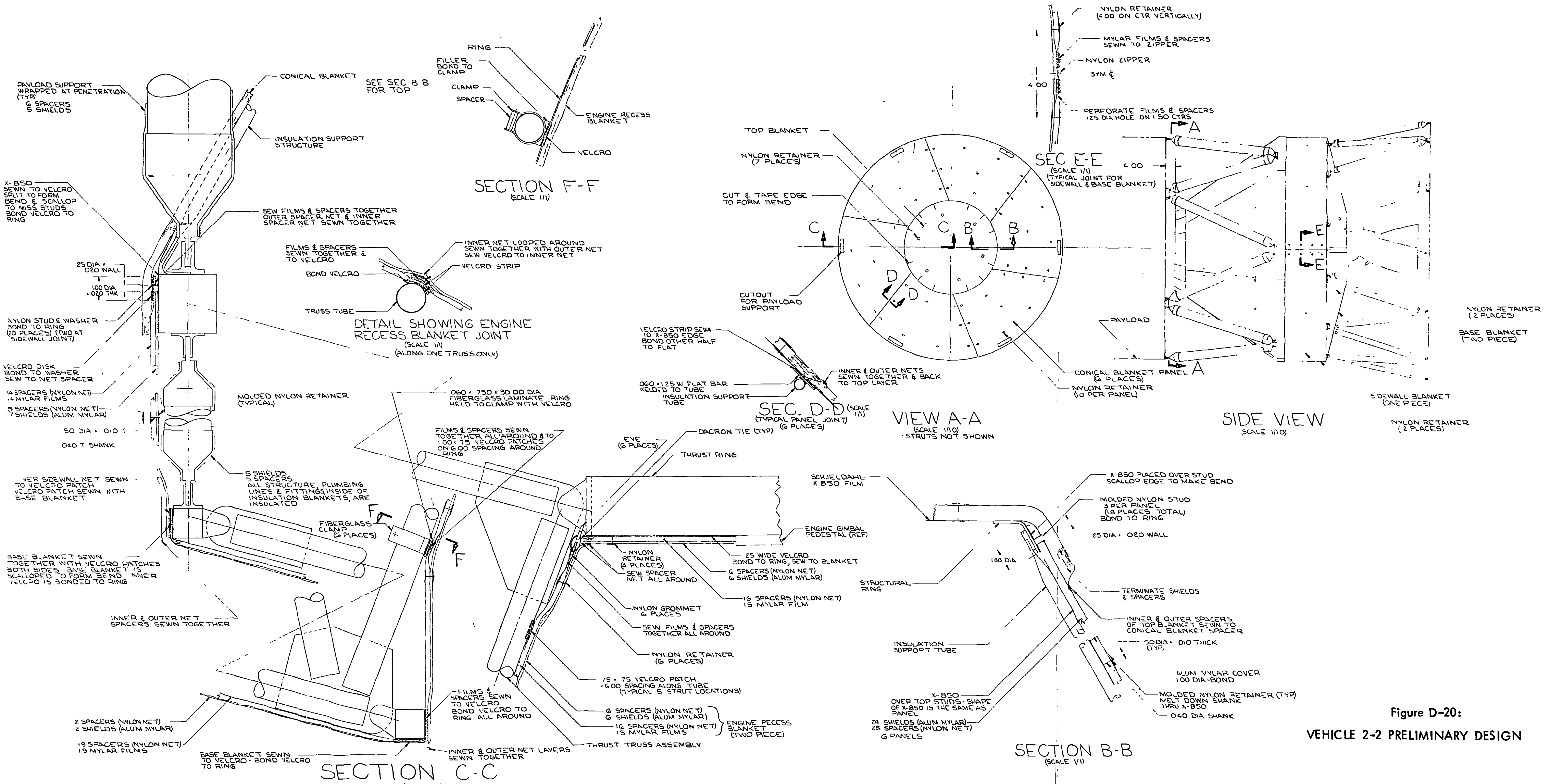


Figure D-20: VEHICLE 2-2 PRELIMINARY DESIGN

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TABLE D-1: SUMMARY WEIGHT COMPARISON

TYPE PROPELLANT	FLOX/CH_4					LF_2/LH_2					COMMENT
CONFIGURATION NO.	2–2	2–3	2–14	2–18	2–19	1–2A	1–2B	1–3	1–7	1–14	
STRUCTURE GROUP	180.1	132.3	119 3	86.2	93.5	199.8	169.2	166.4	135 2	150.7	
Primary Structure	41 6	49.1	62.6	29 5	56.1	51 3	54.7	49 3	95 4	67 7	Including Adapter
Secondary Structure	91 5	72.3	45.8	28.1	28.4	117.7	103.6	106.2	32.5	73.9	Including Thrust Structure, Propellant Tank Supts., Main Body Rings
Payload Support	47.5	10.9	10 9	28 6	9.0	30.8	10.9	10 9	7.3	9 1	Including F.G. Structure Between P/L and Upper Ring
THERMAL SYSTEM GROUP	81.2	89.5	65.5	58.7	65.0	112.5	103 0	125 0	110.7	76.8	
Primary Components	57.2	64.0	59.5	47.6	51.8	75.2	66 1	78 2	88.4	64.8	Including Propellant Tank Membrane Wt., Vapor, Helium & Helium Tank, Basic Insul (as sized by tate program).
Secondary Insul. ΔWeight	16 7	14.6	6.0	7.0	9.6	37.3	20.4	33.2	22 3	12.0	Including Misc."Overlap" Penalties, Velcro and Other Insul Attachments, Insul. Over Internal Structure and Plumbing.
Protection Δ Weight	6.3	10.9	*	4.1	3.6	*	16.5	13.6	*	*	Including Non-aluminized or Aluminized Shields as required for Meteoroid Protection "
PROPULSION SYSTEM GROUP	281.7	294.2	247.2	254.1	245.5	331.7	338.8	360.6	317.1	278.5	
Engine	108.0	108.0	108.0	108.0	108.0	108.0	108.0	108.0	108.0	108.0	Including Thrust Vector Control
Fuel System	80.4	67.3	51.4	44.2	44.9	68.5	67.9	120.6	119.7	62.5	Including Vent, Feed & Fill Plumbing, Supports
Oxidizer System	60 0	86.6	56.2	71.1	61 8	122.5	130.6	99.6	56 2	76.4	& Propellant Tank Outlet Penalties
Penumatic Control	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	
Pressurization Δ Weight	17 3	16.3	15 6	14.8	14 8	16.7	16.3	16.4	17.2	15.6	Total System Except Helium & Helium Tank
TOTAL HARDWARE	542.0	516 0	432.0	399.0	404 0	644 0	611.0	652.0	563 0	506.0	
PROPELLANT	2,440.0	2,440 0	2,440 0	2,440.0	2,440 0	2,170.0	2,170.0	2,170 0	2,170.0	2,170 0	
TOTAL SYSTEM	2,982.0	2,856.0	2,872.0	2,839 0	2,844.0	2,814.0	2,781.0	2,822 0	2,733.0	2,676.0	
** RELATIVE HARDWARE WEIGHT	1.36	1 29	1.08	1.00	1.01	1.27	1 21	1.29	1 11	1.00	

WEIGHT (LB)

* Included in Primary Thermal System Components

** Config. Hardware Weight/Lightest Config. Hardware Weight

TABLE D-1: SUMMARY WEIGHT COMPARISON

TYPE PROPELLANT	FLOX/CH_4					LF_2/LH_2					COMMENTS
CONFIGURATION NO.	2–2	2–3	2–14	2–18	2–19	1–2A	1–2B	1–3	1–7	1–14	
STRUCTURE GROUP	81.8	60.0	54 2	39.1	42.5	90 7	76.8	75.5	84.1	68 4	
Primary Structure	18.9	22 3	28.4	13.4	25.5	23.4	24 8	22 4	43.3	30.7	
Secondary Structure	41.5	32 8	20.8	12.8	12.9	53.4	47.0	48.2	14.8	33.6	
Payload Support	21.6	4.9	4.9	13.0	4.1	13.9	4.9	4 9	3.3	4.1	
THERMAL SYSTEM GROUP	36.9	40.6	29.7	26.6	29.5	51.1	46.8	56.8	50.3	34 9	See Table D–1 for Comments
Primary Components	26.0	29.1	27.0	21.6	23.5	34.1	30.0	35.5	40.1	29.4	
Secondary Insul ΔWeight	7.6	6.6	2.7	3.2	4.4	16.9	9.3	15.1	12.4	5 4	
Protection ΔWeight	2.9	4.9	•	1.9	1 6	•	7.5	6.2	•	•	
PROPULSION SYSTEM GROUP	127.9	133.6	112.2	115.4	111.5	150.6	153.8	163.7	144.0	126.4	
Engine	49.0	40.0	49.0	49.0	49.0	49.0	49.0	49 0	49.0	49.0	
Fuel System	36.5	30.5	23.3	20.0	20.4	31 1	30.8	54 8	53.9	28.4	
Oxidizer System	27.2	39.3	25.5	32.3	28.0	55.6	59.3	45.2	25.5	34 7	
Pneumatic Control	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	
Pressurization Δ Weight	7 8	7.4	7 1	6.7	6.7	7.6	7.4	7.4	7 8	7.1	
TOTAL HARDWARE	246.0	234.3	196.0	191.1	183.4	292 4	277.4	296 1	255.6	229.7	
PROPELLANT	1107.8	1107.8	1107.8	1107.8	1107.8	985.2	985.2	985.2	985.2	985 2	
TOTAL SYSTEM	1353.8	1296.6	1303.9	1288.9	1291.2	1277.6	1262.6	1281.2	1240.8	1214.9	
RELATIVE HARDWARE WT **	1.36	1 29	1.08	1 00	1.01	1.27	1.21	1.29	1.11	1.00	

** Config. Hardware Weight/Lightest Config. Hardware Weight.

WEIGHT (KILOGRAMS)

TABLE D-2: SECONDARY STRUCTURE AND INSULATION DETAIL WEIGHTS

	CONFIGURATION NUMBER														
	1–2A			1–2B			1–3			1–7			1–14		
SECONDARY STRUCTURE			117 7			103.6			106.2			32.5			73 9
Main Body Rings		57.54			66.17			48.12			11.11			57.72	
Upper Ring	28.77			29 41			24.06			1.71*			8.40		
Mid Ring	—			—			—			—			23 00		
Lower Ring	28.77			36.76			24.06			9 40			26.32		
Tank Support Structure		7.81			6.13			6.16			7.73			3.76	
Thrust Structure		52.35			31.30			51.92			13.66			12 42	
Engine Ring	9.10			—			—			—			—		
Thrust Ring Assy.	8.00			8 00			12.03			9.07			7.12		
Thrust Truss/Tube Assy.	33.00			23 30			28.56			4.59			5.30		
Torsion Tubes & Braces	2.25			—			11.33			—			—		
SECONDARY INSULATION			37.3			20.4			33.2			22.3			12.0
Insulation Support Structure		25.63			9.37			17.77			7.73				
Rings	10.81			4 89			—			3.27			—	—	
Support Tubes	8.57			1 64			—			—			—		
Misc. Supports	6.25			2.84			17.77			4.46			—		
Additional Insulation		4.37			3.61			4.29			1 26			0.70	
Tank Support Str. Insulation	0.51			0.50			0.32			0.34			0.17		
Thrust Str. Insulation	0.78			0.64			1.14			—			—		
Plumbing Insulation	0.94			0.91			1.06			0.65			0.35		
Insulation on Other Int. Str.	0.61			0.17			0.38			0.27			—		
Misc Overlaps, Etc.	1.53			1.39			1.39			—			0 18		

* Upper Diagonal Brace

WEIGHT IN LB

TABLE D-2: SECONDARY STRUCTURE AND INSULATION DETAIL WEIGHTS

	CONFIGURATION NUMBER														
	1–2A			1–2B			1–3			1–7			1–14		
SECONDARY STRUCTURE			53.44			47 03			48 21			14 76			33 6
Main Body Rings		26.12			30 0			21 85			5 04			26 20	
Upper Ring	13 06			13.35			10 92			0 776			3.81		
Mid Ring	–			–			–			–			10 44		
Lower Ring	13 06			16 69			10 92			4 27			11 95		
Tank Support Structure		3 55			2.78			2 80			3 51			1 71	
Thrust Structure		23.77			14 21			23.57			6 20			5 64	
Engine Ring	4 13			–			–			–			–		
Thrust Ring Assy	3.63			3 63			5 46			4 12			3 23		
Thrust Truss/Tube Assy	14 98			10.58			12 97			2 08			2 40		
Torsion Tubes & Braces	1 02			–			5 14			–			–		
SECONDARY INSULATION			16.93			9.26			15.07			10 12			5 45
Insulation Support Structure		11.64			4.25			8.07			3.51			–	
Rings	4 91			2 22			–			1.48			–		
Support Tubes	3.89			0.74			–			–			–		
Misc. Supports	2 84			1 29			8.07			2.02			–		
Additional Insulation		1 98			1.64			1 95			0.57			0 32	
Tank Support Str Insulation	0.231			0 227			0 145			0.154			0 077		
Thrust Structure Insulation	0.354			0.291			0.518			–			–		
Plumbing Insulation	0.426			0.413			0.481			0 30			0 158		
Insulation on Other Int. Str	0 277			0.077			0 173			0 123			–		
Misc. Overlaps, Etc.	0.695			0.631			0 631			–			0 082		

WEIGHT (KILOGRAMS)

TABLE D-3: SECONDARY STRUCTURE & INSULATION DETAIL WEIGHTS

	CONFIGURATION NUMBER									
	1–2A		1–2B		1–3		1–7		1–14	
SECONDARY INSULATION (Cont.)										
Major Joint Assemblies		0.72		3 51		6 34		6 34		8.31
Sidewall & Base	0.02		0.03		0.76		0.12		0.08	
At Upper Ring	0 13		1 40		3 22		–		2 12	
At Mid Ring	–		–		–		–		5 79	
At Lower Ring	0 13		0 66		0 66		–		0 19	
At Engine & Thrust Rings	0.35		0.09		1.70		–		0 13	
Other	0.09		1 33		–		6 22		–	
X–850 Film		2.75		2.16		2 15		4 59		1.11
Misc. Attachments [1]		2.35		0.10		0 36		0.13		0.08
Velcro	0.37		0.03		0.03		0.03		0.03	
Clamps, Retainers, Studs, Etc.	0.10		0.07		0.33		0.10		0 05	
Misc Fiberglass Rings, Etc.	1.88		–		–		–		–	
Miscellaneous Insulation Items		1.48		1 65		2.29		2 25		1.80
(Bond. Etc)										

WEIGHT (LB)

[1] Includes items not accounted for under major joints.

TABLE D-3: SECONDARY STRUCTURE AND INSULATION DETAIL WEIGHTS

	CONFIGURATION NUMBER									
	1–2A		1–2B		1–3		1–7		1–14	
SECONDARY INSULATION (Co n t)										
Major Joint Assemblies		0 33		1 59		2 88		2.88		3 77
Sidewall & Base	0.009		0 009		0 35		0.054		0 036	
At Upper Ring	0.059		0.630		1 46		–		0 96	
At Mid Ring	–		–		–		–		2 63	
At Lower Ring	0.059		0 299		0 30		–		0 083	
At Engine & Thrust Rings	0 159		0 041		0.77		–		0 059	
Other	0.041		0.149		–		2.82		–	
X–850 Film		1 25		0.98		0 97		2 08		0.504
Misc. Attachments		1.07		0.0454		0 163		0.059		0.036
Velcro	0 168		0 009		0.009		0 014		0.014	
Clamps, Retainers, Studs, Etc.	0.0454		0 032		0 0149		0 0454		0.023	
Misc. Fiberglass Rings, Etc	0.85		–		–		–		–	
Miscellaneous Insulation Items (Bonds, Etc)		0.67		0 75		1 04		1 02		0.82

WEIGHT (KILOGRAMS)

TABLE D-4: SECONDARY STRUCTURE & INSULATION DETAIL WEIGHTS

	CONFIGURATION NUMBER														
	2–2			2–3			2–14			2–18			2–19		
SECONDARY STRUCTURE			91.5			72.3			45.8			28 1			28 4
Main Body Rings		50.70			21.38			27 21			10 71			25 80*	
Upper Ring	13.12			10 69			2 78			—			12 90		
Mid Ring	—			—			2.78			10 71			—		
Lower Ring	37 58			10 69			21.65			—			12.90		
Tank Support Structure		7 73			8.60			3 33			3.34				
Thrust Structure		33.07			42.32			15 26			14.05			2.60	
Engine Ring	3.30			13 18			—			—			—		
Thrust Ring Assy	7.53			8.32			9.76			9.33			2.60		
Thrust Truss/Tube Assy	20.28			20.12			5.50			4.72			—		
Torsion Tubes & Braces	1.96			.70			—			—			—		
SECONDARY INSULATION			16.7			14.6			6.0			7 0			9.6
Insulation Support Structure		8.45			—			—			—			—	
Rings	0.92			—			—			—			—		
Support Tubes	4.64			—			—			—			—		
Misc. Supports	2.89			—			—			—			—		
Additional Insulation		3.58			3.65			1.08			0 66			1.90	
Tank Support Structure Insul.	0.37			0 40			0.16			0.14			—		
Thrust Structure Insulation	0.50			0.52			—			—			—		
Plumbing Insulation	0.54			0.61			0.23			0.25			0 28		
Insulation on Other Int. Str.	0.70			0.61			0 05			—			0.33		
Misc. Overlaps, Etc.	1 47			1.51			0.64			0 27			1 29		

WEIGHT (LB)

* Tank Y-Rings

TABLE D-4: SECONDARY STRUCTURE AND INSULATION DETAIL WEIGHTS

	CONFIGURATION NUMBER														
	2–2			2–3			2–14			2–18			2–19		
SECONDARY STRUCTURE			41.5			32 8			20 7			12 8			12 9
Main Body Rings		23 1			9.71			12.35			4 86			11.71	
Upper Ring	5.96			4 85			1 26			–			5 86		
Mid Ring	–			–			1 26			4 86			–		
Lower Ring	17.06			4 85			9 83			–			5.86		
Tank Support Structures		3.50			3 90			1.51			1.52				
Thrust Structure		15.01			21.03			6.93			6.38			1.18	
Engine Ring	1.50			5.98			–			–			–		
Thrust Ring Assembly	3.42			1.51			4.43			4.24			1.18		
Thrust Truss/Tube Assembly	9.21			9 13			2 50			2 14			–		
Torsion Tubes & Braces	3.61			0.32			–			–			–		
SECONDARY INSULATION			7 58			6.62			2.72			3.18			4 36
Insulation Support Structure		3.84			–			–			–			–	
Rings	0.42			–			–			–			–		
Support Tubes	2.11			–			–			–			–		
Misc. Supports	1.31			–			–			–			–		
Additional Insulation		1.63			1.66			0 49			0 30			0.86	
Tank Support Structure Insulation	0.17			0.18			0.073			0 064			–		
Thrust Structure Insulation	0.23			0.24			–			–			–		
Plumbing Insulation	0.25			0 28			0 104			0.0114			0.0127		
Insulation on Other Int. Str.	0.32			0.28			0.0023			–			0.0150		
Misc. Overlaps, Etc	0.67			0.69			0.29			0.0126			0.586		

WEIGHT (KILOGRAMS)

TABLE D-5: SECONDARY STRUCTURE & INSULATION DETAIL WEIGHTS

	CONFIGURATION NUMBER														
	2–2			2–3			2–14			2–18			2–19		
SECONDARY INSULATION (Continued)															
Major Joint Assemblies		1.47			4.49			3.30			4 47			4.88	
Sidewall & Base	0.11			0.14			0.08			0.08			0 11		
At Upper Ring	0.27			3.47			1.78			3.97			4 57		
At Mid Ring	–			–			1.04			0.29			–		
At Lower Ring	0.27			0.58			0.27			–			0.18		
At Engine & Thrust Rings	0.14			0.30			0.13			0.13			0.02		
Other	0.68			–			–			–			–		
X–850 Film		1.24			1.84			0.62			0.23			0.29	
Misc. Attachments [1]		0.61			2.30			0.07			0.56			1.04	
Velcro	0.02			0.03			0.03			0.03			0.02		
Clamps, Retainers, Studs, Etc.	0.13			0 07			0.04			0.53			1.02		
Misc. Fiberglass Rings, Etc.	0.46			2.20			–			–			–		
Miscellaneous Insulation Items (Bond, Etc.)		1.35			2.32			0.93			1.08			1.49	

[1] Includes items not accounted for under major joints

WEIGHT (LB)

TABLE D-5: SECONDARY STRUCTURE AND INSULATION DETAIL WEIGHTS

	CONFIGURATION NUMBER									
	2–2		2–3		2–14		2–18		2–19	
SECONDARY INSULATION (Continued)										
Major Joint Assemblies		0.68		2.04		1 50		2 03		2.22
Sidewall and Base	0.049		0.064		0.036		0.036		0.049	
At Upper Ring	0.123		1.575		0.81		1.80		2 075	
At Mid Ring	–		–		0.47		0.132		–	
At Lower Ring	0.123		0.263		0.123		–		0.082	
At Engine & Thrust Rings	0.064		0.136		0.059		0.059		0.009	
Other	0.31		–		–		–		–	
X-850 Film		0.56		0.83		0.28		0.104		0.132
Misc. Attachments [1]		0.28		1.04		0.032		0.29		0.47
Velcro	0.009		0.0136		0.0136		0.0136		0.009	
Clamps, Retainers, Studs, Etc.	0.59		0.032		0.0182			0.24		0.46
Misc. Fiberglass Rings, Etc.	0.21		0.99		–			–		–
Miscellaneous Insulation Items (Bonds, Etc.)		0.613		1.05		0.42		0.49		0.68

WEIGHT (KILOGRAMS)

[1] Includes items not accounted for under major joints.

TABLE D-6: CH_4 SYSTEM WEIGHTS

	CONFIGURATION														
	QTY	2–2		QTY	2–3		QTY	2–14		QTY	2–18		QTY	2–19	
VENT			40.3			33.2			22 7			21.6			22 0
Line 2.00 x 0.035 (0.0613 lb/in.)	150 in	9.2		90 in	5 5		35 in.	2.1		20 in	1 2		30 in	1 8	
Flanges 0.130 lb/ea.	26	3.4		9	1.2		6	0.8		6	0 8		4	0.5	
Solenoid Valve 8.0		8.0			8.0			8.0			8 0			8 0	
Bellows 5.0 ea.	2	10.0		2	10.0			5 0			5 0			5 0	
Disconnect Valve 3.0		3.0			3.0			3.0			3.0			3.0	
Supports 20%		6.7			5.5			3.8			3.6			3.7	
FEED			26.2			20.5			16.0			9.6			10 2
Manifold 1.25 x 0.025 0.027 lb/in.	40" x 3	3.2		90 in.	2.4		–			–			–		
Feed 0.80 x 0.020 0.014 lb/in.	15 in.	0.2		20 in.	0.3		100 in.	1.4		20 in.	0.3		50 in.	0.7	
Flanges—Manifold 0.067 lb/ea.	18	1.2		6	0.4		–			–			–		
Feed 0.042 lb/ea.	2	0.1		2	0.1		9	0.4		5	0.2		6	0.3	
Bellows 1.25D 3.2	3	9.6		2	2.4		–			–			–		
0.8 D 2.0		2.0			2.0		3	6.0			2.0			2.0	
Shutoff Valve 5.5		5.5			5.5			5.5			5 5			5.5	
Supports 20%		4.4			3.4			2.7			1.6			1.7	
FILL			12.1			12.4			12.1			12 4			12.1
Line 0.75 x 0.020 0.013	42 in	0.6		55 in.	2.7		35 in.	0 5		50 in	0.7		35 in.	0.5	
Flange 0.040	2	0.1		4	0.2		4	0.2		4	0.2		4	0.2	
Disconnect 1.9		1.9			1.9			1.9			1.9			1.9	
Fill Valve 5.5		5.5			5.5			5.5			5 5			5.5	
Bellows 2.0		2.0			2.0			2.0			2.0			2.0	
Supports 20%		2.0			2.1			2.0			2.1			2.0	
TANK OUTLET ΔWEIGHT			1.8			1.2			0.6			0.6			0.6
Vent (3) (0.13)/Tank	3	1.2		2	0.8			0.4			0.4			0.4	
Feed (3) (0.067)/Tank	3	0.6		2	0.4			0.2			0.2			0.2	
TOTAL			80.4			67.3			51.4			44.2			44 9

WEIGHT (LB)

TABLE D-6: CH_4 SYSTEM WEIGHTS

		CONFIGURATION														
		QTY	2–2		QTY	2–3		QTY	2–14		QTY	2–18		QTY	2–19	
VENT				18.3			15.1			10.3			9.8			10.0
Line 5.08 x .089 cm	(.028 kg/cm)	381 cm	4.18		228 cm	2.50		88.9 cm			50.8 cm			76.2 cm		
Flanges	(.059 kg/ea	26	1.54		9	0.54		6	0.363		6	0.363		4	0.227	
Solenoid Valve	3.6 kg/ea.		3.63			3.63			3.63			3.63			3.63	
Bellows	2.27 kg/ea.	2	4.54		2	4.54			2.27			2.27			2.27	
Disconnect Valve	1.36 kg/ea.		1.36			1.36			1.36			1.36			1.36	
Supports	20%		3.04			2.50			1.73			1.63			1.68	
FEED				11.89			9.31			7.26			4.36			4.63
Manifold 3.17 x .064 cm (.012 kg/cm)		101.6 x 7.6 cm	1.45		228.6 cm	1.09		–			–			–		
Feed	(.006 kg/cm)	38.1 cm	0.091		50.8 cm	0.136		254.0	0.64		50.8 cm	0.136		127 cm	0.32	
Flanges—Manifold	.034 kg/ea.	18	0.54		6	0.182		–			–			–		
Feed	.019 kg/ea.	2	0.045		2	0.045		9	0.182		5	0.091		6	0.136	
Bellows 3.170	1.45 kg	3	4.36		2	1.09		–			–			–		
2.030	.91 kg		0.908			0.91		3	2.72			0.91			0.91	
Shutoff Valve	2.50 kg		2.50			2.50			2.50			2.50			2.50	
Supports	20%		1.99			1.59			1.27							
FILL				5.5			5.6			5.5			5.6			5.5
Line 1.91 x .051 cm	(.006 kg/cm)	10.7 cm	0.27		13.7 cm	0.32		8.9 cm	0.23		12.7 cm	0.32		8.9 cm	0.23	
Flange	.002 kg/ea	2	0.045		4	0.091		4	0.041		4	0.091		4	0.091	
Disconnect	.86 kg		0.86			0.86			0.86			0.86			0.86	
Fill Valve	2.49 kg		2.5			2.49			2.49			2.49			2.49	
Bellows	0.91 kg		0.91			0.91			0.91			0.91			0.91	
Supports	20%		0.91			0.91			0.91			0.91			0.91	
TANK OUTLET Δ WEIGHT				0.817			0.544			0.272			0.272			0.272
Vent	3/.059/Tank	3	0.544		2	0.363			0.363			0.363			0.363	
Feed	3/.031/Tank	3	0.272		2	0.181			0.091			0.091			0.091	
TOTAL				36.50			30.55			23.34			20.07			20.29

WEIGHT (KILOGRAMS)

TABLE D-7: FLOX SYSTEM WEIGHTS

		CONFIGURATION														
		QTY	2–2		QTY	2–3		QTY	2–14		QTY	2–18		QTY	2–19	
VENT				25.9			33.0			22.4			23.9			26.0
Line 2.00 x 0.035	(0.0613 lb/in.)	78 in.	4.8		90 in.	5.5		35 in.	2.1		50 in.	3.1		80 in.	4.9	
Flanges	0.13 lb/ea.	6	0.8		8	1.0		6	0.8		6	0.8		6	0.8	
Solenoid Valves	8.0 lb/ea.		8.0			8.0			8.0			8.0			8.0	
Disconnect Valves	3.0 lb/ea.		3.0			3.0			3.0			3.0			3.0	
Bellows	5.0 lb/ea.		5.0		2	10.0			5.0			5.0			5.0	
Supports	20%		4.3			5.5			3.5			4.0			4.3	
FEED				15.6			34.2			15.6			29.9			17.6
Line 1.60 x 0.035	0.0497	25 in.	1.2		25 in.	1.2		25 in.	1.2		90 in.	4.5		50 in.	2.5	
Flanges	0.10 lb/ea.	3	0.3		8	0.9		3	0.3		8	0.9		6	0.7	
Bellows	4.0		4.0		3	12.0			4.0		3	12.0			4.0	
Shutoff Valve	7.5		7.5			7.5			7.5			7.5			7.5	
Supports	20%		2.6			5.7			2.6			5.0			2.9	
Manifold 2.50 x 0.035	0.0769	–			90 in.	6.9		–			–			–		
FILL				17.8			17.9			17.5			16.6			17.5
Line 1.50 x 0.020	0.0264	50 in.	1.3		55 in.	1.4		40 in.	1.1		15 in.	0.4		35 in.	0.9	
Flanges	0.060	4	0.2		4	0.2		4	0.2		4	0.2		6	0.4	
Bellows	3.8		3.8			3.8			3.8			3.8			3.8	
Fill Valve	7.0		7.0			7.0			7.0			7.0			7.0	
Disconnect Valve	2.5		2.5			2.5			2.5			2.5			2.5	
Supports	20%		3.0			3.0			2.9			2.7			2.9	
TANK OUTLET DELTA WEIGHT				0.7			1.5			0.7			0.7			0.7
Vent	(3) (0.13)/Tank		0.4		2	0.8			0.4			0.4			0.4	
Feed	(3) (0.14)/Tank		0.3		2	0.7			0.3			0.3			0.3	
TOTAL				60.0			86.6			56.2			71 1			61.8

WEIGHT (LB)

TABLE D-7: FLOX SYSTEM WEIGHTS

		CONFIGURATION NUMBER														
		QTY	2–2		QTY	2–3		QTY	2–14		QTY	2–18		QTY	2–19	
VENT				11 76			14.98			10.17			10.85			11 80
Line 5 08 x .089 cm	(.028 kg/cm)	198 cm	2.18		229 cm	2.50		89 cm	0.95		127 cm	1 41		203 cm	2.22	
Flange	.059 kg/ea	6	0.36		8	0.45		6	0.36		6	0 36		6	0.36	
Solenoid Valves	3.6 kg/ea.		3.63			2.62			3.63			3.63			3.63	
Disconnect Valves	1 36 kg/ea.		1.36			1.36			1.36			1.36			1.36	
Bellows	2 27 kg/ea.		2 27		2	4.54			2.27			2.27			2 27	
Supports	20%		1.95			2.50			1 60			1.82			1.95	
FEED				7 1			15.53			7.1			13.57			7.99
Line 4.06 x .089 cm	(.026 kg/cm)	63.5 cm	0.55		63.5 cm	0.55		63.5 cm	0.55		229 cm	20.4		127 cm	1.14	
Flanges	.045 kg/ea.	3	0 14		8	0.41		3	0 14		8	0 41		6	0.32	
Bellows	1.81 kg/ea.		1.81		3	5.45			1 81		3	5.45			1.81	
Shut-Off Valve	3.4 kg/ea		3.4			3.4			3 4			3.4			3.4	
Supports	20%		1.18			2.68			0 99			2 27			1.32	
Manifold 6.35 x .089 cm	(.0349 kg/cm)				228 cm	3.13			–			–			–	
FILL				8.08			8.13			7.95			7.54			7.95
Line 3.81 x .051 cm	(.012 kg/cm)	127 cm	0.59		140 cm			102 cm			38 cm			89 cm		
Flanges	.027 kg/ea.	4	0.09		4	0.09		4	0.09		4	0 09		6	0 18	
Bellows	1.73 kg/ea.		1.73			1.73			1.73			1.73			1.73	
Fill Valve	3.18		3.18			3.18			3.18			3.18			3.18	
Disconnect Valve	1.14		1 14			1.14			1.14			1.14			1 14	
Supports	20%		1.36			1.36			1 32			1 23			1 32	
TANK OUTLET ΔWEIGHT				0.32			0.68			0.32			0.32			0.32
Vent	(3) .059 kg/Tank		0.18		2	0.36			0.18			0.18			0 18	
Feed	(3) .064 kg/Tank		0.14		2	0.32			0.14			0.14			0 14	
TOTAL				27.24			39.32			25 51			32 28			28.06

WEIGHT (KILOGRAMS)

TABLE D-8: PNEUMATIC CONTROL AND PRESSURIZATION WEIGHTS

		CONFIGURATION														
		2–2			2–3			2–14			2–18			2–19		
		QTY			QTY			QTY			QTY			QTY		
PNEUMATIC CONTROL				16.0			16.0			16 0			16.0			16 0
He PRESSURIZATION DELTA WEIGHT				17.3			16.3			15.6			14 8			14.8
Lines ½ XD.020	0.0085	180 in.	1.5		150 in	1.3		110 in.	0.9		60 in.	0.5		65 in.	0.6	
¼ x 0.020	0.0041	85 in.	0.4		20 in.	0.1		110 in.	0.2		45 in	0.2		20 in.	0 1	
Fittings	75%		1.4			1.1			0.8			0 5			0.5	
Regulators	3.5 lb/ea.	2	7.0		2	7.0		2	7.0		2	7.0		2	7.0	
Filter	1.0 ea.		1.0			1.0			1.0			1.0			1.0	
¼" Squib	0.7 ea.		0.7			0.7			0 7			0.7			0 7	
Check Valves	0.6 ea.	2	1.2		2	1.2		2	1.2		2	1.2		2	1.2	
Disconnects	0.6 ea.	2	1.2		2	1.2		2	1 2		2	1.2		2	1 2	
Supports	20%		2.9			2.7			2.6			2.5			2.5	
TOTAL PROPELLANT FEED				173.7			186.2			139.5			146 2			137 5

WEIGHT (LB)

TABLE D-8: PNEUMATIC CONTROL AND PRESSURIZATION WEIGHTS

	CONFIGURATION NUMBER														
	2–2			2–3			2–14			2–18			2–19		
	QTY			QTY			QTY			QTY			QTY		
PNEUMATIC CONTROL			7.26			7 26			7.26			7.26			7.26
He PRESSURIZATION ΔWEIGHT			7.85			7.40			7.08			6.72			6.72
Lines 1.27 x .051 cm (.0039 kg/cm)	457 cm	0.68		381 cm			279 cm			152 cm			165 cm		
0.635 x .051 cm (.0019 kg/cm)	216 cm	0.18		50.8 cm			102 cm			114 cm			50.8 cm		
Fittings 75%		0.64													
Regulators 1.60 kg/ea.	2	3.19		2	3.19		2	3.19		2	3.19		2	3.19	
Filter 0.454 kg/ea.		0.454			0.454			0.454			0 454			0.454	
Squib .635 cm .318 kg/ea.		0.318			0.318			0.318			0.318			0.318	
Check Valves .272 kg/ea.	2	0.544		2	0.544		2	0.544		2	0.544		2	0.544	
Disconnect .272 kg/ea.	2	0.544		2	0.544		2	0.544		2	0.544		2	0 544	
Supports 20%		1.32			1.23			1.18			1.14			1.14	
TOTAL PROPELLANT FEED			78.86			84.53			63.33			66.37			62 46

WEIGHT (KILOGRAMS

TABLE D-9: LH_2 SYSTEM WEIGHTS

		CONFIGURATION														
		QTY	1–2A		QTY	1–2B		QTY	1–3		QTY	1–7		QTY	1–14	
VENT				26.4			24 7			34 8			34 6			22.3
LINE 2.00 x 0 035	(0.0613 Lb/In)	85 in	5.2		65 in	4 0		110 in.	6 7		105 in	6 4		35 in	2 1	
Flanges	0.130 Lb/Ea	6	0.8		5	0.6		10	1 3		11	1 4		4	0 5	
Solenoid Valve	8 0 Lb/Ea.		8 0			8.0			8.0			8 0			8.0	
Bellows	5.0 Lb/Ea.		5.0			5.0		2	10.0		2	10.0			5 0	
Disconn Valve	3.0 Lb/Ea.		3 0			3 0			3 0			3 0			3 0	
Supports	20%		4.4			4.1			5.8			5 8			3 7	
FEED				16 7			16.7			59 4			60 0			17 0
Manifold 3.25 x 0 049	(0.1386 lb/in.)	–			–			120 in	16 6		135 in	18 7		–		
Feed 2.1 x 0.035	(0.0644 lb/in)	35	2.2		35	2.2		50 in.	3 2		25 in.	1.6		35 in	2.2	
Flanges–Manifold	0 26 lb/ea	–			–			10	2 6		10	2 6		–		
Feed	0.14 lb/ea	2	0 3		2	0.3		2	0 3		2	0.3		4	0 6	
Bellows –	5 2 lb/ea.		5.2			5.2			5 2			5.2			5 2	
	7 7 lb/ea.	–			–			2	15 4		2	15 4		–		
Shutoff Valve	6.2 lb/ea.		6.2			6.2			6.2			6 2			6.2	
Supports	20%		2.8			2.8			9.9			10 0			2 8	
FILL				24.6			25.7			24 0			22.7			22 4
Line 2.00 x 0.035	(0.0613 lb/in.)	65 in.	4.0		80 in	4.9		55 in	3.4		38 in	2.3		35 in.	2 1	
Flanges	0.130	4	0.5		4	0.5		5	0.6		5	0.6		5	0 6	
Disconnect	3.0		3.0			3.0			3 0			3 0			3 0	
Fill Valve	8.0		8 0			8.0			8.0			8 0			8 0	
Bellows	5.0		5.0			5.0			5 0			5 0			5 0	
Supports	20%		4.1			4.3			4.0			3 8			3 7	
TANK OUTLET ΔWeight				0 8			0 8			2 4			2 4			0.8
Vent	(3) (0 130) lb/tank		0 4			0.4		2	0 8		2	0 8			0 4	
Feed	(3) (0.140) lb/tank		0 4			0.4		–			–				0.4	
	(3) (0.26) lb/tank		–			–		2	1 6		2	1 6			–	
TOTAL				68.5			67 9			120 6			119 7			62 5

(WEIGHT IN LBS)

TABLE D-9: LH_2 SYSTEM WEIGHTS

		CONFIGURATION NUMBER														
		QTY	1–2A		QTY	1–2B		QTY	1–3		QTY	1–7		QTY	1–14	
VENT				12 0			11.2			15.8			15.7			10 1
Line 5.08 x 089 cm	(.028 kg/cm)	216 cm	2.36		165 cm	1.82		279 cm	3 04		268 cm	2 91		89 cm	0.95	
Flange	059 kg ea.	6	0.36		5	0.27		10	0.59		11	0.64		4	0 23	
Solenoid Valve	3.6 kg ea.		3.63			3.36			3.36			3 36			3.36	
Bellows	2.27 kg ea.		2.27			2.27		2	4.54		2	4.54			2 27	
Disconnect Valve	1.36 kg ea.		1.36			1.36			1.36			1 36			1.36	
Supports	20%		2.00			1 86			2 63			2 63			1 68	
FEED				7 58			7.58			27.0			27.24			7.72
Manifold 8.26 x .124 cm	(.063 kg/cm)	–			–			305 cm	7.54		343 cm	8.44		–		
Feed 5.33 x .089 cm	(029 kg/cm)	89 cm	1.0		89 cm	1.0		127 cm	1.45		66 cm	0.73		89 cm	1 0	
Flanges – Manifold	.118 kg ea.	–			–			10	1.18		10	1 18		–		
– Feed	.064 kg ea.	2	0.14		2	0 14		2	0 14		2	0.14		4	0.27	
Bellows	2.361 kg ea.		2.36			2.36			2.36			2.36			2.36	
	3.5 kg ea.	–			–			2	7.0		2	7.0		–		
Shut-Off Valve	2.82 kg ea		2.82			2.82			2.82			2.82			2.82	
Supports	20%		1 27			1.27			4.50			4.54			1.27	
FILL				11.17			11.66			10.9			10.31			10.17
Line 5.08 x .089cm	(.028 kg/cm)	165 cm	1.82		203 cm	2.22		140 cm	1.54		97 cm	1.04		89 cm	0.95	
Flanges	.059 kg ea	4	0.23		4	0.23		5	0.27		5	0.27		5	0.27	
Disconnect	1.362 kg ea.		1.36			1.36			1 36			1.36			1.36	
Fill Valve	3.63 kg ea.		3.63			3.36			3.36			3.36			3.36	
Bellows	2.27 kg ea.		2.27			2.27			2.27			2.27			2.27	
Supports	20%		1.86			1.95			1.82			1.73			1.68	
TANK OUTLET Δ WEIGHT				0.36			0.36			1.09			1.09			0.36
Vent	(3) .059 kg/Tank		0.18			0.18		2	0.36		2	0 36			0.18	
Feed	(3) .064 kg/tank		0.18			0.18		–	–		–	–			0.18	
	(3) 118 kg/Tank		–			–		2	0 73		2	0.73			–	
TOTAL				31 1			30.83			54 75			54.34			28.38

WEIGHT (KILOGRAMS)

TABLE D-10: LF_2 SYSTEM WEIGHTS

		CONFIGURATION														
		QTY	1–2A		QTY	1–2B		QTY	1–3		QTY	1–7		QTY	1–14	
VENT				53.6			46 3			35 3			22 0			22.7
Line 2 00 x 0 035	(0.0613 lb/in.)	195 in	12.0		180 in.	11.0		115 in	7 0		25 in	1 5		35 in	2.1	
Flanges	0.13 lb/ea.	13	1 7		12	1 6		11	1.4		6	0 8		6	0.8	
Solenoid Valves	8 lb/ea.		8.0			8 0			8 0			8.0			8.0	
Disconnect	3 lb/ea		3.0			3 0			3.0			3.0			3 0	
Bellows	5 lb/ea	4	20.0		3	15.0		2	10.0			5 0			5 0	
Supports	20%		8.9			7 7			5.9			3.7			3.8	
FEED				48 5			64 9			44.8			16 3			35 5
Line 1 60 x 0.035	(0.0497 lb/in.)	35 in.	1 7		65 in	3.2		50 in	2 5		35 in	1 7		105 in.	5 2	
Manifold 2.50 x 0.035	(0 0769 lb/in	175 in.	13.4		175 in.	13.4		125 in	9.6		–			–		
Flanges	0.111 lb/ea.	4	0.4		3	0.3		2	0.2		4	0.4		8	0 9	
	0.153 lb/ea.	9	1.4		11	1.7		10	1.5		–			–		
Bellows–Feed	4 0 lb/ea.		4.0			4.0			4.0			4.0		4	16.0	
Shut-off Valve	7.5 lb/ea.		7.5			7 5			7.5			7 5			7 5	
Supports	20%		8.1			10.8			7.5			2 7			5 9	
Bellows–Manifold	6.0 lb/ea.	2	12.0		4	24.0		2	12 0		–			–		
FILL				17 8			16.8			17.8			17.0			17 3
Line 1 50 x 0.020	(0 0264 lb/in)	50 in	1.3		20 in	0.5		50	1.3		25 in	0 7		35 in	0.8	
Flanges	0.060 lb/ea.	4	0.2		3	0.2		3	0 2		4	0.2		4	0 2	
Bellows	3.8 lb/ea.		3.8			3.8			3.8			3 8			3 8	
Fill Valve	7.0 lb/ea		7.0			7.0			7 0			7 0			7.0	
Disconnect	2 5 lb/ea.		2 5			2 5			2.5			2 5			2 5	
Support	20%		3.0			2.8			3.0			2.8			2 9	
TANK OUTLET DELTA WEIGHT				2.6			2 6			1.7			0 9			0 9
Vent	(3) (0.13) lb/Tank	3	1.2		3	1 2		2	0 8			0 4			0 4	
Feed	(3) (0.153) lb/Tank	3	1.4		3	1.4		2	0 9			0 5			0.5	
TOTAL				122 5			130 6			99 6			56 2			76 4

WEIGHT (LB)

TABLE D-10: LF_2 SYSTEM WEIGHTS

	CONFIGURATION NUMBER														
	QTY	1–2A		QTY	1–2B		QTY	1–3		QTY	1–7		QTY	1–14	
VENT			24 3			21.02			16 03			9.99			10 31
Line 5.08 x .089 cm (.028 kg/cm)	495 cm	5.45		457 cm	4.99		292 cm	3 18		63 cm	0 68		89 cm	0 95	
Flanges 059 kg/ea.	13	0.77		12	0.73		11	0.64		6	0 36		6	0.36	
Solenoid Valve 3.60 kg/ea.		3.63			3 60			3.60			3 60			3.60	
Disconnect 1.36 kg/ea.		1 36			1.36			1.36			1 36			1.36	
Bellows 2.27 kg/ea.	4	9.08		3	6.81		2	4 54			2 27			2.27	
Supports 20%		4 04			3.49			2.68			1.68			1.73	
FEED			22.10			29.5			20 34			7.4			16.12
Line 4 06 x .089 cm (023 kg/cm)	89 cm	0 77		165 cm	1.45		127 cm	1.14		89 cm	0 77		268 cm	2.36	
Manifold (035 kg/cm)	445 cm	6.08		445 cm	6.08		318 cm	4.36		–			–		
Flanges .054 kg/ea.	4	0.18		3	0.14		2	0 09		4	0 18		8	0.41	
.0695 kg/ea.	4	6.36		11	0.77		10	0.68		–			–		
Bellows–Feed 1.816 kg/ea.		1.82			1 82			1.82			1 82		4	1.82	
Shut-Off Valve 3.405 kg/ea.		3.41			3.41			3.41			3 41			3.41	
Support 20%		3.68			4.90			3.41			1.23			2.68	
Bellows–Manifold 2.72 kg/ea.	2	5.44		4	10.88		2								
FILL			8.08			7 63			8.08			7 72			7 85
Line 3.81 x .051 cm (.012 kg/cm)	127 cm	0.59		50.8 cm	0.23		127 cm	0.59		63 cm	0.32		89 cm	0.36	
Flanges .0272 kg/ea.	4	0.091		3	0.091		3	0.091		4	0.091		4	0 091	
Bellows 1.725 kg/ea.		1.73			1.73			1.73			1 73			1.73	
Fill Valve 3.178 kg/ea.		3.18			3.18			3.18			3.18			3.18	
Disconnect 1.135 kg/ea.		1.14			1.14			1.14			1 14			1.14	
Supports 20%		1.36			1 27			1 36			1 27			1.32	
TANK OUTLET Δ WEIGHT			1.18			1 18			0.772			0.409			0 409
Vent (3) .059 kg/tank	3	0.54		3	0.54		2	0.36			0 18			0.18	
Feed (3) .069 kg/tank	3	0.64		3	0.64		2	0.41			0.23			0 23	
TOTAL			55.62			59 29			45.22			25.51			34 69

WEIGHT (KILOGRAMS)

TABLE D-11: PNEUMATIC CONTROL AND PRESSURIZATION WEIGHTS

	CONFIGURATION														
	1–2A			1–2B			1–3			1–7			1–14		
	QTY			QTY			QTY			QTY			QTY		
PNEUMATIC CONTROL			16.0			16.0			16.0			16.0			16 0
Pressurization Delta Weight			16.7			16.3			16.4			17.2			15.6
Lines ½ x 0.020 0.0085 lb/in.	175 in.	1.5		160 in.	1.4		160 in.	1.4		200 in	1 7		105 in	0.9	
¼ x 0.020 0.0041 lb/in.	25 in.	0.1		10 in.	Neg.		35 in.	0 1		35 in	0.1		40 in.	0.2	
Fittings 75%		1.2			1.1			1.1			1.4			0.8	
Regulators, Filters, Squib															
Check Valves & Disconnect		11.1			11.1			11.1			11.1			11.1	
(See Table D–8)															
Supports 20%		2.8			2.7			2.7			2.9			2.6	
TOTAL PROPELLANT FEED			223.7			230.8			252.6			209.1			170.5

WEIGHT (LB)

TABLE D-11: PNEUMATIC CONTROL & PRESSURIZATION WEIGHTS

	CONFIGURATION NUMBER														
	1–2A			1–2B			1–3			1–7			1–14		
	QTY			QTY			QTY			QTY			QTY		
PNEUMATIC CONTROL			7.26			7 26			7.26			7.26			7.26
Pressurization ΔWeight			7.58			7.40			7.45			7 81			7 08
Lines 1.37 x .051 cm (.0039 kg/cm)	446 cm	0.68		406 cm	0.64		406 cm	0.64		508 cm	0.77		267 cm	0.41	
.635 x .051 cm (.0019 kg/cm)	63 cm	0.045		25 cm	Neg.		89 cm	0.045		89 cm	0.045		102 cm	0 091	
Fittings 75%		0.545			0 499			0.499			0.636			0.363	
Regulators, Filters, Squibs, Check Valves, Disconnect (See Table D–8)		0.504			0.504			0.504			0 504			0.504	
Supports 20%		1.27			1.23			1.23			1 32			1.18	
TOTAL PROPELLANT FEED			101.56			104.78			114 68			94.93			77.41

WEIGHT (KILOGRAMS)

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APPENDIX E

THERMAL TEST RESULTS AND ANALYSIS

This appendix presents the temperature data obtained in the thermal performance tests. The material is organized by test number, in the order discussed in Section 2.2.3 of the Volume I document, NASA CR-121103. This material supplements the discussion on correlation of analysis and results in Section 2.2.3 of that document. Figure E-1 is a drawing of the test article showing locations of the thermocouples discussed in this appendix.

The analytical models used in the analysis of results, and the temperatures predicted by means of these models are also described here.

Test Results

Test T-1 - This was the first of a baseline test series consisting of Tests T-1, T-2 and T-3. The test series was intended to evaluate heat transfer rates of the test article with two different warm boundaries and two cryogenic fluids. Test T-1 used LH_2 in the test tank and guard and ≈ 70°F (295°K) water in the thermal shroud.

The temperatures measured at points on the thermal shroud, and the ambient temperature are shown in Figure E-2. The temperature spike at 3300 minutes was due to an over-adjustment of the shroud thermostat. A gradual drift downwards had been noted in the shroud temperatures and in an attempt to correct this situation the water heater was activated.

Figure E-3 shows the temperatures on the outside of the MLI at the upper edge of the test article. These temperatures reflect the fluctuations in the shroud, including the spike at 3300 minutes. The MLI surface ranged from one to three degrees colder than the shroud as measured by Thermocouple T13.

Figure E-4 represents the temperatures on the inside of the MLI at the same locations as in Figure E-3. These values had become very stable after about 2600 minutes, indicating thermal equilibrium had been attained.

Figure E-5 shows temperatures on the exterior of the MLI, across the lap joint. Figure E-6 shows the temperatures on the inside of the MLI at the same locations. The outside temperatures followed the same general pattern as the shroud except with somewhat greater deviations. The inside temperatures were very stable except for the period at 3300 minutes.

Figure E-7 is the temperature of the wet test meter exhaust gas. The heat exchanger, water saturator and wet test meter were located in an environmentally controlled room, therefore the gas temperature was expected to remain constant.

However, the door was opened several times during the test to make adjustments, which accounts for the variations in the plot.

Figure E-8 gives the pressure in the guard tank and Figure E-9 shows vacuum chamber pressure. Normally, when a test series was started, the chamber pumps were started on a Friday and allowed to pump over the weekend. A decision was then made on the following Monday whether to load the cryogen into the tanks or to continue pumping.

Figure E-10 shows the temperature in the guard tank during the test.

Test T-2 - This was a repeat of Test T-1 except that LN_2 was used in the guard and test tanks. The thermal shroud and ambient temperatures are shown in Figure E-11. External and internal MLI temperatures at two locations are shown in Figures E-12 through E-15. The external temperatures followed the shroud whereas the internal temperatures were very stable.

Wet test meter exhaust gas temperature is shown in Figure E-16. Figure E-17 shows the guard tank pressure. A mistake was made in filling the water manometer which controlled the guard pressure. This is evident at 1200 minutes, where the pressure rose abruptly.

Figure E-18 shows vacuum chamber pressure and Figure E-19 shows the temperature in the guard tank.

Test T-3 - In this test the fluid in the tanks was LH_2 and the thermal shroud was filled with LN_2 to represent the warm boundary temperature of the propulsion vehicle sidewall. The thermal shroud and ambient temperatures are shown in Figure E-20. There was no explanation for the discrepancy noted for Thermocouple T-705.

External and internal MLI temperatures are shown in Figures E-21 through E-24. The external temperatures did not reach the shroud temperature in this test, instead they were approximately 25°F (14°K) warmer.

Temperature of the wet test meter exhaust gas is shown in Figure E-25. Figures E-26 and E-27 show altitude chamber and guard tank pressures, respectively. Figure E-28 gives the temperature data in the guard tank.

Test T-4 - This was a repeat of Test T-1, after the simulated launch loads were applied to the test article. Thermal shroud and ambient temperatures are shown in Figure E-29.

The temperatures on the external surface of the MLI in Figure E-30 follow the shroud temperatures. Internal MLI temperatures are shown in Figure E-31.

Figure E-32 shows temperatures on the aluminum tubing framework. These temperatures are reasonably uniform regardless of location. T-45 was located on a different part of the framework than the other thermocuples shown.

