NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum 33-341

Design, Fabrication, and Testing of the Applications Technology Satellite Apogee Motor Insulation

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Preface

The work described in this report was performed by the Propulsion Division of the Jet Propulsion Laboratory.

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Abstract

The Jet Propulsion Laboratory has completed the design, development, formal qualification, and flight phases of the *Applications Technology Satellite* (*ATS*) solid propellant apogee motor program. This report describes in detail the design concept, type of material, fabrication, and performance of the titanium motor chamber insulation system. The motor is insulated with Gen-Gard V-52, which is a material formulated of polybutadiene-acrylonitrile rubber, hydrated silica, asbestos fiber, reinforcing resin, plasticizer, antioxidant, and processing and vulcanizing agents. To develop and confirm the insulation design, numerous motor chambers were instrumented with thermocouples on the external surface to obtain temperature data during and after motor firing. The temperature results of these tests are presented for units instrumented in the motor development and qualification phase. On Dec. 7, 1966, Nov. 6, 1967, and Aug. 12, 1969, the JPL apogee motors placed the *ATS-B, ATS-C,* and *ATS-E* satellites into synchronous equatorial orbit.

Design, Fabrication, and Testing of the *Applications Technology Satellite* Apogee Motor Insulation

I. Introduction

To place the *Applications Technology Satellite* (*ATS*) into synchronous orbit, the Jet Propulsion Laboratory (JPL) furnished a solid propellant rocket motor (Fig. 1) to provide the final required velocity increment at the apogee of the elliptical transfer orbit. A total of six apogee units were delivered to the Air Force Eastern Test Range (AFETR) for flight support.

The apogee motor configuration consists of five major components: (1) motor chamber, (2) chamber insulation, (3) nozzle, (4) propellant, and (5) igniter and safe/arm assembly. The complete unit weighs approximately 841 lb and has a maximum diameter of 28.2 in. with an overall length of 54.6 in.

The motor chamber, constructed of titanium (6AL-4V), consists of two half-shells and a forward end mounting ring that is used to attach the apogee unit to the spacecraft. Each half-shell consists of a 2:1 ellipsoidal dome with a cylindrical skirt. Nominal dimensions for the diameter and length of the chamber are 28 and 29 in., respectively.

The motor chamber is insulated with Gen-Gard V-52, a polybutadiene-acrylonitrile rubber. Additional design, fabrication, and performance details are discussed in the following sections of this report.