Figures E-33, E-34, and E-35 show wet test meter gas temperature, altitude chamber pressure and guard tank pressure, respectively. Figure E-36 gives the temperatures in the guard tank.

Test T-5 - The test article was modified to add a fiberglass tubular strut connected between the aluminum framework and the test tank. A cutout of the MLI was necessary to attach the strut to the framework. The strut was equipped with a heater at the outboard (warm) end and was instrumented with thermocouples for about one-half its length.

Thermal shroud and ambient temperatures are shown in Figure E-37. The external and internal surface temperatures of the MLI are presented in Figures E-38 and E-39. The inner surface reflected the effects of the MLI penetration at the strut location, as evidenced by T-416, T-415 and T-413. The influence of the strut heater is evident at approximately 3100 minutes.

Figure E-40 shows the temperatures on the aluminum framework. The effect of heater activation at 3100 minutes is very apparent in this figure. Thermocouple T-45 was located on an adjacent framework member and was used as a control for application of heater power.

Figure E-41 shows the temperature distribution along the fiberglass strut. The thermocouple nearest the heater (T-41) reflected the addition of heater power at 3100 minutes as was expected. This effect was essentially "washed-out" at Thermocouple T-43.

Figure E-42 shows the heater power settings.

Figures E-43, E-44 and E-45 show gas temperature at the wet test meter, vacuum chamber pressure and guard tank pressure, respectively. Figure E-46 shows the guard tank temperature.

Test T-6 - The test article was modified for this series by adding a stainless steel fluid line section. The line connected between the aluminum framework and the test tank, and a cutout in the MLI was necessary. The fluid line was equipped with a heater at the warm end and was instrumented with thermocouples. The test was run with the heaters off during the initial phase, then the heaters were activated.

Figure E-47 shows the thermal shroud and ambient temperatures.

Figures E-48, E-49 and E-50 show temperatures on the inside and outside of the MLI during the test. In Figure E-48, Thermocouple T-519 was closest to the cut in the MLI which was made to represent an assembly joint. This thermocouple was warmer than the other two which were farther away from the joint. All of these curves reflect the heater activation point at 5000 minutes. Thermocouple T-55 in Figure E-50 was closest to the pipe penetration and was considerably warmer than other thermocouples farther away. This location was also influenced more by heater activation.

Figure E-51 shows temperatures on the aluminum framework in the vicinity of the line penetration, and at more remote locations. Thermocouple T-532 was located farthest away from the penetration.

Figure E-52 shows the temperature on the fluid line support plate at the warm end (T-525) and temperatures along the fluid line. The influence of heater activation is evident at 5000 minutes.

Figure E-53 shows the heater power settings.

Figures E-54, E-55 and E-56 present wet test meter gas temperature results, pressure in the guard tank and vacuum chamber pressure, respectively.

Test T-7 - This was a repeat of the preceding test, except that LN_2 was the fluid rather than LH_2. Figure E-57 shows thermal shroud and ambient temperatures.

Figure E-58 shows the external and internal temperatures on the MLI near the fluid line penetration. The heaters were not used in this test. Figures E-59 and E-60 show more MLI temperatures.

Figure E-61 shows temperatures on the aluminum framework. Figure E-62 shows the temperature distribution along the fluid line and on the mounting plate (T-525) at the warm end.

Figures E-63, E-64 and E-65 show wet test meter gas temperature, vacuum chamber pressure and guard tank pressure, respectively.

Test T-8 - This test incorporated a new base MLI blanket which was lapped over the outside of the sidewall blanket. The joint resembled the top deck lap joint of the vehicle final designs described in Volume I. The base section of the thermal shroud was isolated from the sidewall section by micarta blocks. Warm water was used in the base section and LN_2 was used in the sidewall section to represent the flight thermal environment. Figure E-66 shows the shroud and ambient temperatures.

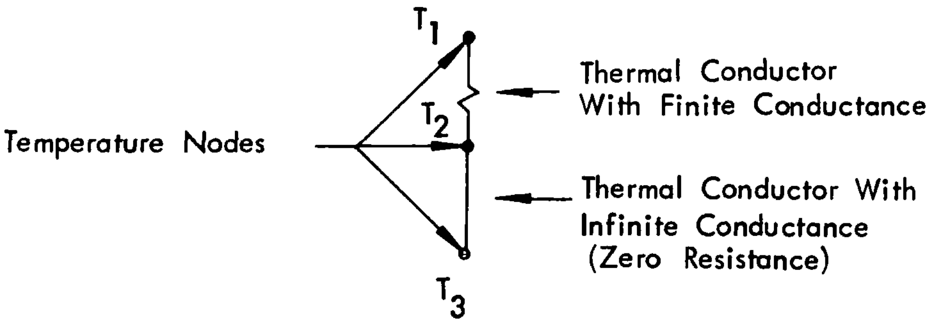
Figures E-67 and E-68 show MLI temperatures on the outside and inside at the lap joint location. The heaters were inactive during this test.

Figure E-69 shows temperatures on the aluminum framework and on the fluid line.

Figures E-70 and E-71 show the wet test meter gas temperature, the guard tank pressure and the vacuum chamber pressure.

Analysis

Figures E-72 through E-81 illustrate the nodal networks that formed the basis for analytical models used for theoretical predictions of temperatures and heat flow at the test conditions. Symbolism used throughout the figures is as follows:



The temperature nodes were the points at which temperatures were evaluated. Incremental surface areas involved in radiant heat interchange were assumed concentrated at the temperature nodes. The conductance value of each thermal conductor was based on the cross section area normal to the heat flow, length between temperature node terminals, and thermal conductivity of the segment of material represented by that conductor. Where necessary these areas, lengths, and conductivities were determined as the appropriate mean values for the conductor span.

Radiation connectors, which included the effects of incremental areas, geometric view factors, and material emittances upon thermal radiation interchange, were not shown in the figures. In general, radiation connectors joined each pair of temperature nodes lying on surfaces absorbing or emitting thermal radiation. Some radiation connectors, where very small radiative interchange factors would have resulted in insignificant heat transfer, were omitted for simplification. Radiation through the MLI was accounted for in the MLI effective conductivity property.

The nodal network representing the basic MLI assembly with the original miter base joint, shown in Figure E-72, was a two-dimensional network, a simplification made possible by the assumption of axial symmetry of the tank-insulation-shroud assembly. This network was representative of the configuration of Tests T-1 through T-7 and was used in the analytical predictions for Tests T-1 through T-4.

Figure E-73 shows the nodal network used to analyze the longitudinal joint for Tests T-1 through T-4 and for Test T-8. The use of a two-dimensional network here was based on the assumption of invariance of properties, geometry, and boundary conditions along the length of the joint.

The network used for analyzing typical nylon pin fasteners for Tests T-1 through T-4 and for Test T-8 is shown in Figure E-74. Axial symmetry about the pin centerline was assumed, again permitting the use of a two-dimensional model. The figure shows the addition of a one-dimensional model for heat flow through the MLI at a location remote from fastener (or other) influence. This feature was added to the fastener analysis to provide an accurate basis for computing the net heat flow attributable to the fastener and for checking the adequacy of the fastener model in isolating the fastener influence. Results of the remote-location one-dimensional analysis were also used as baseline values for assessing longitudinal joint incremental heat flow.

The nodal network used for analyzing the strut penetration for Tests T-5, T-7 and T-8 is shown in part in Figure E-75. For the purpose of these analyses, the MLI surrounding the penetration was divided into 3 layers, each one node thick, in the same manner as for the basic MLI of Figure E-72. These layers are shown schematically in Figure E-75 and are illustrated as a developed view in Figure E-76. Note that the strut itself is considered a one-dimensional conductor and that the nodes on the inner surface of the strut MLI were identical to the strut nodes, consistent with the assumptions made for this model. Heat flow between the main MLI and the strut attach pad, the strut bracket, and the upper strut end fitting was assumed to occur by radiation only; hence, no conductors were shown connecting the main MLI and the strut heat flow path. The symmetry of the strut MLI permitted representing all circumferential conductors with a set lying on only one-half of the MLI tube.

The nodal network for the plumbing line penetration, used in analyzing tests T-6, T-7 and T-8, is illustrated in Figures E-77 and E-78, in a manner similar to the strut penetration network in the two previous figures. In the case of the plumbing line penetration, conduction paths were assumed to exist between the main MLI and the plumbing line MLI. Therefore, the diagram included a sub-network representing the joint resistances between these two components. In a manner similar to the strut and strut MLI network, the nodes on the plumbing line MLI inner surface were identical to the plumbing line nodes.

The nodal network for the basic MLI assembly with the lap base joint made extensive use of the network for the original basic MLI configuration. The network for the revised joint, used for the analysis of Test T-8, is shown in Figures E-79 through E-81. In addition to the obvious changes in the MLI network and the inclusion of the base joint support assembly, the model for Test T-8 also differed from that of the earlier tests in that the shroud side wall and base, having different temperatures, could no longer be represented by a common node.

The predicted steady state temperatures from the thermal analyses are listed in Tables E-1 through E-13. The node identification is that used on the diagrams of the nodal networks, Figures E-72 through E-81.

Details of both the computed and the measured heat flow results are presented in Table E-14. This table is a more detailed version of the heat flow summary, Table 2.2-2 of the Volume I report. The analytical basic heat flow ($\dot{Q}_{Basic}$), the additional heat flow due to the longitudinal joint ($\Delta \dot{Q}_{Long.\ Joint}$), and the additional heat flow due to the fasteners ($\Delta \dot{Q}_{Fasteners}$) were all evaluated at the inner surface of the main MLI.

The predicted additional heat flow associated with the strut penetration ($\Delta \dot{Q}_{Strut}$) consisted of three components. The first two, the heat conducted into the strut itself and the heat conducted into the strut MLI, were evaluated at the intersection of the plane of the main MLI inner surface with these components. The third component of the incremental heat flow was the additional heat radiated from the inner surface of the main MLI, that heat having entered the MLI by radiation or conduction at the opening for the strut bracket.

The predicted additional heat flow due to the plumbing line ($\Delta \dot{Q}_{Plumb.\ Line}$) penetration was synthesized from three components in a manner very similar to that for the strut heat flow. The entry in Table E-11 for heat conducted into the plumbing line includes that heat transfer by radiation in the line interior at the heat flow evaluation plane.

Examination of the three components of incremental heat flow in the case of the strut and plumbing line penetrations permitted limited assessment of the effectiveness of the insulation designs for those components. The heat conducted into the penetrating member (strut or plumbing line) and into its MLI were interrelated and depended upon the length, cross-section area, and conductivity of the member and upon the thickness of the MLI wrap. The additional heat radiated by the main MLI, on the other hand, was primarily a function of the design at the penetration.

The advantage of the low conductivity strut material was quite evident, while the strong heat leak contribution of the relatively heavy metal plumbing line was also clear. Because of the high conductance of the plumbing line, most of the heat conducted into its upper end probably continued through the length of the line. Therefore, there appeared to be little advantage to increasing the thickness of the plumbing line MLI. Insulation of the plumbing line from the structure at its support points and increasing the length of insulated line inside or outside the main MLI assembly would have reduced the heat leak.

In cases of tests with no applied heat, it was seen that the additional heat radiated from the main MLI was greater near the strut than near the plumbing line, even th ough the plumbing line penetration required a larger opening. The difference was probably due to the extension of the plumbing line MLI through the opening in the main MLI and indicated an advantage of this feature.

The total measured heat flow ($\dot{Q}_{Meas}$) was computed from two components. Part of the heat reaching the test vessel was absorbed in vaporizing the liquid cryogen and is identified as $\dot{Q}_{Vap}$. The remainder of the heat, $\dot{Q}_{\Delta T}$ acted to raise the temperature of the resulting gas prior to its discharge from the insulated part of the system. The sum of $\dot{Q}_{Vap}$ and $\dot{Q}_{\Delta T}$ constituted the total measured heat flow.

Table E-1: PREDICTED STEADY STATE TEMPERATURES TEST T-1 & T-4, BASIC MLI ASSEMBLY

* Boundary Nodes (Temperatures Input)

NODE	TEMPERATURE °R	TEMPERATURE °K	NODE	TEMPERATURE °R	TEMPERATURE °K	NODE	TEMPERATURE °R	TEMPERATURE °K	NODE	TEMPERATURE °R	TEMPERATURE °K
T1	527	292.8	T23	421	233.9	T45	531	293.9	T70*	37.0	20.4
T2	429	238.3	T24	243	135	T46	520	288.9	T71*	532	295.6
T3	257	142.8	T25	526	292.2	T47	530	294.4	T72	209	116.1
T4	527	292.8	T26	420	233.3	T48	498	276.6	T73	219	121.6
T5	429	238.3	T27	229	127.25	T49	366	203.3	T76	526	292.2
T6	259	144.9	T28	526	292.2	T50*	37.0	20.4	T77	526	292.2
T7	527	292.8	T29	419	232.8	T51	529	293.8			
T8	429	238.8	T30	213	118.3	T52	480	266.6			
T9	258	143.3	T31	526	292.2	T53	528	293.3			
T10	527	292.8	T32	418	232.3	T54	443	246.1			
T11	428	237.8	T33	223	132.5	T55	166	92.2			
T12	255	141.65	T34	526	292.2	T56	206	114.5			
T13	527	292.8	T35	415	230.5	T57	220	122.1			
T14	428	237.8	T36	250	116.4	T58	195	108.3			
T15	254	141.1	T37	519	288.4	T59	219	121.6			
T16	527	292.8	T38	402	223.3	T60	179	97.8			
T17	427	237.2	T39	268	148.9	T61	213	118.3			
T18	254	141.1	T40	464	257.8	T62	160	88.9			
T19	527	292.8	T41	382	212.2	T63	179	99.4			
T20	423	235.0	T42	316	175.5	T64	138	76.6			
T21	251	139.5	T43	532	295.5	T65	108	60.0			
T22	527	292.8	T44	526	292.2	T66	75.1	41.5			

Table E-2: PREDICTED STEADY STATE TEMPERATURES TEST T-1 & T-4, MLI LONGITUDINAL JOINT

* Boundary Nodes (Temp. Input)

NODE	TEMPERATURE °R	TEMPERATURE °K	NODE	TEMPERATURE °R	TEMPERATURE °K	NODE	TEMPERATURE °R	TEMPERATURE °K	NODE	TEMPERATURE °R	TEMPERATURE °K
T1	529	293.8	T23	499	272.2	T45	468	260.0	T67	431	239.4
T2	500	277.8	T24	468	260.0	T46	432	240.0	T68	389	216.1
T3	458	260.0	T25	433	240.6	T47	391	217.3	T69	339	188.3
T4	430	238.9	T26	390	216.7	T48	341	189.5	T70	276	153.4
T5	385	213.9	T27	340	188.9	T49	277	154.0	T71	527	292.8
T6	330	183.3	T28	275	152.8	T50	527	292.8	T72	499	272.2
T7	254	141.1	T29	527	292.8	T51	499	272.2	T73	468	260.0
T8	529	293.8	T30	499	272.2	T52	468	260.0	T74	431	239.4
T9	500	277.8	T31	469	260.6	T53	432	240.0	T75	389	216.1
T10	468	260.0	T32	433	240.6	T54	390	217.6	T76	338	187.8
T11	431	239.4	T33	391	217.3	T55	341	189.5	T77	273	151.6
T12	388	215.5	T34	340	188.9	T56	277	154.0	T78	529	293.8
T13	334	185.6	T35	276	153.4	T57	527	292.8	T79	500	277.8
T14	258	143.3	T36	527	292.8	T58	499	272.2	T80	468	260.0
T15	527	292.8	T37	499	272.2	T59	468	260.0	T81	431	239.4
T16	499	277.2	T38	468	260.0	T60	431	239.4	T82	388	215.5
T17	468	260.0	T39	433	240.6	T61	389	216.1	T83	333	185.0
T18	432	240.0	T40	390	216.7	T62	340	188.9	T84	258	198.9
T19	390	216.7	T41	341	189.5	T63	277	154.0	T85	529	293.8
T20	338	187.8	T42	277	154.0	T64	527	292.8	T86	500	277.8
T21	273	151.6	T43	527	292.6	T65	499	272.2	T87	467	259.4
T22	527	292.8	T44	499	272.2	T66	468	260.0	T88	430	238.9
									T89	385	213.9
T94	469	260.6	T98	432	240.0	T102	389	216.1	T90	330	183.3
T95	433	240.6	T99	391	217.3	T103	340	188.9	T91	254	141.1
T96	499	272.2	T100	342	190.0	T104*	532	295.6	T92	526	292.2
T97	469	260.6	T101	278	154.6	T105*	37.0	20.4	T93	490	272.2

Table E-3: PREDICTED STEADY STATE TEMPERATURES TEST T-1 & T-4, FASTENER AND SURROUNDING MLI

*Boundary Nodes (Temp. Input)

NODES	TEMPERATURE		NODE	TEMPERATURE		NODE	TEMPERATURE	
	°R	°K		°R	°K		°R	°K
T1	290	161.1	T25	492	273.4	T47	403	223.8
T2	341	189.5	T26	526	292.2	T48	451	250.6
T3	401	222.6	T27	259	143.9	T49	492	273.4
T4	450	250.0	T28	342	190.1	T50	527	292.8
T5	491	272.8	T29	403	223.8	T51	258	143.3
T6	522	290.0	T30	451	250.6	T52	342	190.1
T8	287	159.5	T31	492	273.4	T53	403	223.8
T9	342	190.1	T32	527	292.8	T54	451	250.6
T10	401	222.6	T33	258	143.3	T55	492	273.4
T11	450	250.0	T34	342	190.1	T56	527	292.8
T12	491	272.8	T35	403	223.8	T60	284	157.8
T13	522	290.0	T36	451	250.6	T61	277	153.9
T15	271	150.5	T37	492	273.4	T62	276	153.3
T16	342	190.1	T38	527	292.8	T63	276	153.3
T17	402	223.2	T39	258	143.3	T64	525	291.6
T18	451	250.6	T40	342	190.1	T65	529	293.9
T19	492	273.4	T41	403	223.8	T66	529	293.9
T20	525	291.8	T42	451	250.6	T67	529	293.9
T21	262	145.5	T43	492	273.4	T58*	532	295.6
T22	342	190.1	T44	527	292.8	T57*	37.0	20.4
T23	402	223.2	T45	258	143.3			
T24	451	250.6	T46	342	190.1			

Table E-4: PREDICTED STEADY STATE TEMPERATURES TEST T-2, BASIC MLI ASSEMBLY

* Boundary Nodes (Temp. Input)

NODE	TEMPERATURES		NODE	TEMPERATURES		NODE	TEMPERATURES	
	°R	°K		°R	°K		°R	°K
T1	527	292.8	T23	423	235.0	T45	531	293.9
T2	430	240.0	T24	251	139.5	T46	520	288.9
T3	262	145.5	T25	527	292.8	T47	530	294.4
T4	527	292.8	T26	422	234.5	T48	499	277.2
T5	430	240.0	T27	241	133.9	T49	373	207.2
T6	264	146.7	T28	527	292.8	T50*	140	77.8
T7	527	292.8	T29	422	234.5	T51	529	293.9
T8	430	240.0	T30	229	127.2	T52	482	267.6
T9	264	146.7	T31	526	292.2	T53	528	293.3
T10	527	292.8	T32	421	233.9	T54	448	248.9
T11	429	238.3	T33	237	131.6	T55	197	109.4
T12	260	144.5	T34	526	292.2	T56	224	124.5
T13	527	292.8	T35	417	231.7	T57	234	130.0
T14	429	238.3	T36	257	142.8	T58	217	120.5
T15	260	144.5	T37	519	288.4	T59	231	128.3
T16	527	292.8	T38	406	225.5	T60	206	114.5
T17	428	237.7	T39	274	152.2	T61	226	125.5
T18	260	144.5	T40	466	258.9	T62	194	107.8
T19	527	292.8	T41	387	215.0	T63	204	113.4
T20	425	236.1	T42	322	178.9	T64	181	100.5
T21	258	143.3	T43	532	295.6	T65	165	91.6
T22	527	292.8	T44	527	292.8	T66	151	83.9
T70*	140	77.8	T73	234	130.0			
T71*	532	295.6	T76	526	292.2			
T72	227	126.1	T77	527	292.8			

Table E-5: PREDICTED STEADY STATE TEMPERATURES TEST T-2, MLI LONGITUDINAL JOINT

* *Boundary Node (Temp Input)*

NODE	TEMPERATURE		NODE	TEMPERATURE		NODE	TEMPERATURE		NODE	TEMPERATURE	
	°R	°K		°R	°K		°R	°K		°R	°K
T1	529	293 9	T28	279	155.0	T55	344	195 6	T82	389	216.1*
T2	500	277 8	T29	527	292.8	T56	281	156 2	T83	336	186.6*
T3	468	260.0	T30	499	277.2	T57	527	292.8	T84	263	146 1
T4	431	240 6	T31	469	260.6	T58	499	277 2	T85	529	293 9
T5	387	215 0	T32	434	242.2	T59	468	260 0	T86	501	278 4
T6	333	185.0	T33	392	217.9	T60	433	240.5	T87	468	260 0
T7	259	143.9	T34	343	195.0	T61	391	217 3	T88	431	240 6
T8	529	293.9	T35	280	155 6	T62	343	195 0	T89	387	215 0
T9	500	277.8	T36	527	292.8	T63	281	156 2	T90	333	185.0
T10	469	260.6	T37	499	277 2	T64	527	292.8	T91	259	143 9
T11	433	241.8	T38	469	260.6	T65	499	277.2	T92	526	293.9
T12	390	216 7	T39	434	242.2	T66	468	260 0	T93	499	277 2
T13	337	187 2	T40	392	217.9	T67	432	241.2	T94	469	260.6
T14	263	146.2	T41	343	195.0	T68	391	217 3	T95	434	242.2
T15	527	292.8	T42	281	155.0	T69	342	190 0	T96	499	277 2
T16	500	277.8	T43	527	292 8	T70	280	155 6	T97	469	260 6
T17	469	260.6	T44	499	277.2	T71	527	292 8	T98	433	240 5
T18	433	241.8	T45	469	260.6	T72	500	277 8	T99	392	217.7
T19	391	217.3	T46	433	240.5	T73	468	260.0	T100	344	195 6
T20	341	189.5	T47	392	217 9	T74	432	241 2	T101	282	155 6
T21	278	154 5	T48	344	195 6	T75	391	217 3	T102	391	217.3
T22	527	292.8	T49	281	156.2	T76	340	188 9	T103	343	190.7
T23	499	277 2	T50	527	292.8	T77	277	153.9	T104*	532	295.6
T24	469	260 6	T51	499	277.2	T78	529	293 9	T105*	140	77.8
T25	434	242.2	T52	469	260 6	T79	500	277 8			
T26	392	217 9	T53	433	240.5	T80	468	260 0			
T27	342	190 1	T54	392	217.9	T81	432	241 2			

Table E-6: PREDICTED STEADY STATE TEMPERATURES TEST T-2, FASTENER AND SURROUNDING MLI

* Boundary Nodes (Temperatures Input)

NODE	TEMPERATURE °R	TEMPERATURE °K	NODE	TEMPERATURE °R	TEMPERATURE °K	NODE	TEMPERATURE °R	TEMPERATURE °K
T1	294	163.4	T25	492	273.3	T47	405	225 1
T2	344	191 1	T26	526	292 2	T48	452	251 1
T3	403	223.9	T27	263	146.2	T49	492	273 3
T4	451	250.6	T28	345	191 7	T50	527	292 8
T5	492	273.3	T29	404	224 5	T51	262	145 6
T6	522	290.0	T30	452	251 1	T52	345	191 7
T8	290	161 1	T31	492	273 3	T53	405	225 1
T9	344	191 1	T32	527	292 8	T54	452	251 1
T10	403	223 9	T33	263	146 2	T55	492	273 3
T11	451	250.6	T34	345	191 7	T56	527	292 8
T12	492	273.3	T35	405	225.1	T60	288	160.0
T13	523	290.6	T36	452	251 1	T61	280	155 6
T15	275	152 8	T37	492	273 3	T62	280	155 6
T16	345	191 7	T38	527	292.8	T63	280	155 6
T17	404	224 5	T39	263	146 2	T64	525	291 7
T18	452	251 1	T40	345	191 7	T65	529	293 9
T19	492	273.3	T41	405	225 1	T66	529	293 9
T20	525	291 7	T42	452	251 1	T67	529	293 9
T21	267	148.4	T43	492	273 3	T57*	140	77 8
T22	345	191 7	T44	527	292 8	T58*	532	295 6
T23	404	224 5	T45	263	146 2			
T24	452	251 1	T46	345	191 7			

Table E-7: PREDICTED STEADY STATE TEMPERATURES TEST T-3, BASIC MLI ASSEMBLY

* Boundary Nodes (Temperatures Input)

NODE	TEMPERATURE °R	TEMPERATURE °K	NODE	TEMPERATURE °R	TEMPERATURE °K	NODE	TEMPERATURE °R	TEMPERATURE °K
T1	133	73 9	T23	109	60 6	T45	136	75 6
T2	118	65.6	T24	84 0	46 6	T46	127	70 5
T3	100	55.6	T25	129	71 6	T47	134	74 5
T4	133	73 9	T26	108	61 1	T48	119	66 1
T5	118	65.6	T27	77 4	43 0	T49	82 5	45 8
T6	101	56 1	T28	129	71 6	T50*	37 0	20 6
T7	133	73.9	T29	107	59 4	T51	133	73.9
T8	118	65.6	T30	71 4	38.6	T52	113	62 8
T9	101	56 1	T31	129	71 6	T53	129	71 6
T10	133	73.9	T32	107	59 4	T54	103	57 2
T11	117	64 9	T33	74 6	41 5	T55	58 6	32 5
T12	99 3	55.2	T34	127	70 5	T56	69 0	38.3
T13	133	73 9	T35	105	58 3	T57	73 2	40 6
T14	117	64 9	T36	84 0	46 6	T58	65 9	36.7
T15	98.9	55 4	T37	120	66 6	T59	72 2	40 1
T16	132	73 3	T38	97 9	54 4	T60	61 3	35 2
T17	115	63 9	T39	84 9	47 1	T61	68 1	38 0
T18	97 8	54 3	T40	100	55 5	T62	56 1	31 2
T19	131	72 7	T41	89 0	49 5	T63	55 6	31 0
T20	111	61 6	T42	83 1	46 1	T64	51 2	29 6
T21	91 0	50 5	T43	137	76 1	T65	45 6	25 3
T22	130	72 2	T44	129	71 6	T66	40 7	22 6
T70*	37 0	20 6	T73	73 5	40 8			
T71*	140	77 8	T76	129	71 6			
T72	70 3	39 1	T77	129	71 6			

Table E-8: PREDICTED STEADY STATE TEMPERATURES TEST T-3 & T-8, MLI LONGITUDINAL JOINT

* Boundary Nodes (Temperatures Input)

NODE	TEMPERATURE		NODE	TEMPERATURE		NODE	TEMPERATURE		NODE	TEMPERATURE	
	°R	°K		°R	°K		°R	°K		°R	°K
T1	136	75.5	T23	130	72.2	T45	125	69.5	T67	121	67.2
T2	131	72.7	T24	125	69.5	T46	121	67.2	T68	116	64.5
T3	126	70.0	T25	121	67.2	T47	116	64.5	T69	110	61.1
T4	120	66.7	T26	116	64.5	T48	111	61.6	T70	105	58.4
T5	115	63.9	T27	111	61.6	T49	106	58.9	T71	134	74.5
T6	108	60.0	T28	105	58.4	T50	134	74.5	T72	130	72.2
T7	102	56.6	T29	134	74.5	T51	130	72.2	T73	125	69.5
T8	136	75.5	T30	130	72.2	T52	125	69.5	T74	121	67.2
T9	131	72.7	T31	125	69.5	T53	121	67.2	T75	115	64.0
T10	126	70.0	T32	121	67.2	T54	116	64.5	T76	110	61.1
T11	121	67.3	T33	116	64.5	T55	111	61.6	T77	105	58.4
T12	115	63.9	T34	111	61.6	T56	106	58.9	T78	136	75.5
T13	109	60.6	T35	106	60.0	T57	134	74.5	T79	131	72.8
T14	103	57.2	T36	134	74.5	T58	130	72.2	T80	126	70.0
T15	134	74.5	T37	130	72.2	T59	125	69.5	T81	120	66.7
T16	130	72.2	T38	125	69.5	T60	121	67.2	T82	115	64.0
T17	125	69.5	T39	121	67.2	T61	116	64.5	T83	109	60.5
T18	121	67.2	T40	116	64.5	T62	111	61.6	T84	103	57.2
T19	116	64.5	T41	111	61.6	T63	106	58.9	T85	136	75.5
T20	110	61.1	T42	106	60.0	T64	134	74.5	T86	131	72.7
T21	105	58.4	T43	134	74.5	T65	130	72.2	T87	126	70.0
T22	134	74.5	T44	130	72.2	T66	125	69.5	T88	120	66.7
									T89	114	63.3
T94	125	69.5	T98	121	67.2	T102	116	64.5	T90	108	60.0
T95	121	67.2	T99	116	64.5	T103	111	61.6	T91	102	56.6
T96	130	72.2	T100	111	61.6	T104*	140	77.8	T92	134	74.5
T97	125	69.5	T101	106	58.9	T105*	37	20.6	T93	130	72.2

Table E-9: PREDICTED STEADY STATE TEMPERATURES TEST T-3, FASTENER AND SURROUNDING MLI

* Boundary Nodes (Temperatures Input)

NODE	TEMPERATURE		NODE	TEMPERATURE		NODE	TEMPERATURE	
	°R	°K		°R	°K		°R	°K
T1	111	61.6	T25	127	70.6	T47	115	63.9
T2	112	62.2	T26	132	73.3	T48	121	67.3
T3	117	65.0	T27	102	56.6	T49	127	70.6
T4	122	67.8	T28	109	60.5	T50	133	73.9
T5	127	70.6	T29	116	64.5	T51	101	56.1
T6	130	72.2	T30	122	67.8	T52	108	60.0
T8	110	61.1	T31	127	70.6	T53	116	63.9
T9	112	62.2	T32	133	73.9	T54	121	67.3
T10	117	65.0	T33	102	56.6	T55	127	70.6
T11	122	67.8	T34	109	60.5	T56	133	73.9
T12	127	70.6	T35	115	63.9	T60	111	61.6
T13	130	72.2	T36	121	67.3	T61	112	62.2
T15	106	58.9	T37	127	70.6	T62	112	62.2
T16	111	61.6	T38	133	73.9	T63	112	62.2
T17	116	64.5	T39	101	56.1	T64	130	72.2
T18	122	67.8	T40	109	60.5	T65	131	72.8
T19	127	70.6	T41	115	63.9	T66	131	72.8
T20	132	73.3	T42	121	67.3	T67	131	72.8
T21	104	57.8	T43	127	70.6	T57*	37.0	20.6
T22	110	61.1	T44	133	73.9	T58*	140	77.8
T23	116	64.5	T45	101	56.1			
T24	122	67.8	T46	108	60.0			

Table E-10: PREDICTED STEADY STATE TEMPERATURES TEST T-5, TANK SUPPORT STRUT AND SURROUNDING MLI

* Boundary Nodes (Temp. Input)
( ) Heater On

NODE	TEMPERATURE		NODE	TEMPERATURE		NODE	TEMPERATURE		NODE	TEMPERATURE		NODE	TEMPERATURE		NODE	TEMPERATURE		NODE	TEMPERATURE	
	°R	°K		°R	°K		°R	°K		°R	°K		°R	°K		°R	°K		°R	°K
T001*	532	295.6	T023	101	56.1	T045	102	56.7	T112	526	292.2	T238	431	239.5	T260	428	237.8	T282	428	237.8
T005*	37.0	20.4	T024	114	63.4	T046	115	64.0	T113	526	292.2	T239	430	238.9	T261	428	237.8	T283	428	237.8
T006	40.1	22.3	T025	126	70.0	T047	128	71.2	T114	526	292.2	T240	430	238.9	T262	428	237.8	T284	428	237.8
T007	44.2	24.6	T026	138	76.6	T048	140	77.8	T115	526	292.2	T241	429	238.3	T263	428	237.8	T301	256	142.2
T008	119	66.1	T027	149	82.7	T049	152	84.4	T116	526	292.2	T242	429	238.3	T264	428	237.8	T302	256	142.2
T002	524 (529)	291 (294)	T028	160	88.9	T050	164	91.1	T117	526	292.2	T243	428	237.8	T265	428	237.8	T303	256	142.2
T003	524 (529)	291 (294)	T029	171	95.0	T051	176	97.8	T118	526	292.2	T244	428	237.8	T266	428	237.8	T304	259	143.9
T004	524 (529)	291 (294)	T030	182	101.1	T052	187	103.9	T119	525 (526)	291.7 (292.2)	T245	428	237.8	T267	428	237.8	T305	272	151.1
T009	184	102.2	T031	192	106.6	T053	197	109.5	T120	524 (529)	291.1 (293.9)	T246	428	237.8	T268	428	237.8	T306	309 (318)	171.6 (176.6)
T010	236	131.1	T032	202	112.2	T054	207	115.0	T121	524 (529)	291.1 (293.9)	T247	429	238.3	T269	428	237.8	T307	309 (318)	171.6 (176.6)
T011	283	157.2	T033	211	117.2	T055	216	120.0	T122	524 (529)	291.1 (293.9)	T248	430	238.9	T270	428	237.8	T308	309 (318)	171.6 (176.6)
T012	332	184.5	T034	220	122.2	T101	526	292.2	T123	525 (526)	291.7 (292.2)	T249	430	238.9	T271	428	237.8	T309	292 (294)	162.2 (163.3)
T013	384	213.3				T102	526	292.2	T124	526	292.2	T250	430	238.9	T272	428	237.8	T310	279	155.0
T014	436 (438)	242.2 (243.3)				T103	526	292.2	T125	526	292.2	T251	430	238.9	T273	428	237.8	T311	269	149.5
T015	481 (484)	267.2 (268.9)				T104	526	292.2	T126	526	292.2	T252	429	238.3	T274	428	237.8	T312	264	146.6
T016	517 (520)	287.2 (288.9)				T105	525 (526)	291.7 (292.2)	T127	526	292.2	T253	429	238.3	T275	428	237.8	T313	261	145.0
T017	519 (523)	288.4 (290)				T106	524 (529)	291.1 (293.9)	T128	526	292.2	T254	428	237.8	T276	428	237.8	T314	258	143.3
T018	520 (525)	288.9 (291.7)				T107	524 (529)	291.1 (293.9)	T129	526	292.2	T255	428	237.8	T277	428	237.8	T315	256	142.2
T019	521 (525)	289.5 (291.7)				T108	524 (529)	291.1 (293.9)	T130	526	292.2	T256	428	237.8	T278	428	237.8	T316	256	142.2
T020	524 (529)	291.1 (293.9)				T109	525 (526)	291.7 (292.2)	T131	526	292.2	T257	428	237.8	T279	428	237.8	T317	256	142.2
T021	524 (529)	291.1 (293.9)				T110	526	292.2	T132	526	292.2	T258	428	237.8	T280	428	237.8	T318	259	143.9
T022	524 (529)	291.1 (293.9)	T044	88.2	49.0	T111	526	292.2	T133	525 (526)	291.7 (292.2)	T259	428	237.8	T281	428	237.8	T319	272	151.1
T134	525 (526)	291.7 (292.2	T156	526	292.2	T178	526	292.2	T216	428	237.8	T320	309 (318)	171.6 (176.6)	T342	258	143.3	T364	256	142.2
T135	525 (526)	291.7 (292.2	T157	526	292.2	T179	526	292.2	T217	428	237.8	T321	309 (318)	171.6 (176.6)	T343	256	142.2	T365	256	142.2
T136	525 (526)	291.7 (292.2)	T158	526	292.2	T180	526	292.2	T218	429	238.3	T322	309 (318)	171.6 (176.6)	T344	256	142.2	T366	256	142.2
T137	525 (526)	291.7 (292.2)	T159	526	292.2	T181	526	292.2	T219	434	241.1	T323	275 (276)	152.8 (153.3)	T345	256	142.2	T367	256	142.2
T138	526	292.2	T160	526	292.2	T182	526	292.2	T220	441 (448)	245 (249)	T324	268	148.9	T346	257	142.7	T368	256	142.2
T139	526	292.2	T161	526	292.2	T183	526	292.2	T221	441 (448)	245 (249)	T325	266	147.8	T347	258	143.3	T369	256	142.2
T140	526	292.2	T162	526	292.2	T184	526	292.2	T222	441 (448)	245 (249)	T326	262	145.5	T348	260	144.4	T370	256	142.2
T141	526	292.2	T163	526	292.2	T201	428	237.8	T223	436 (437)	242 (242.7)	T327	260	144.4	T349	260	144.4	T371	256	142.2
T142	526	292.2	T164	526	292.2	T202	428	237.8	T224	433	240.5	T328	258	143.3	T350	260	144.4	T372	256	142.2
T143	526	292.2	T165	526	292.2	T203	428	237.8	T225	432	240.0	T329	256	142.2	T351	260	144.4	T373	256	142.2
T144	526	292.2	T166	526	292.2	T204	429	238.3	T226	430	238.9	T330	256	142.2	T352	259	143.9	T374	256	142.2
T145	526	292.2	T167	526	292.2	T205	434	241.1	T227	430	238.9	T331	256	142.2	T353	258	143.3	T375	256	142.2
T146	526	292.2	T168	526	292.2	T206	441 (448)	245 (249)	T228	428	237.8	T332	258	143.3	T354	257	142.7	T376	256	142.2
T147	526	292.2	T169	526	292.2	T207	441 (448)	245 (249)	T229	428	237.8	T333	270	150.0	T355	257	142.7	T377	256	142.2
T148	526	292.2	T170	526	292.2	T208	441 (448)	245 (249)	T230	428	237.8	T334	272	151.1	T356	257	142.7	T378	256	142.2
T149	526	292.2	T171	526	292.2	T209	437 (440)	242.7 (244.4)	T231	428	237.8	T335	272	151.1	T357	256	142.2	T379	256	142.2
T150	526	292.2	T172	526	292.2	T210	438	243.3	T232	429	238.3	T336	272	151.1	T358	256	142.2	T380	256	142.2
T151	526	292.2	T173	526	292.2	T211	433	240.5	T233	435	241.7	T337	268	148.9	T359	256	142.2	T381	256	142.2
T152	526	292.2	T174	526	292.2	T212	432	240.0	T234	436	242.1	T338	263	146.1	T360	256	142.2	T382	256	142.2
T153	526	292.2	T175	526	292.2	T213	430	238.9	T235	436	242.1	T339	260	144.5	T361	256	142.2	T383	256	142.2
T154	526	292.2	T176	526	292.2	T214	429	238.3	T236	436	242.1	T340	259	143.9	T362	256	142.2	T384	256	142.2
T155	526	292.2	T177	526	292.2	T215	428	237.8	T237	434	241.1	T341	258	143.3	T363	256	142.2			

Table E-11: PREDICTED STEADY STATE TEMPERATURES TEST T-6, PLUMBING LINE AND SURROUNDING MLI

* Boundary Node (Temp Input)
( ) Heaters On

NODE	TEMPERATURE		NODE	TEMPERATURE		NODE	TEMPERATURE		NODE	TEMPERATURE	
	°R	°K		°R	°K		°R	°K		°R	°K
T001*	532	295.6	T023	468 (528)	260 (293)	T045	78 (83)	43.3 (46.1)	T103	526	292.2
T002*	37	20.4	T024	61	34	T046	94 (102)	52 2 (56 7)	T104	525 (526)	291 6 (292 2)
T003	46 (55)	25 5 (30.5)	T025	91	50 5	T047	122 (137)	67 8 (76.1)	T105	520 (524)	288 9 (291 1)
T004	62 (73)	34 5 (40.5)	T026	114	63.3	T048	140 (151)	77 8 (84)	T109	513 (519)	285 (288 3)
T005	74 (95)	41 1 (52 7)	T027	138 (139)	76.6 (77 2)	T049	156 (168)	86.7 (93 3)	T110	524	291 1
T006	95 (131)	52 7 (72.8)	T028	159 (164)	88 3 (91 1)	T050	173 (187)	95 (104)	T111	525	291.6
T007	139 (173)	77 2 (96.1)	T029	182 (189)	101 (105)	T051	185 (198)	103 (110)	T112	525	291 6
T008	170 (210)	94 4 (116.6)	T030	198 (205)	110 (114)	T052	196 (208)	109 (116)	T113	525	291 6
T009	198 (247)	110 (137 2)	T031	213 (223)	118 (124)	T053	211 (228)	117 (127)	T114	525	291 6
T010	227 (282)	126 (156.6)	T032	226 (236)	125 (131)	T054	220 (238)	122 (132)	T115	525	291 6
T011	255 (314)	141 6 (174.4)	T033	237 (251)	132 (138)	T055	240 (256)	133 (142)	T116	526	292 2
T012	283 (345)	126.6 (191 6)	T034	250 (269)	139 (149)	T056	260 (275)	144 (153)	T117	526	292 2
T013	310 (373)	172 2 (207 2)	T035	265 (280)	147 (156)	T057	278 (304)	155 (169)	T118	526	292 2
T014	336 (397)	186.7 (215)	T036	280 (295)	156 (164)	T058	297 (316)	165 (176)	T119	522 (525)	290 (291 6)
T015	361 (420)	200.5 (233.3)	T037	298 (312)	166 (173)	T059	320 (326)	178 (181)	T120	520 (524)	288 9 (291 1)
T016	385 (491)	213.9 (272 6)	T038	310 (329)	172 (183)	T060	336 (353)	186 (196)	T122	520 (524)	288.9 (291 1)
T017	408 (459)	226.7 (310.5)	T039	330 (345)	183.6 (192)	T061	344 (363)	191 (202)	T123	516 (520)	286 6 (288.9)
T018	428 (475)	238 (264)	T040	342 (359)	190 (199)	T062	350 (369)	194 (205)	T124	524	291 1
T019	444 (508)	247 (282)	T041	349 (365)	194 (203)	T063	353 (371)	196 (206)	T125	525	291 6
T020	452 (492)	251 (273)	T042	353 (388)	196 (204)				T126	525	291.6
T021	459 (510)	311 (283)	T043	355 (370)	197 (206)	T101	526	291 6	T127	525	291 6
T022	463 (522)	257 (290)	T044	56 (57)	31 1 (31 6)	T102	525	291.6	T128	525	291.6
T129	526	292 2	T151	526	292 2	T201	415	230.6	T226	421 (422)	233 9 (234 5)
			T152	526	292 2	T202	415	230.6	T227	416	231 1
T131	526	292.2	T153	526	292 2	T203	421	233.9	T228	416	231 1
T132	526	292 2	T154	526	292 2	T204	425 (426)	236 1 (236 6)	T229	413	229.5
T133	624 (526)	288.9 (292.2)	T155	526	292 2	T205	437 (445)	242.8 (247 2)	T231	418 (420)	232.3 (233 4)
T134	522 (526)	290 (291.6)	T156	526	292 2	T209	436 (444)	242 3 (246.6)	T232	423 (426)	235 (236.6)
T135	522 (525)	290 (291.6)				T210	425 (427)	236.1 (237 1)	T233	437 (443)	242.8 (246)
T136	522 (525)	290 (291 6)				T211	424 (425)	237 6 (236 1)	T234	438 (445)	243 2 (247.3)
T137	525 (526)	291 6 (292 2)	T159	526	292.2	T212	422 (425)	234 6 (236 1)	T235	438 (445)	243.2 (247 3)
T138	525	291.6	T160	526	292.2	T213	417	231 7	T236	438 (445)	243 2 (247 3)
T139	526	292.2	T161	526	292 2	T214	415	230.6	T237	436 (443)	242 2 (246)
T140	526	292.2	T162	526	292 2	T215	415	230.6	T238	427 (429)	237 1 (238.3)
T141	526	292.2	T163	526	292 2	T216	413	229 5	T239	422 (424)	234.5 (237 6)
T142	526	292 2	T164	526	292.2	T217	421	233.9	T240	420 (426)	233 4 (236.1)
			T165	526	292 2	T218	426 (427)	236.6 (237 1)	T241	416	231 1
			T166	526	292 2	T219	439 (448)	243.9 (248 9)	T242	415	230 6
T145	526	292.2	T167	526	292.2	T220	438 (447)	243.4 (248.5)	T245	417	231 7
T146	526	292 2	T168	526	292.2				T246	422	234.5
T147	526	292 2	T169	526	292.2	T222	428 (447)	237 6 (248.5)	T247	422	234.5
T148	526	292 2	T170	526	292.2	T223	437 (439)	242.8 (243.9)	T248	422	234.5
T149	526	292 2				T224	425 (427)	236.1 (237 1)	T249	423	235
T150	525	292.2				T225	424 (425)	237 6 (236.1)	T250	424	237 6
T251	424	237 6	T301	264	146.6	T327	267	148.3	T352	275	152.8
T252	424	237.6	T302	264	146.6	T328	265	147 3	T353	271	150.6
T253	423	237 1	T303	273 (276)	151 6 (153)	T329	257	142.8	T354	268	148.8
T254	421	233.9	T304	283 (286)	157 (159)	T331	271 (274)	150 (152)	T355	262	145.5
T255	418	232.3	T305	312 (326)	173 (181)	T332	280 (284)	156 (158)	T356	260	144.5
T258	417	231 7	T309	318 (331)	177 (184)	T333	307 (319)	171 (177)	T359	267	148 3
T259	421	233.9	T310	284 (287)	158 (160)	T334	312 (326)	173 (181	T360	268	148.8
T260	421	233.9	T311	279 (282)	155 (157)	T335	312 (326)	173 (181)	T361	269	149.5
T261	421	233.9	T312	276 (279)	153 (155)	T336	312 (326)	173 (181)	T362	269	149.5
T262	421	233.9	T313	267	148	T337	308 (320)	172 (178)	T363	269	149.5
T263	421	233.9	T314	265	147.3	T338	284 (286)	158 (158)	T364	269	149.5
T264	421	233.9	T315	265	147.3	T339	274 (278)	152 (154	T365	269	149.5
T265	421	233.9	T316	259	143.8	T340	272 (279)	151 (155)	T366	270	150.0
T266	422	234.5	T317	273 (276)	151.6 (152.6)	T341	265	147.3	T367	268	148.8
T267	421	233.9	T318	283 (286)	157 (159)	T342	263	146	T368	264	146.6
T268	419	232.8	T319	312 (326)	173 (181)	T343	268 (269)	149 (149.6)	T369	260	144.5
T269	417	231 7	T320	312 (325)	173 (181)	T346	272 (274)	151 (152)	T370	258	143.3
T270	416	231 1	T322	312 (326)	173 (181)	T347	274 (277)	152 (154)			
			T323	316 (326)	175 (182)	T348	275 (278)	152.8 (154.6)			
			T324	284 (287)	158 (160)	T349	278	154 8			
			T325	279 (281)	155 (157)	T350	278	154.6			
			T326	276 (278)	153 (155)	T351	277	154			

Table E-12: PREDICTED STEADY STATE TEMPERATURES TEST T-7, PLUMBING LINE AND SURROUNDING MLI

* Boundary Nodes – Temp Input

NODE	TEMPERATURE		NODE	TEMPERATURE		NODE	TEMPERATURE		NODE	TEMPERATURE	
	°R	°K		°R	°K		°R	°K		°R	°K
T001*	632	295.6	T023	501	278.3	T045	158	87 8	T103	526	292 3
T002*	140	77 8	T024	157	87 3	T046	166	92.2	T104	525	291 7
T003	148	82.2	T025	181	100.6	T047	182	101 1	T105	520	288 9
T004	170	94 5	T026	202	112.2	T048	200	111 1	T109	513	285
T005	189	105	T027	218	121 1	T049	220	122 2	T110	524	291 2
T006	212	117 7	T028	233	129 6	T050	236	131 1	T111	525	291 7
T007	240	133 3	T029	247	137 3	T051	252	140.0	T112	525	291 7
T008	265	152 8	T030	260	144 5	T052	268	148 9	T113	525	291 7
T009	289	160.6	T031	272	151 1	T053	283	157 2	T114	525	291 7
T010	314	174 5	T032	286	158.9	T054	297	166.1	T115	526	292 3
T011	334	185.5	T033	301	167 1	T055	309	171 6	T116	527	292 8
T012	353	196.1	T034	311	172.7	T056	310	172 2	T117	527	292 8
T013	372	206.6	T035	320	179 7	T057	332	184 5	T118	526	292 3
T014	392	217 8	T036	330	183 4	T058	344	191 1	T119	522	290
T015	411	228.4	T037	339	188.3	T059	352	195.6	T120	520	288.9
T016	430	238.9	T038	350	194 5	T060	358	198.9	T122	520	288 9
T017	447	248.4	T039	363	201 6	T061	365	202 8	T123	521	289 5
T018	466	258.9	T040	373	208.4	T062	374	207 8	T124	524	291 2
T019	478	265.6	T041	379	210 5	T063	383	212 8	T125	525	291 7
T020	487	270 6	T042	383	212 7				T126	525	291 7
T021	493	273.9	T043	385	213.9	T101	525	291 7	T127	525	291 7
T022	498	276.6	T044	152	84 5	T102	525	291 7	-T128-	525	291 7
T129	527	292 8	T154	526	292 3				T232	440	244 4
T131	527	292 8	T155	527	292 8	T209	461	255 2	T233	442	245 5
T132	527	292 8	T156	527	292 8	T210	452	251 1	T234	461	255 2
T133	524	291 4	T159	527	292 8	T211	442	245 5	T235	463	257 2
T134	522	290	T160	527	292 8	T212	438	243.4	T236	460	255 5
T135	522	290	T161	527	292 8	T213	434	241.1	T237	443	246.1
T136	522	290	T162	527	292.8	T214	431	239 5	T238	442	245 5
T137	523	290 6	T163	527	292 8	T215	430	238.9	T239	441	245
T138	525	291 7	T164	527	292 8	T216	429	238 3	T240	436	242 2
T139	526	292.3	T165	527	292 8	T217	438	243 4	T241	433	240 5
T140	526	292.3	T166	527	292 8	T218	443	246 1	T242	432	240
T141	526	292.3	T167	527	292.8	T219	456	253 4			
T142	526	292 3	T168	527	292.8	T220	476	264 4			
T145	527	292.8	T169	527	292 8	T222	476	164 4	T245	434	241 1
T146	527	292.8	T170	527	292 8	T223	475	263 9	T246	439	243 9
T147	526	292.3	T201	431	239 5	T224	446	247 7	T247	439	243 9
T148	526	292.3	T202	431	239 5	T225	442	245.5	T248	442	245 5
T149	526	292.3	T203	438	243.4	T226	438	243.4	T249	443	246 1
T150	526	292 3	T204	442	245 5	T227	434	241 1	T250	444	246 7
T151	526	292.3	T205	455	252 8	T228	431	239 5	T251	443	246 1
T152	526	292.3				T229	434	241 1	T252	442	245 5
T153	526	292.3				T231	436	242 2	T253	439	243 9
T254	434	241 1	T309	330	183.4	T333	289	160.7	T359	268	148.9
T255	431	239.5	T310	299	166.1	T334	320	177 7	T360	275	152.8
T256	430	238.9	T311	287	159.5	T335	324	179.9	T361	275	152.8
			T312	279	155.1	T336	320	177 7	T362	275	152 8
			T313	272	151 1	T337	291	161 6	T363	275	152.8
T259	433	240.5	T314	266	147 8	T338	288	160.1	T364	275	152 8
T260	437	242.8	T315	263	146.1	T339	284	175.8	T365	275	152.8
T261	437	242.8	T316	260	144 5	T340	274	152 2	T366	275	152.8
T262	437	242.8	T317	277	153.9	T341	268	148.9	T367	273	151 7
T263	437	242.8	T318	288	160.1	T342	266	147.8	T368	268	148.9
T264	437	242.8	T319	320	177 7	T345	269	149.5	T369	262	145.6
T265	437	242.8	T320	355	197 2	T346	279	155.1	T370	260	144.5
T266	437	242.8	T322	355	197 2	T347	281	156.0			
T267	436	242.2	T323	325	180.5	T348	286	158.9			
T268	435	241 7	T324	296	164.5	T349	289	160.7			
T269	435	241 7	T325	287	159.6	T350	291	161.6			
T270	434	241 1	T326	279	155.1	T351	288	160.1			
T301	266	147 8	T327	272	151 1	T352	287	159.6			
T302	265	147 2	T328	260	144 5	T353	281	156.0			
T303	278	154.5	T329	260	144 5	T354	270	150.1			
T304	288	160	T331	272	151 1	T355	264	146.6			
T305	319	177 2	T332	282	156.6	T356	262	145.4			

Table E-13: PREDICTED STEADY STATE TEMPERATURES TEST T-8, BASIC MLI ASSEMBLY, INCLUDING BASE JOINT SUPPORT RINGS

* Boundary Nodes – Temp. Input

NODE	TEMPERATURE		NODE	TEMPERATURE		NODE	TEMPERATURE		NODE	TEMPERATURE	
	°R	°K		°R	°K		°R	°K		°R	°K
T1	525	291.7	T28	133	69.9	T55	74	41.2	T105	358	198 9
T2	385	213.9	T29	121	67.2	T56	93	51 7	T106	189	105.0
T3	183	101.7	T30	96	55.3	T57	106	58.9	T107	189	105 0
T4	505	280.6	T31	132	73.3	T58	89	49.3	T108	185	102.8
T5	367	203.9	T32	119	66 1	T59	109	60 5	T109	174	96 7
T6	186	103.3	T33	93	51 6	T60	84	46.7	T110	159	88.3
T7	233	129.5	T34	130	72.2	T61	107	59 4	T111	160	88.9
T8	183	101.7	T35	113	62 8	T62	76	42.3	T112	142	78 9
T9	159	88.4	T36	94	52 2	T63	87	48.3	T113	141	78 4
T10	144	80.0	T37	121	67.2	T64	67	37 2	T114	142	78 9
T11	147	81 7	T38	103	57.2	T65	56	31.1	T115	139	77 2
T12	138	76.7	T39	90	50.0	T66	46	25.5	T116	139	77.2
T13	140	77.8	T40	102	66.6	T67	470	261.1	T117	138	76.7
T14	140	77.8	T41	92	51.1	T68	389	216.1	T118	143	79.4
T15	139	77.2	T42	86	47.8	T69	326	181 1	T123	178	98.9
T16	138	76.7	T43	137	74 2	T70*	37	20.6	T124	190	105.5
T17	134	74.5	T44	129	71 6	T71*	140	77 8	T125	363	201.6
T18	134	74.5	T45	136	73.6	T72	92	51.1	T126	338	187 8
T19	136	73.6	T46	127	70 5	T73	100	55.5	T127	346	192 2
T20	130	72 2	T47	134	74 5	T76	133	69.9	T128	186	103 3
T21	125	69.5	T48	120	66.6	T77	133	69.9	T129	348	193.4
T22	134	74.5	T49	85	47.2	T78	290	161.1	T130	352	195.5
T23	125	69.5	T50*	37	20 6	T79	269	149.5	T131	403	223 9
T24	115	63.9	T51	133	69 9	T101	521	290.6	T132	190	105 5
T25	134	74 5	T52	114	63 4	T102	376	210.6	T172*	532	295.6
T26	122	67 8	T53	129	71.6	T103	186	103.3			
T27	106	58.9	T54	103	57 2	T104	447	248.4			

TABLE E-14: HEAT FLOW DETAILS

ALL VALUES ARE HEAT FLOW TO TEST TANK IN BTU/HR

Test	$\dot{Q}_{Basic}$		$\Delta\dot{Q}$ Longitudinal Joint	$\Delta\dot{Q}$ Fasteners	ΔQ Strut				$\Delta\dot{Q}$ Plumbing Line				Q Total	Q Measured			Notes
	Analytical	Empirical			Conducted Into Strut	Conducted Into Strut MLI	Additional Radiation from Main MLI	Total	Conducted Into Pipe	Conducted Into pipe MLI	Additional Radiation from Main MLI	Total	Predicted	Q_{vap}	$Q_{\Delta T}$	Total	
T-1	6.558		1537	.884				0				0		7 739	.516		
													7 596			8 255	
T-2	6.477		1324	.963				0				0		8 60	233		
													7 572			8 833	
T-3	.1294		0805	.0423				0				0		670	145		
													2522			.815	
T-4	6.558		1537	.884				0				0		8 47	478		
													7 596			8 948	
T-5					.056	0307	0640										Q_{Basic} is Q_{Total} measured from Test 4
No		8.948*						1507				0		9 60	806		
Heat													9 0999			10 406	
T-5					056	.0307	0640										Q_{Basic} is Q_{Total} measured from Test 4
Heater		8.948*						1507				0		9 60	90		
On							*						9 0999			10 50	
T-6									1.952	145	058						Q_{Basic} is Q_{Total} Measured from Test 5
		10.406*										2 155		12.13	675		
No Heat													12 561			12 805	
T-6							*		2.427	198	074						$\dot{Q}_{Basic}$ is $\dot{Q}_{Total}$ Measured from Test 5 ▲Included assumed 273 ΔQ Conducted into Truss & Eventually Reaching Tank
Heater		10.406*										2.699		13 03	538		
On													13 384▲			13 628	
					0494	0251	0599		1.865	0201	0262						Q_{Basic} is $\dot{Q}_{Total}$ Measured from Test 2
T-7		8.833*						1344				1 9113		12 35	200		
													10 88			12 55	
					.00421	.00105	00123		.377	0082	000556						
T-8	.7025		.0806	.1318				006445				.3858		2.94	202		
													1.307			3.142	

* Included in $\dot{Q}_{BASIC}$

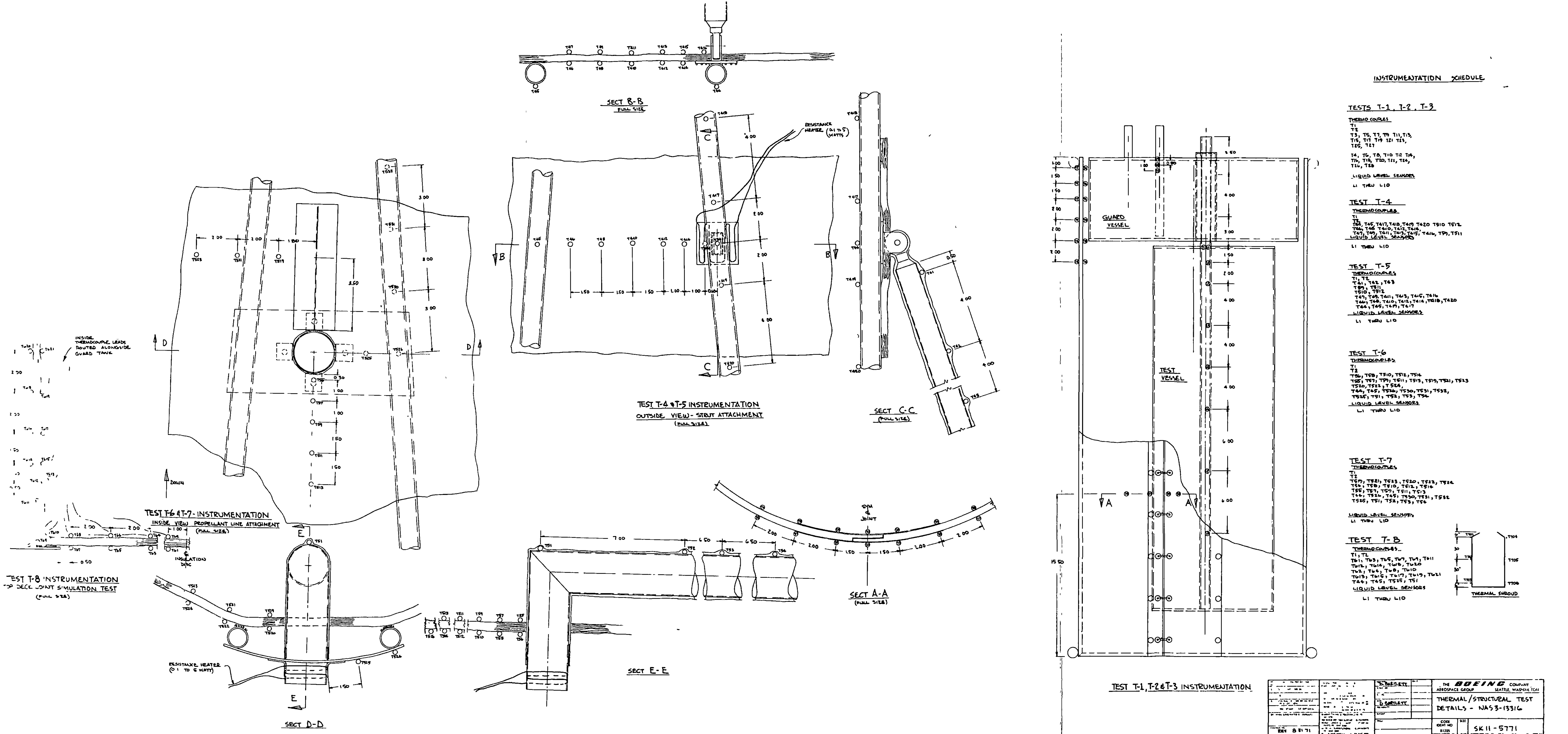


FIGURE E-1: TEST ARTICLE INSTRUMENTATION PLAN

PAGE MISSING FROM AVAILABLE VERSION

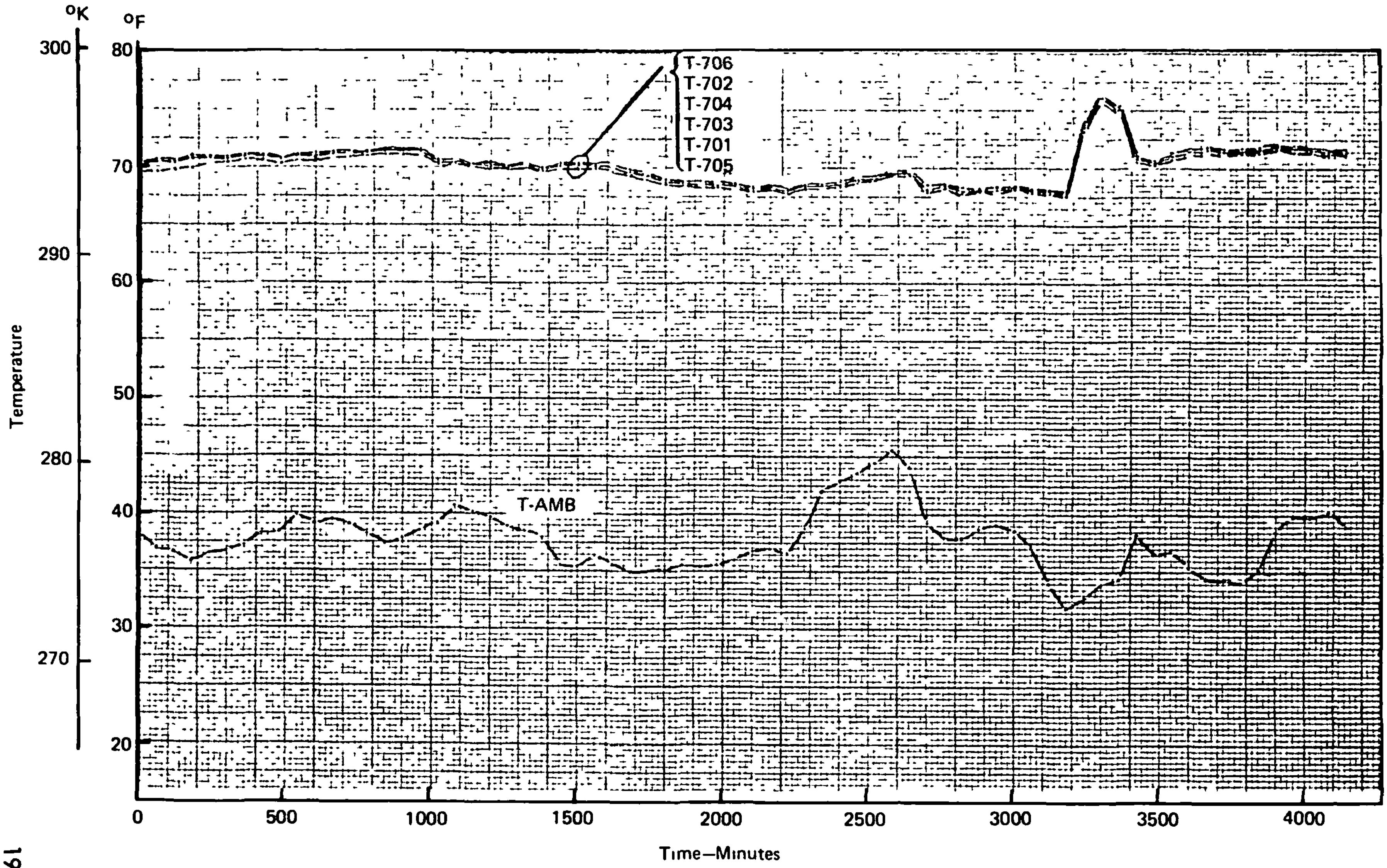


FIGURE E-2: TEST #1 - TEMPERATURES

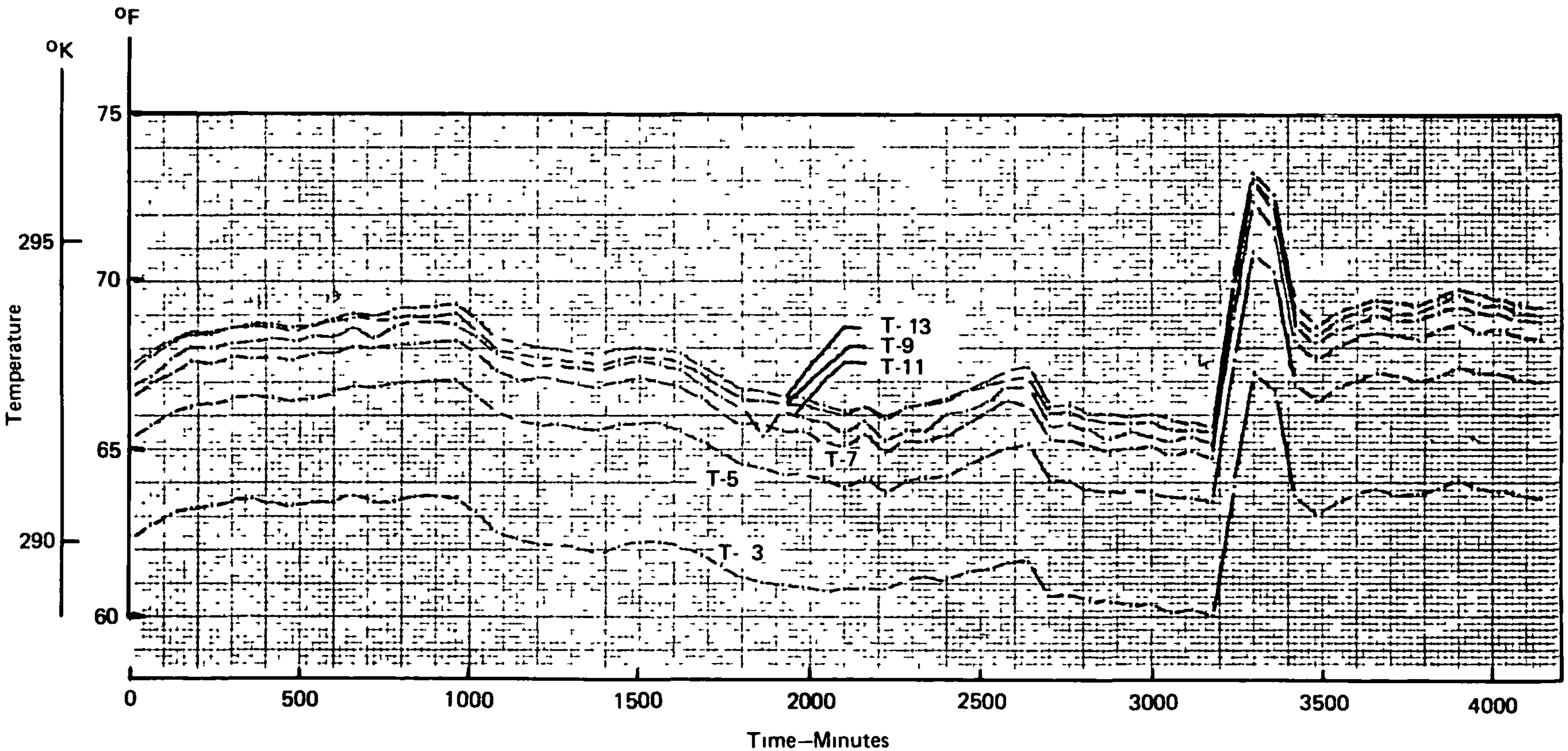


FIGURE E-3: TEST #1 - TEMPERATURES

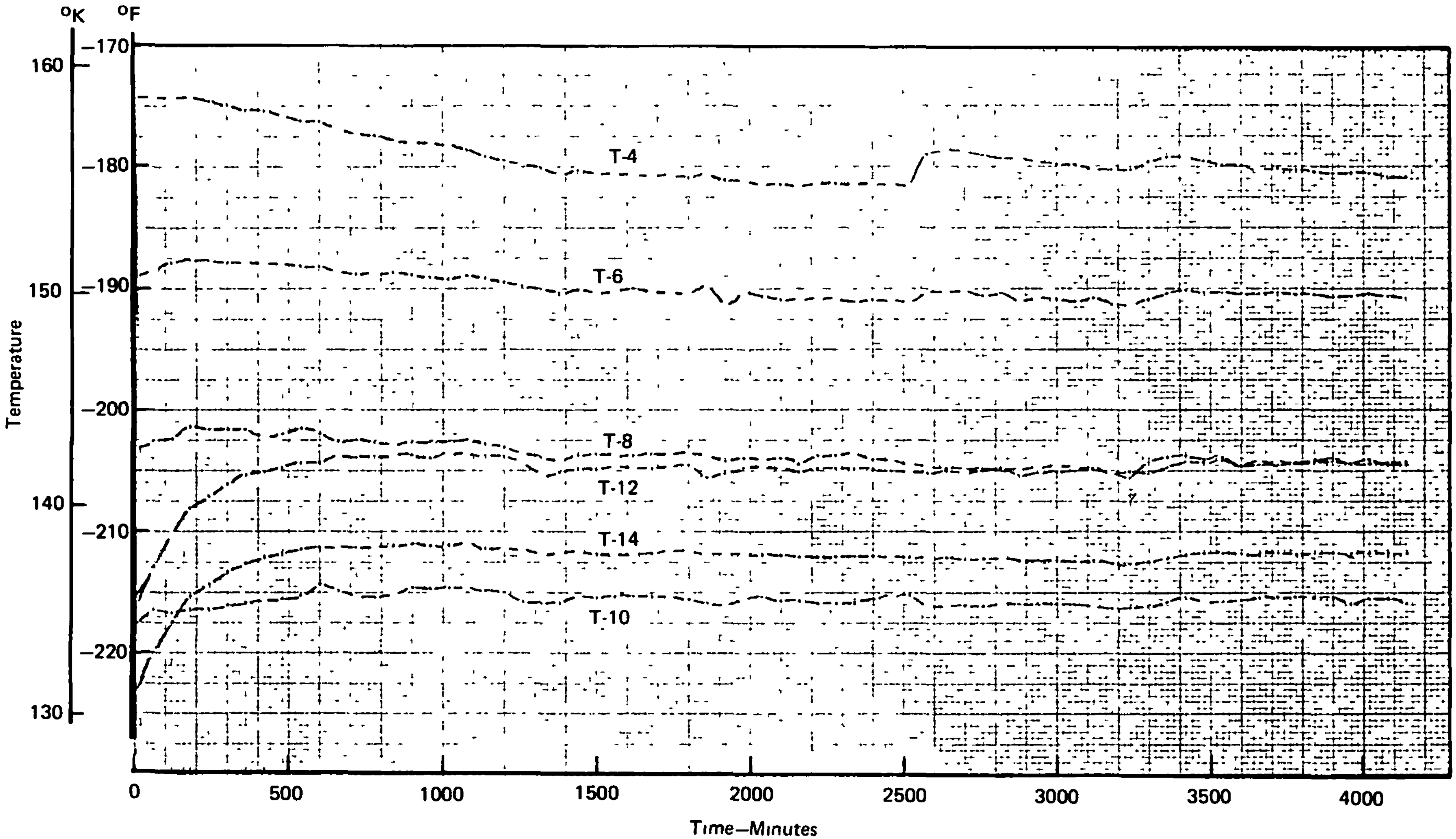


FIGURE E-4: TEST #1 - TEMPERATURES

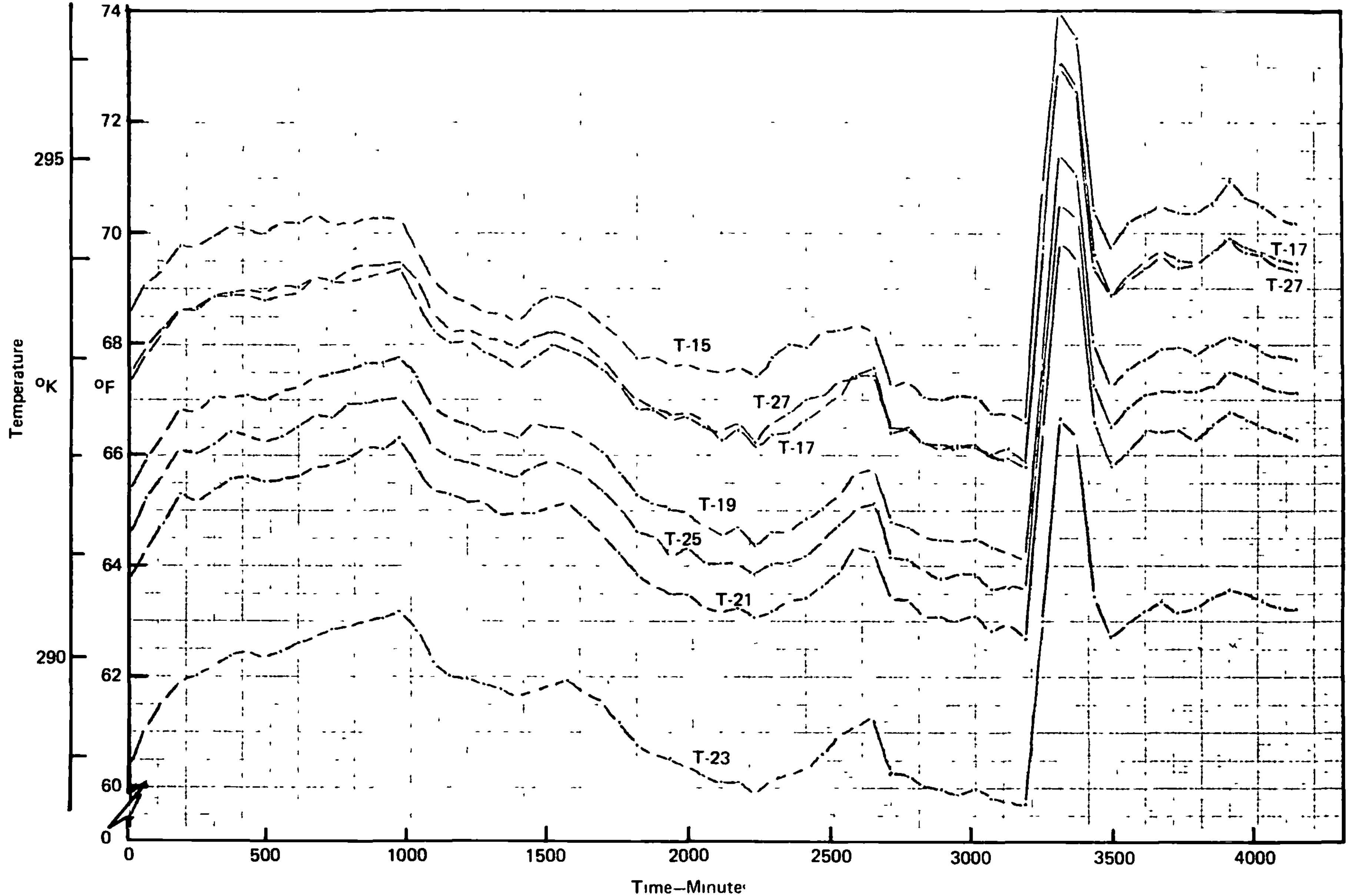


FIGURE E-5: TEST #1 - TEMPERATURES

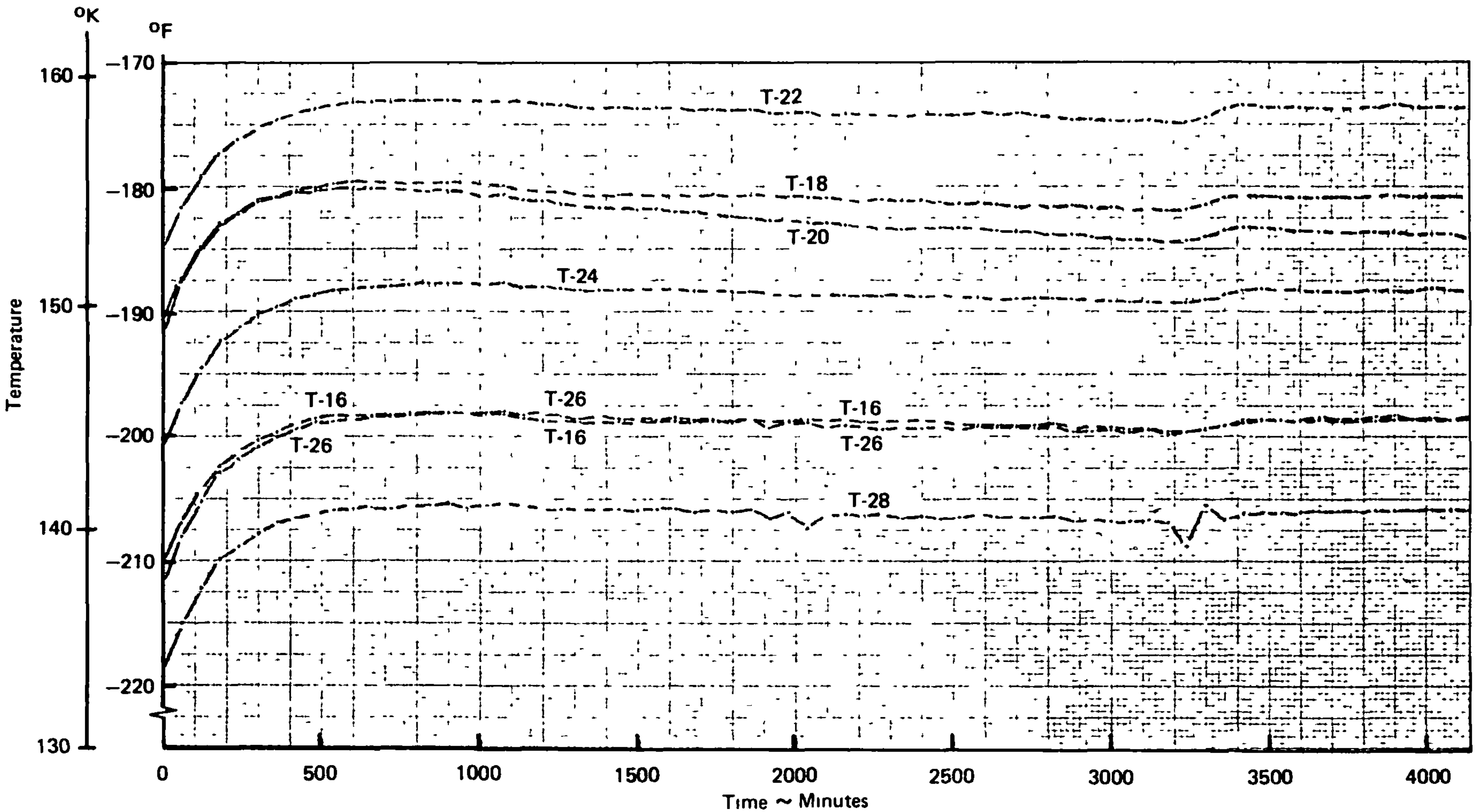


FIGURE E-6: TEST #1 - TEMPERATURES

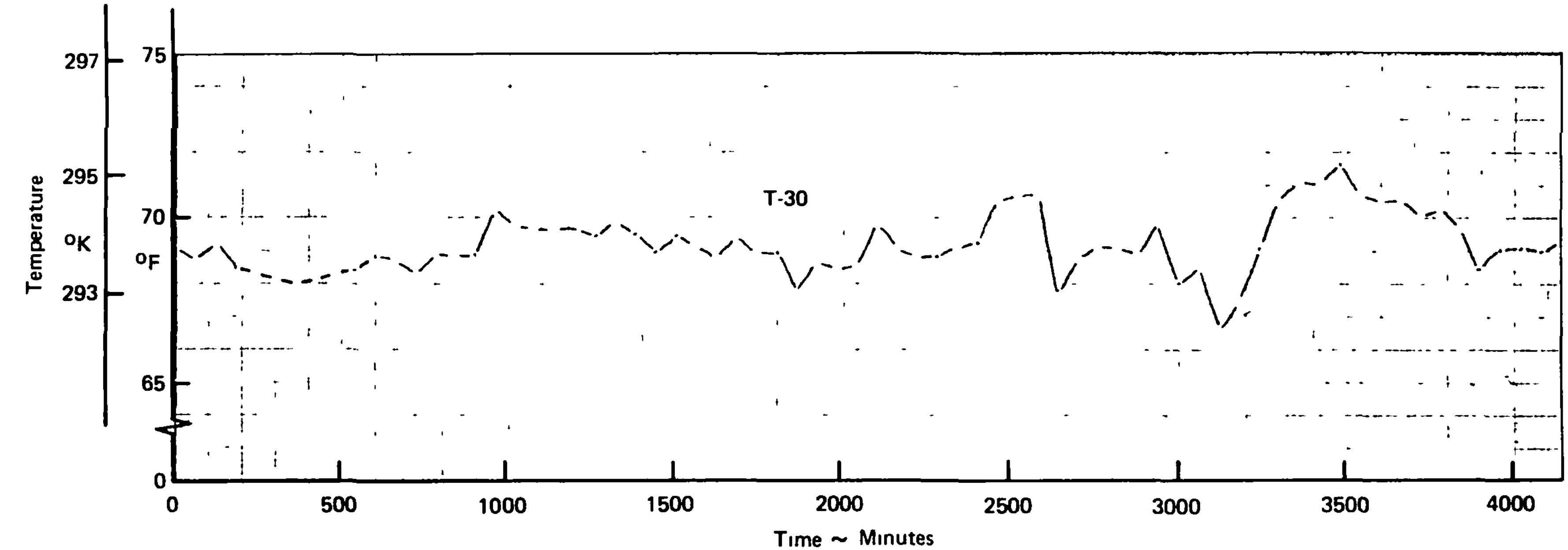


FIGURE E-7: TEST #1 - TEMPERATURES

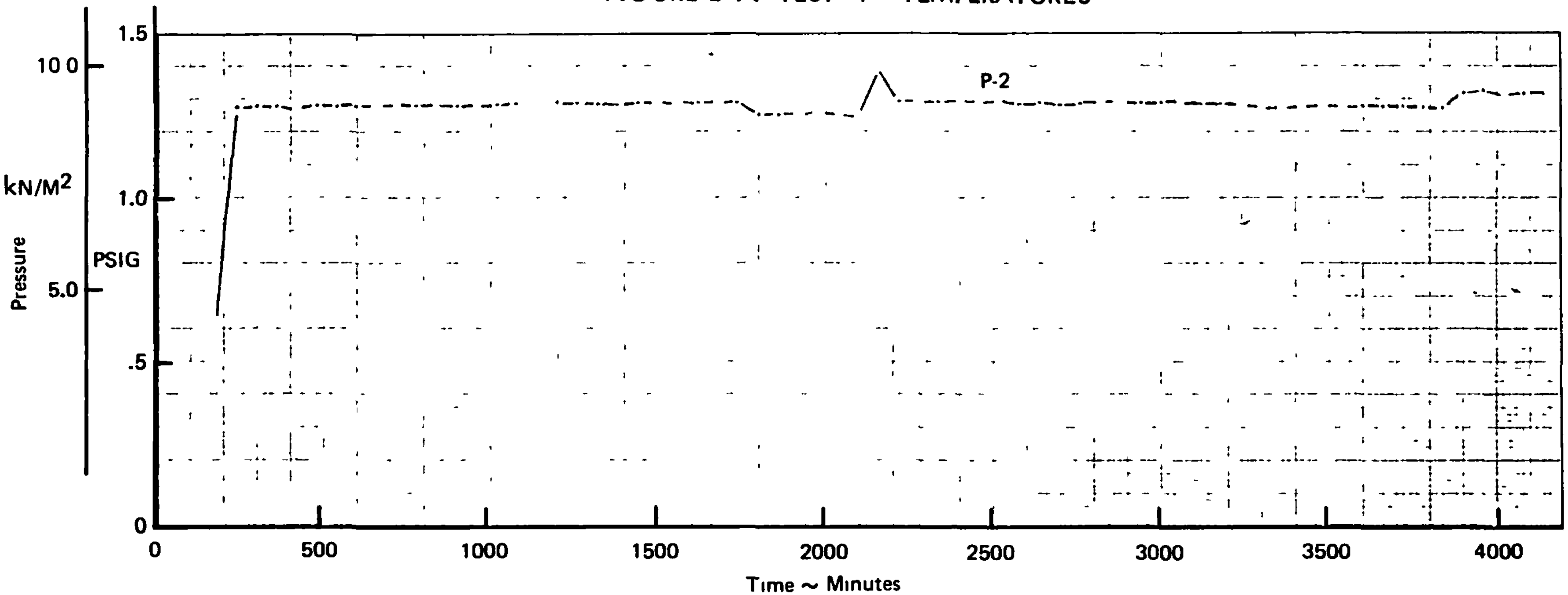


FIGURE E-8: TEST #1 - GUARD TANK PRESSURE

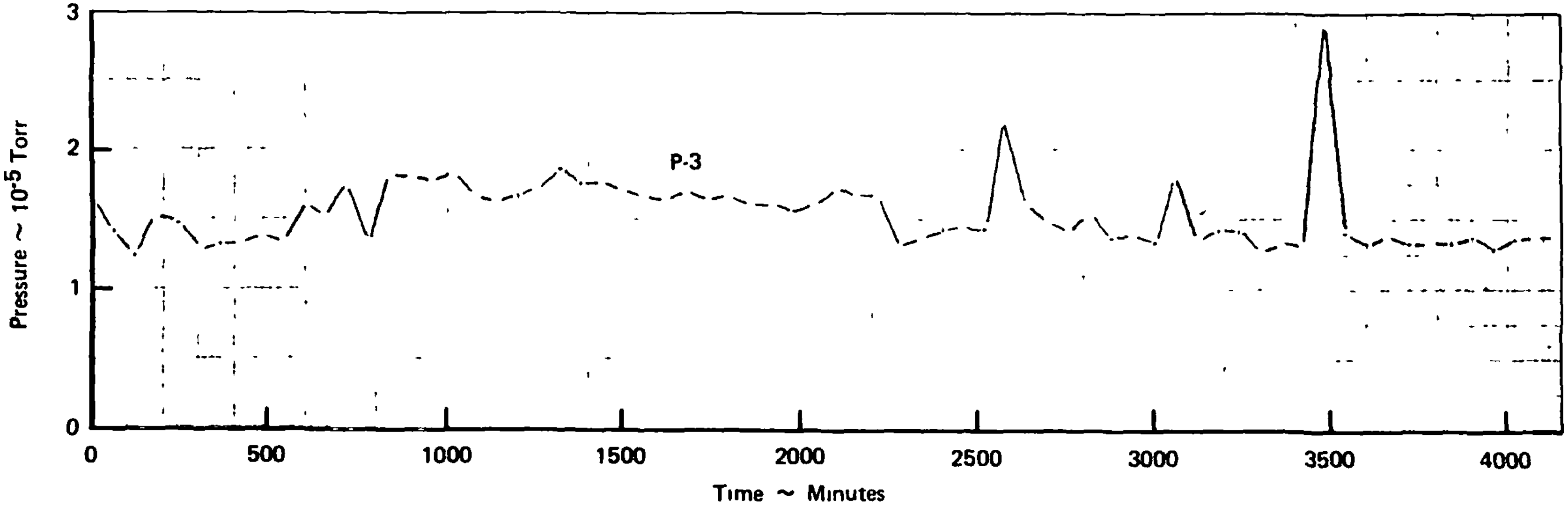


FIGURE E-9: TEST #1 - ALTITUDE CHAMBER PRESSURE

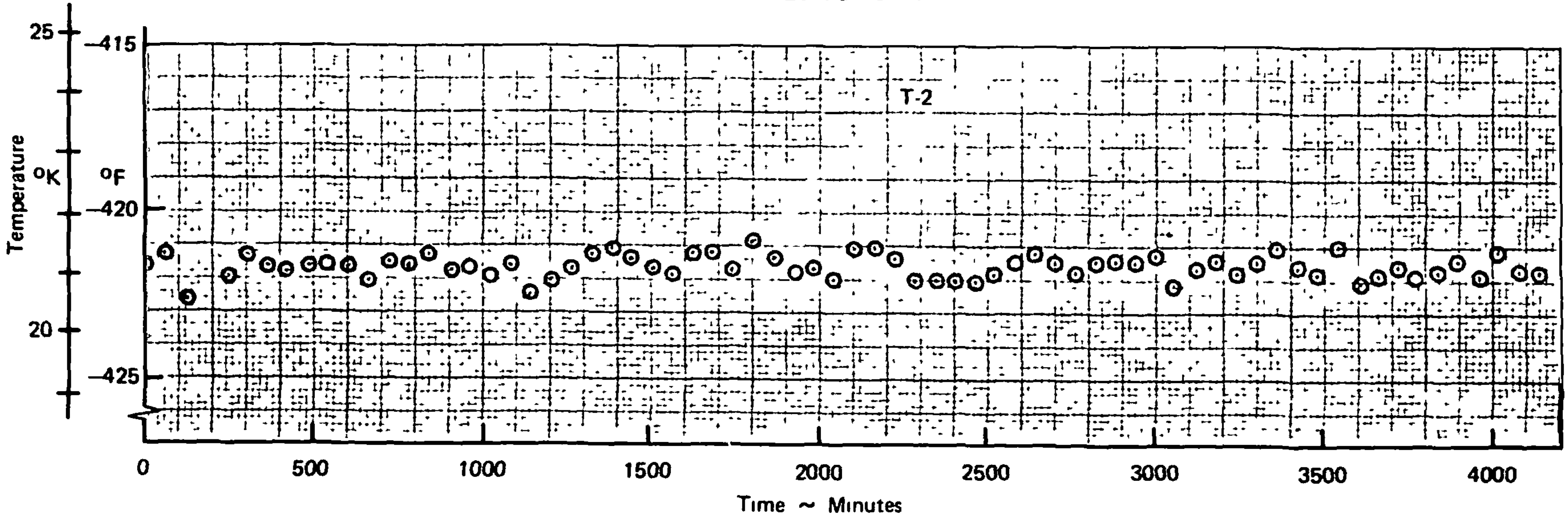


FIGURE E-10: TEST #1 - TEMPERATURE

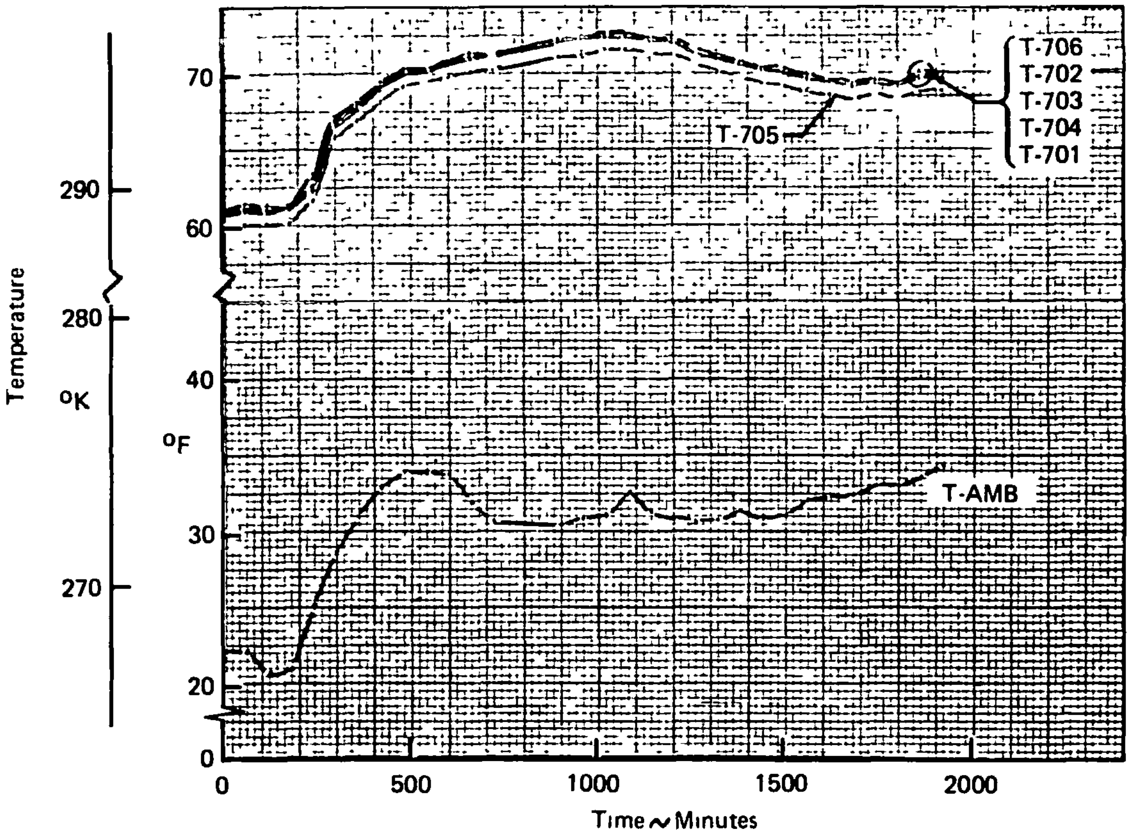


FIGURE E-11: TEST #2 - TEMPERATURES

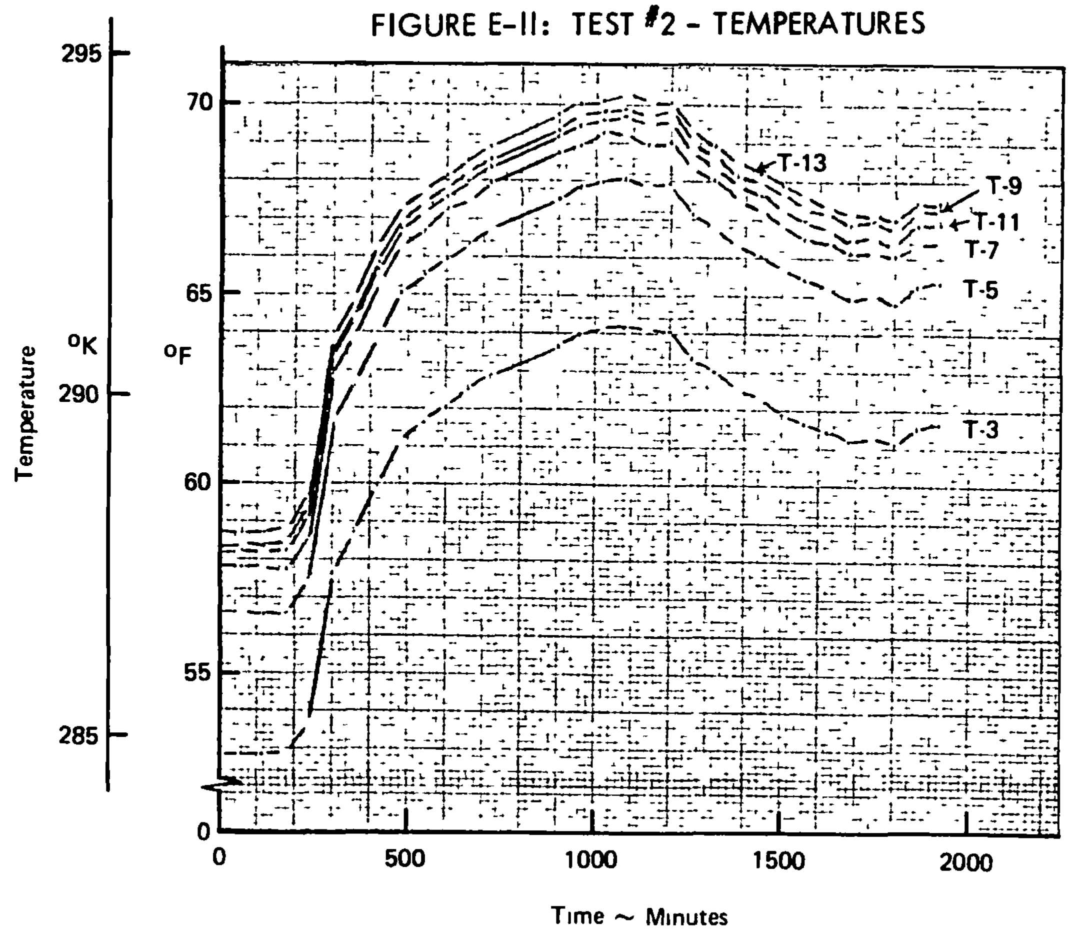
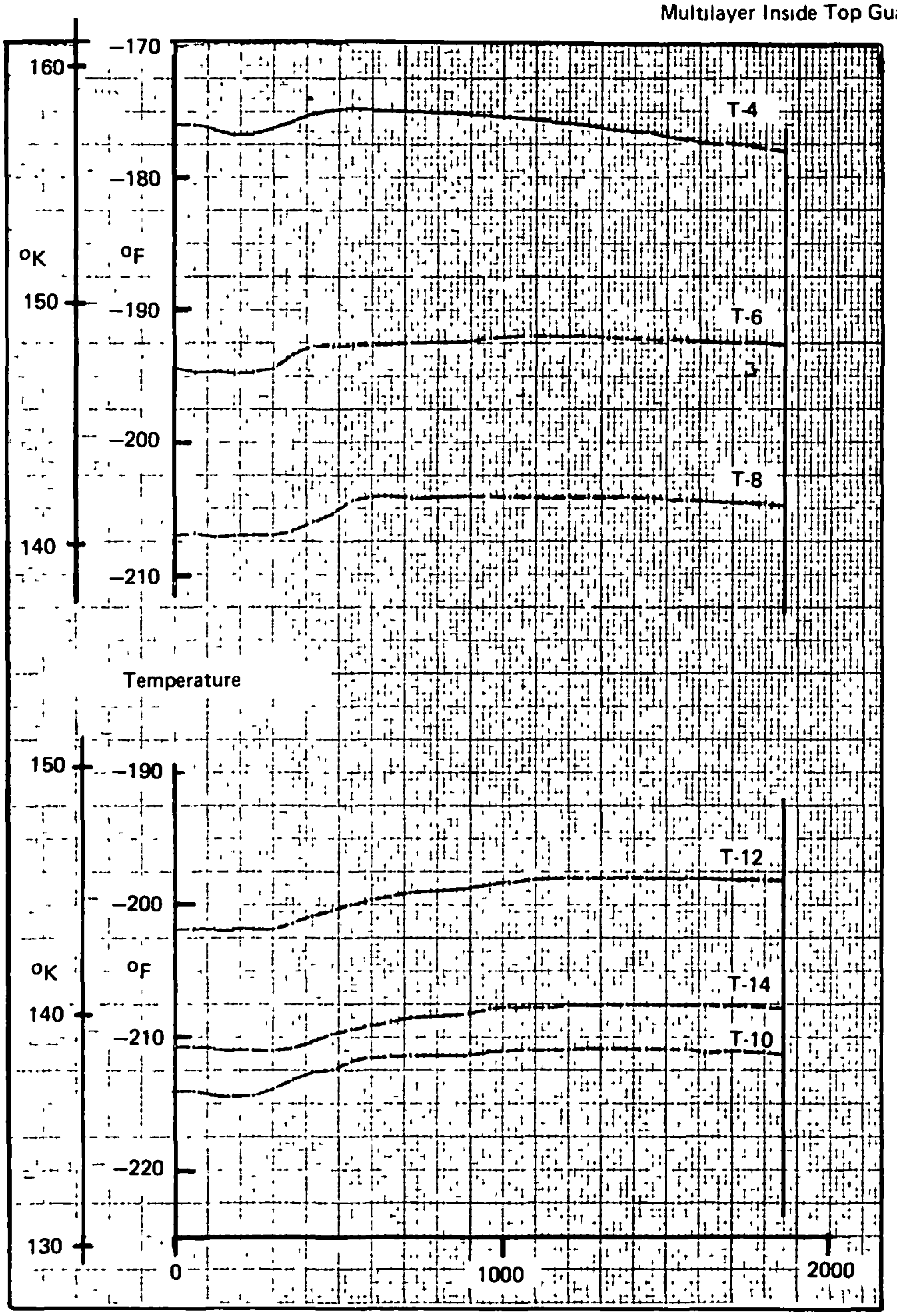