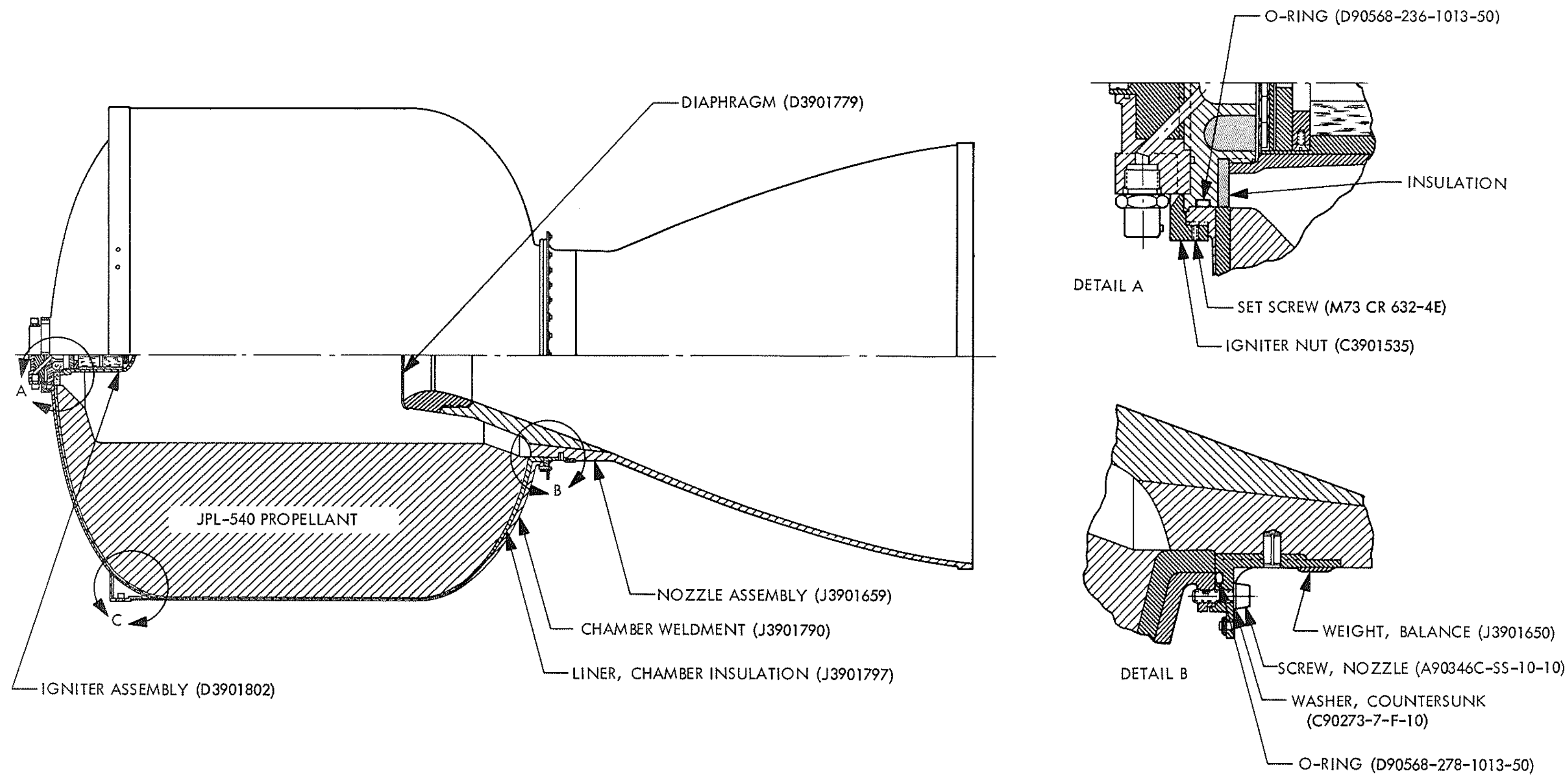
The apogee motor nozzle is contoured and partially submerged into the motor chamber; it has an expansion ratio of 35:1. The four-piece nozzle consists of an aluminum attachment ring, a high-density graphite throat insert, a tape-wrapped carbon fabric throat section, and a silica cloth tape-wrapped exit cone.

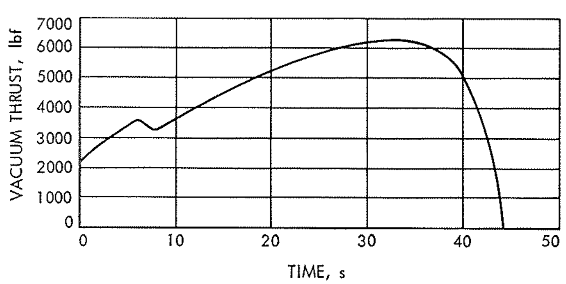
The rocket motor propellant, JPL 540, is a composite polyurethane fuel binder, ammonium perchlorate oxidizer, and aluminum fuel additive system. The propellant is cast directly against the completely case-bonded insulation system.

The igniter assembly consists of an aluminum basket loaded with 19 ALCLO pellets and 2 ALCLO main grains, a safe/arm device developed by Harry Diamond Laboratories, and 2 Hi-Shear PC-37 squibs.

JPL has completed the design, development, formal qualification, and flight phases of the *ATS* apogee motor program. This report describes the design, fabrication, and testing of the titanium chamber insulation assemblies used in the *ATS* apogee motor development, qualification, and flight phases.

Appendix A includes the chamber insulation design drawings; Appendix B is the chamber insulation specification.