FIGURE E-12: TEST #2 - TEMPERATURES

Multilayer Inside Top Guard Area



Time—Minutes

FIGURE E-13: TEST #2 - TEMPERATURES

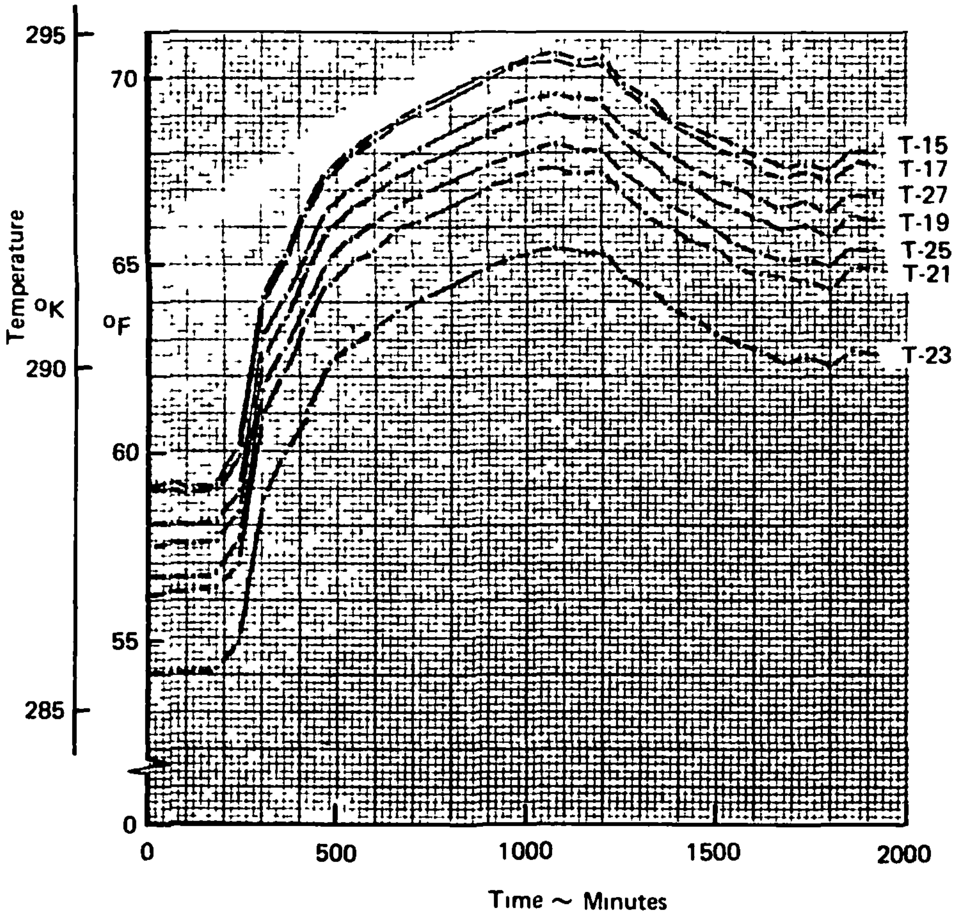


FIGURE E-14: TEST #2 - TEMPERATURES

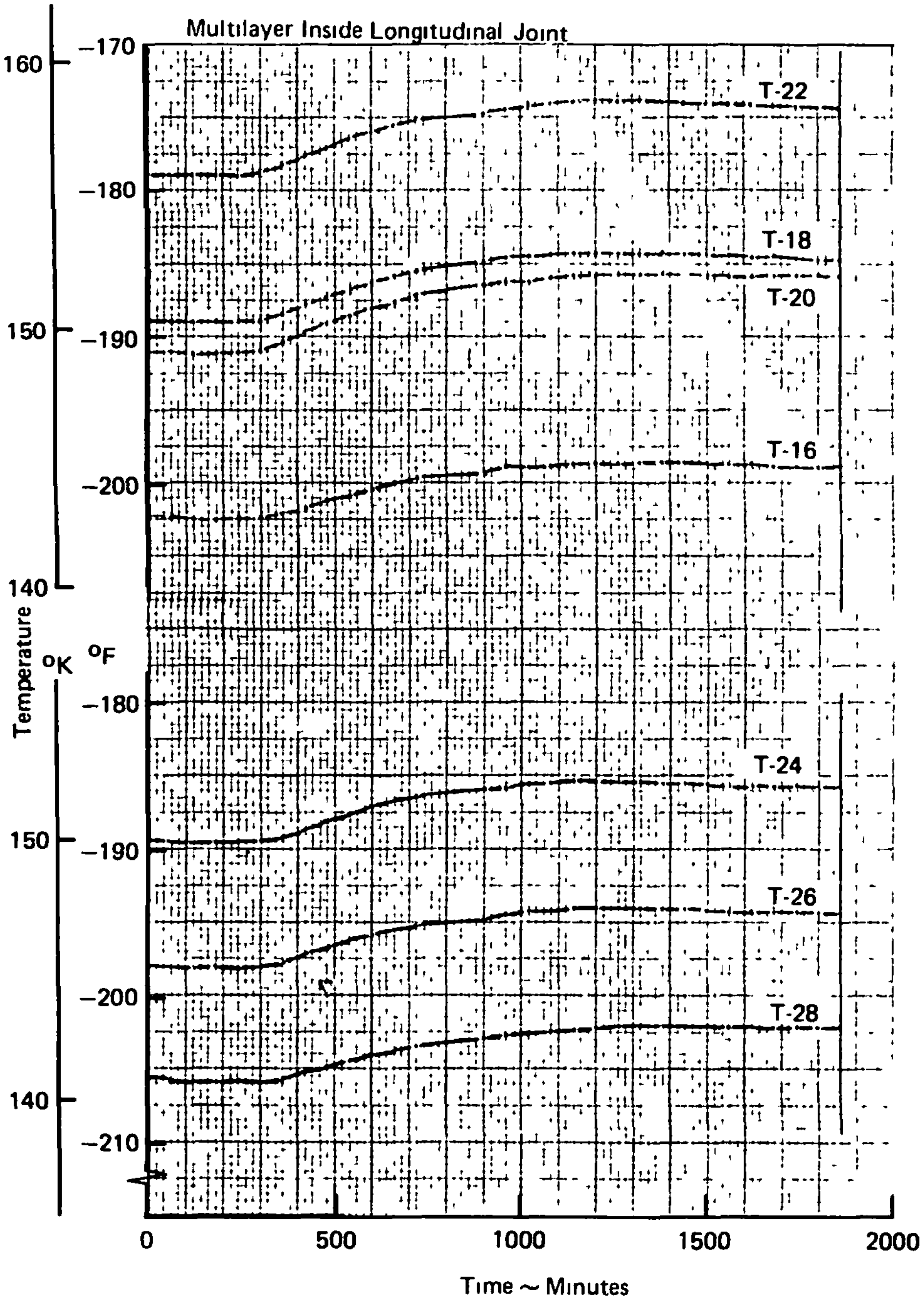


FIGURE E-15: TEST #2 - TEMPERATURES

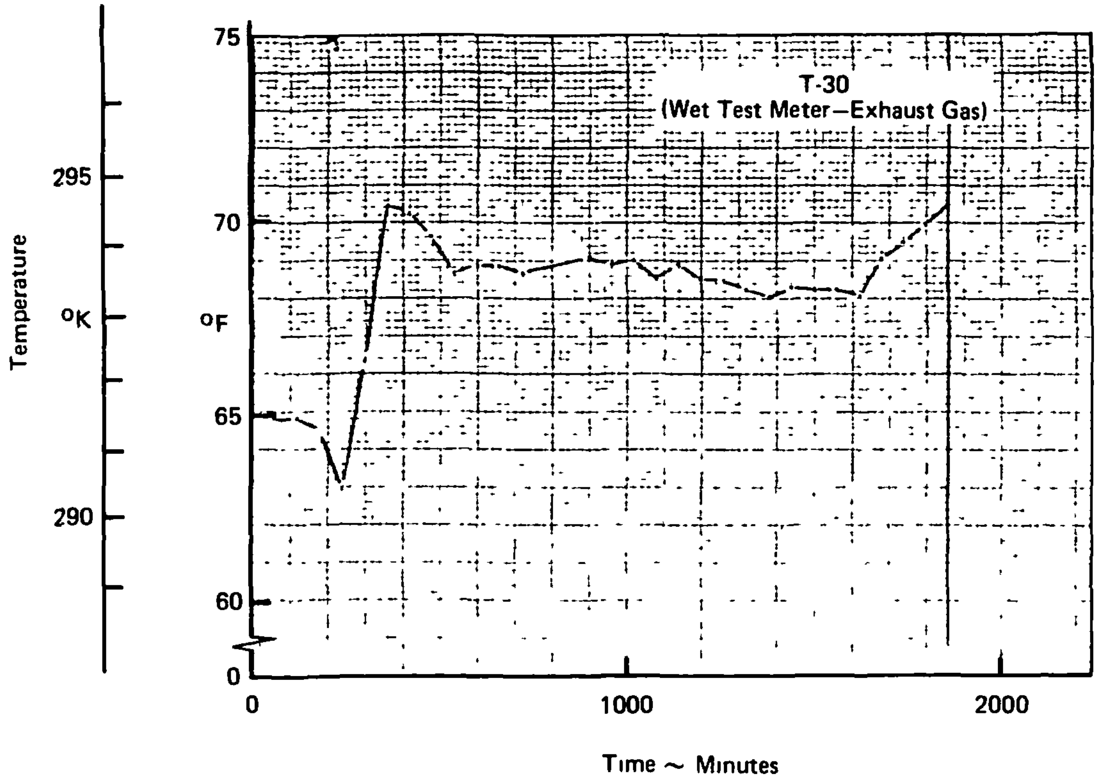


FIGURE E-16: TEST #2 - TEMPERATURES

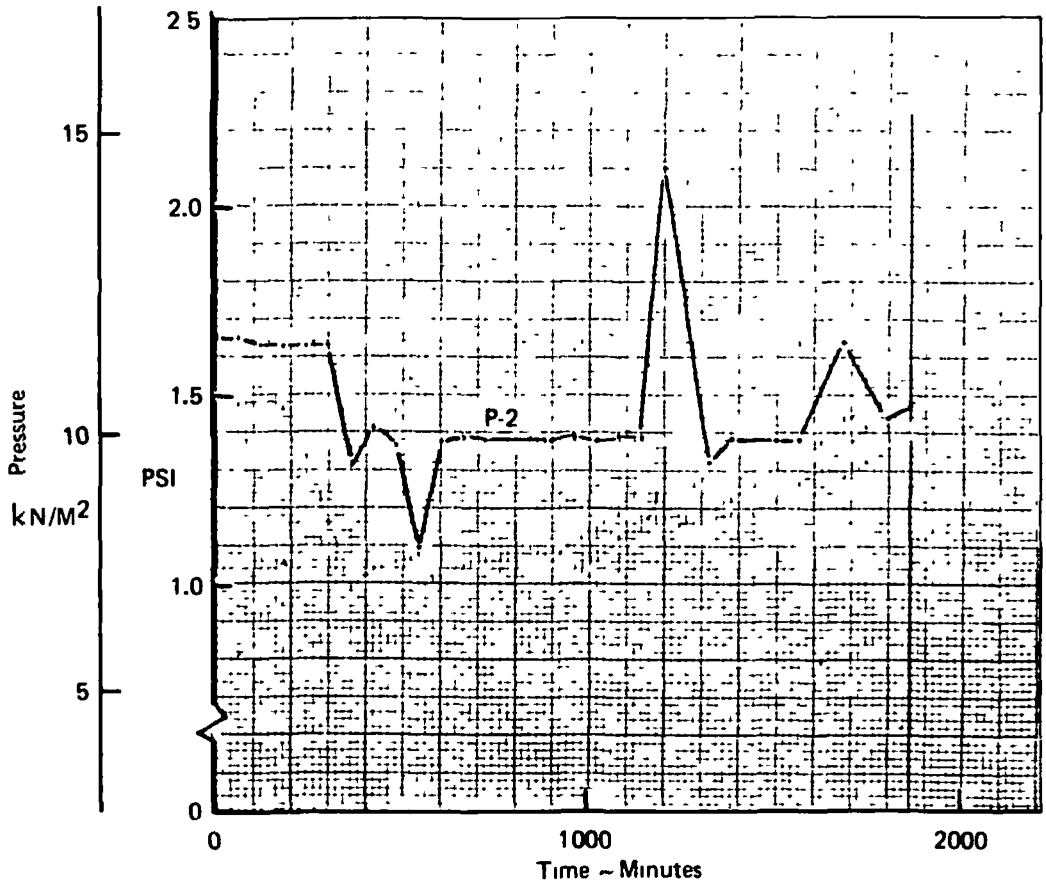


FIGURE E-17: TEST #2 - GUARD TANK PRESSURE

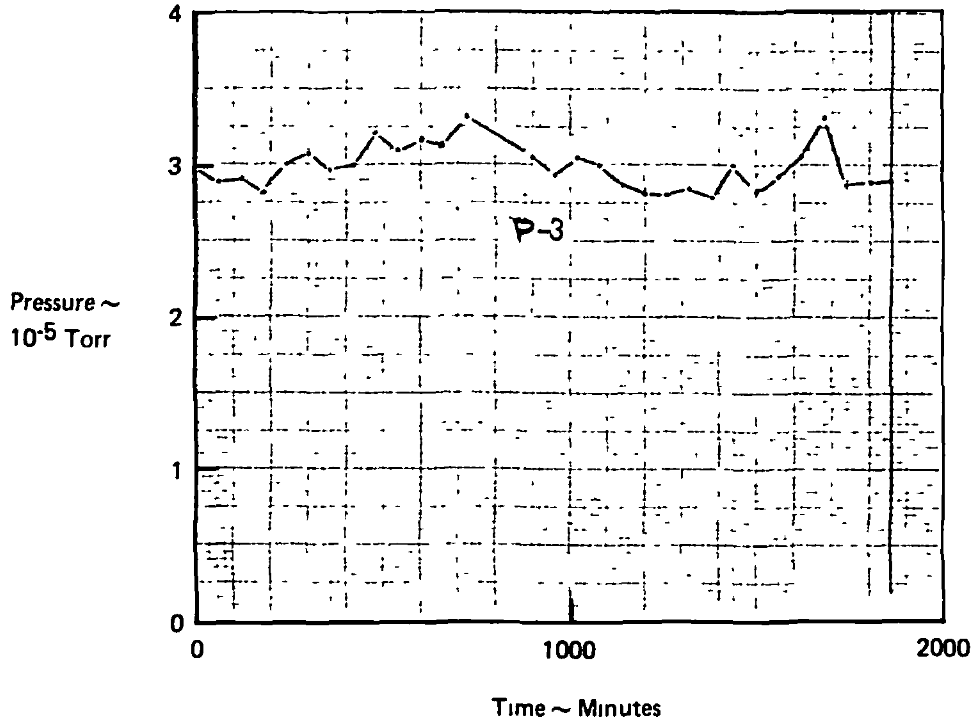


FIGURE E-18: TEST #2 - ALTITUDE CHAMBER PRESSURE

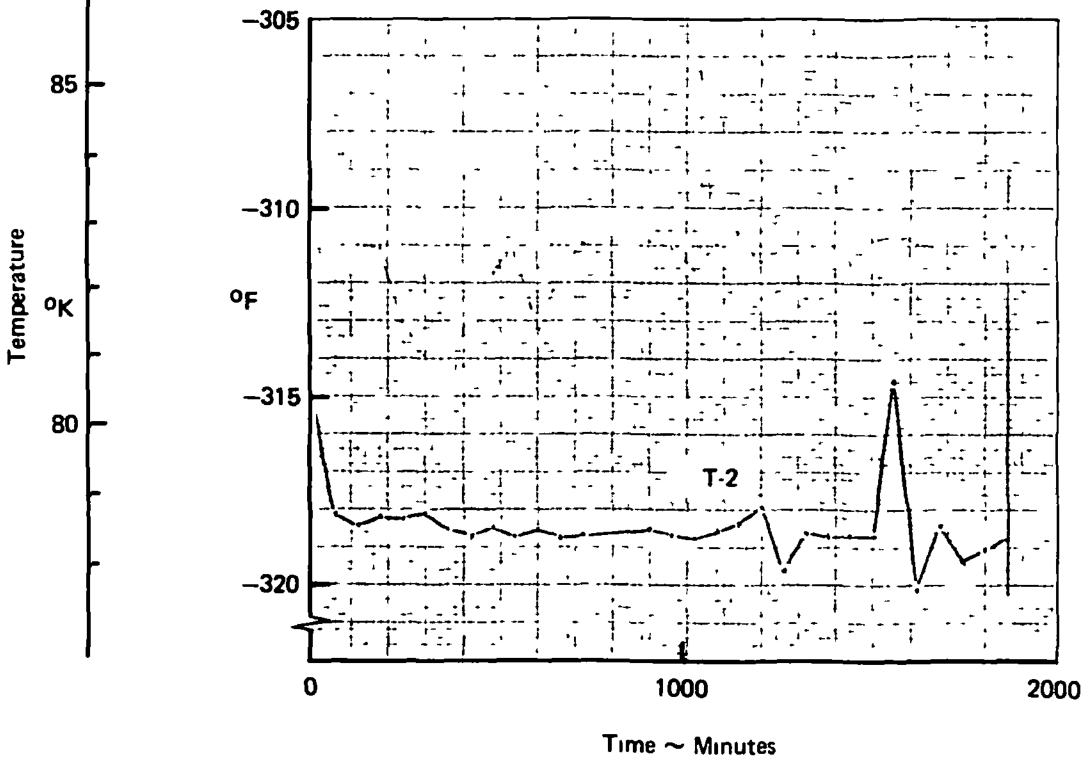


FIGURE E-19: TEST #2 - TEMPERATURES

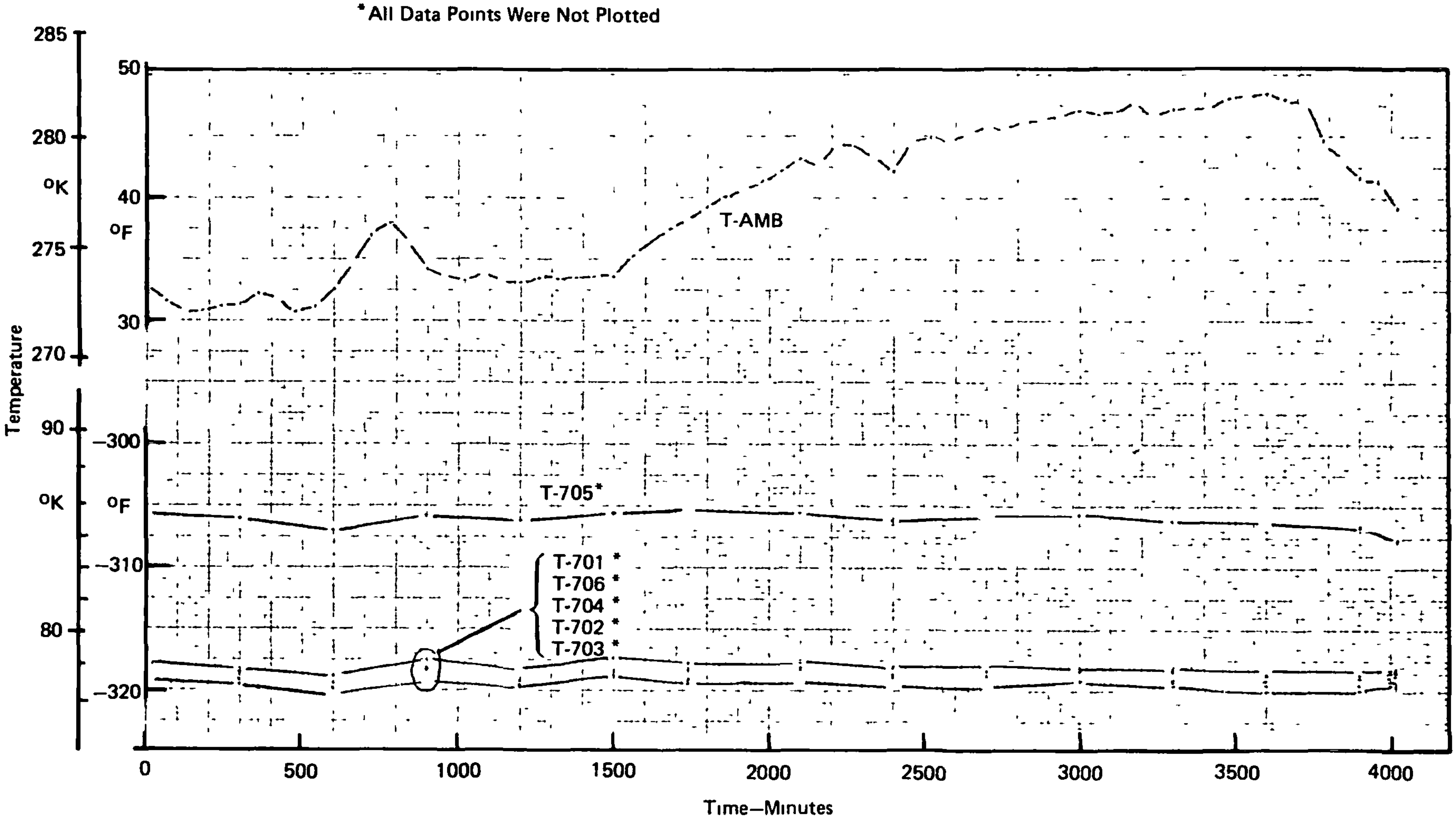


FIGURE E-20: TEST #3 - TEMPERATURES

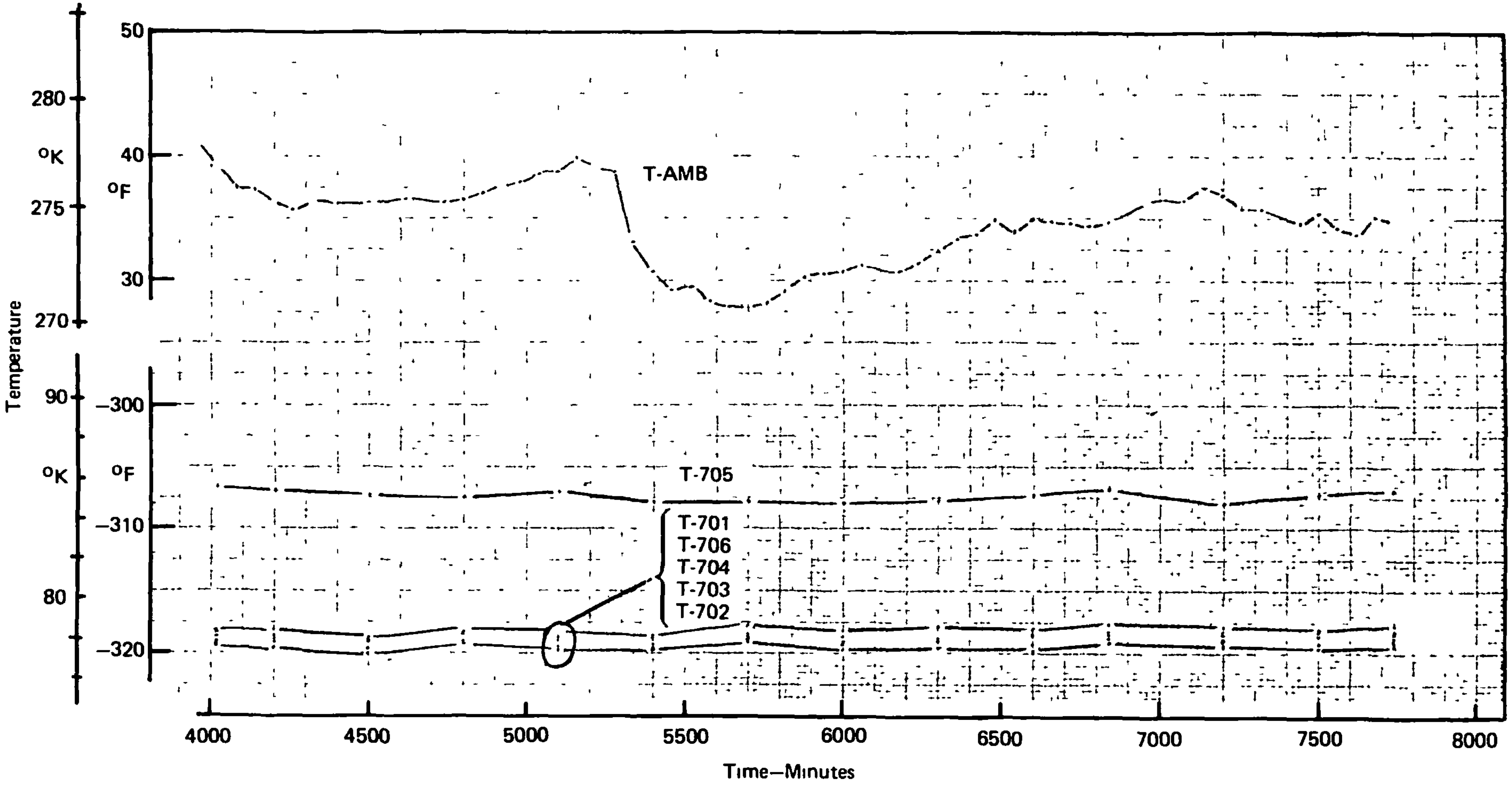


FIGURE E-20: TEST #3 - TEMPERATURES

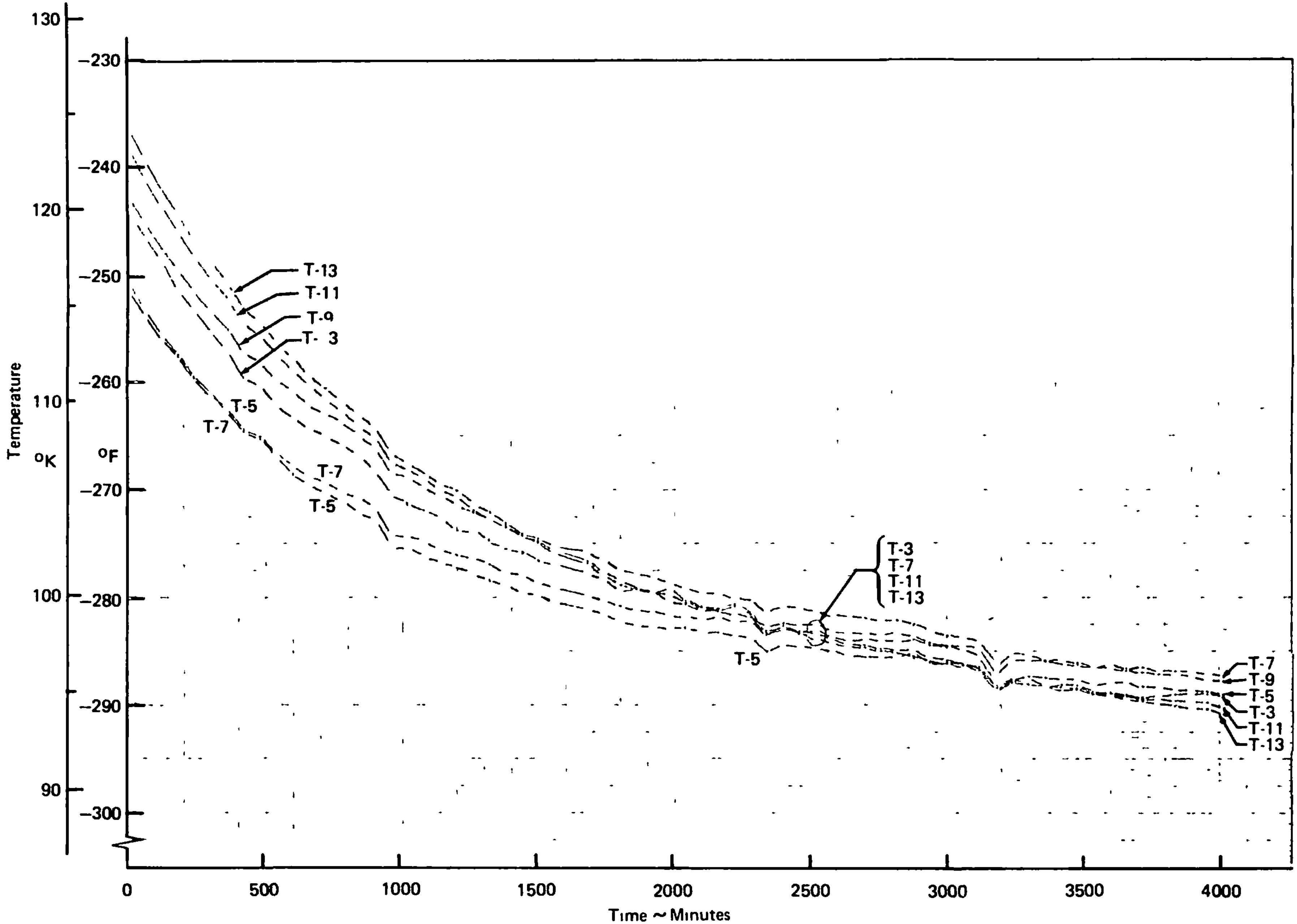


FIGURE E-21: TEST #3 - TEMPERATURES

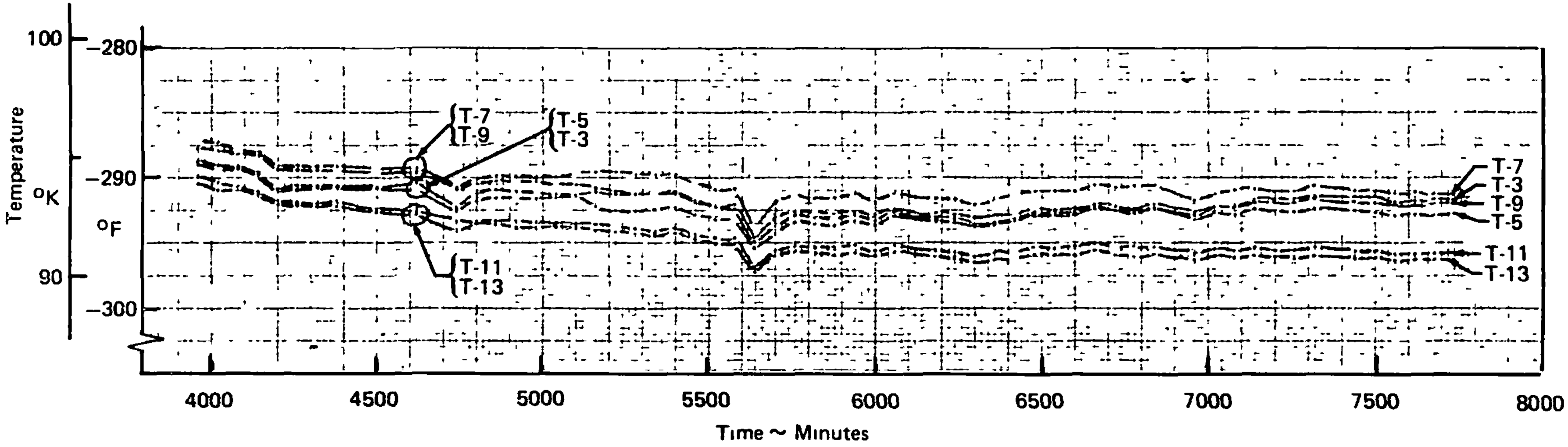


FIGURE E-21: TEST #3 - TEMPERATURES

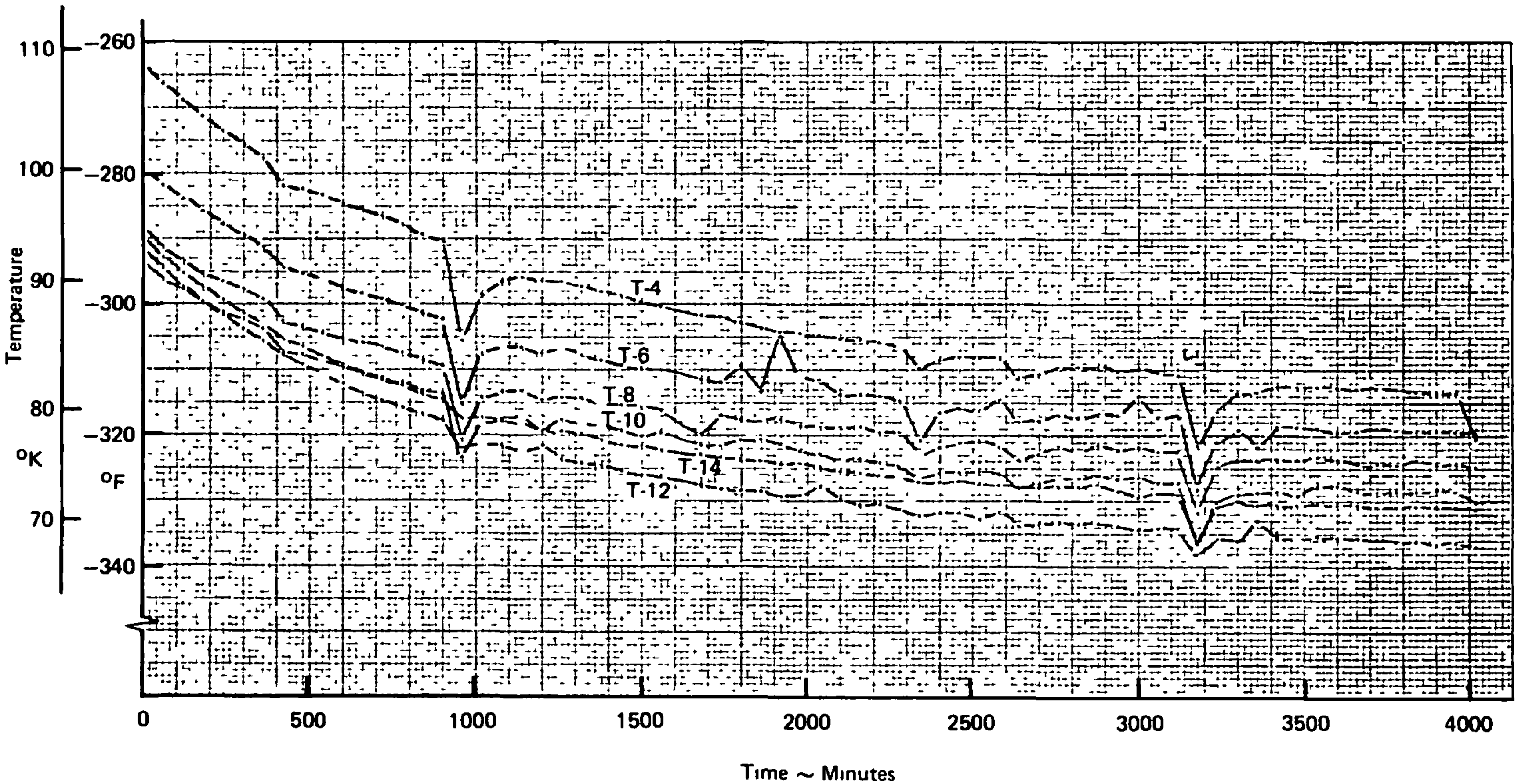


FIGURE E-22: TEST #3 - TEMPERATURES

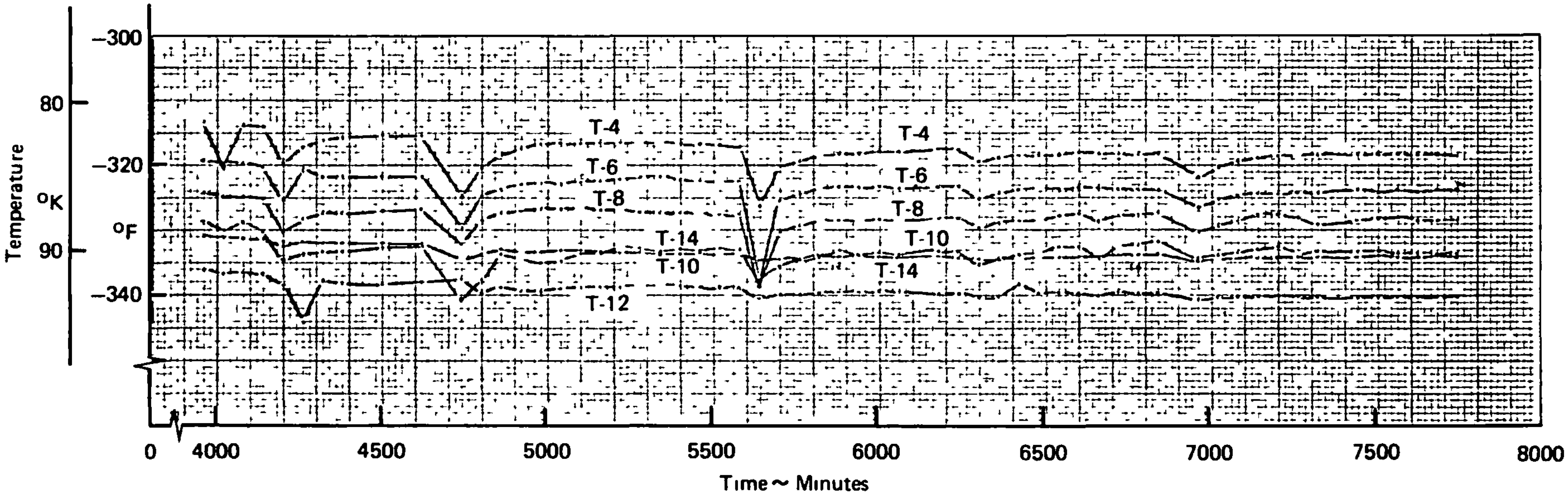


FIGURE E-22: TEST #3 - TEMPERATURES (Continued)

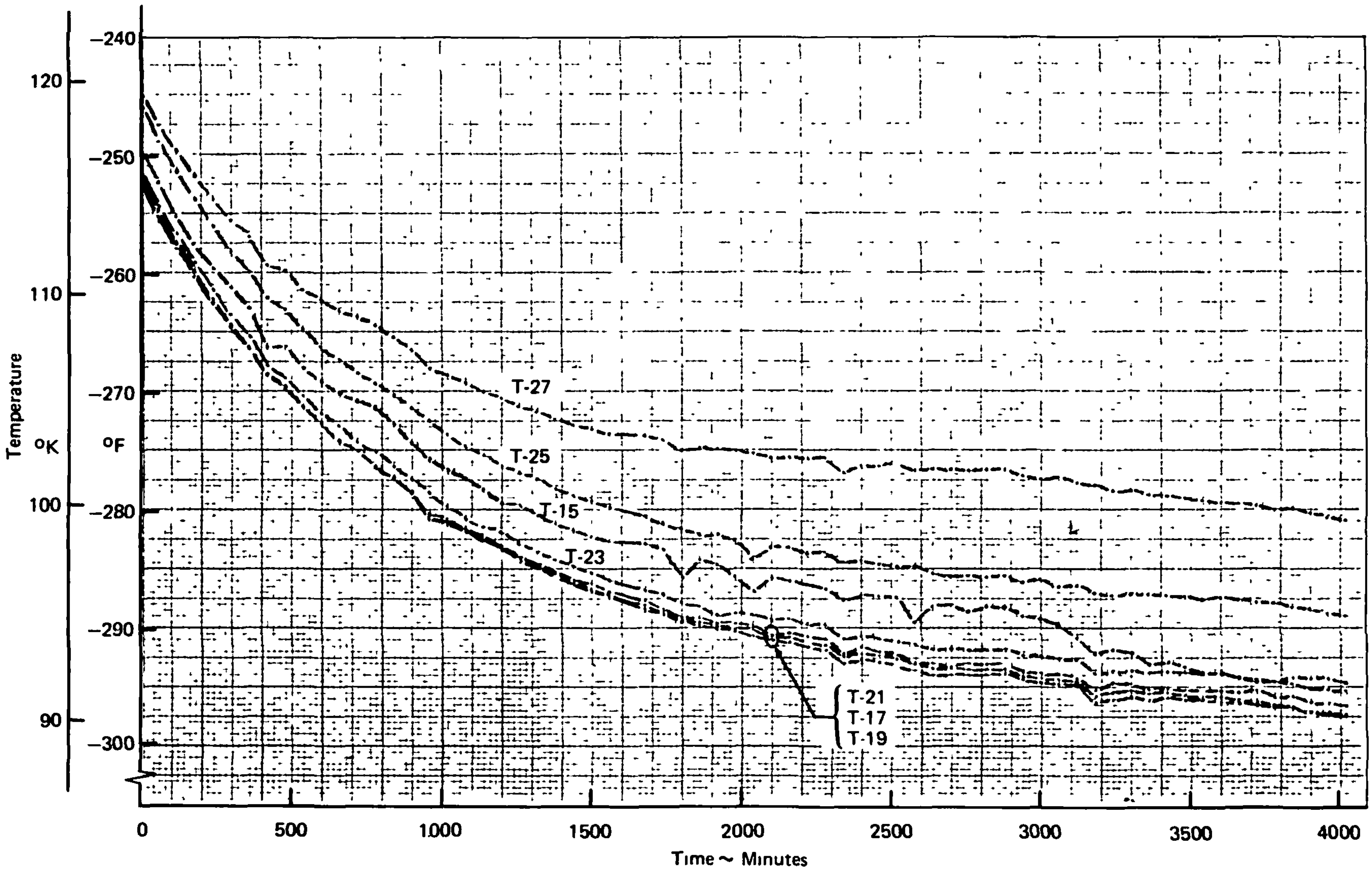


FIGURE E-23: TEST #3 - TEMPERATURES

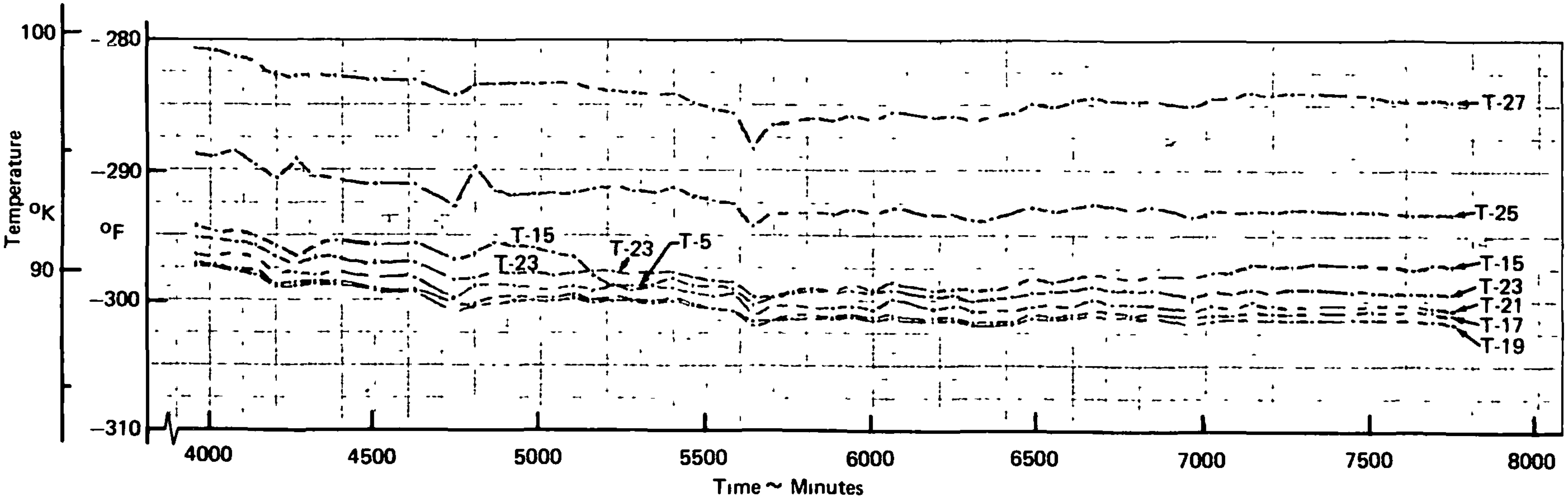


FIGURE E-23: TEST #3 - TEMPERATURES

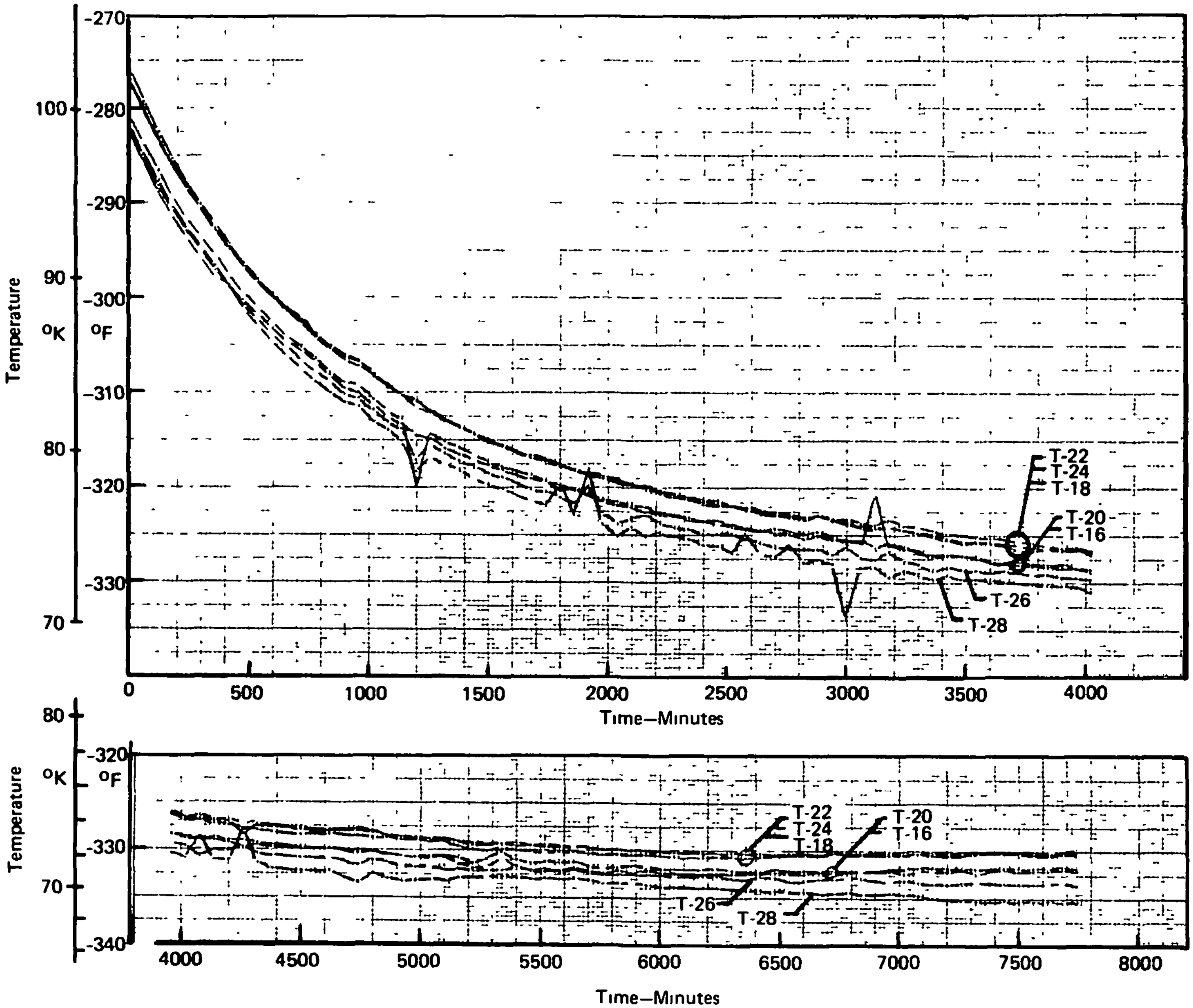
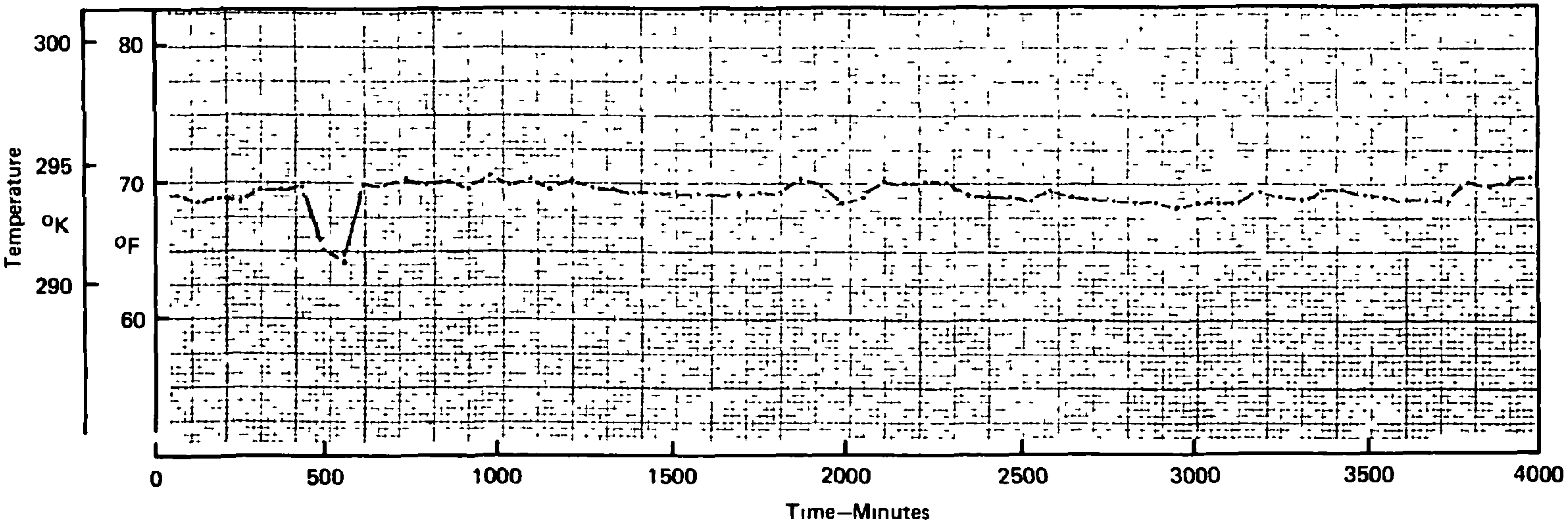


FIGURE E-24: TEST #3 - TEMPERATURES



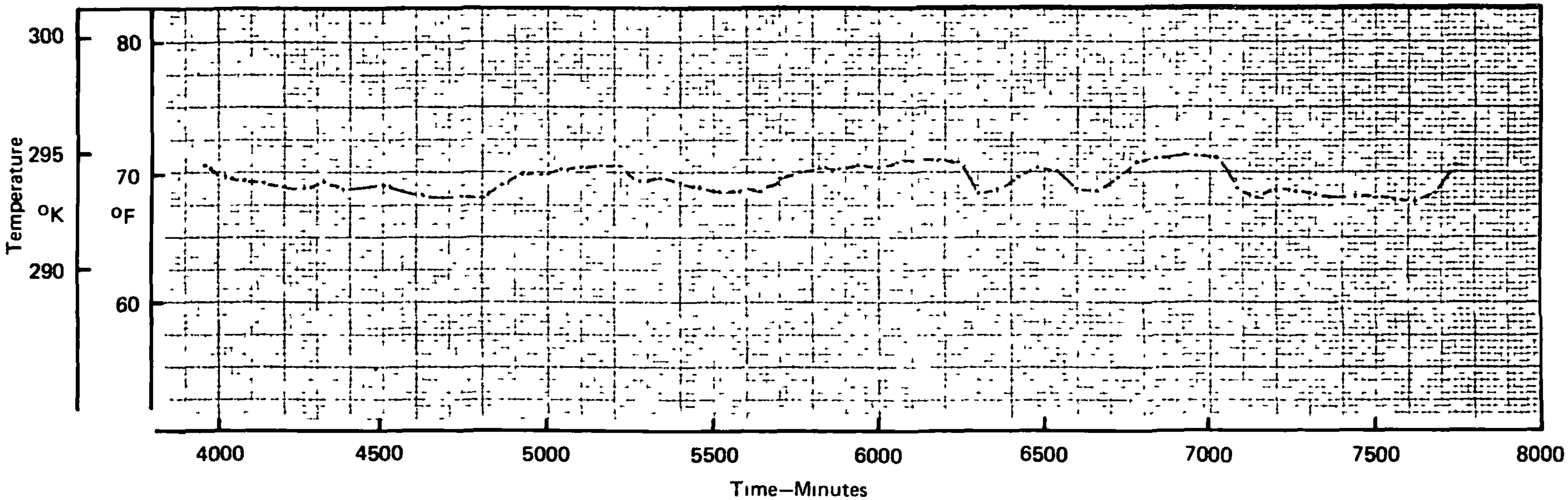


FIGURE E-25: TEST #3 - TEMPERATURES

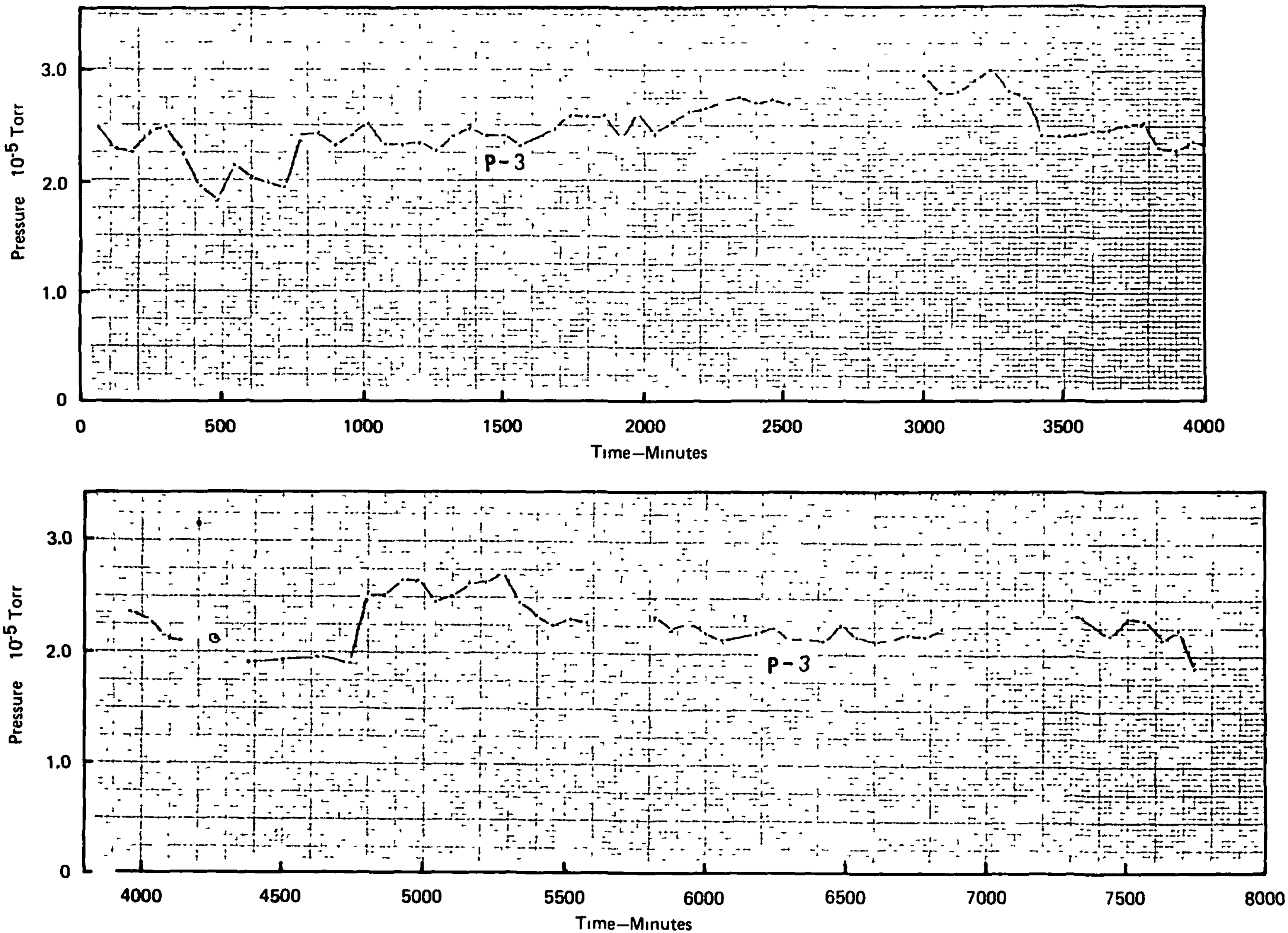
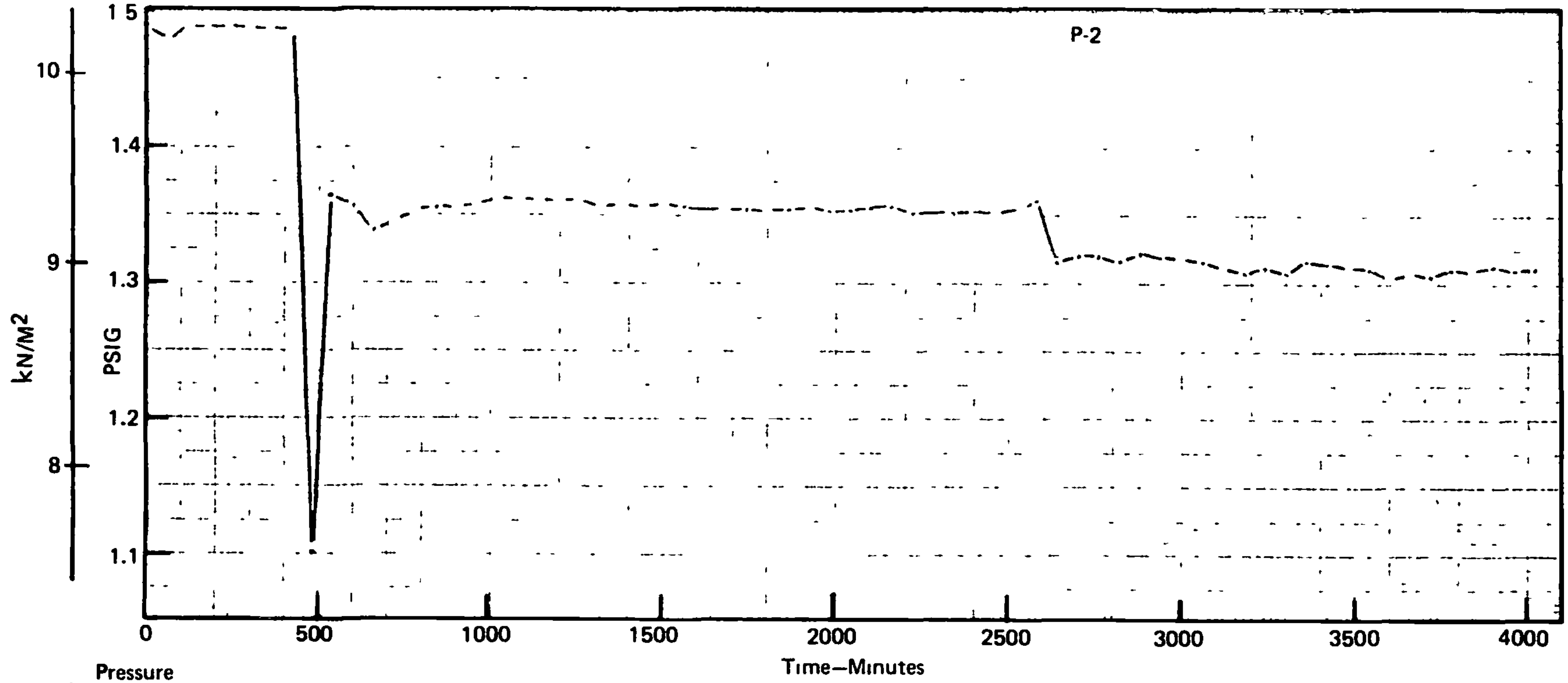