NOMINAL DATA (AT 60°F)

BURNING TIME	43.5	s
MAXIMUM CHAMBER PRESSURE	260	lb(a)/in.^{2}
MAXIMUM VACUUM THRUST	6250	lbf
TOTAL WEIGHT	840.7	lbm
PROPELLANT WEIGHT	760	lbm
PREFIRE INERT WEIGHT	80.7	lbm
MAXIMUM DIAMETER	28.2	in.
OVERALL LENGTH	54.6	in.
THROAT DIAMETER	4.08	in.
NOZZLE EXPANSION RATIO	35:1	

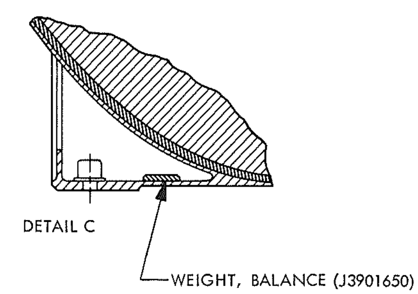


Fig. 1. *ATS* apogee motor assembly

II. Design

A. Background

The primary purpose of the chamber insulation system is to provide thermal protection to the rocket motor pressure vessel during motor operation. Thermal protection of the unit is required since the chamber is designed to operate as a pressure vessel only at moderate temperatures (less than 200°F). Therefore, the insulation system must protect the motor case from the evolving 5250°F combustion gases. Accordingly, it becomes obvious that any failure of the insulation system to adequately protect the chamber from the propellant flame front could result in a catastrophic motor failure.

During flight, the apogee motor is deeply submerged into the center section of the spacecraft. As a result of this configuration, an excessive temperature rise during or after motor operation could result in damage to the surrounding spacecraft. Therefore, a secondary purpose of the insulation system is to prevent a large case-wall temperature rise during or after motor operation.

The postfire heat loads, which were considered in the design of the insulation system, are generated as a result of the motor and spacecraft configuration. The rocket nozzle, which contains a 4-lb, high heat absorbing graphite throat entrance, is submerged into the motor chamber. Thus, after motor operation, the graphite throat insert radiates heat to the chamber wall. This heat and the quantity absorbed by the chamber and insulation during motor operation, in turn, radiates and conducts heat to the surrounding spacecraft. To assist in reducing the rate of heat transfer to the spacecraft, a highly aluminized Mylar blanket is installed between the spacecraft and rocket motor chamber. However, the Mylar blanket alone is not sufficient to deter an extreme temperature rise in the spacecraft during the motor postfire heat-soak period. Therefore, a design constraint to maintain the postfire chamber temperature below 700°F was imposed upon the motor insulation system.

Attitude control of the *ATS* spacecraft is maintained by a spin stabilization system. A strict requirement to optimize the system is a balanced spacecraft. The balance consideration assists in improving the life span of the spacecraft by minimizing the rate of hydrogen peroxide attitude control gas consumed during the mission. To meet the balance requirement, the spacecraft and apogee motor are separately balanced dynamically and statically prior to flight, since the motor stays with the spacecraft. However, the rocket motor is balanced prior to propellant loading. This condition simulates as close as possible the configuration that exists after motor operation and during the life span of the spacecraft. Nevertheless, the motor will be imbalanced after propellant expulsion because of the heat loads that distort and delaminate the chamber insulation.

To achieve the specified requirements for motor postfire imbalance (Fig. 2), the insulation system must be overdesigned from a thermal protection standpoint. Specifically, the design must allow for excess virgin insulation to remain against the chamber wall after motor operation and heat soak. This condition retains geometric symmetry for the insulation. The virgin insulation and uncharred chamber-to-insulation bonding medium adheres to the chamber better than a charred interface. If the insulation was designed to char completely during the postfire heat soak, any minor disturbances would cause the insulation to fall from the chamber and degrade the motor balance.