FIGURE E-26: TEST #3 - ALTITUDE CHAMBER PRESSURE



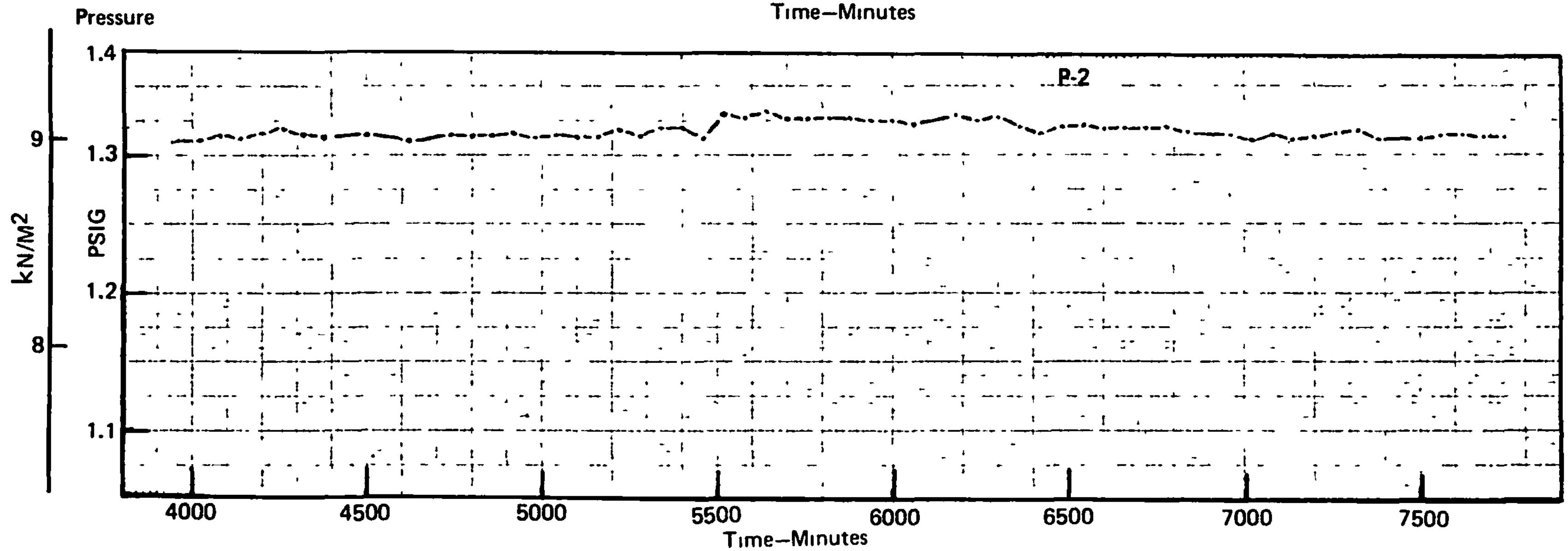


FIGURE E-27: TEST #3 - GUARD TANK PRESSURE

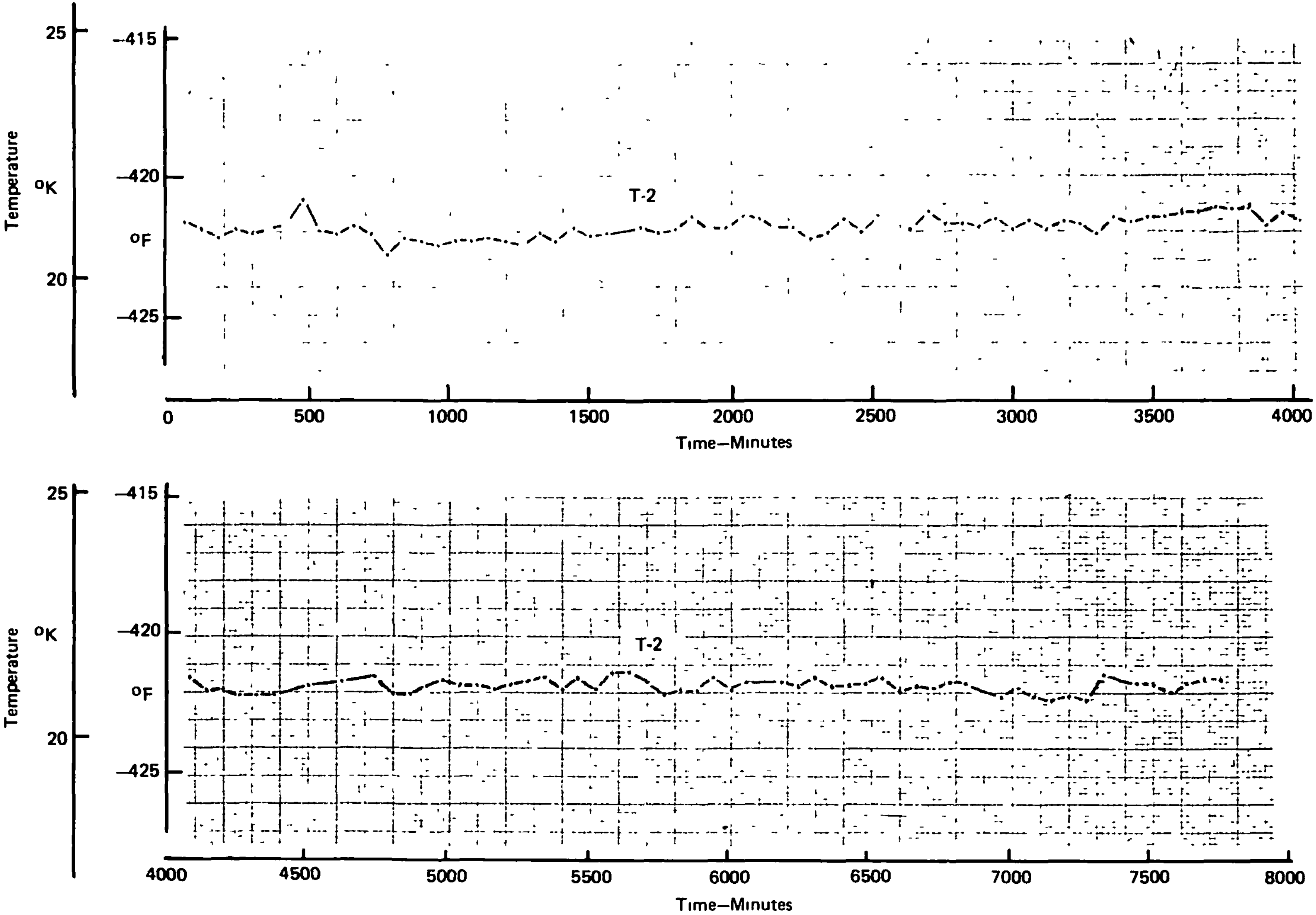


FIGURE E-28: TEST #3 - TEMPERATURES

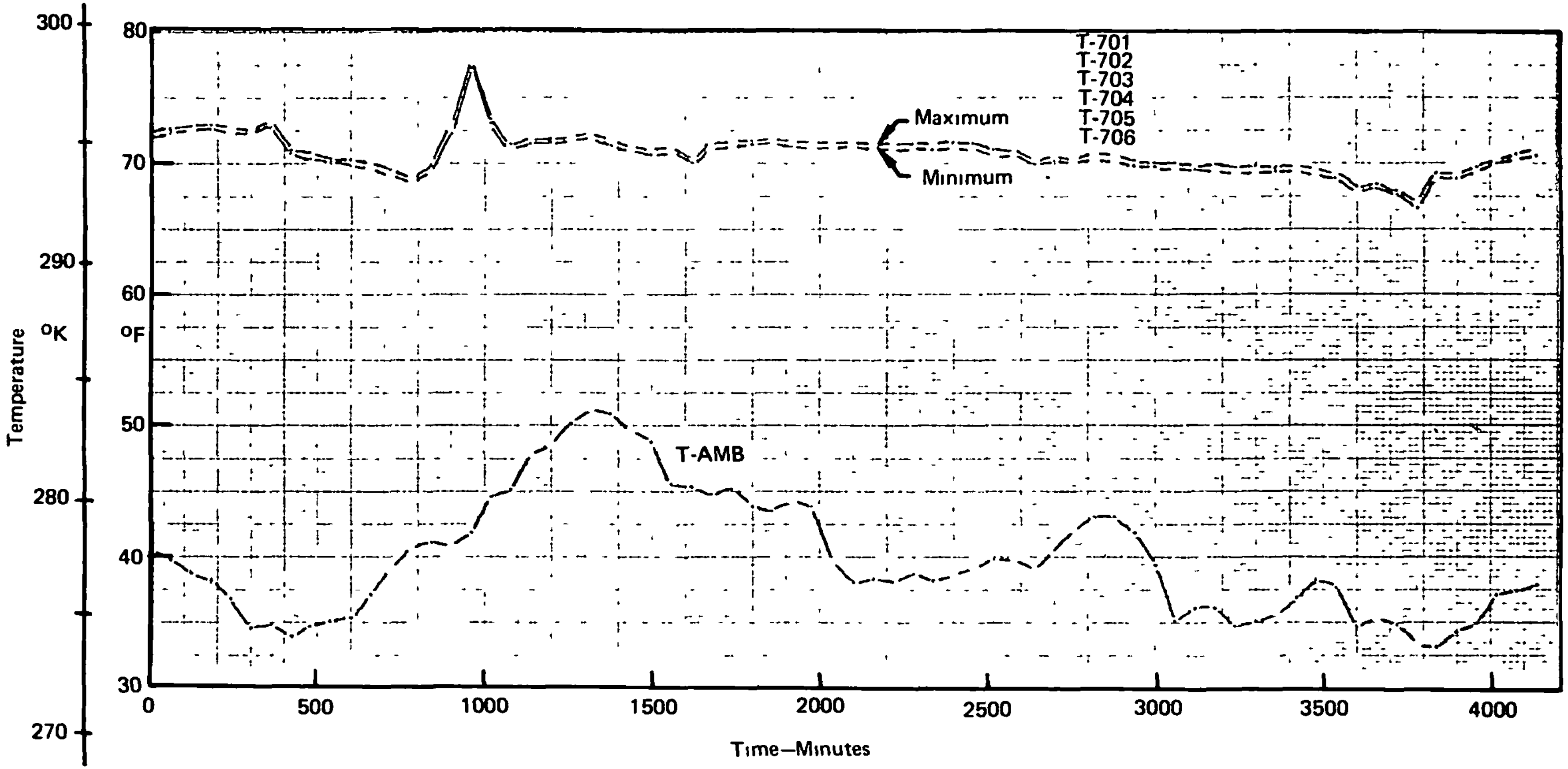


FIGURE E-29: TEST #4 - TEMPERATURES

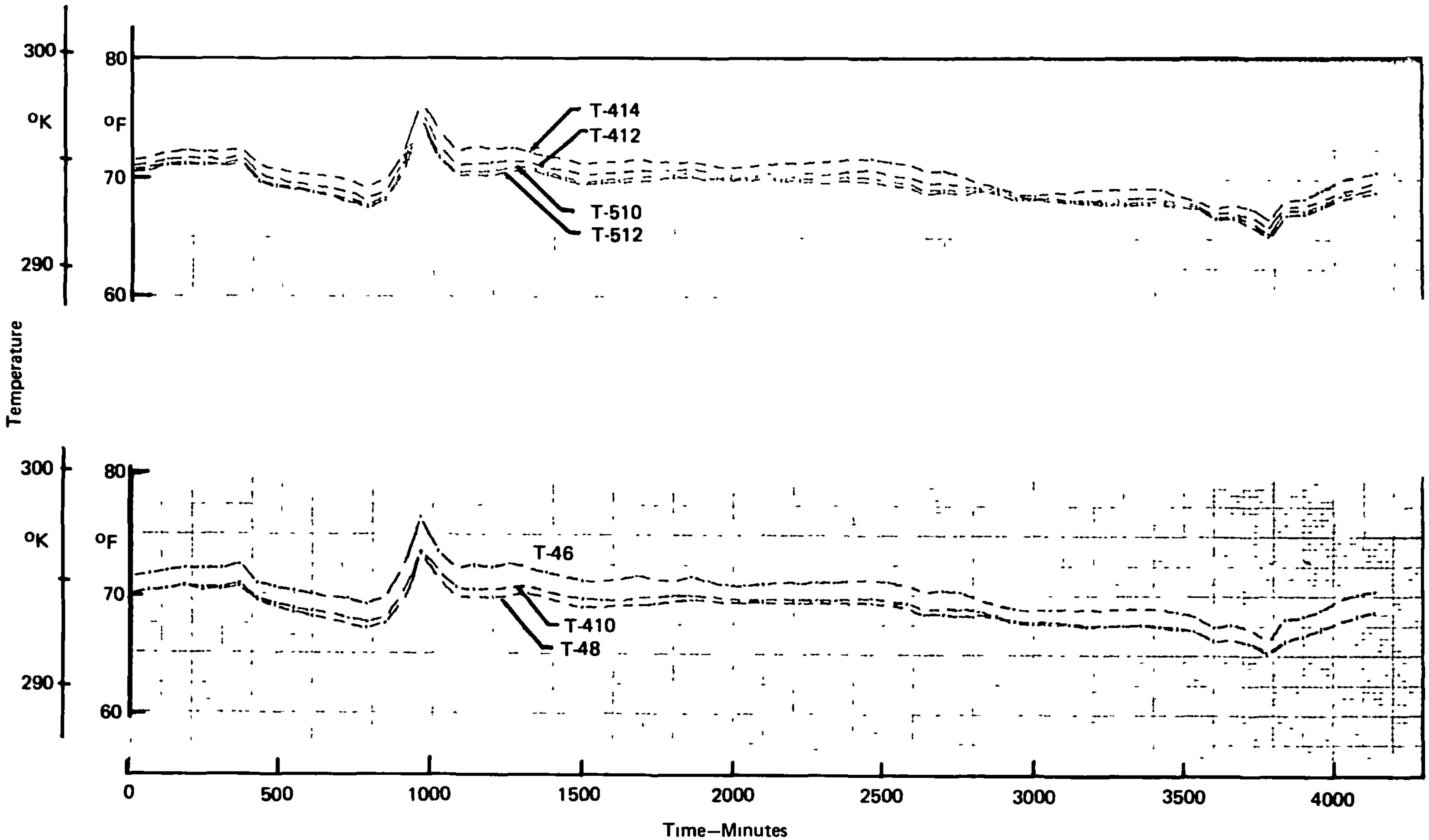


FIGURE E-30: TEST #4 - TEMPERATURES

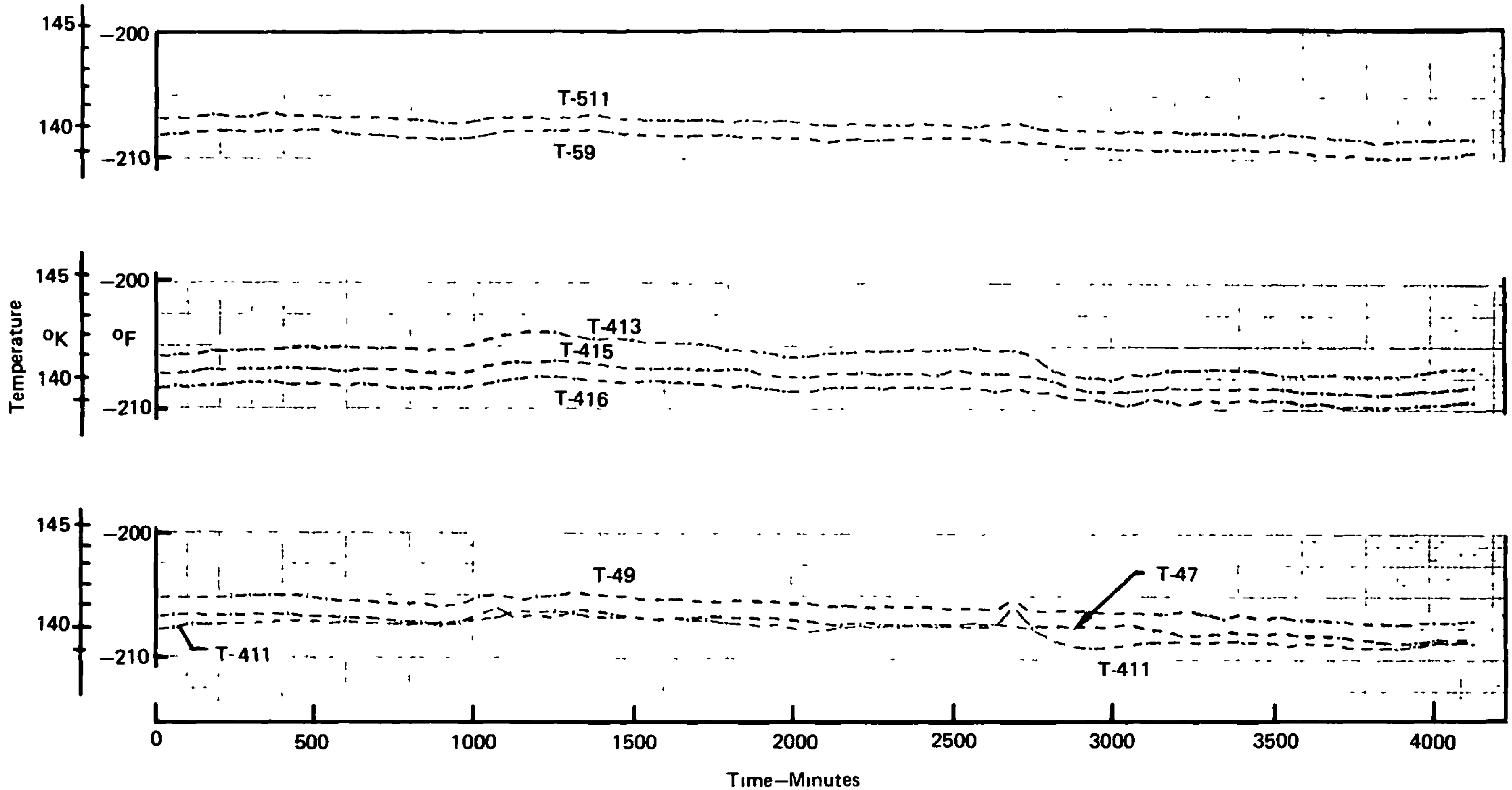


FIGURE E-31: TEST #4 - TEMPERATURES

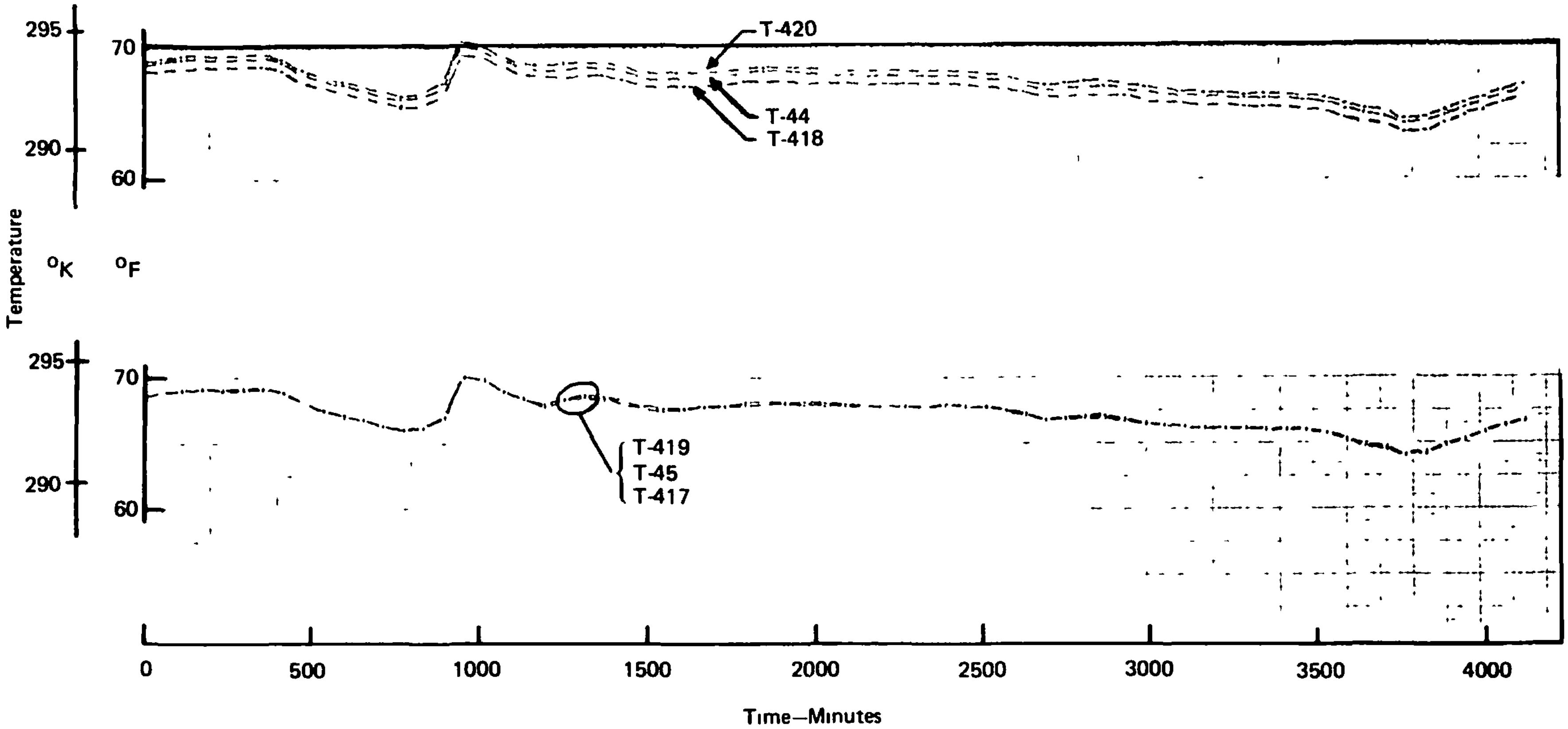


FIGURE E-32: TEST #4 - TEMPERATURES

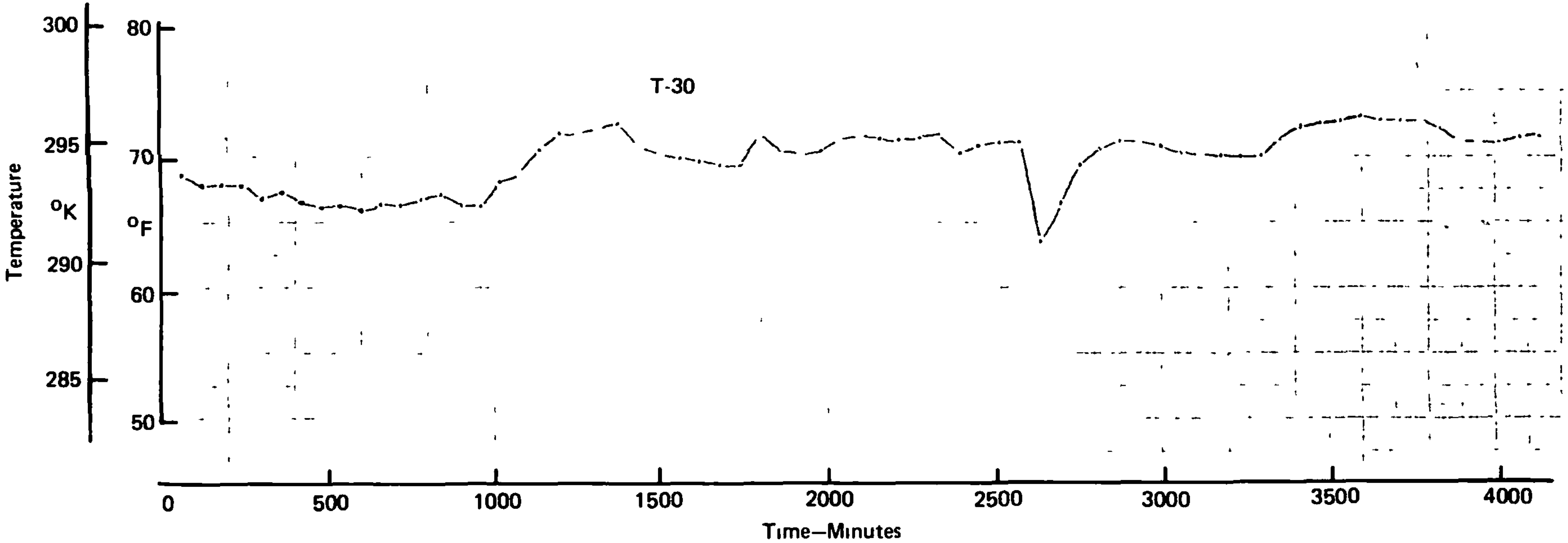


FIGURE E-33: TEST #4 - TEMPERATURES

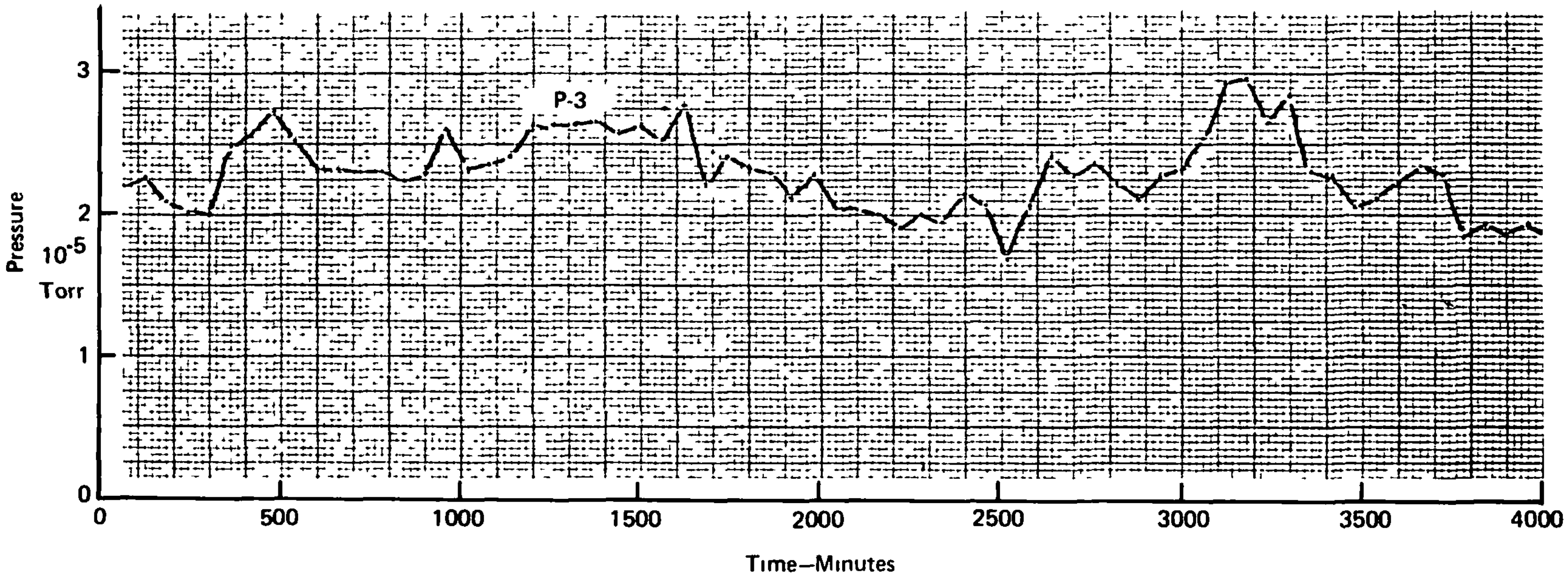


FIGURE E-34: TEST #4 - ALTITUDE CHAMBER PRESSURE

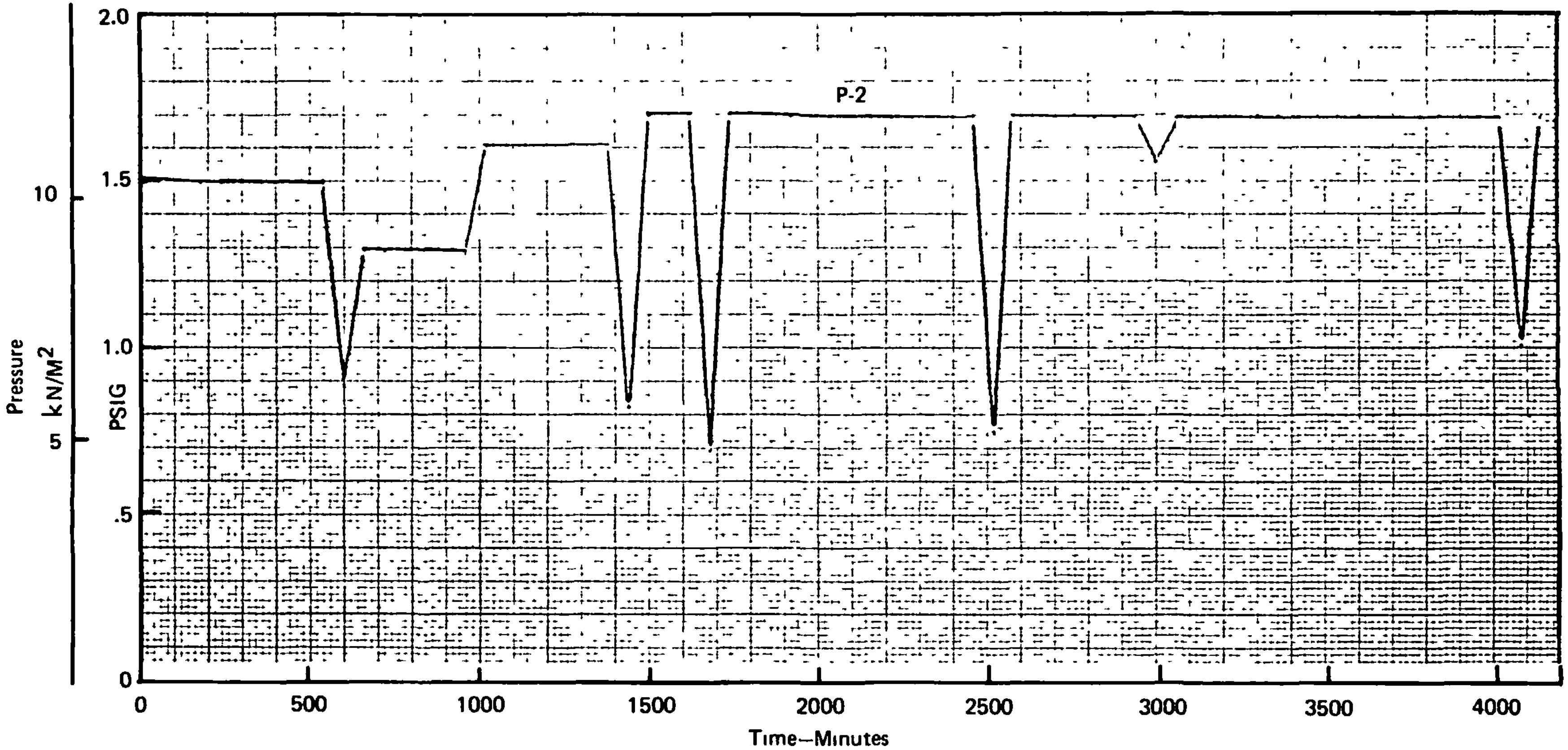


FIGURE E-35: TEST #4 - GUARD TANK PRESSURE

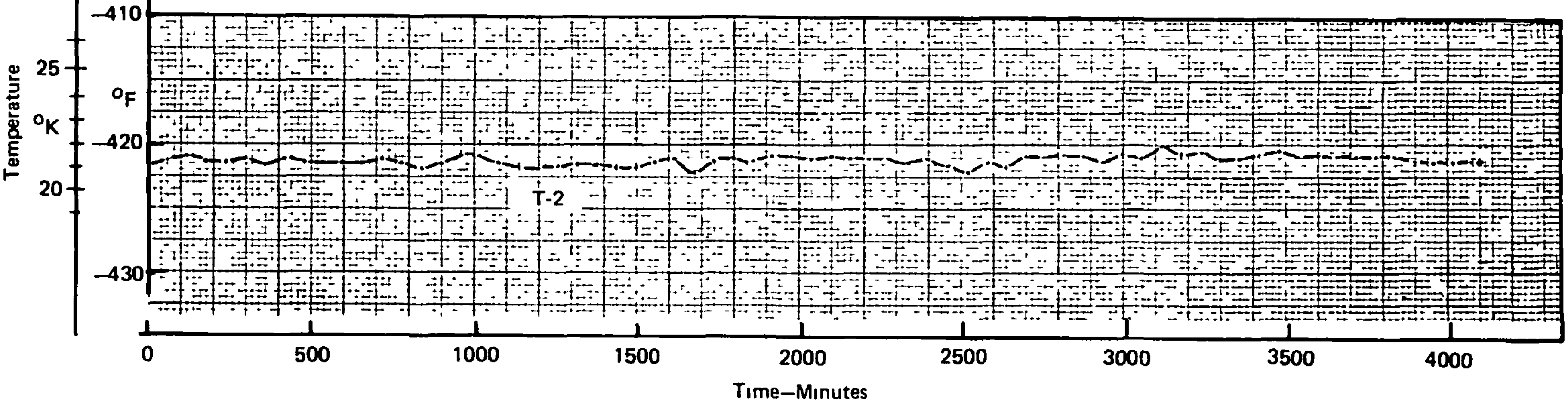


FIGURE E-36: TEST #4 - TEMPERATURE

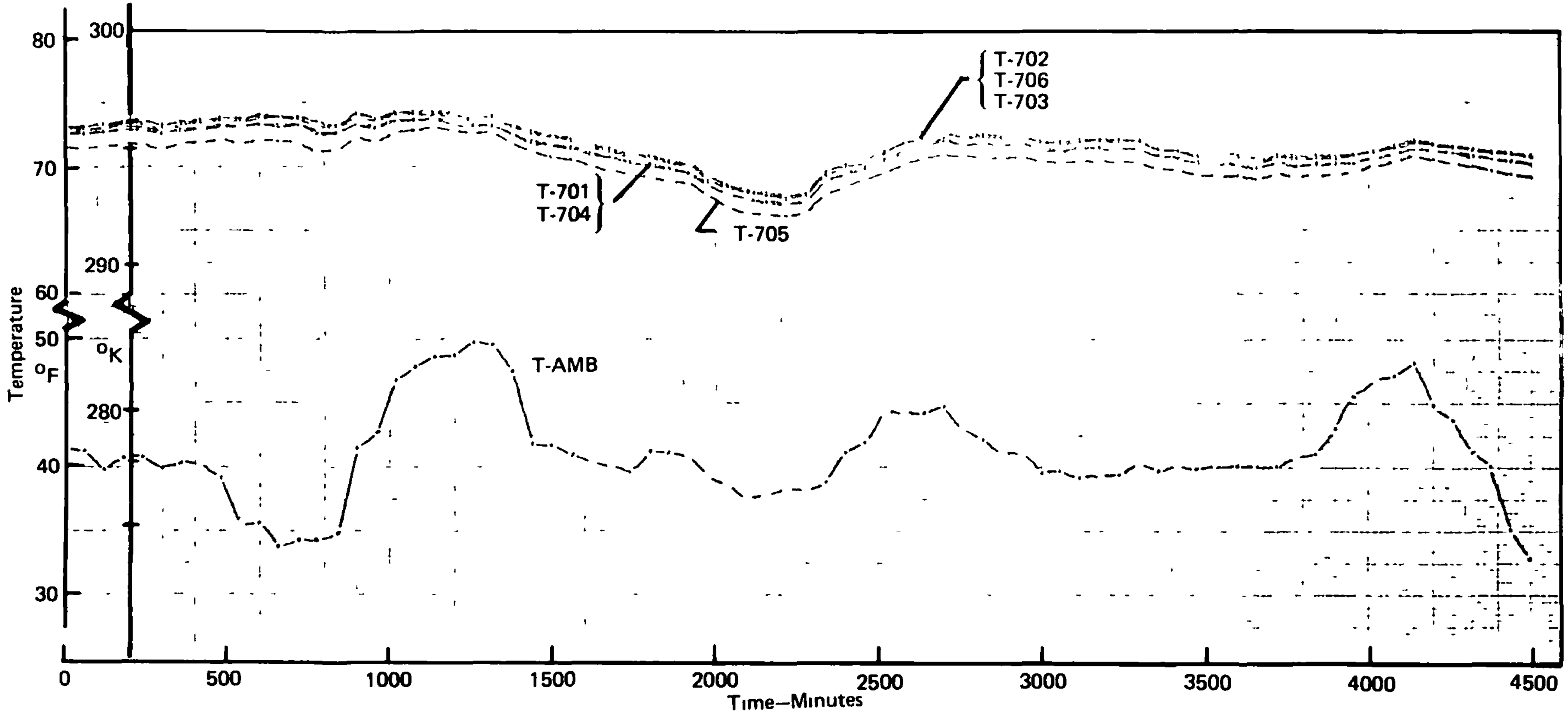


FIGURE E-37: TEST #5 - TEMPERATURE

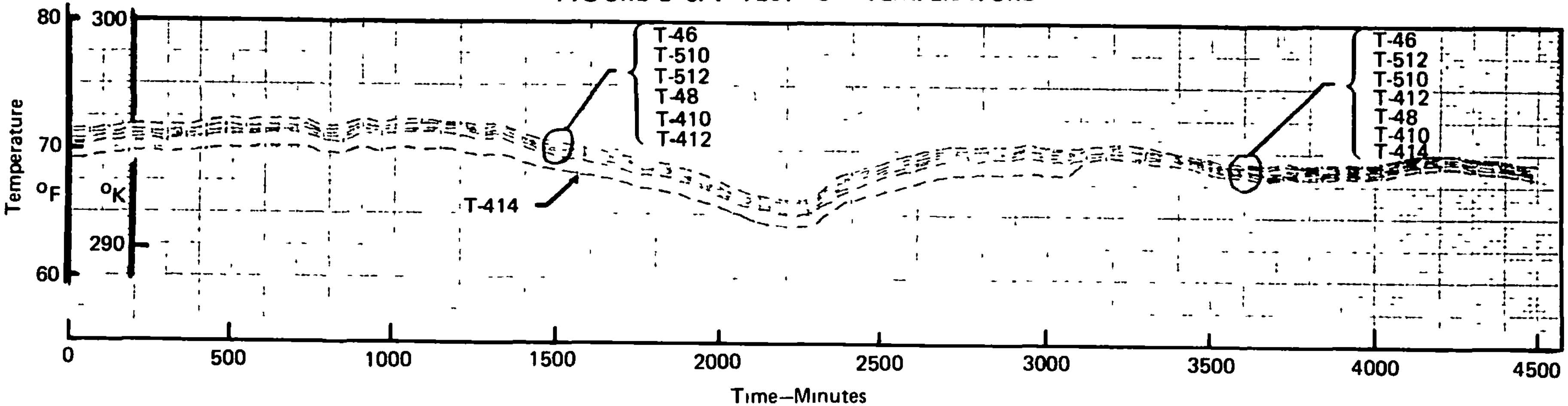


FIGURE E-38: TEST #5 - TEMPERATURES

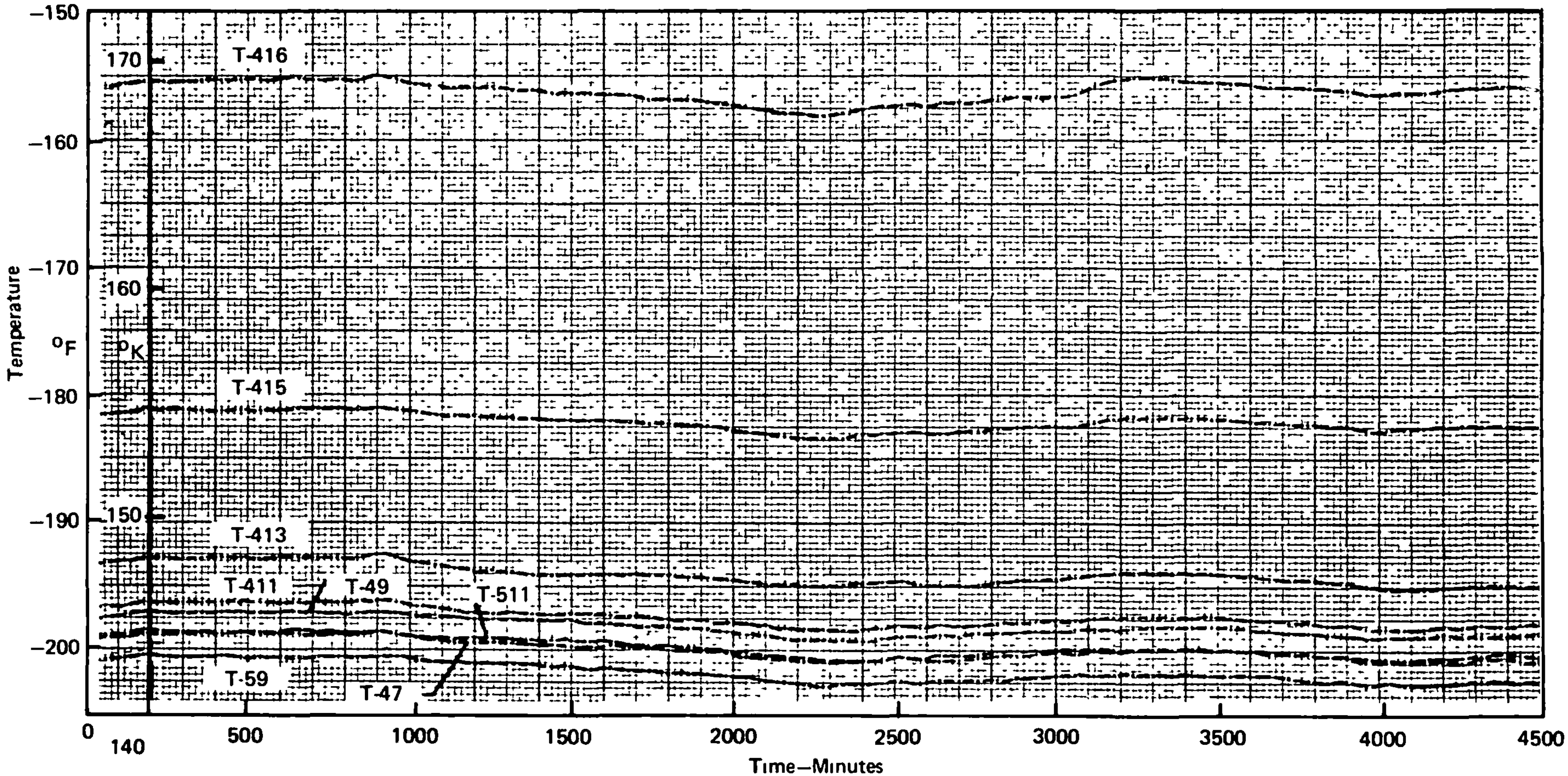


FIGURE E-39: TEST #5 - TEMPERATURES

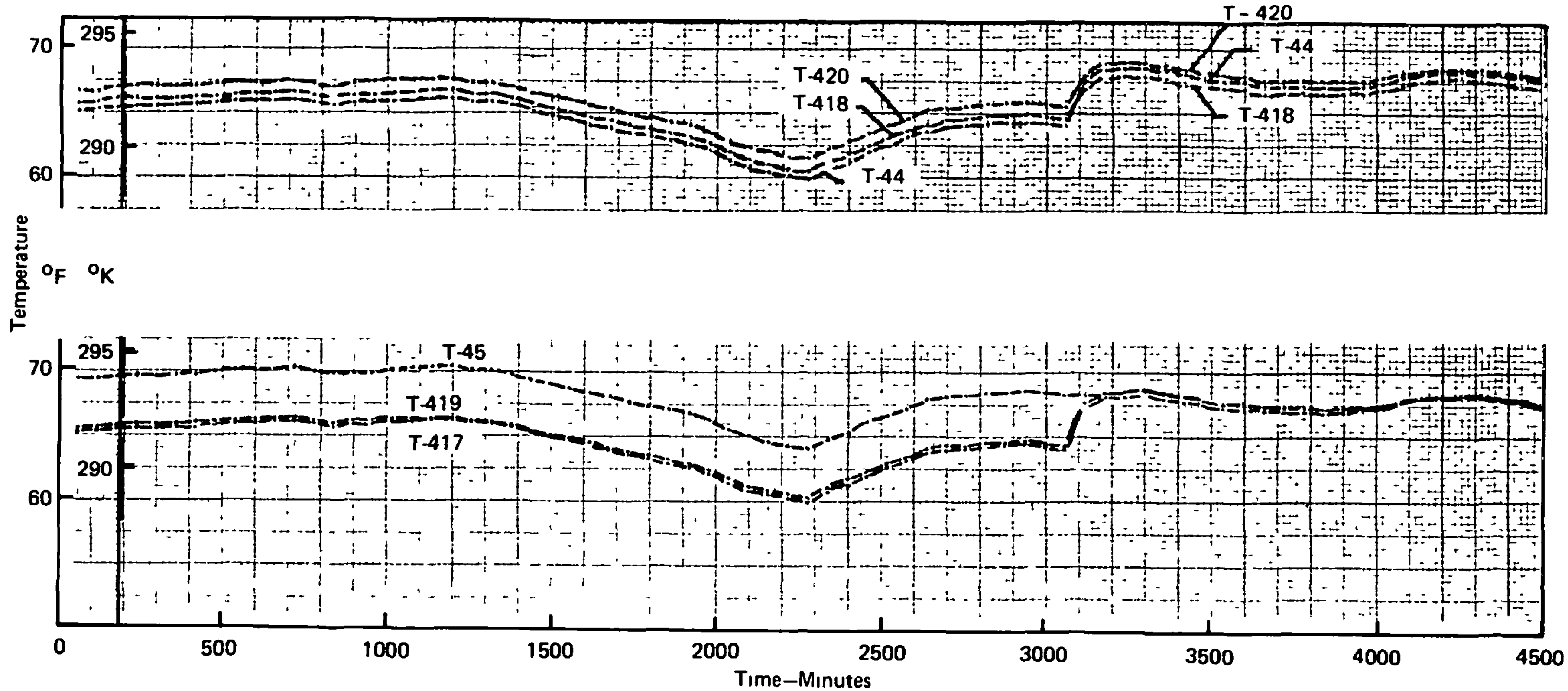


FIGURE E-40: TEST #5 - TEMPERATURES

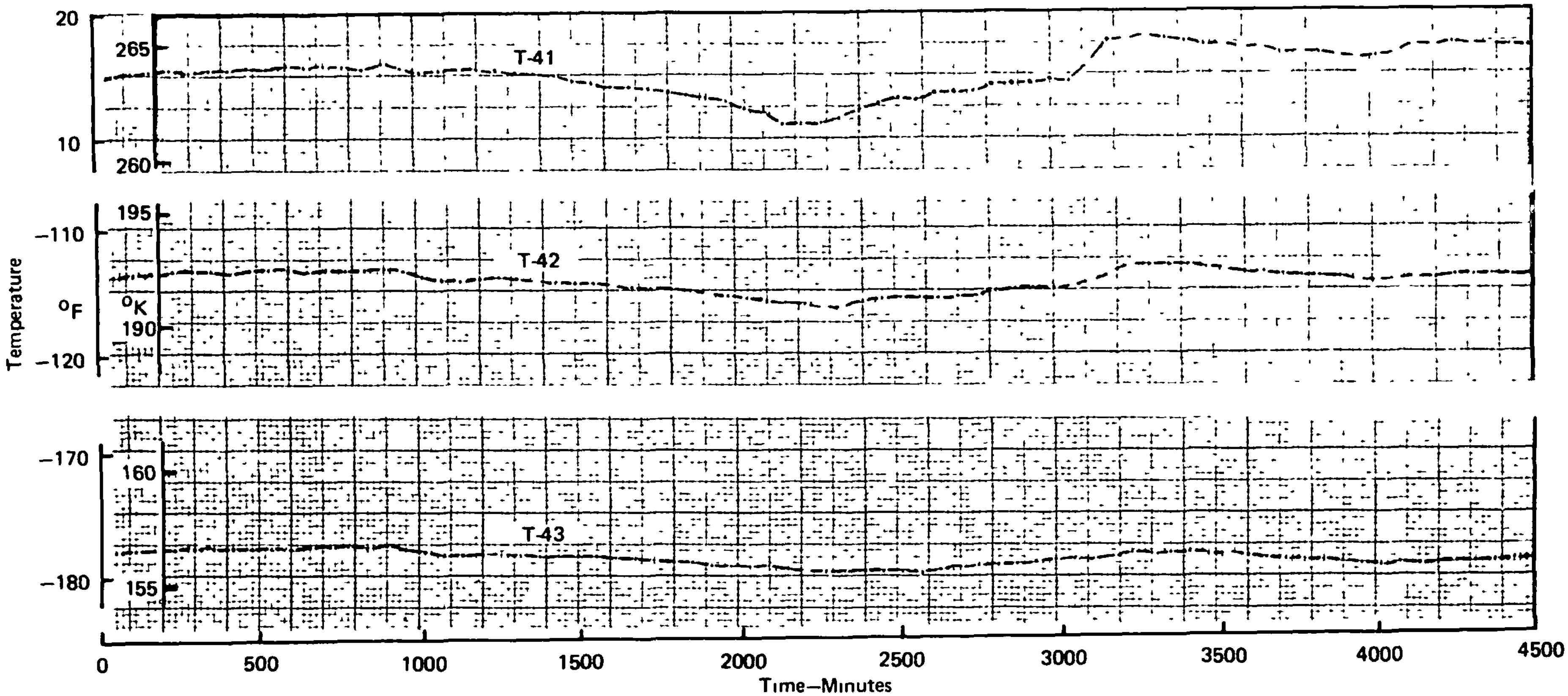


FIGURE E-41: TEST #5 - TEMPERATURES

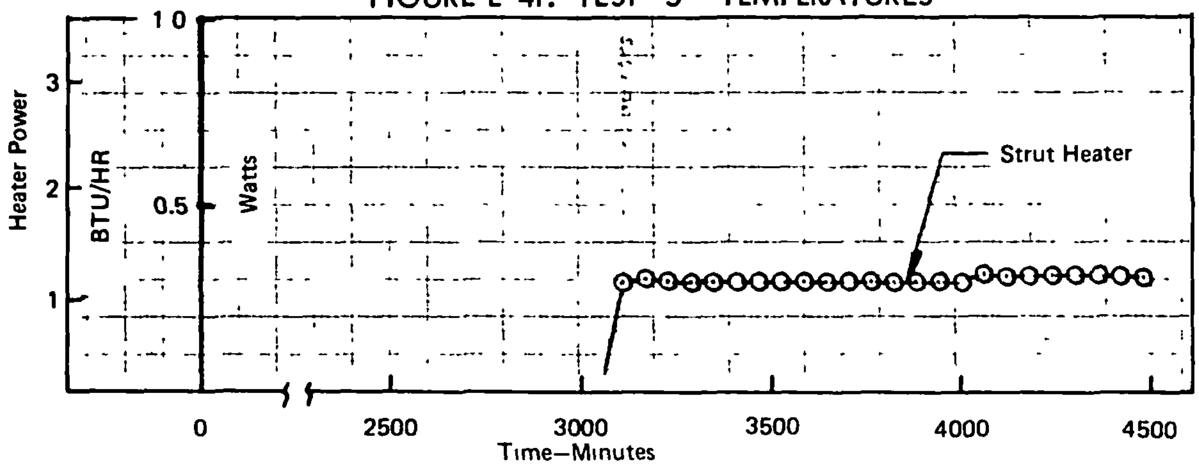


FIGURE E-42: TEST #5 - HEATER POWER

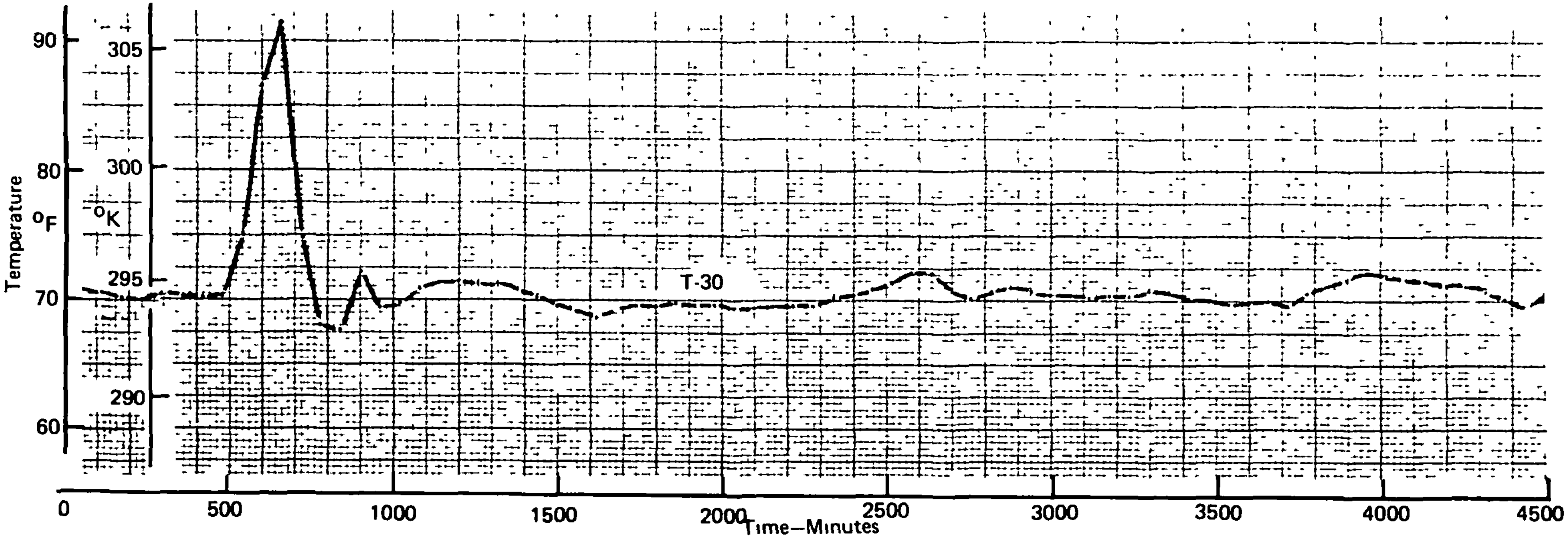


FIGURE E-43: TEST #5 - TEMPERATURE

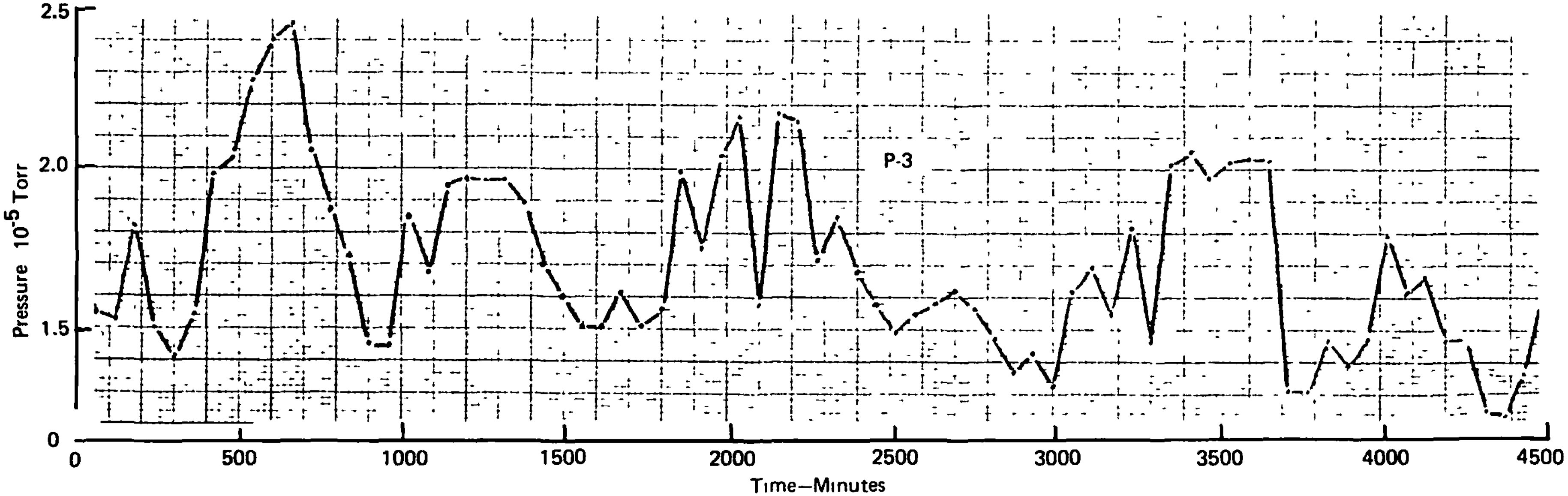


FIGURE E-44: TEST #5 ALTITUDE CHAMBER PRESSURE

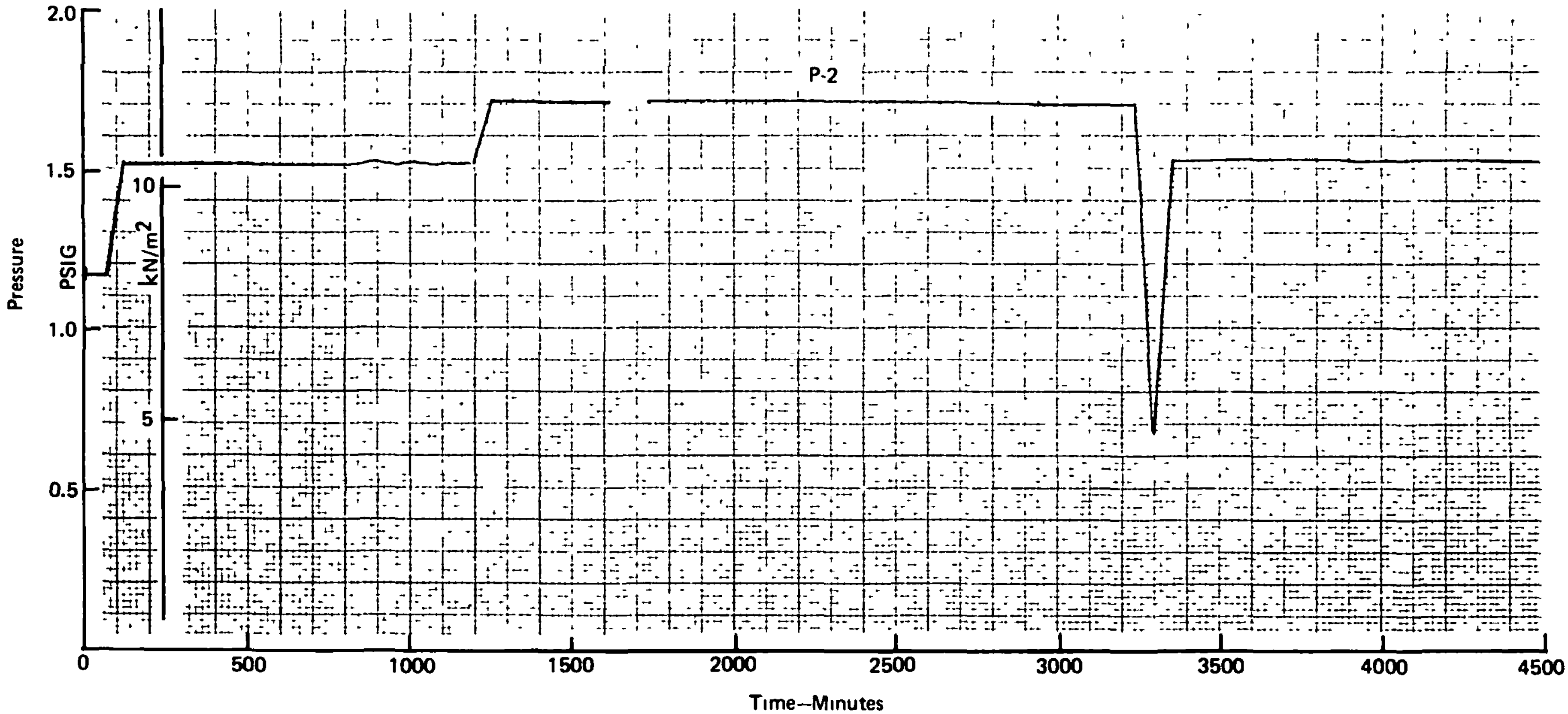


FIGURE E-45: TEST #5 GUARD TANK PRESSURE

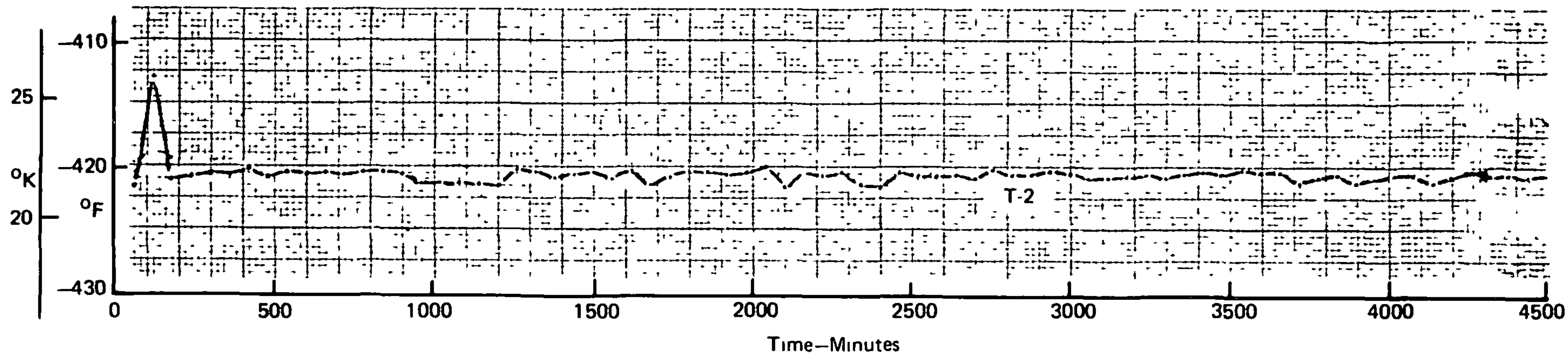


FIGURE E-46: TEST #5 - TEMPERATURE

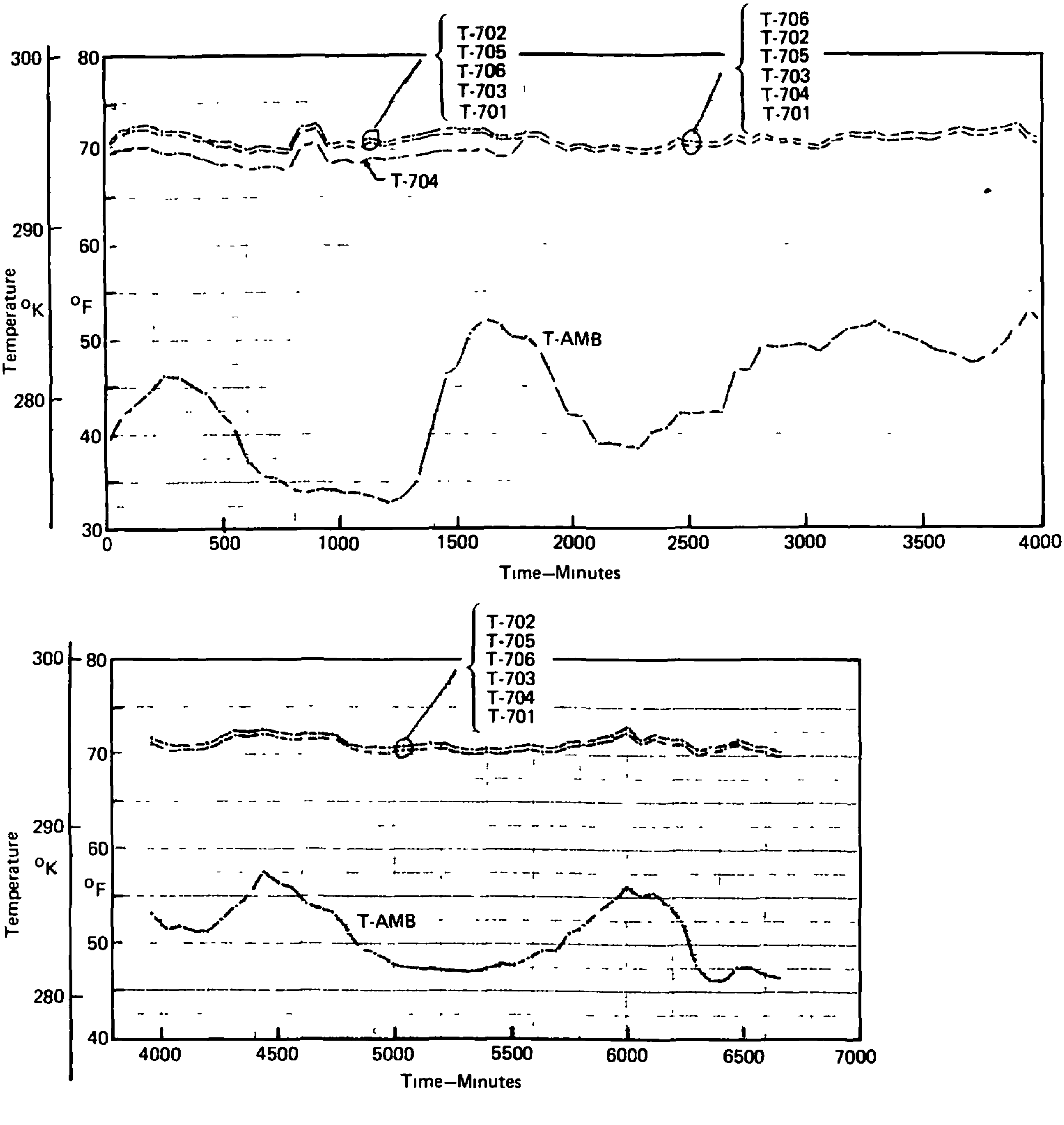


FIGURE E-47: TEST #6 - TEMPERATURES

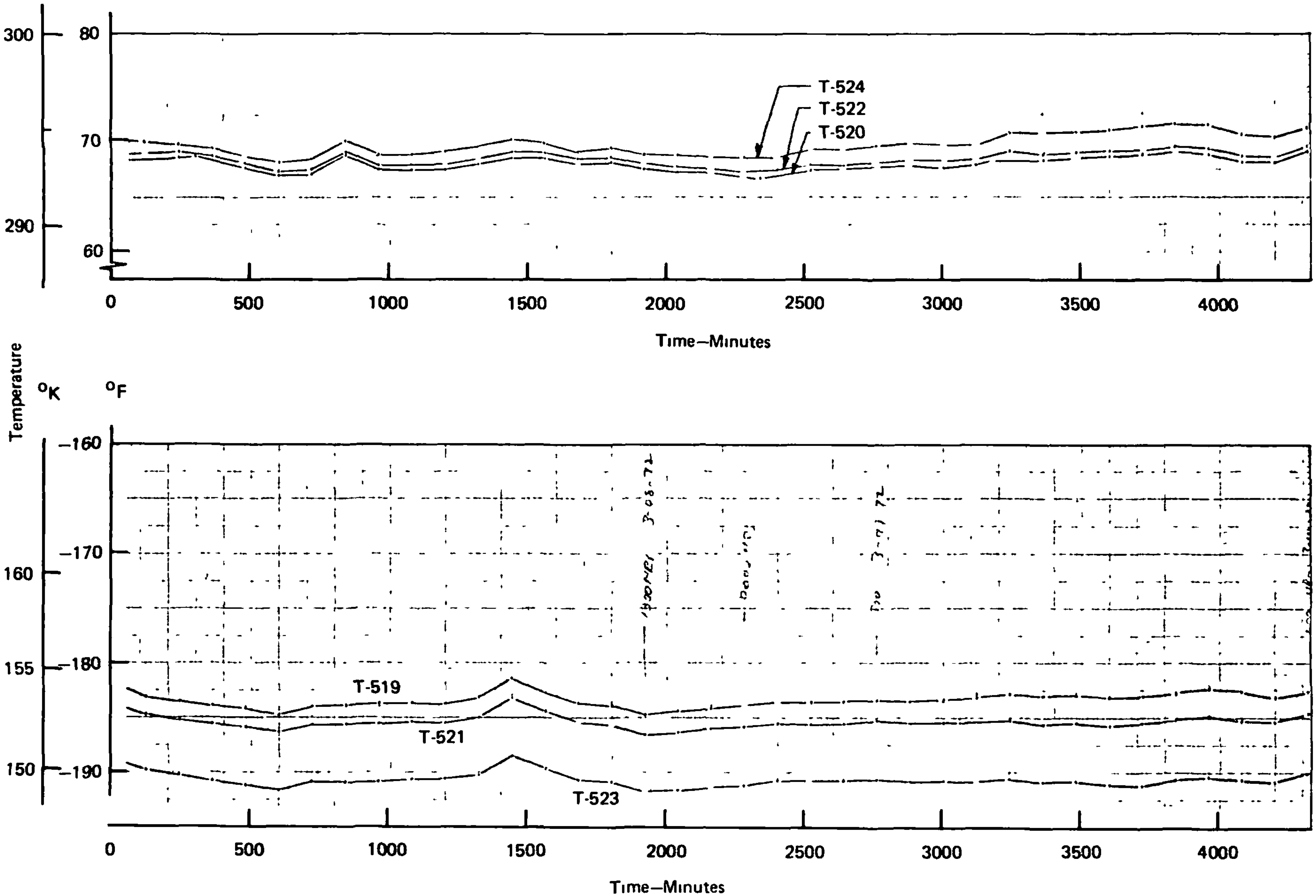


FIGURE E-48: TEST #6 - TEMPERATURES

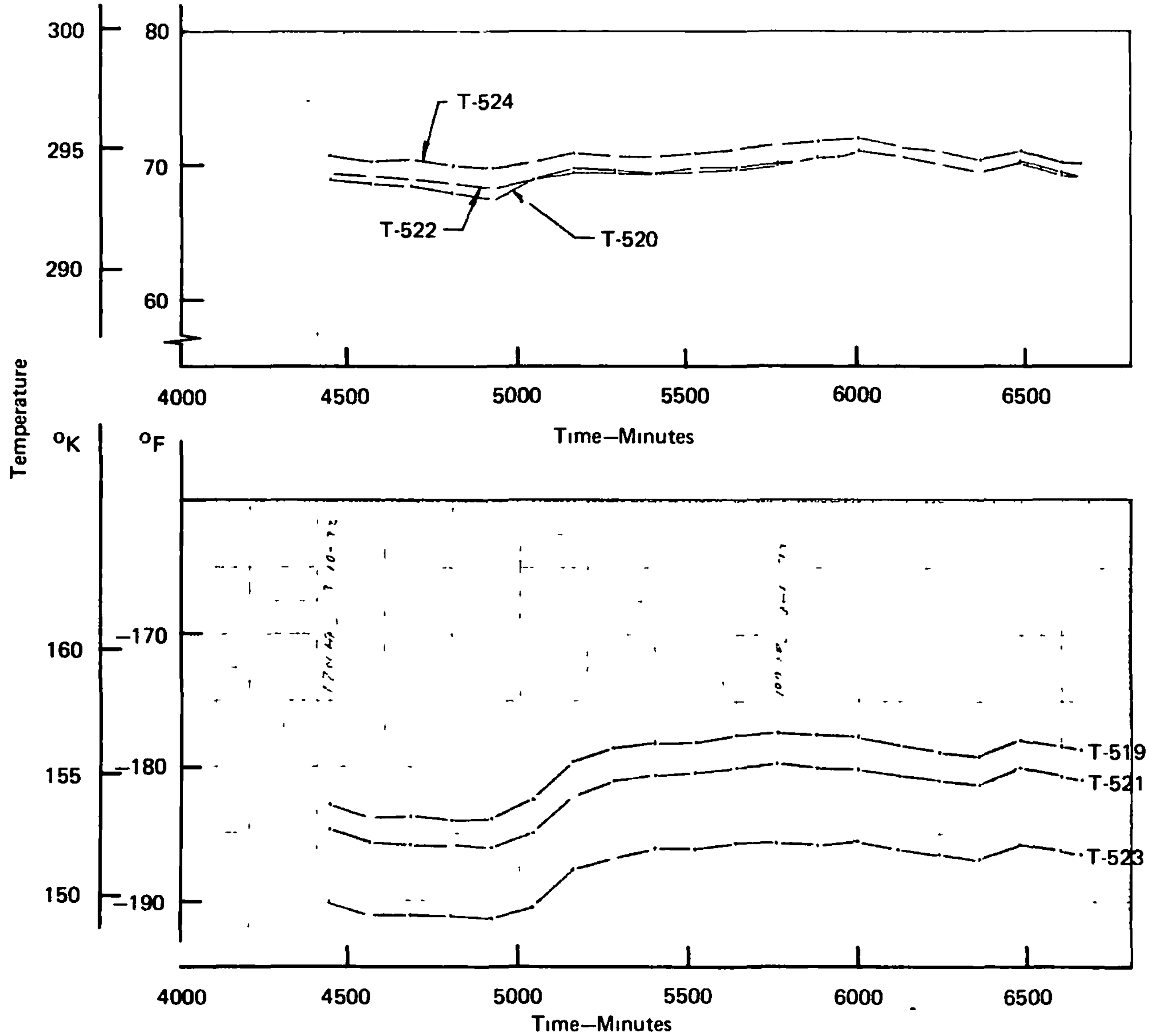
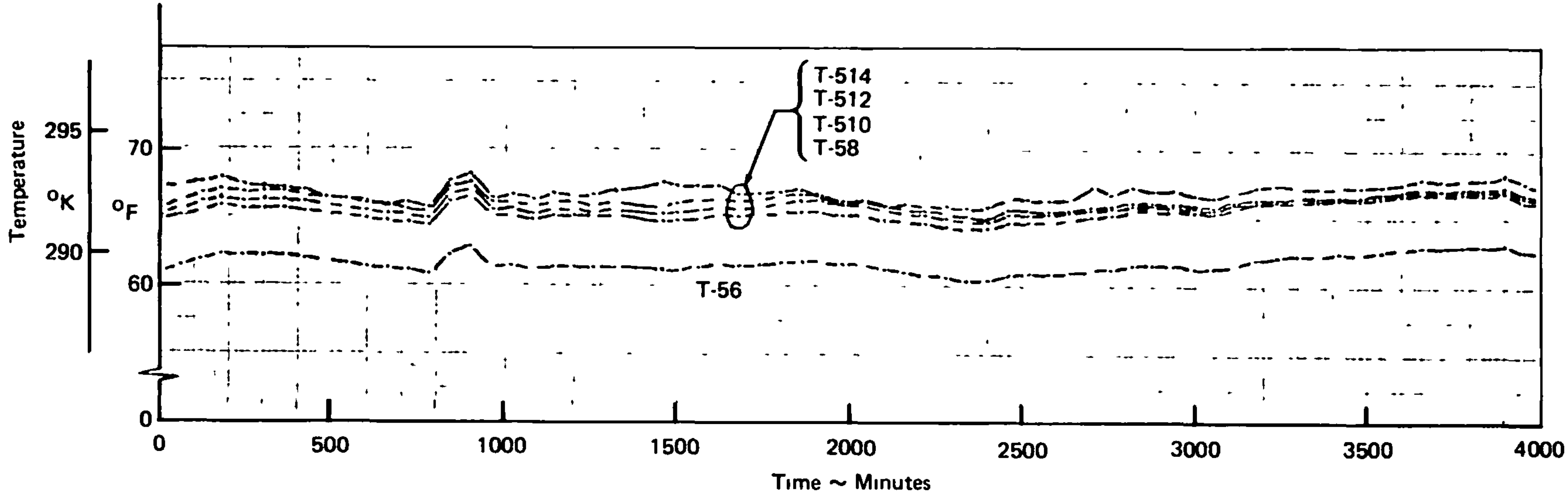


FIGURE E-48: TEST #6 - TEMPERATURES (Continued)



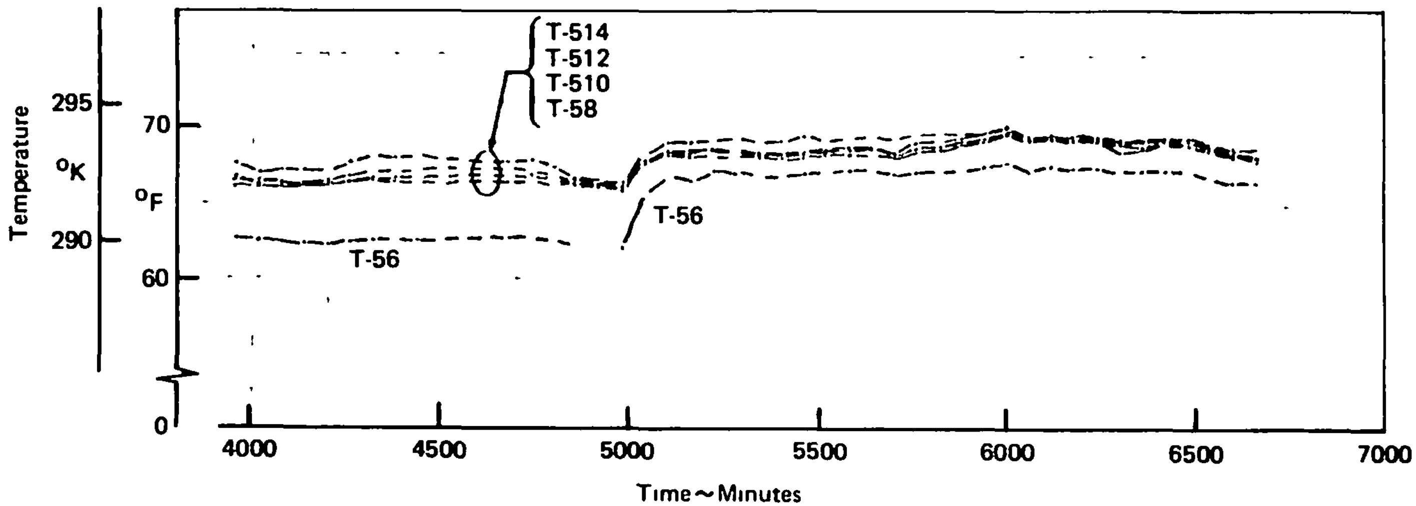


FIGURE E-49: TEST #6 - TEMPERATURES

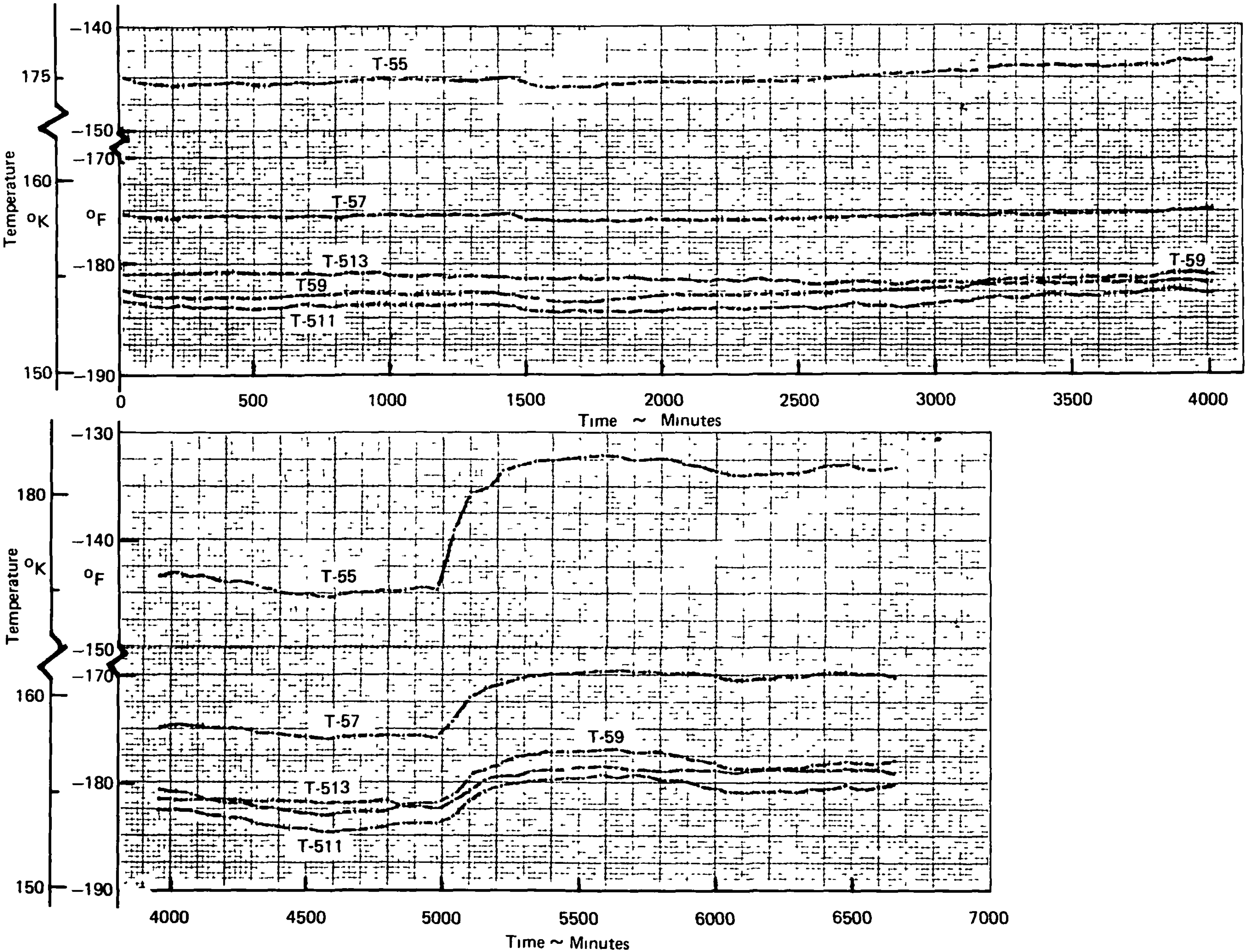


FIGURE E-50: TEST #6 - TEMPERATURES

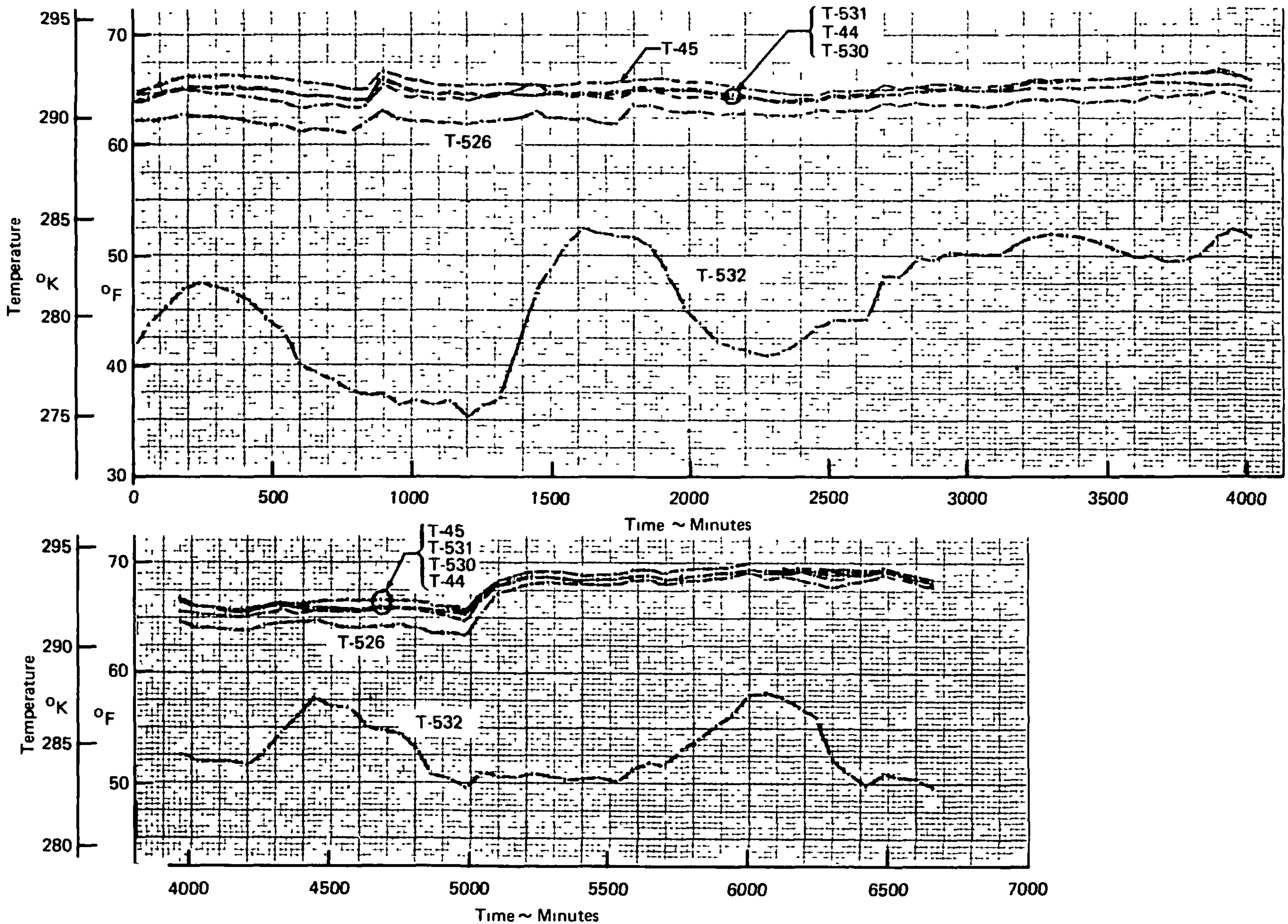


FIGURE E-51: TEST #6 - TEMPERATURES

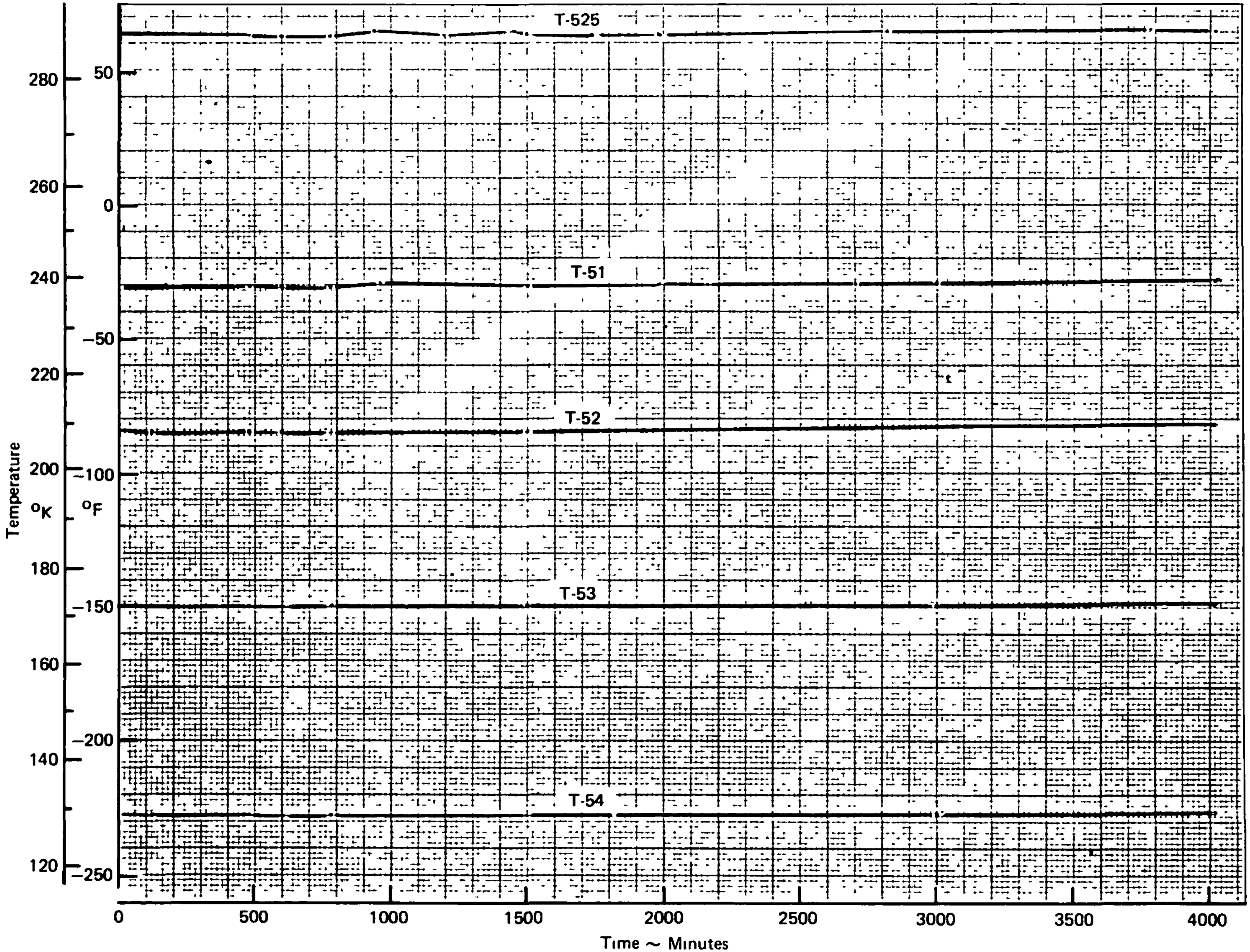


FIGURE E-52: TEST #6 - TEMPERATURES

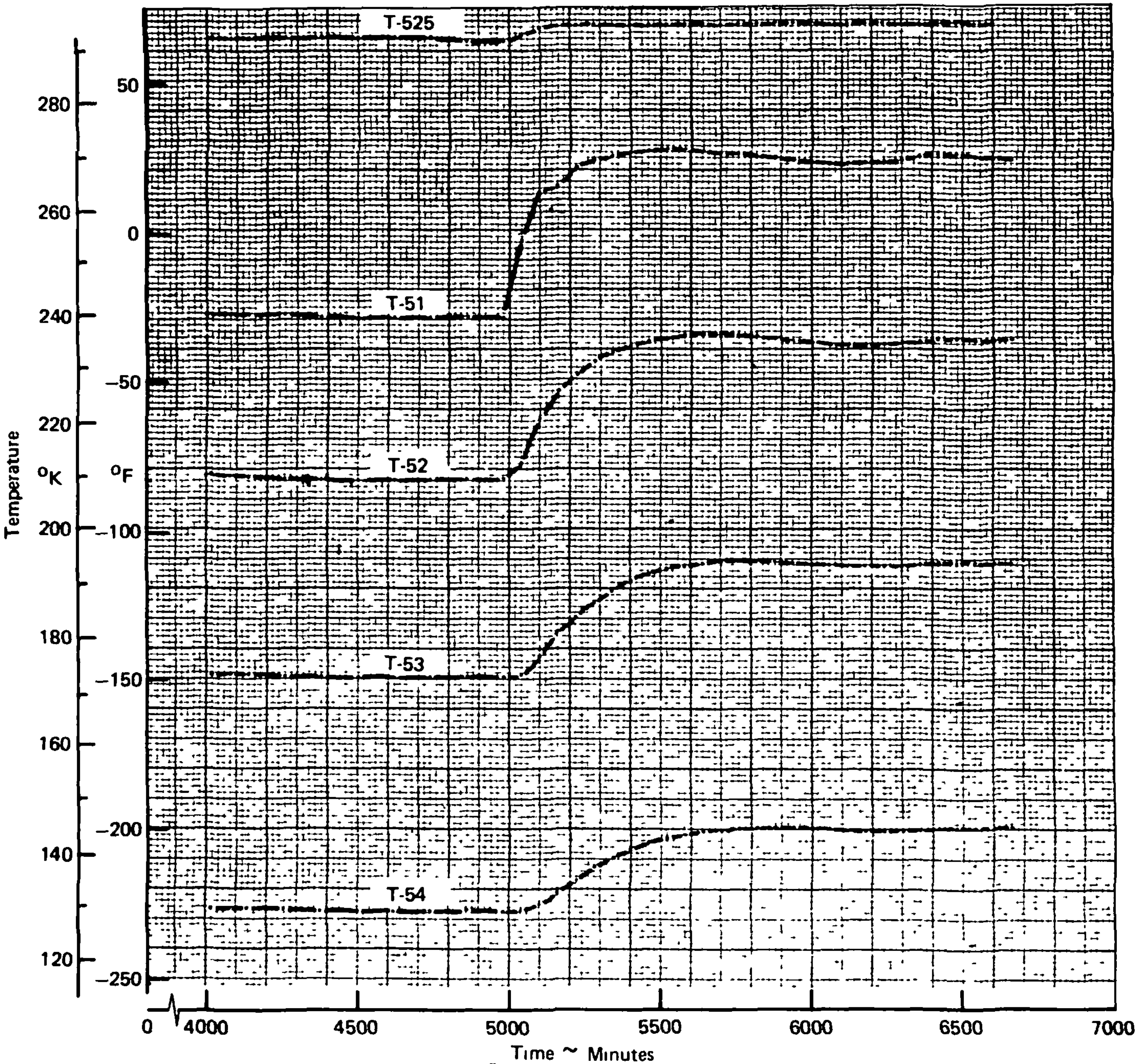


FIGURE E-52: TEST #6 - TEMPERATURES (Continued)