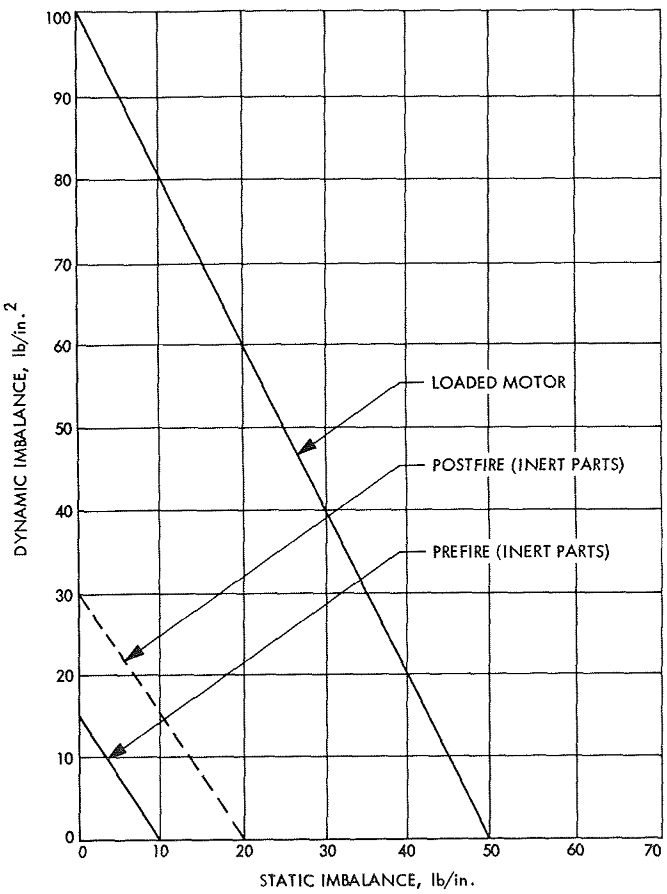


Fig. 2. Maximum allowable sum of static and dynamic imbalance

B. Concept

At the beginning of the apogee motor development program, the design guidelines for the insulation system were (1) to incorporate features of the JPL *Synchronous Communications Satellite* (*SYNCOM*) apogee motor, (2) to utilize the SYNCOM type of insulation material, and (3) to innovate any state-of-the-art improvements. The *ATS* apogee motor is a 2.3 scale-up of the successful *SYNCOM* apogee unit. In addition, the insulation/propellant system would be 100% case-bonded and the propellant would be bonded directly to the rubber insulation; i.e., without a liner interface.

The insulation system is designed to achieve the following objectives:

(1) Provide adequate thermal protection to the rocket motor pressure vessel during motor operation.

(2) Maintain a maximum postfire chamber temperature of 700°F.

(3) Contribute to minimum postfire imbalance consistent with motor assembly imbalance requirements.

Adequate thermal protection for the chamber during motor operation is achieved when, in any location, the chamber operating stress does not exceed the corresponding elevated temperature case material yield strength. To analytically confirm this requirement, the actual operating stress is determined and compared with the elevated temperature yield strength of the titanium chamber. The pressure–time curve of the motor is reviewed to determine the operating stress as a function of time. The corresponding chamber temperature is determined for numerous locations on the forward and aft chamber domes. The chamber operating stress at each location can be calculated with the following equation:

$$S_\theta = \frac{N_\theta P_c}{t \times 270}$$

where

S_θ = motor operating stress at P_c, lb/in.^{2}

N_θ = stress factor (see Fig. 3) at 270 lb(g)/in.^{2}

t = chamber thickness, in.

This equation is not valid in the dome sections within 1½ in. of the openings or cylindrical section, since bending stresses are not accounted for.

The titanium yield strength at elevated temperature is determined with an ambient (80°F) yield strength of 150,000 psi. Figure 4 shows the effect of temperature on the tensile yield strength of 6AL-4V annealed titanium alloy (sheet and bar). Of course this condition, annealed titanium alloy sheet and bar, does not precisely represent the chamber material condition, but was the closest condition available in published metallurgical handbooks.