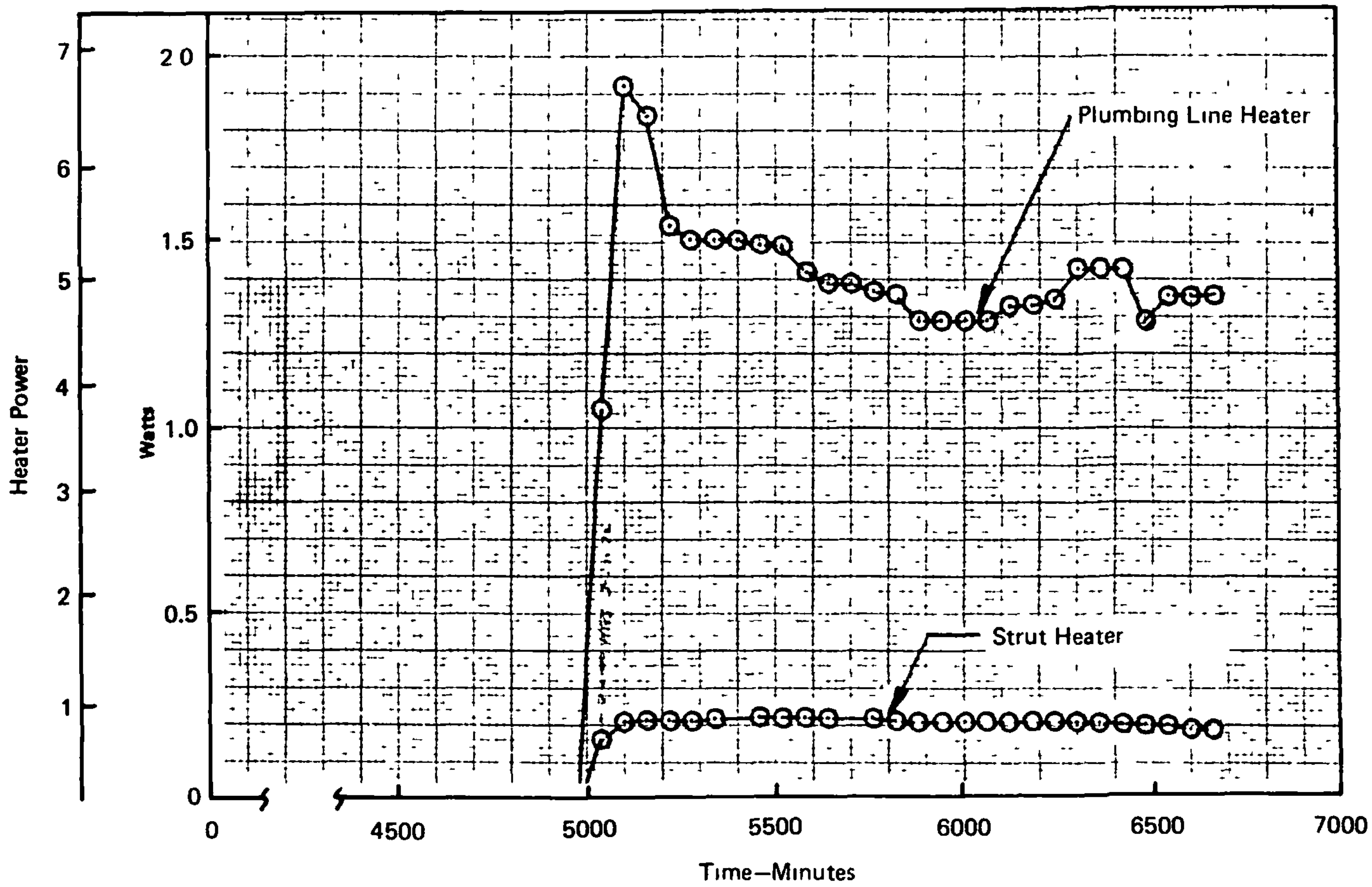


FIGURE E-53: TEST #6 - HEATER POWER

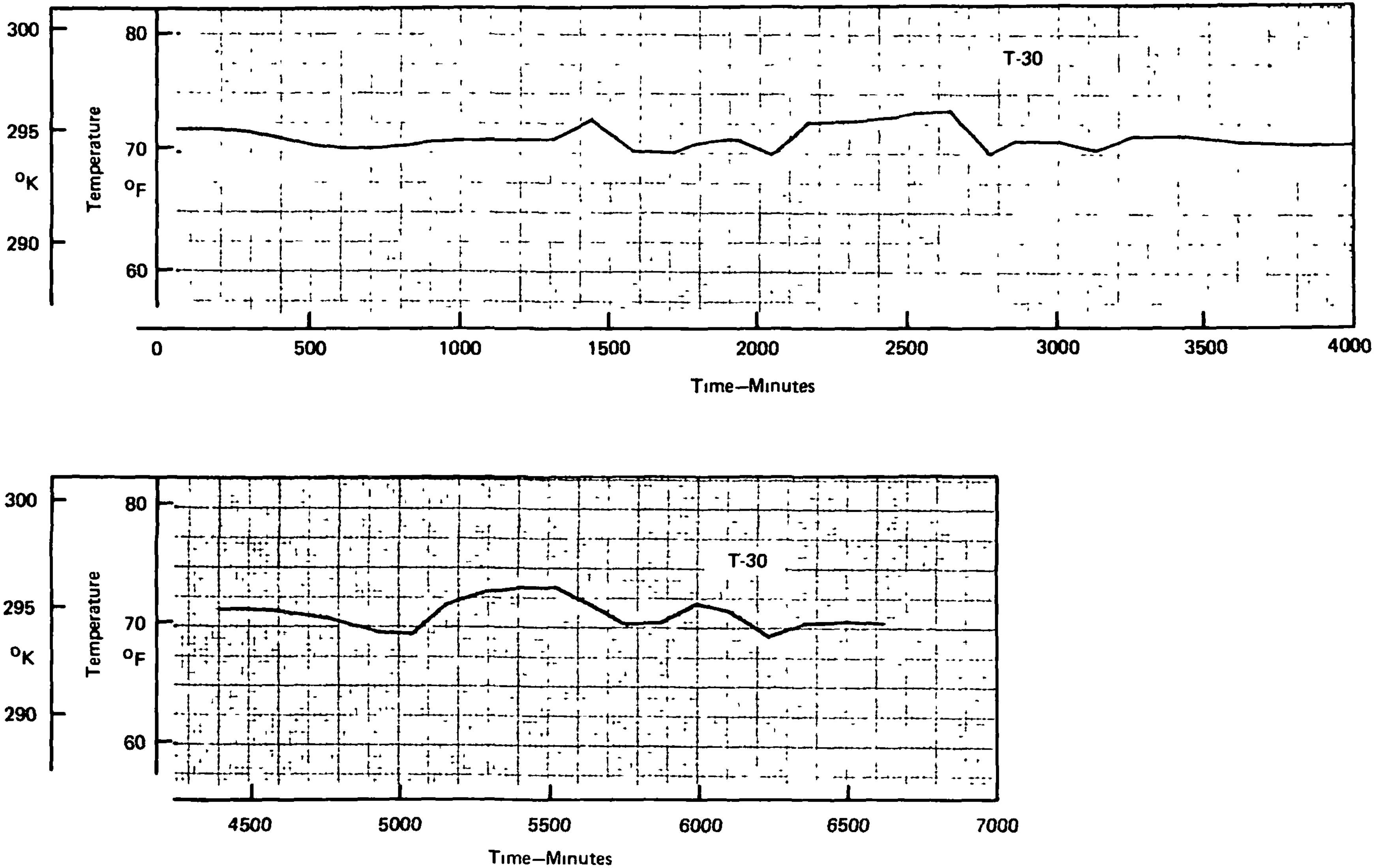


FIGURE E-54: TEST #6 - TEMPERATURE

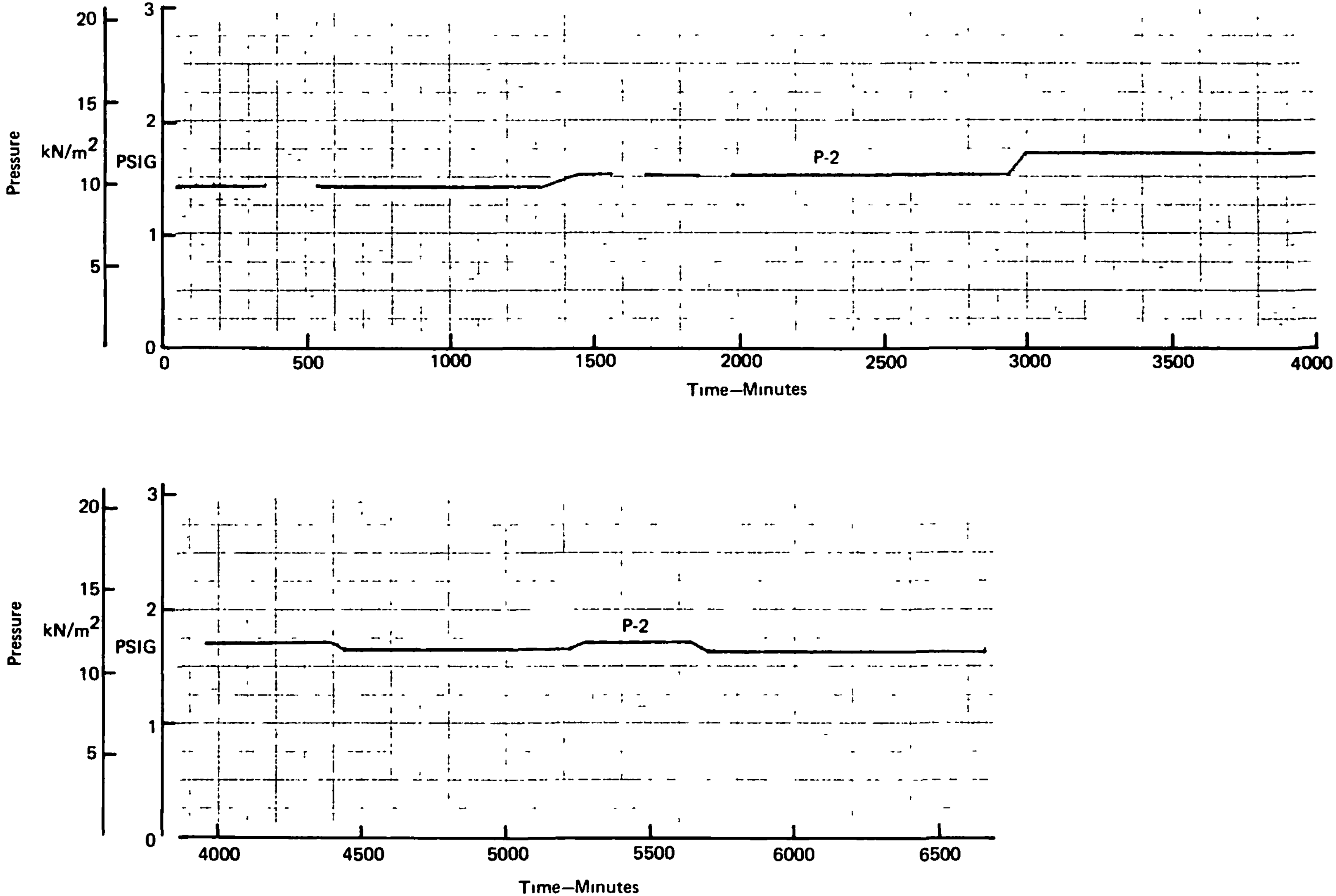


FIGURE E-55: TEST #6 - GUARD TANK PRESSURE

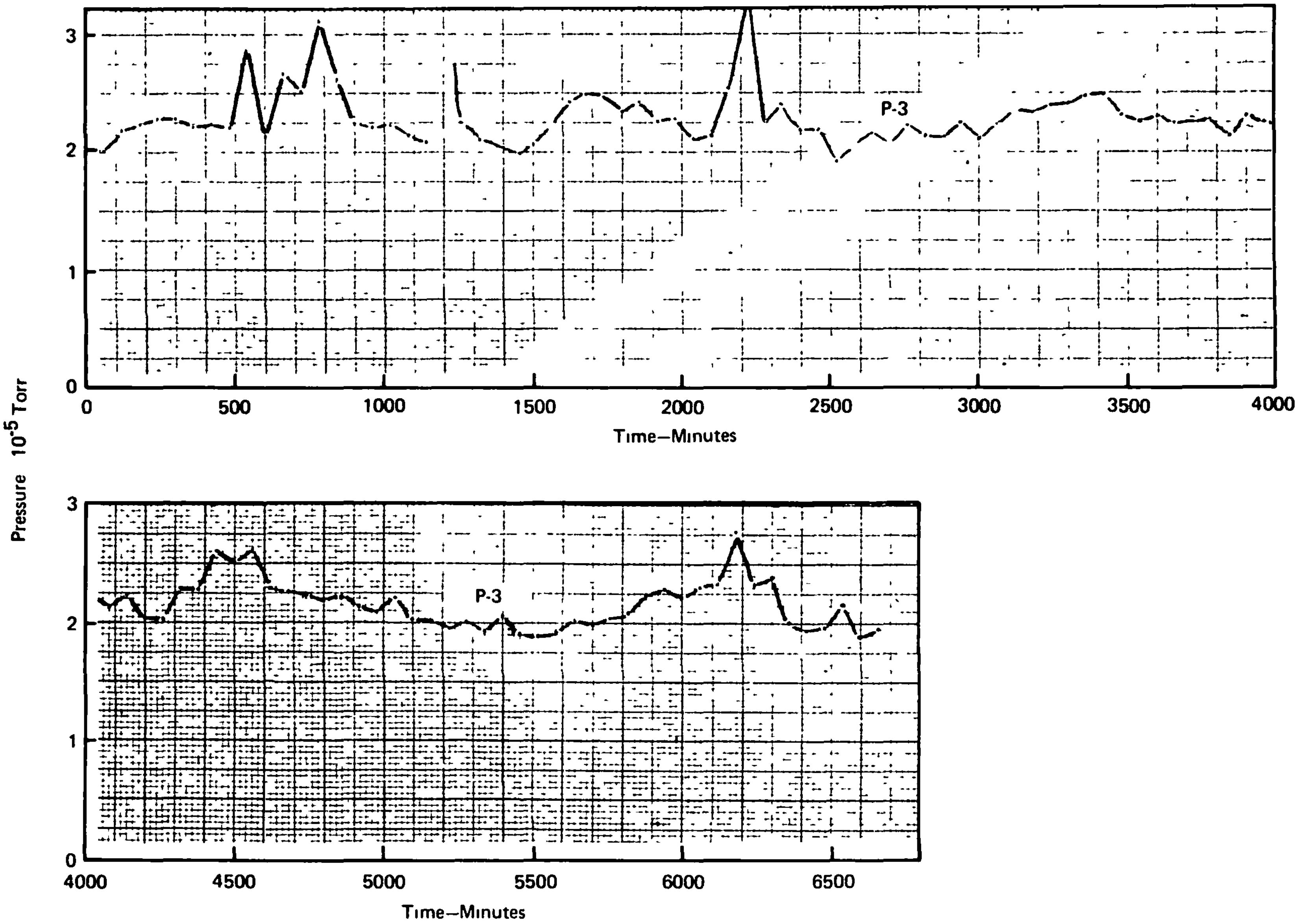


FIGURE E-56: TEST #6 - ALTITUDE CHAMBER PRESSURE

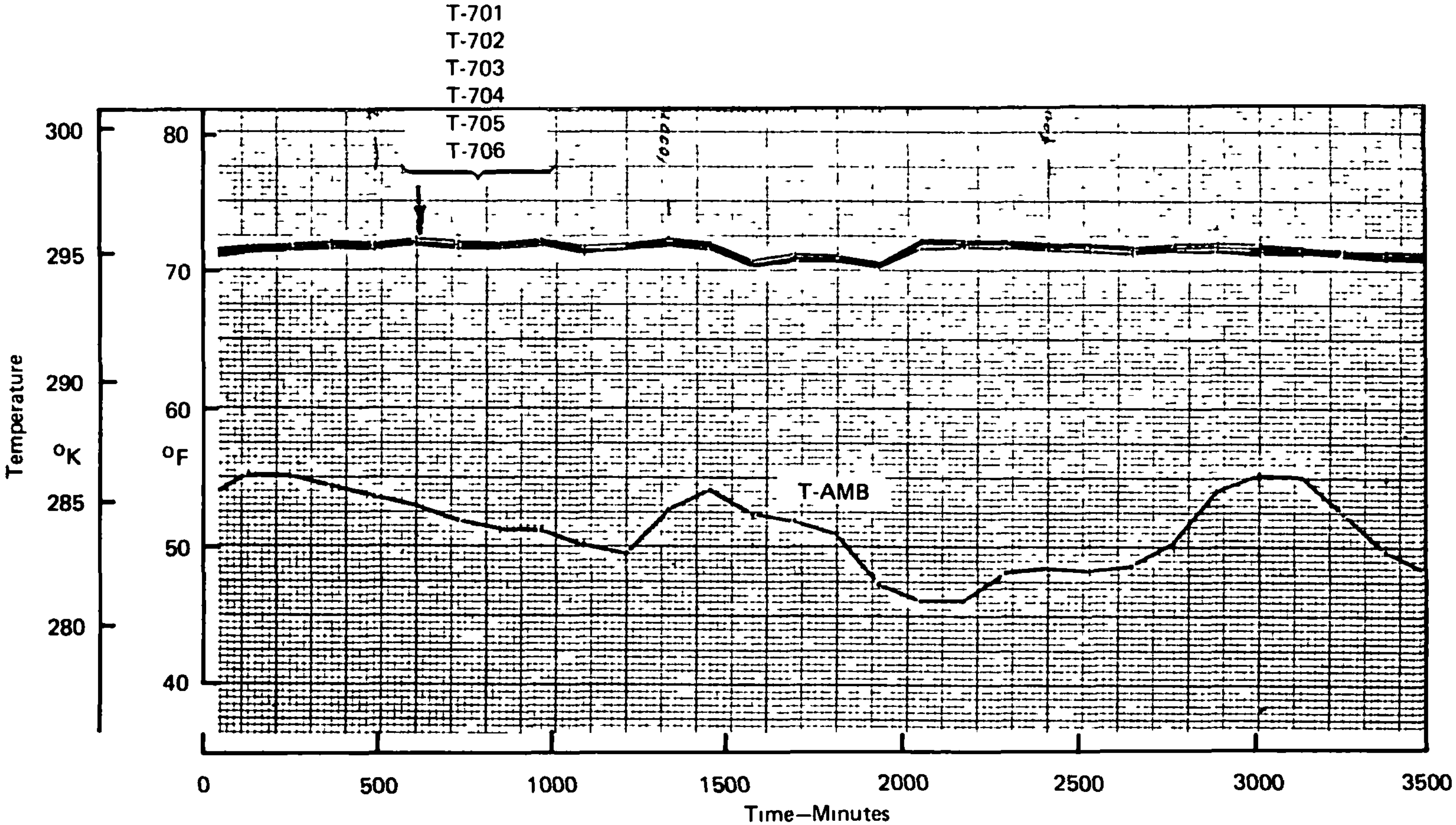


FIGURE E-57: TEST #7 - TEMPERATURES

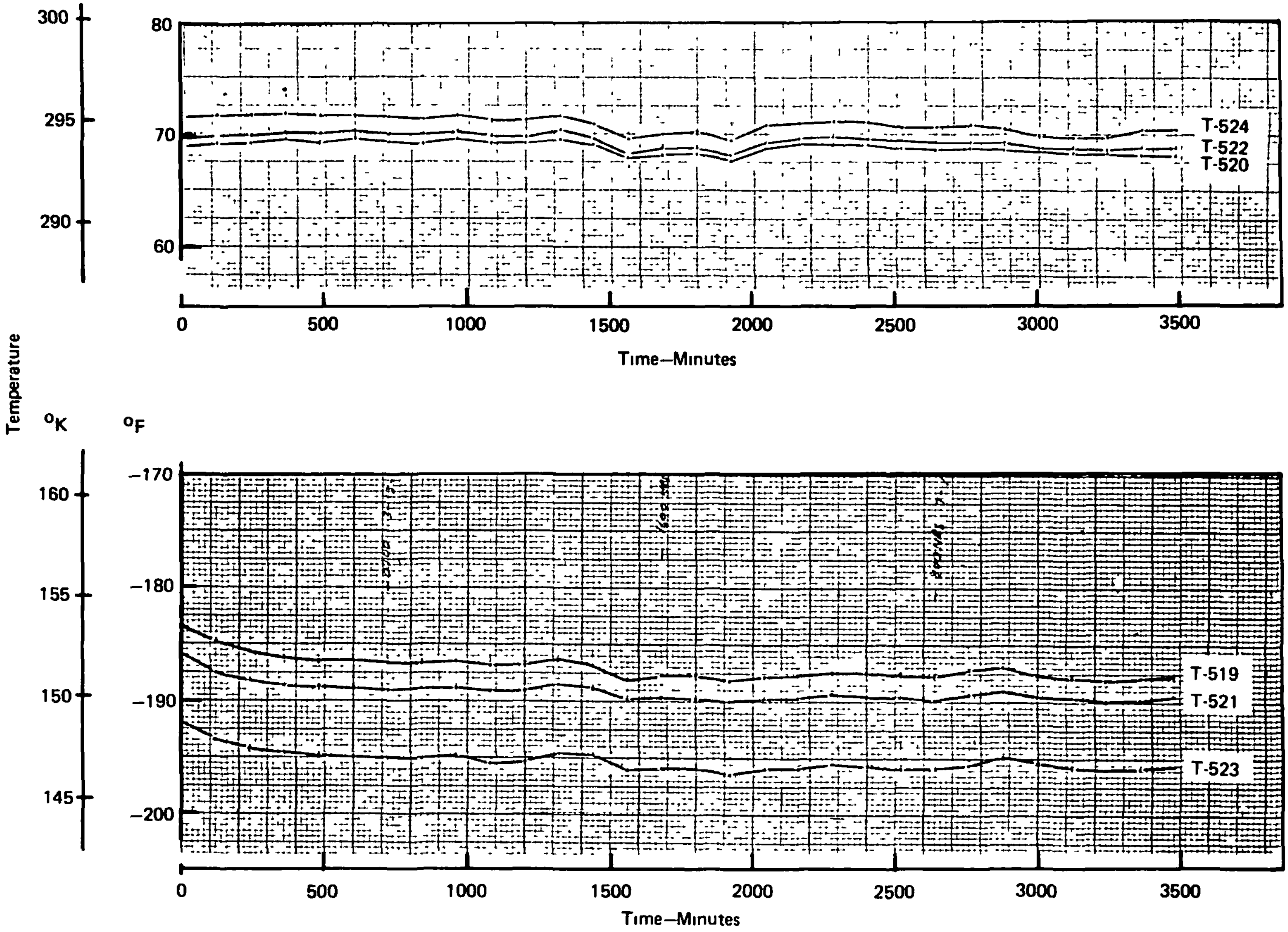


FIGURE E-58: TEST #7 – TEMPERATURES

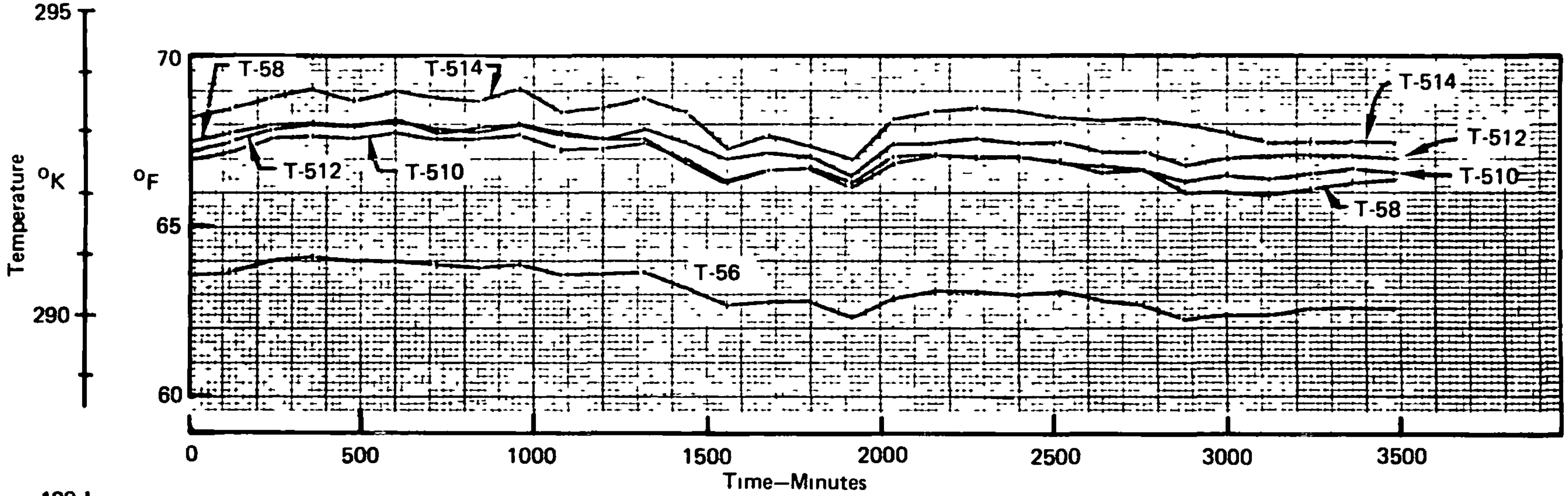


FIGURE E-59: TEST #7 - TEMPERATURES

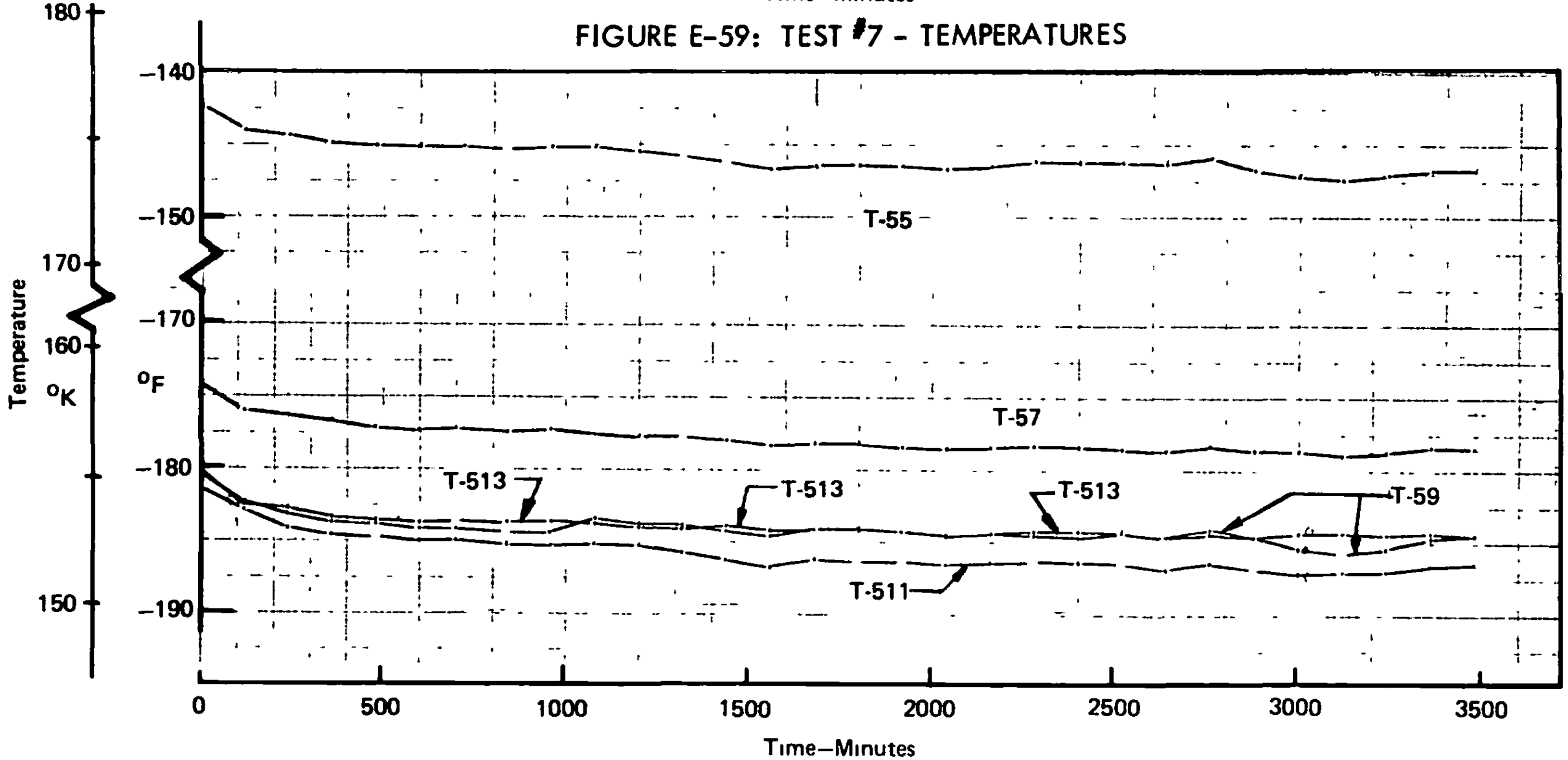


FIGURE E-60: TEST #7 - TEMPERATURES

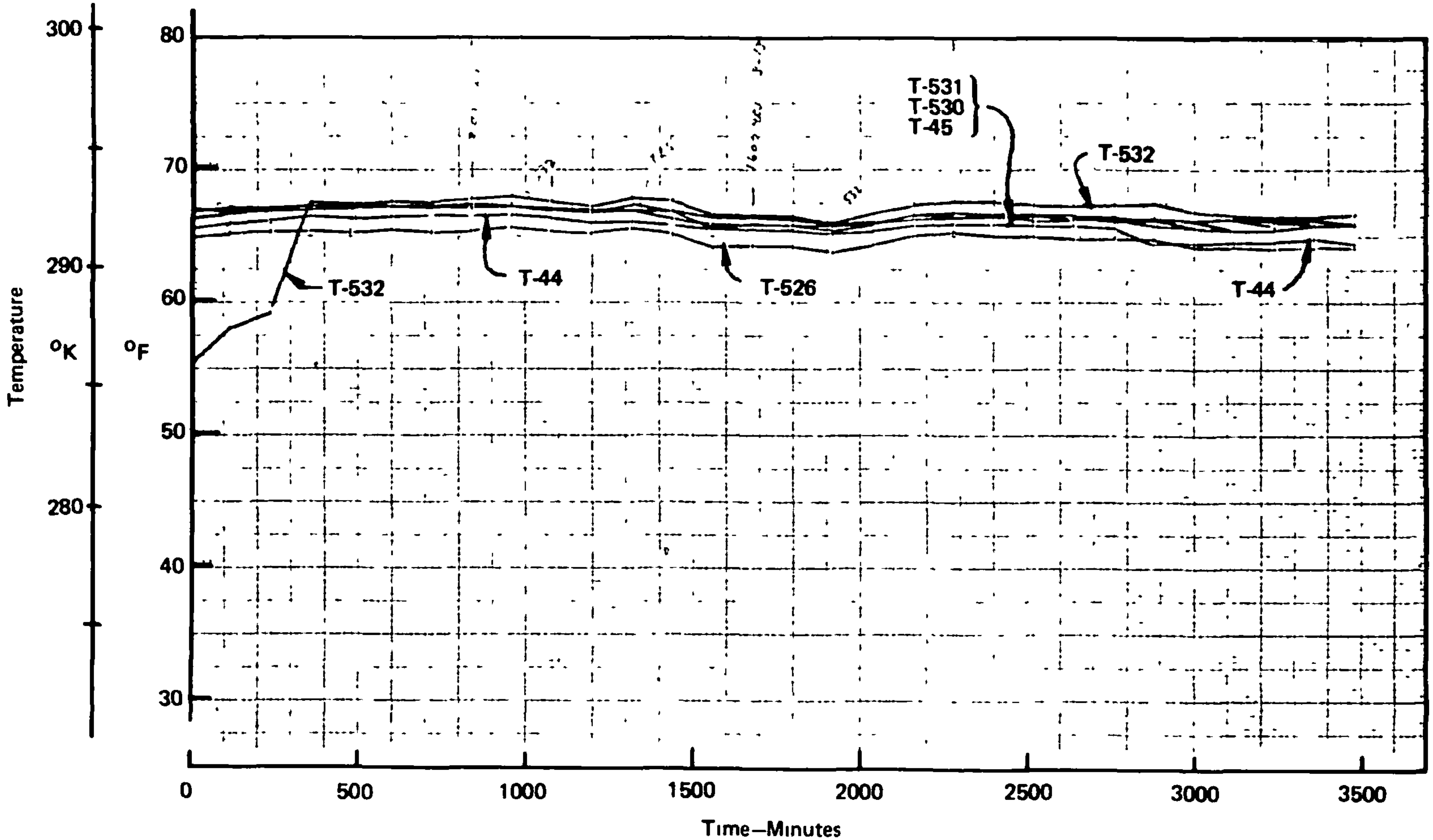


FIGURE E-61: TEST #7 - TEMPERATURES

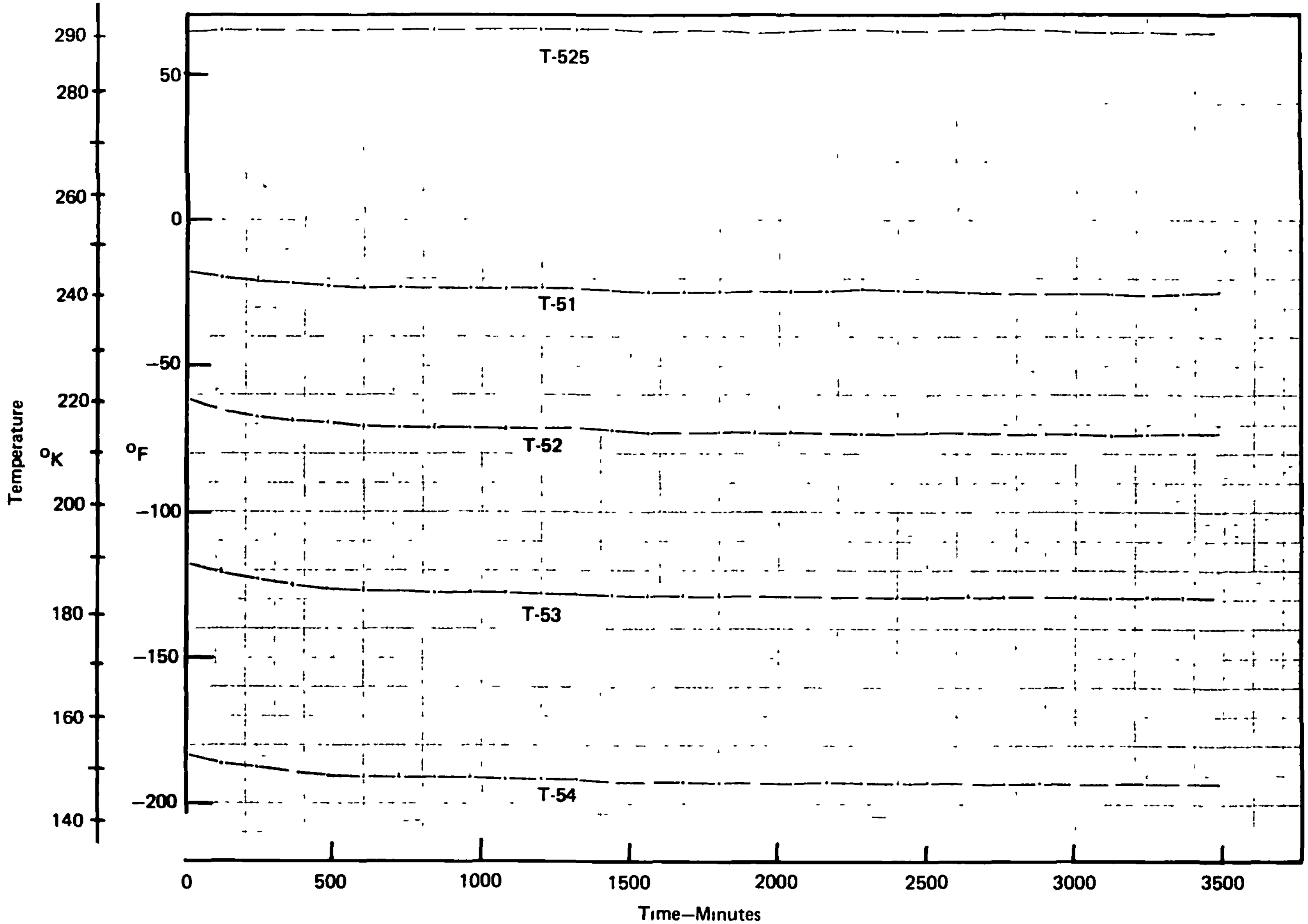


FIGURE E-62: TEST #7 - TEMPERATURES

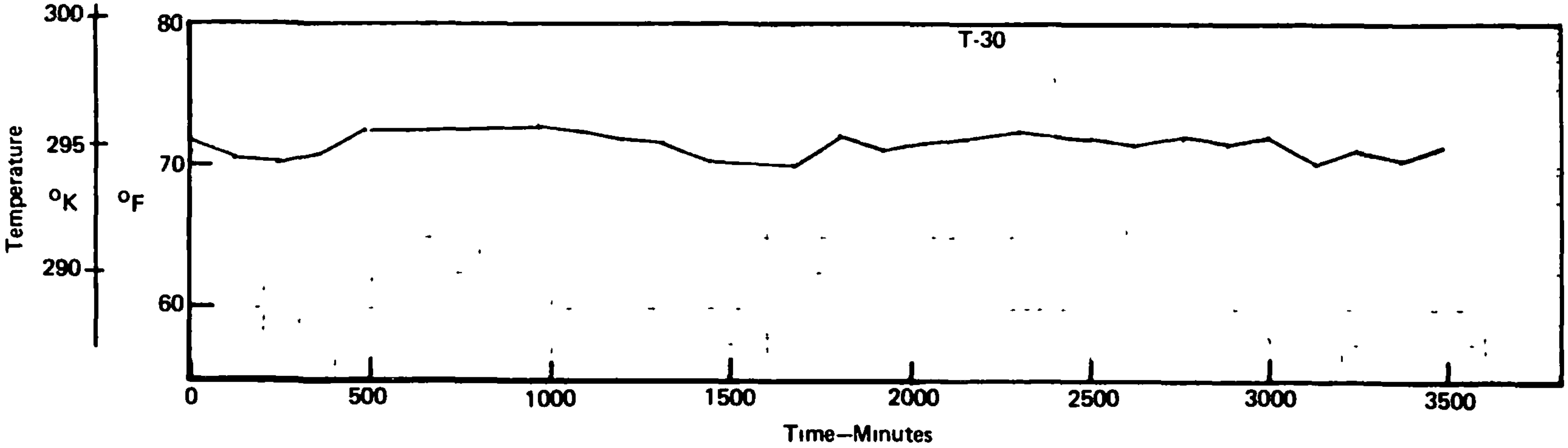


FIGURE E-63: TEST #7 - TEMPERATURE

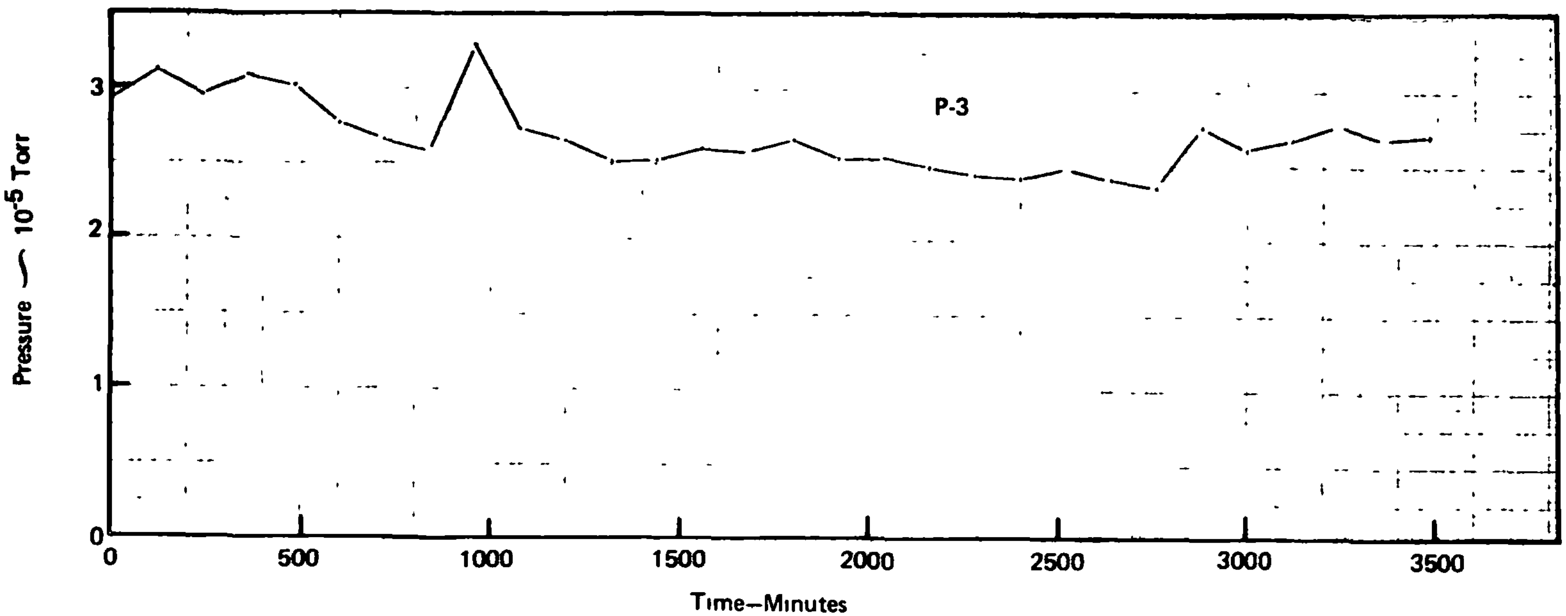


FIGURE 64: TEST #7 - ALTITUDE CHAMBER PRESSURE

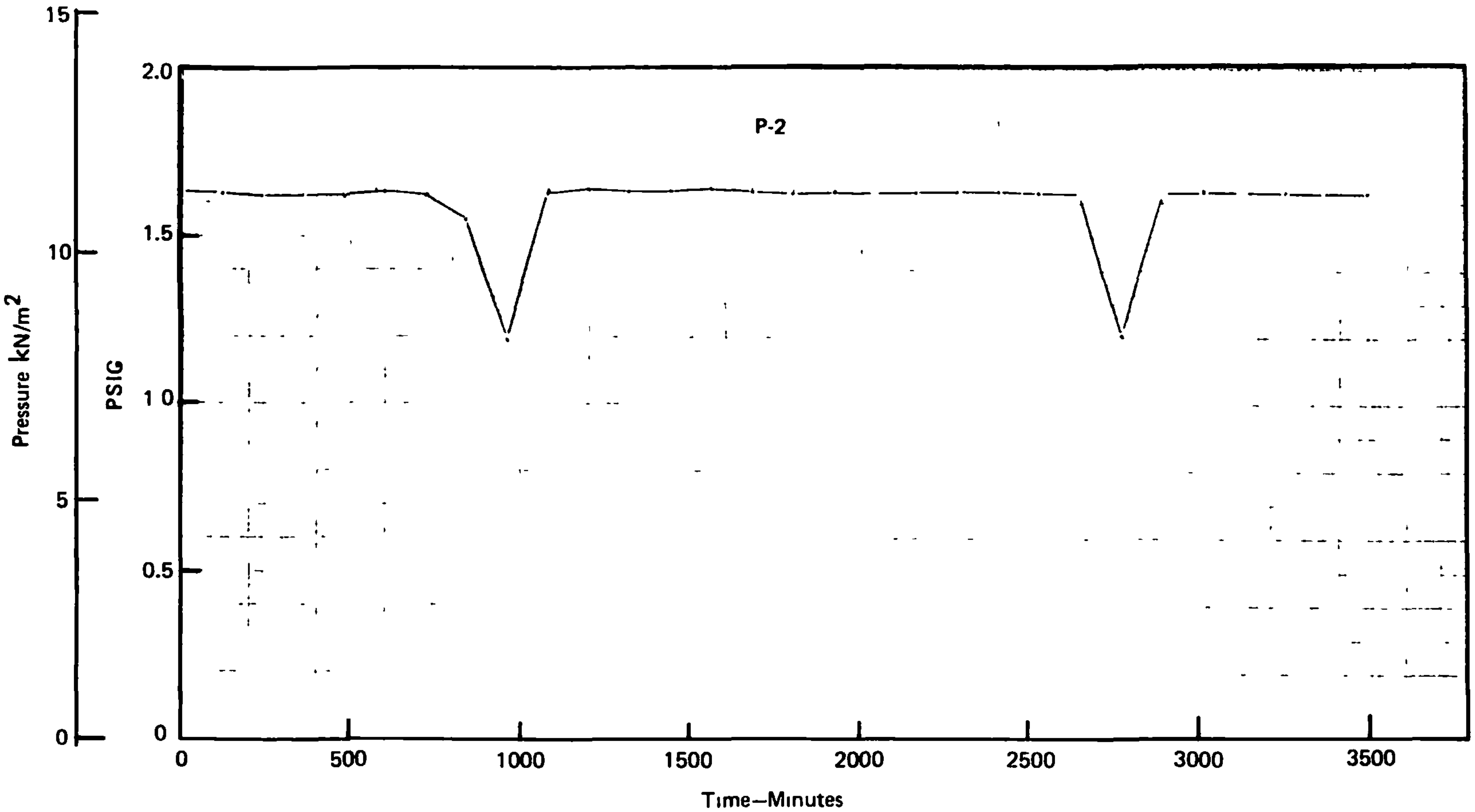


FIGURE E-65: TEST #7 - GUARD TANK PRESSURE

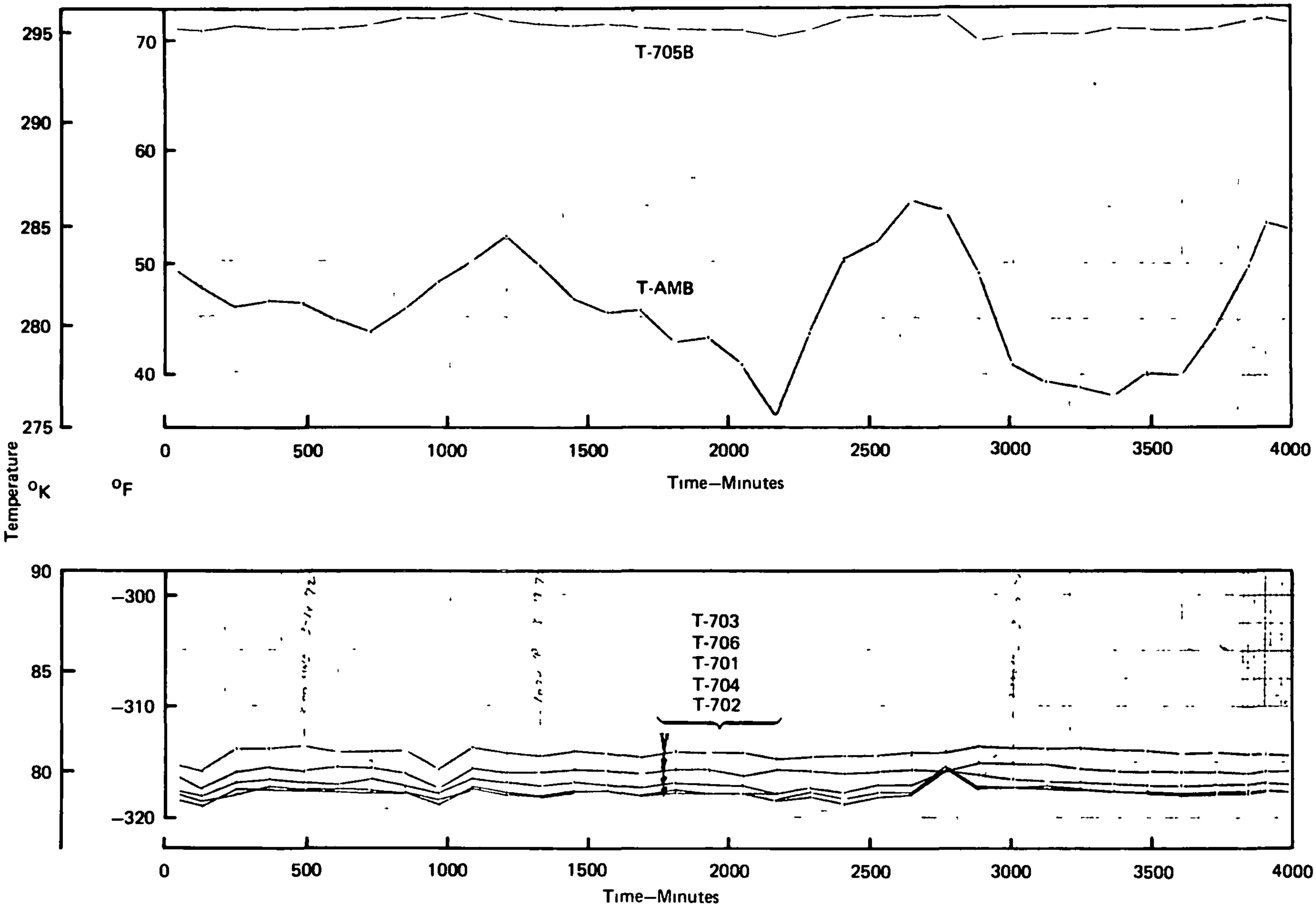


FIGURE E-66: TEST #8 - TEMPERATURES

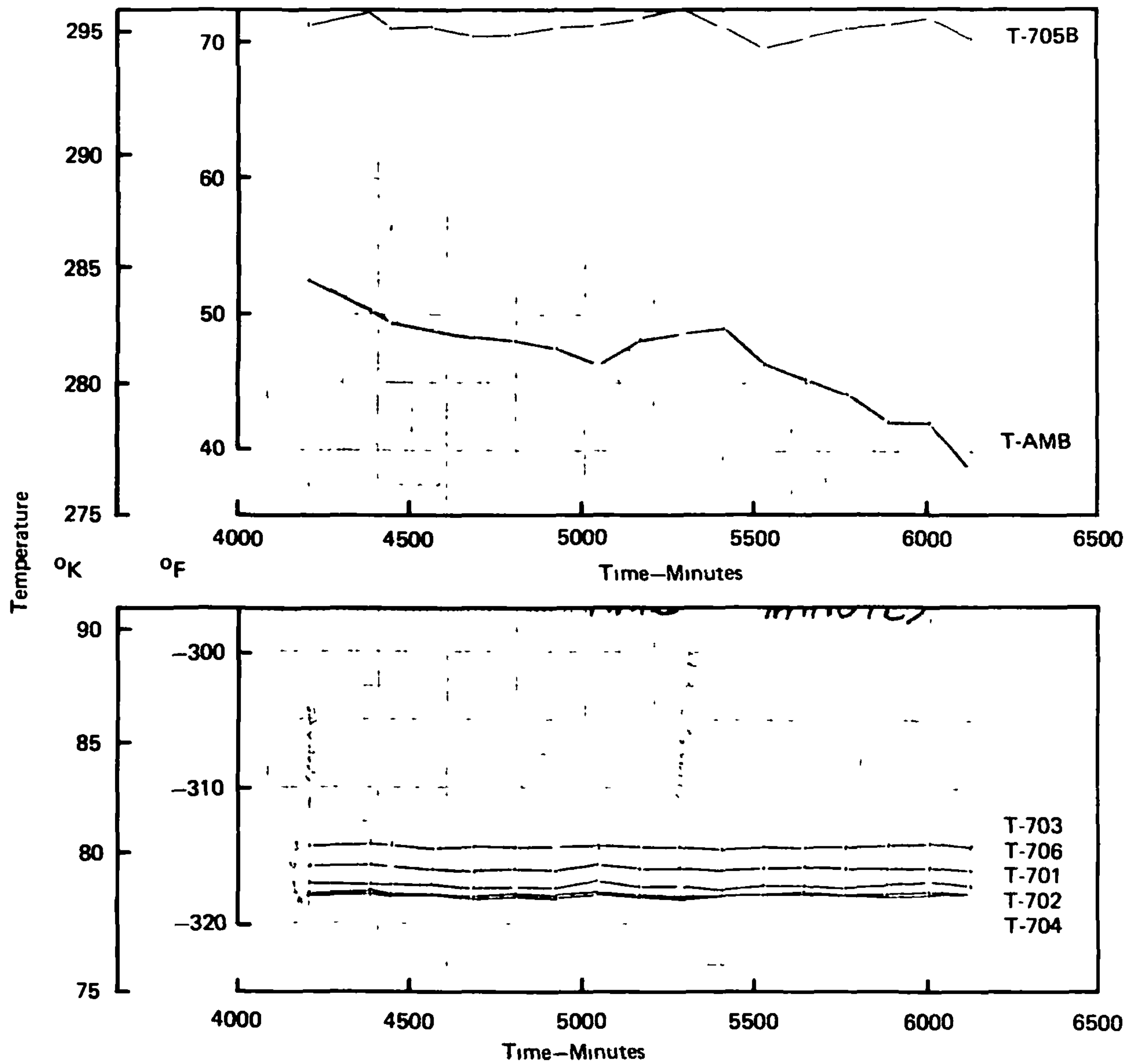


FIGURE E-66: TEST #8 - TEMPERATURES (Continued)

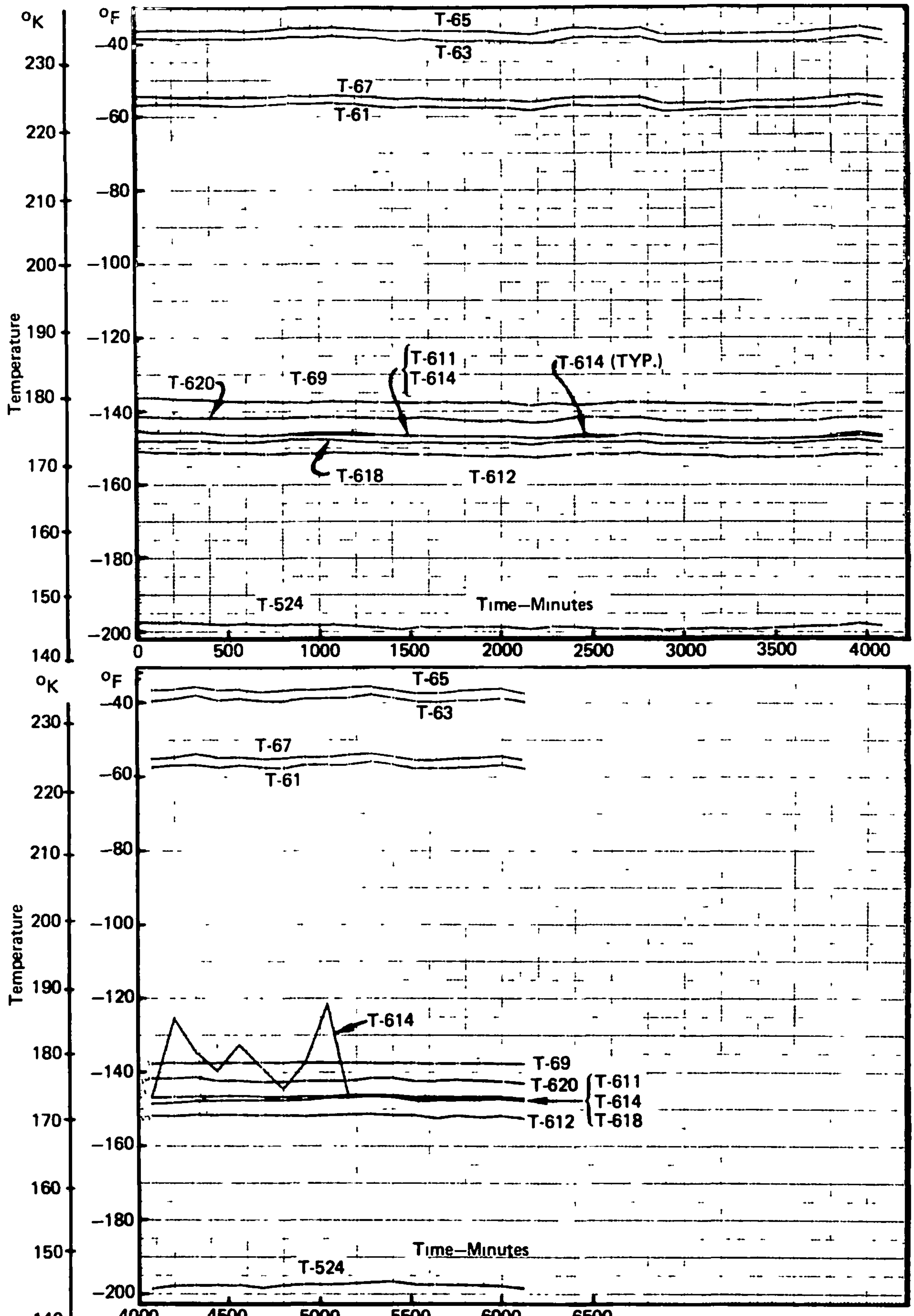


FIGURE E-67: TEST #8 - TEMPERATURES

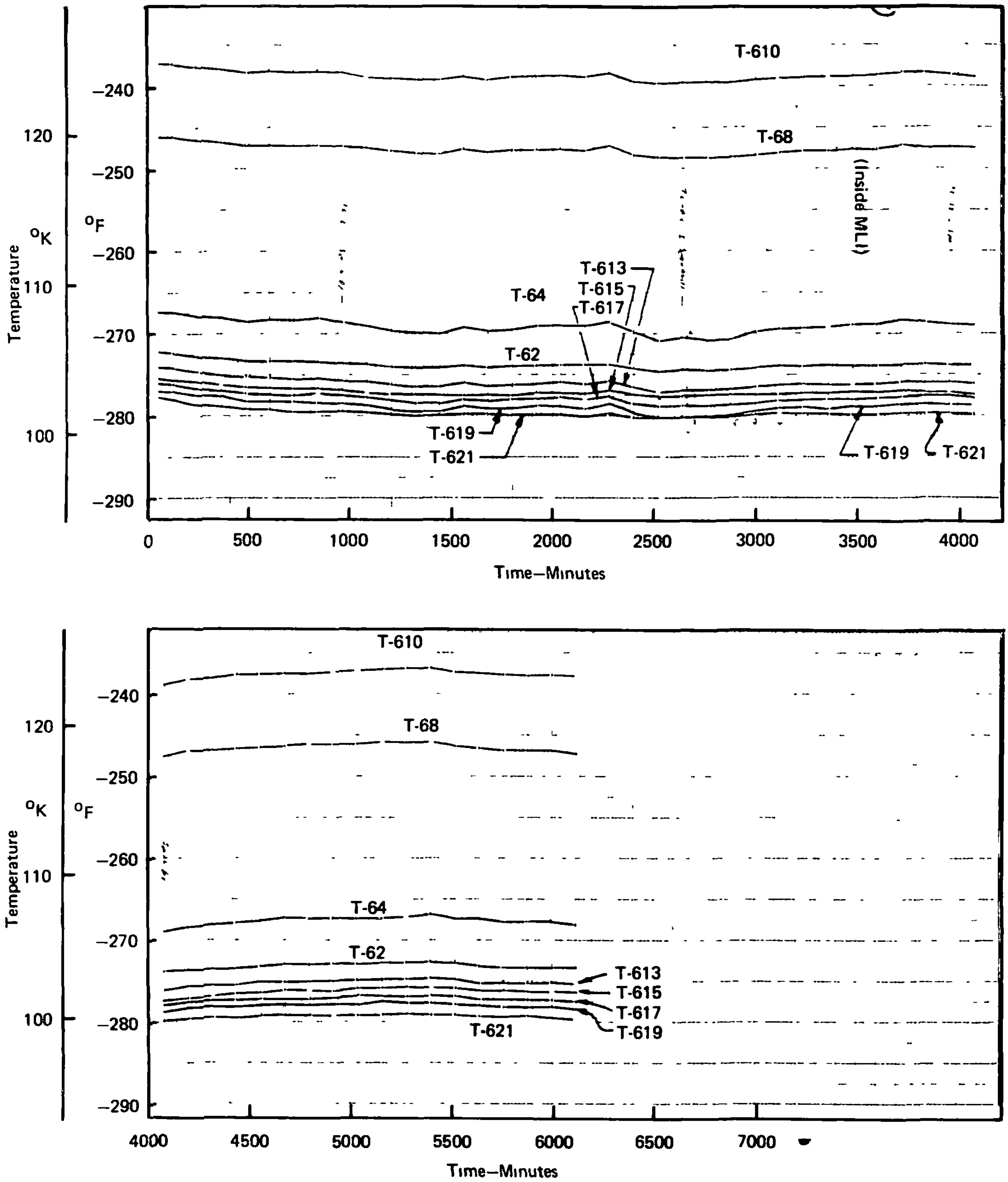


FIGURE E-68: TEST #8 - TEMPERATURES

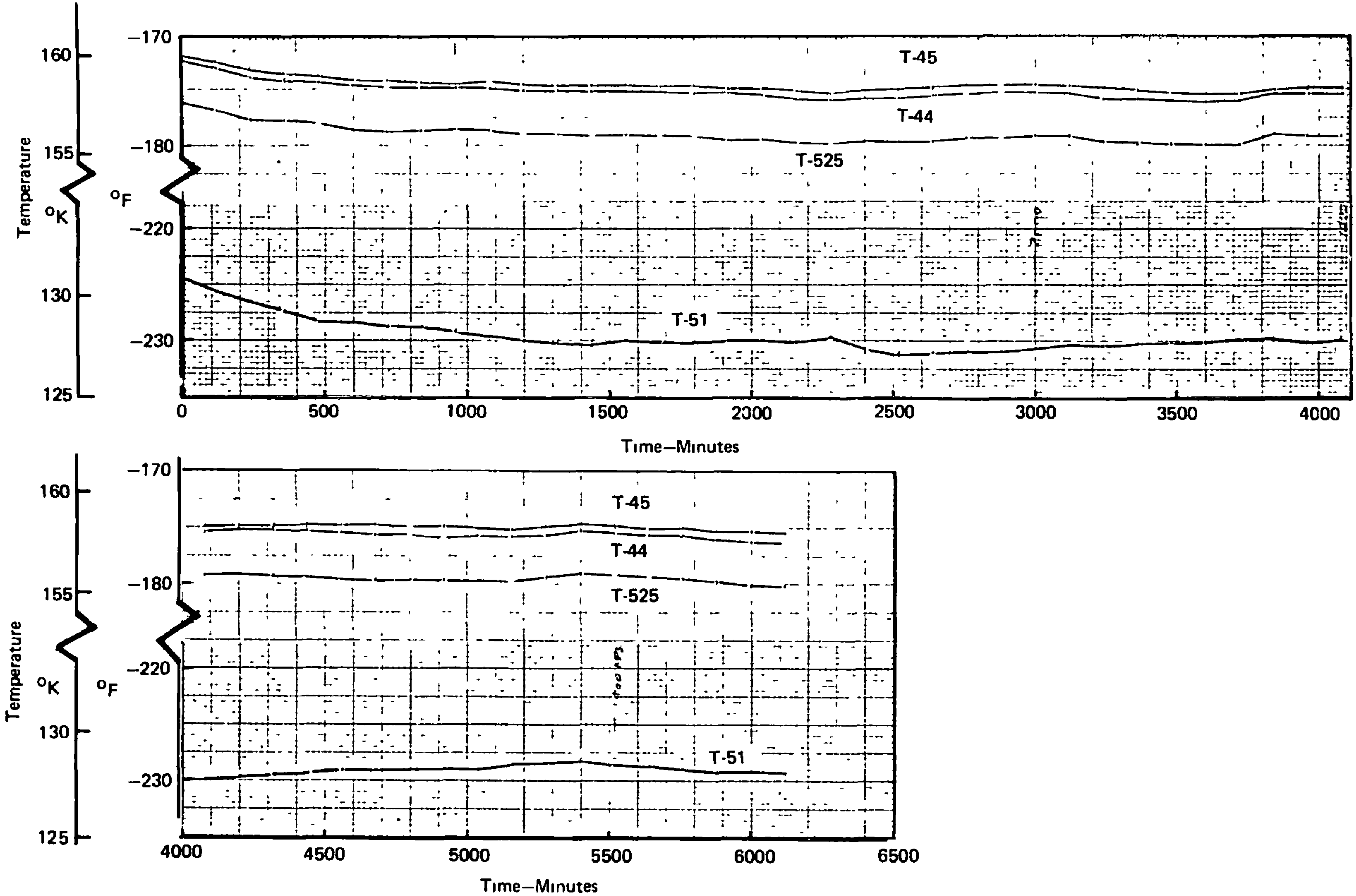


FIGURE E-69: TEST #8 - TEMPERATURES

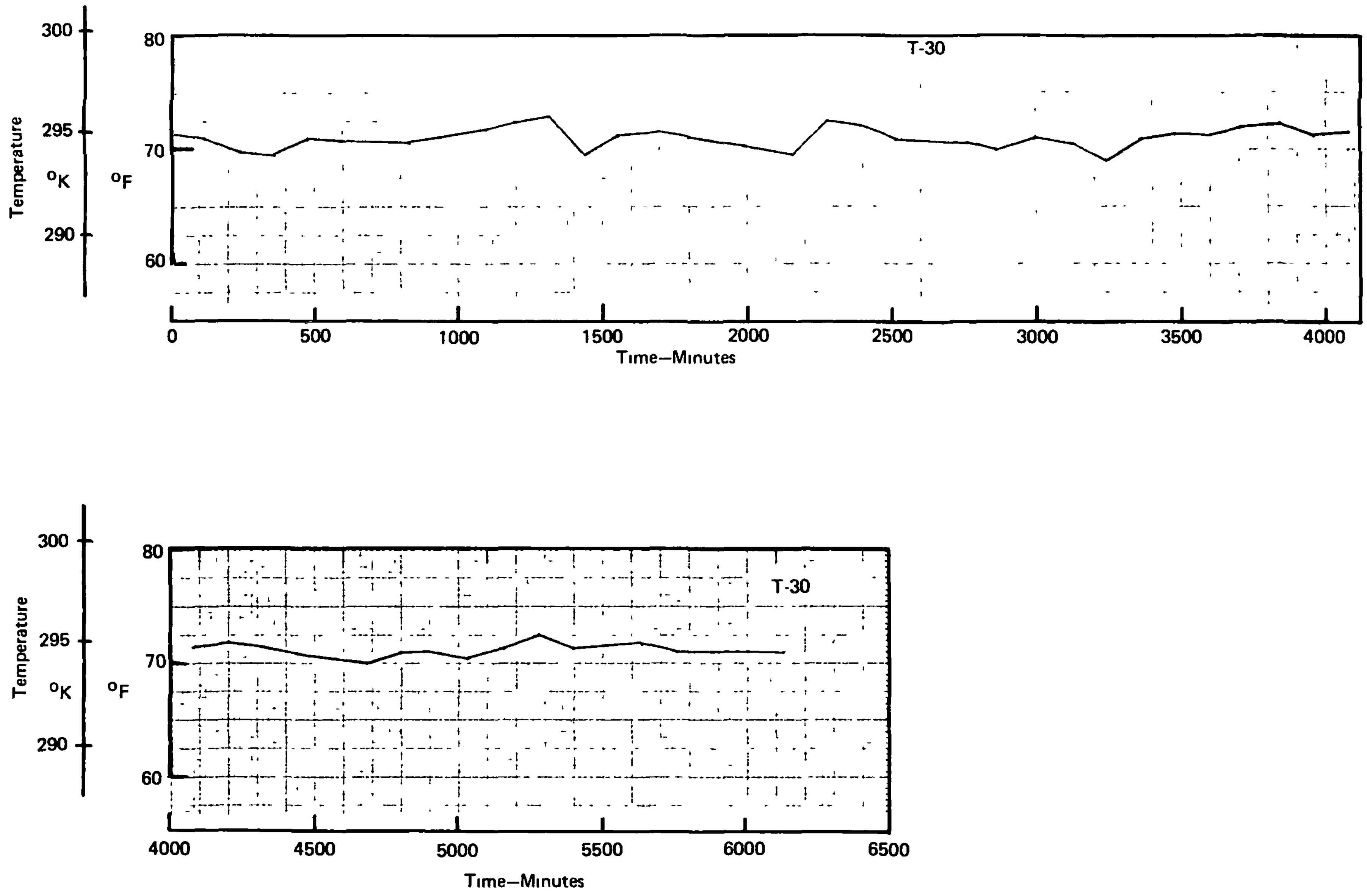


FIGURE E-70: TEST #8 - TEMPERATURES

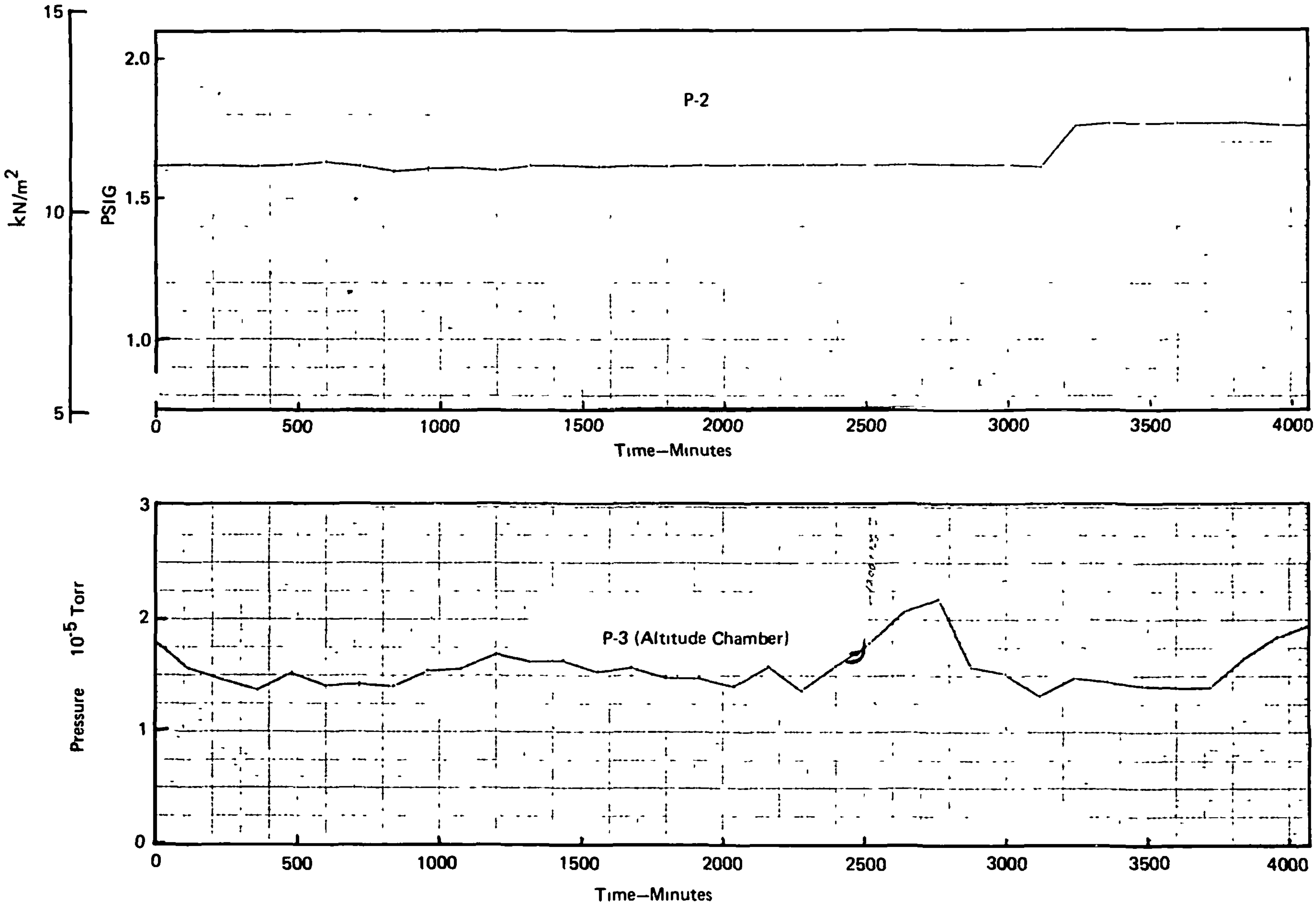
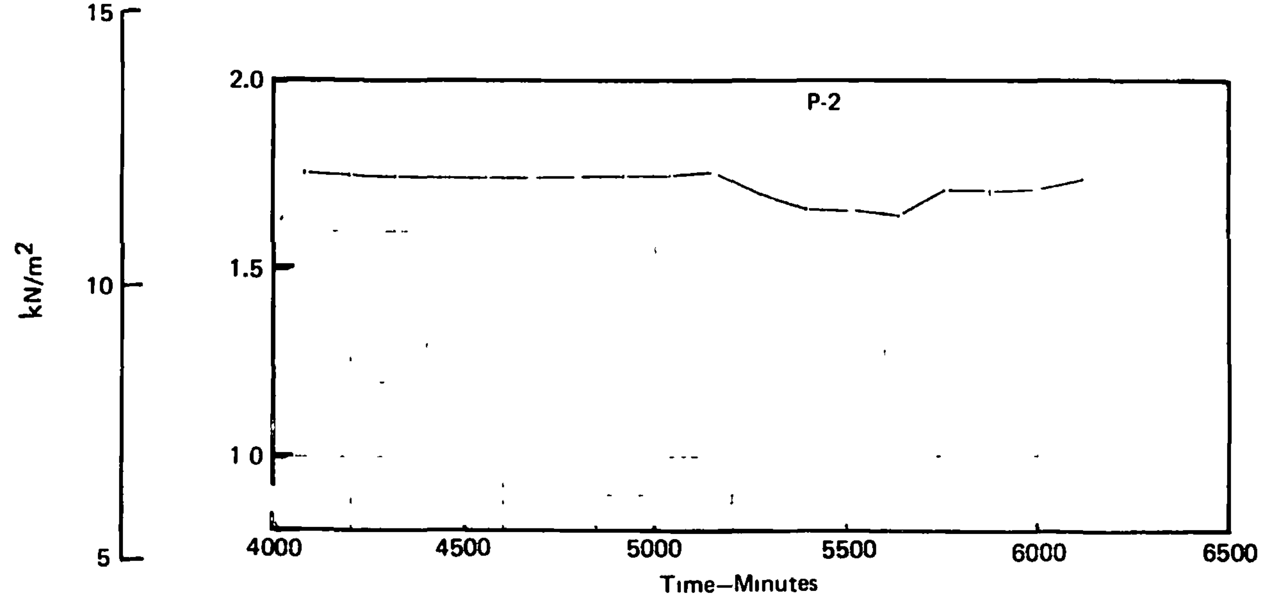


FIGURE E-71: TEST #8 - GUARD TANK AND ALTITUDE CHAMBER PRESSURE



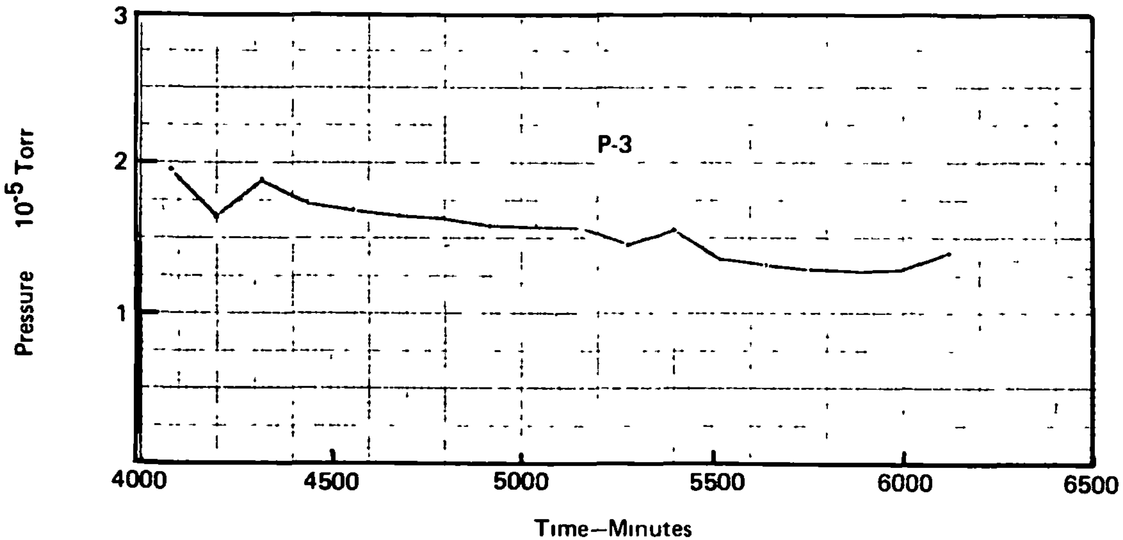


FIGURE E-71: TEST #8 - GUARD TANK AND ALTITUDE CHAMBER PRESSURE (Continued)

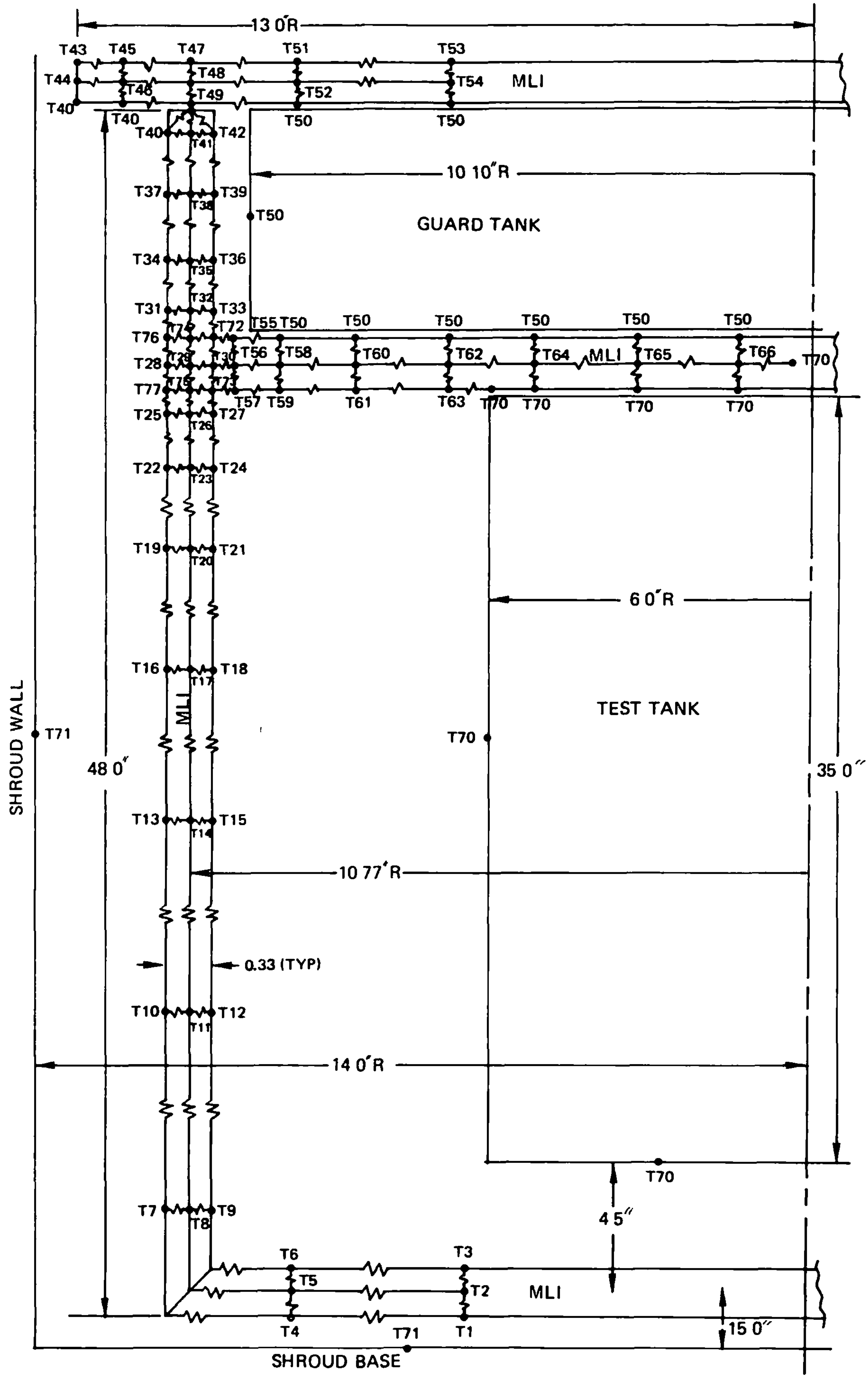


FIGURE E-72· NODAL NETWORK - BASIC MLI ASSEMBLY, MITER BASE JOINT

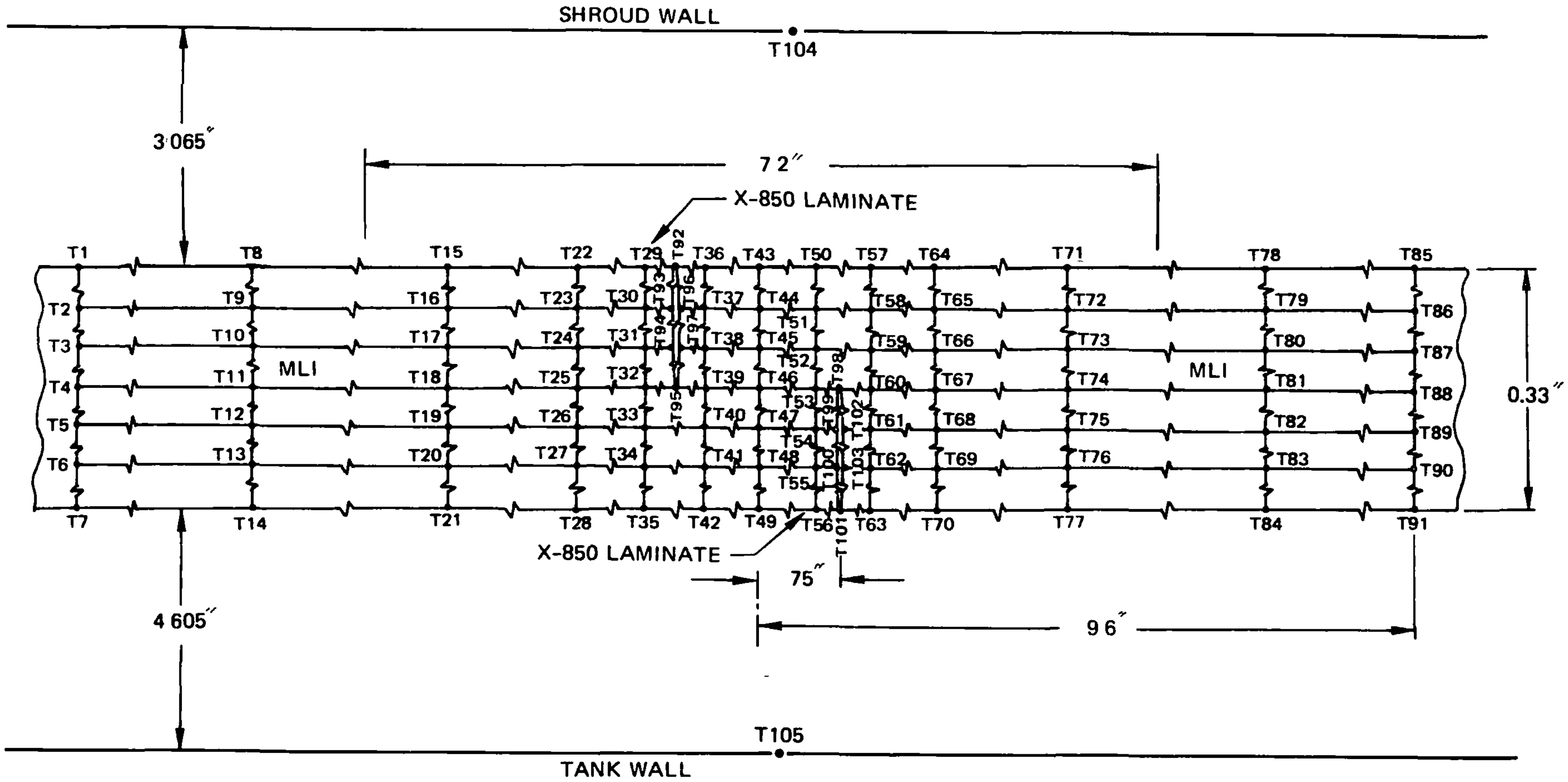


FIGURE E-73. NODAL NETWORK - MLI LONGITUDINAL JOINT

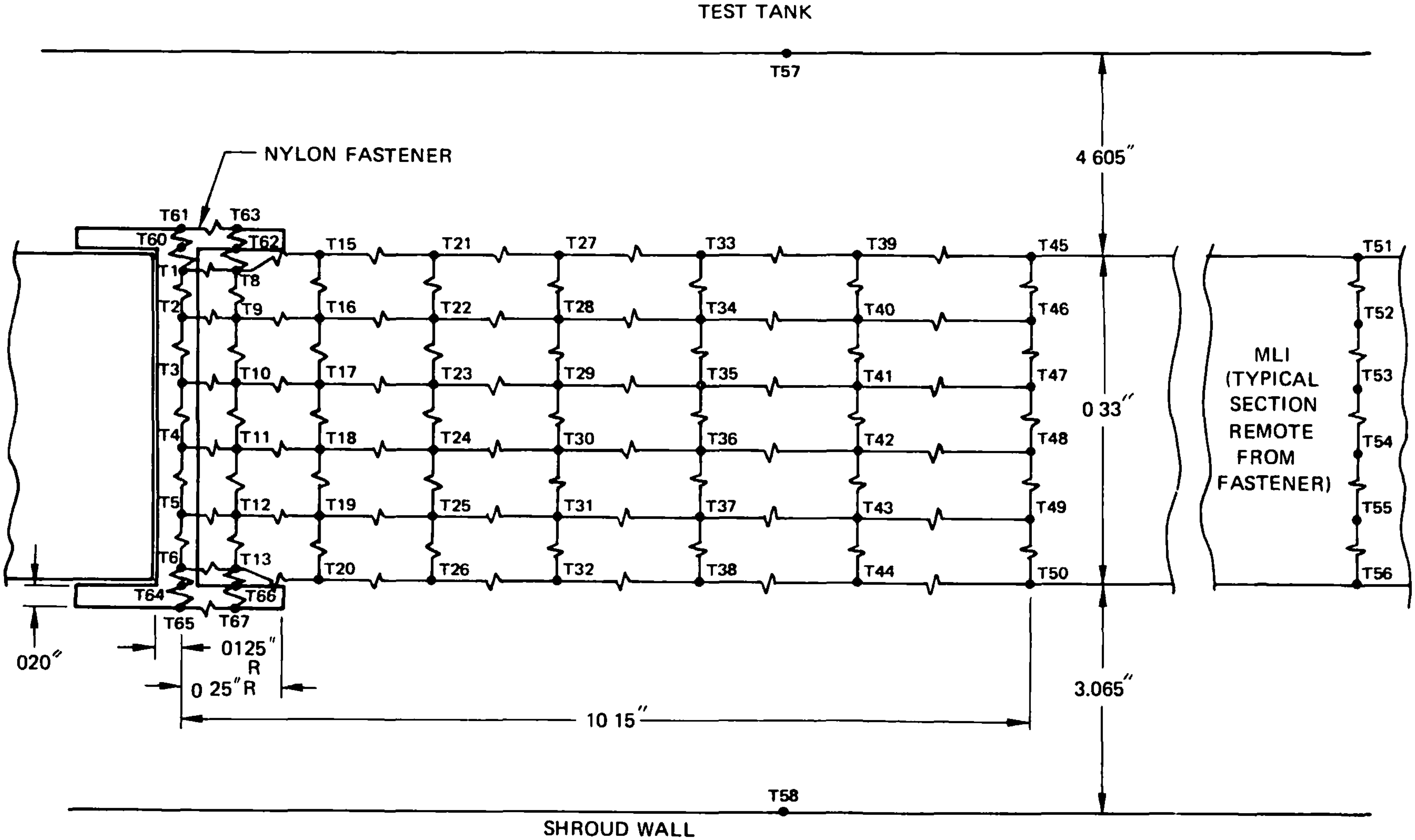


FIGURE E-74· NODAL NETWORK - TYPICAL NYLON FASTENER AND SURROUNDING MLI

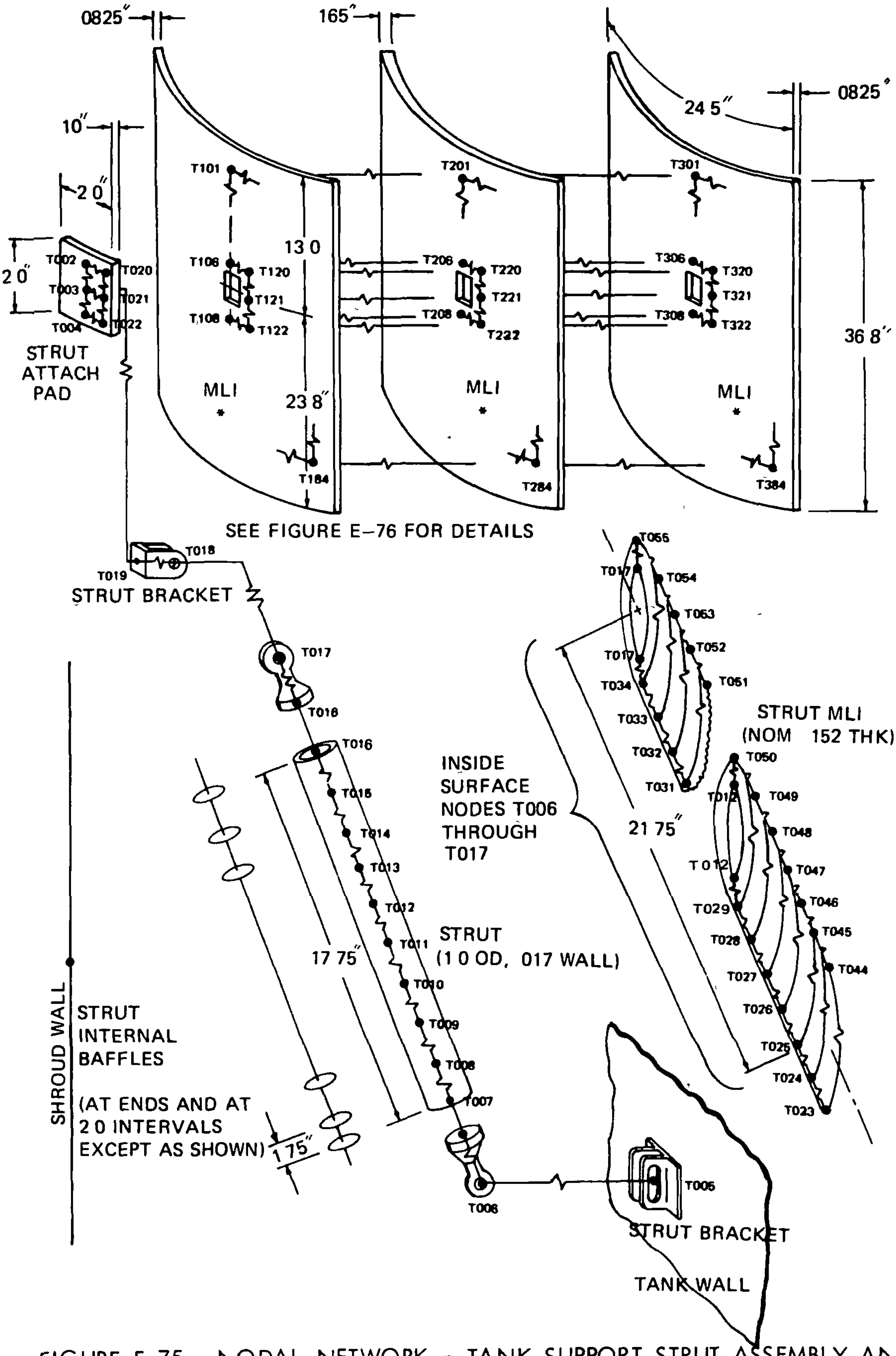


FIGURE E-75 NODAL NETWORK - TANK SUPPORT STRUT ASSEMBLY AND SURROUNDING MLI

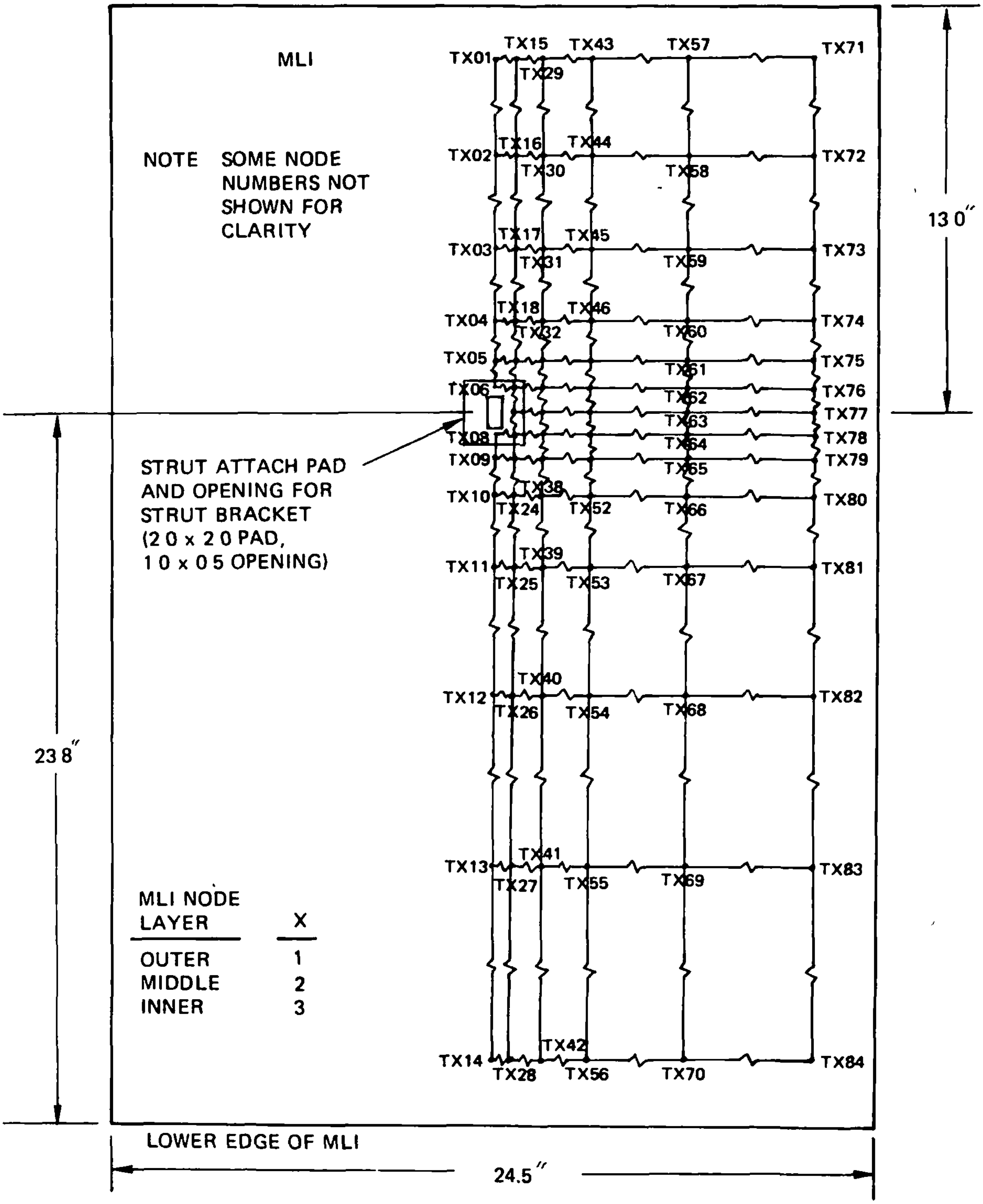


FIGURE E-76: NODAL NETWORK - MLI IN VICINITY OF TANK SUPPORT STRUT PENETRATION

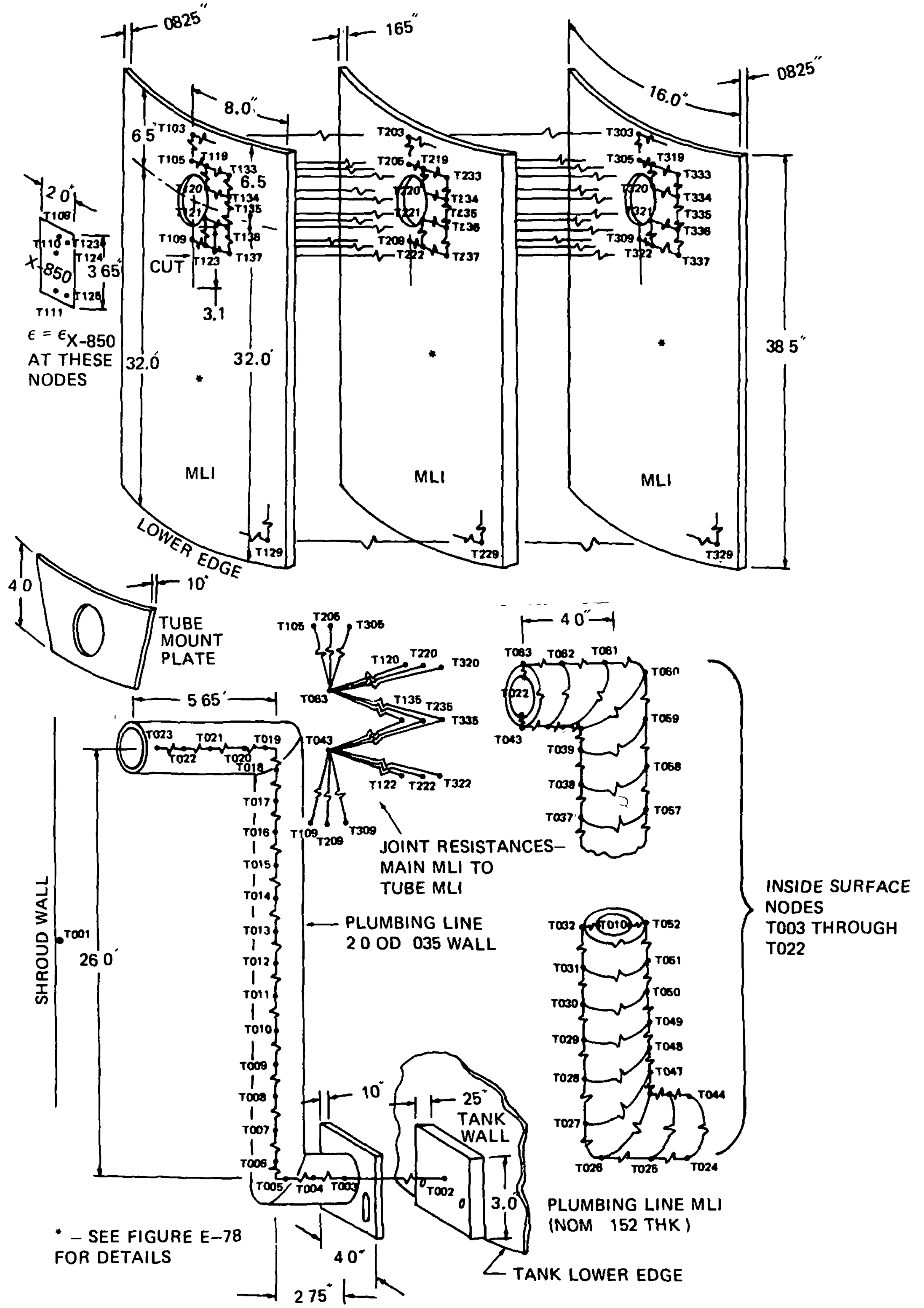


FIGURE E-77. NODAL NETWORK - PLUMBING LINE ASSEMBLY AND SURROUNDING MLI

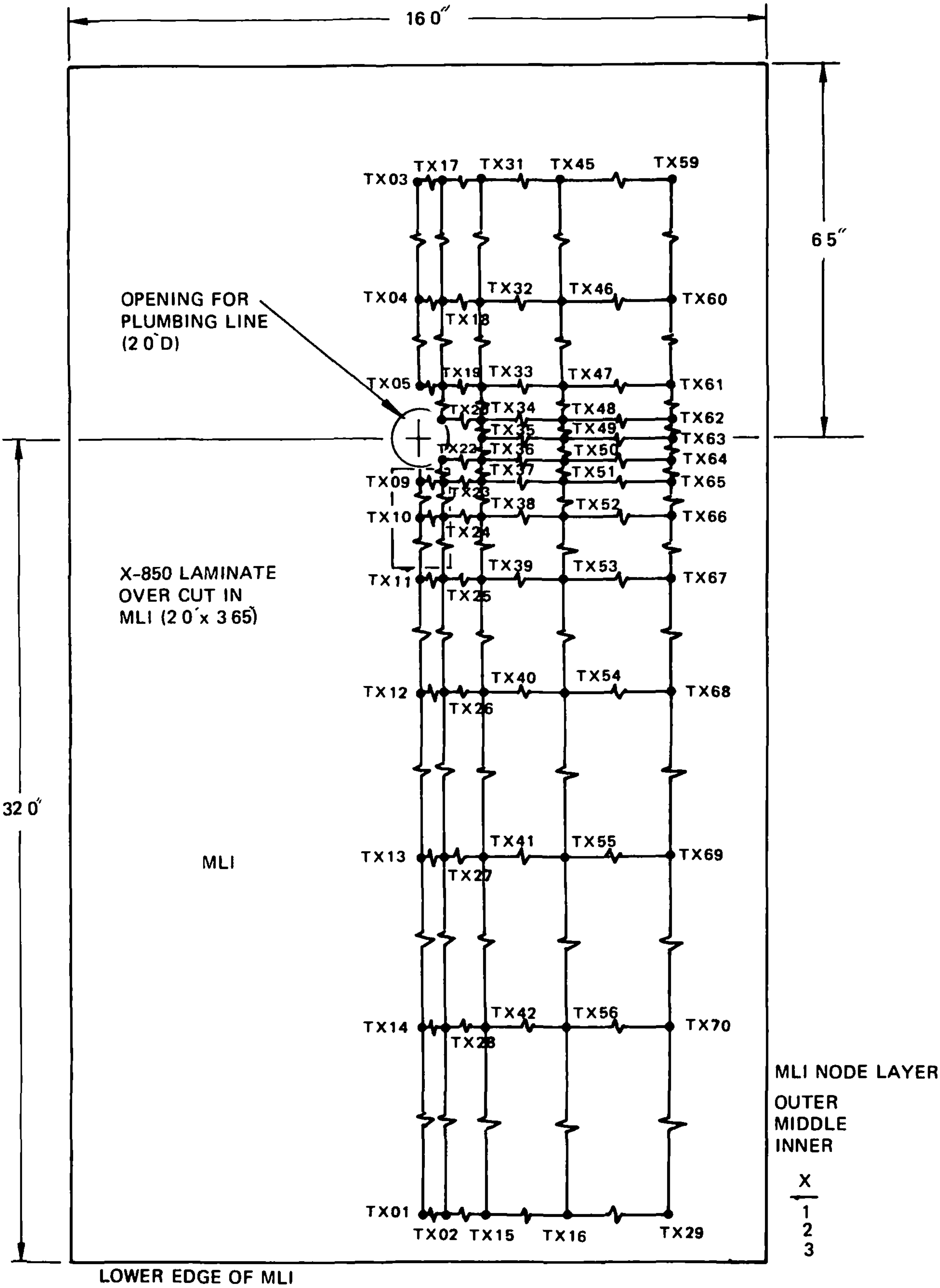


FIGURE E-78· NODAL NETWORK - MLI IN VICINITY OF PLUMBING LINE PENETRATION

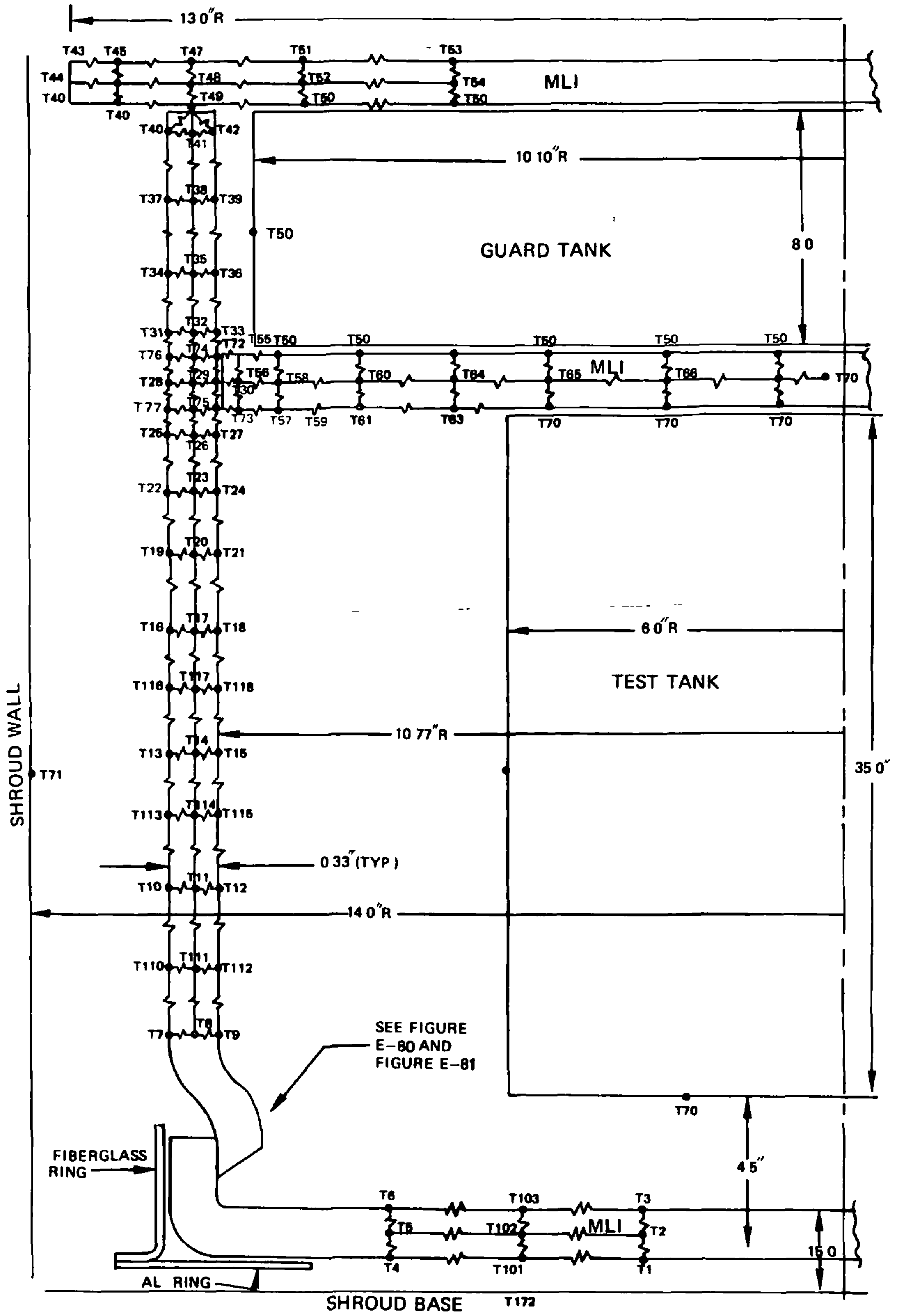


FIGURE E-79· NODAL NETWORK – BASIC MLI ASSEMBLY, LAP BASE JOINT

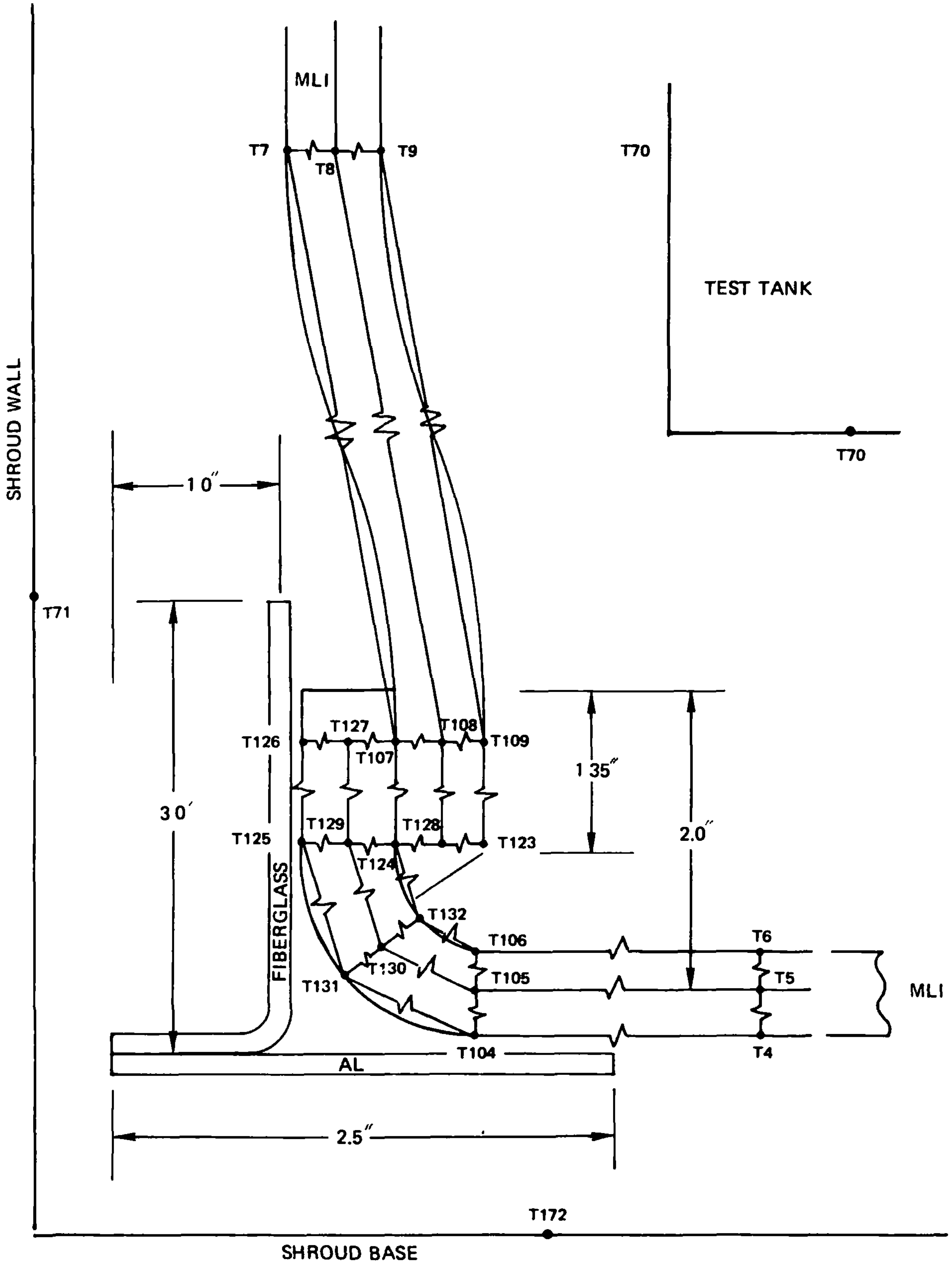


FIGURE E-80: NODAL NETWORK - MLI LAP BASE JOINT

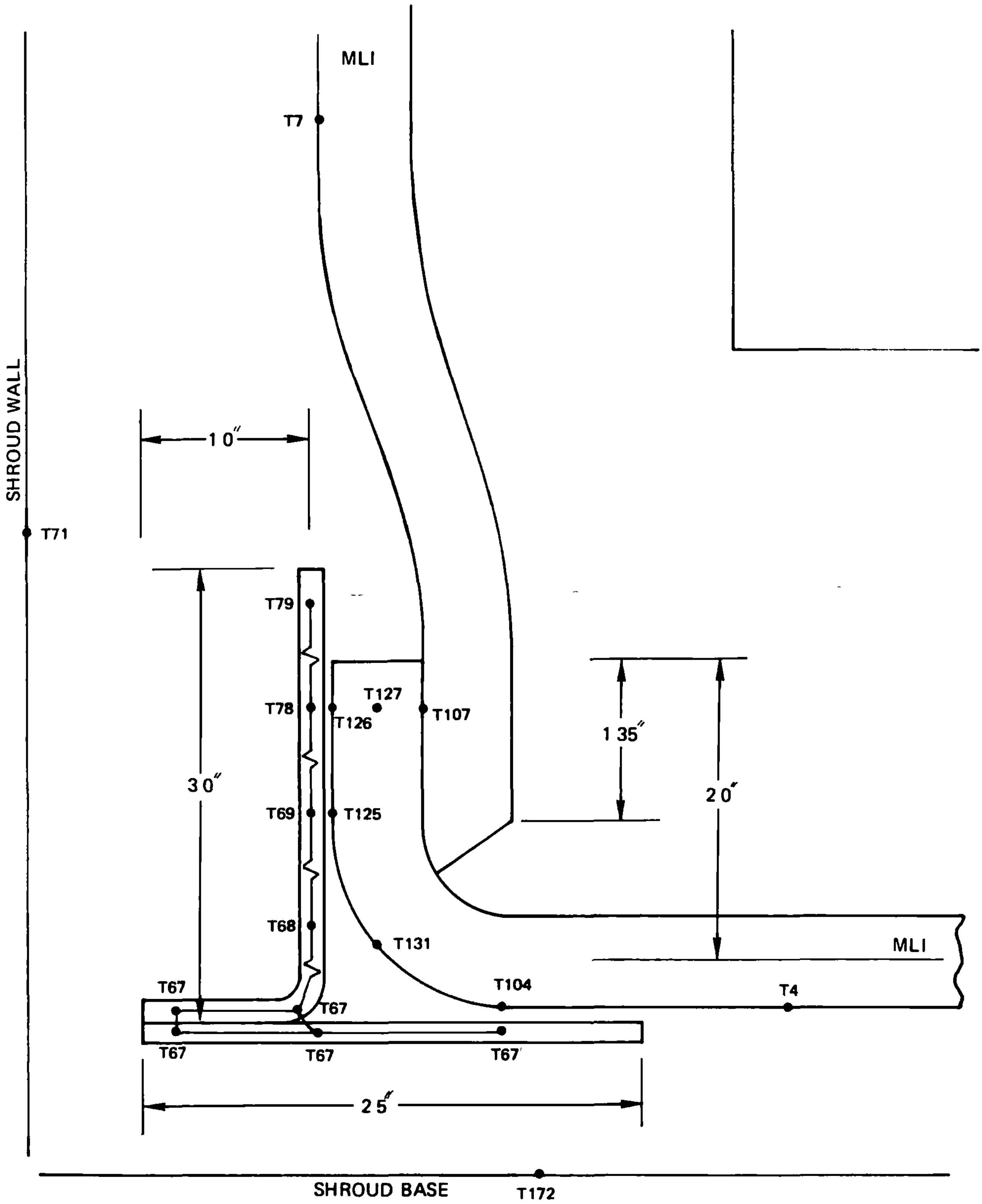


FIGURE E-81: NODAL NETWORK - BASE JOINT SUPPORT ASSEMBLY

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