The motor, which has a progressive pressure–time curve (Fig. 5), achieves maximum chamber pressure at 34 s, then regresses until tailoff at 43 s. As a result of this ballistic profile, the minimum safety factor between chamber material yield strength (at operating temperature) and operating stress occurs at peak chamber pressure. This occurs because, as the temperature of the chamber rises, the motor operating stress decreases at a faster rate than the chamber material yield strength after peak chamber pressure is achieved. However, to insure that this condition exists, a chamber temperature—chamber stress—titanium yield strength is calculated as shown in Fig. 6. Generally, the minimum margin of safety between yield stress and operating stress occurs at a radius of approximately 7 to 8 in., but each location

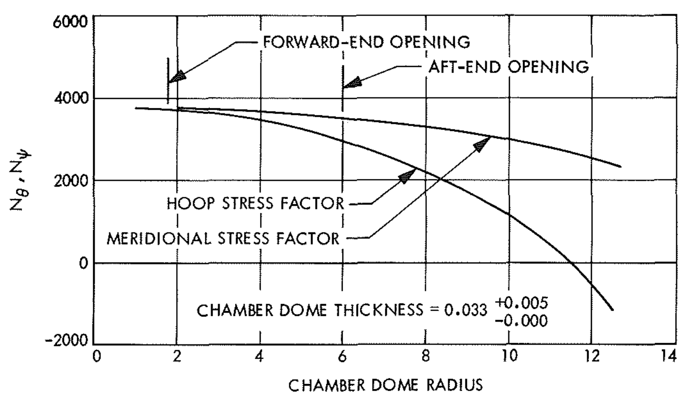


Fig. 3. Chamber dome stress factor at 270 lb(g)/in.^{2}

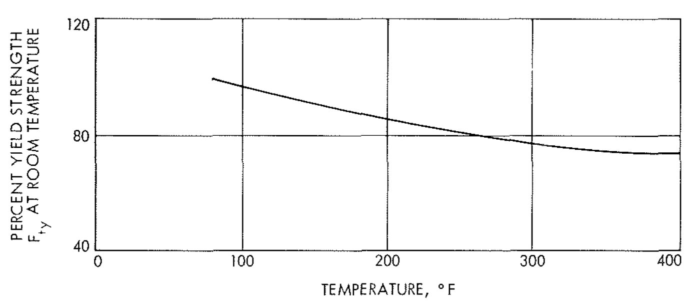


Fig. 4. Effect of temperature on tensile yield strength of 6AL-4V

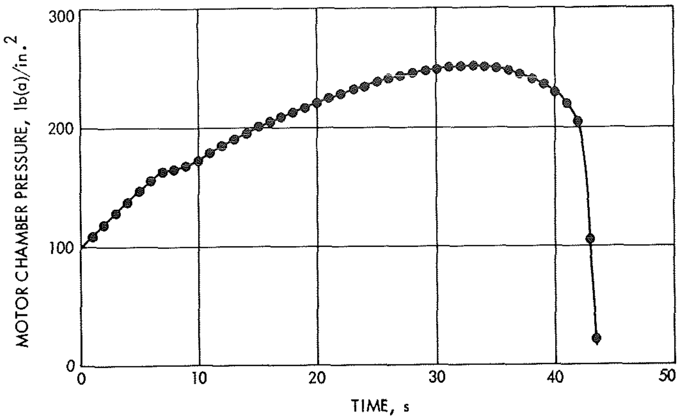


Fig. 5. Motor chamber pressure vs operating time

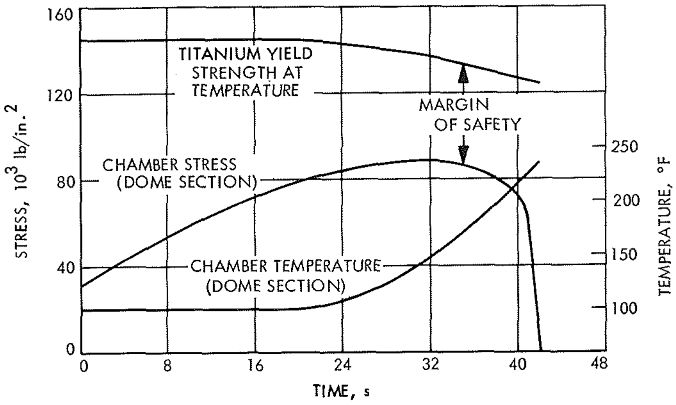


Fig. 6. Chamber temperature—chamber stress—titanium yield strength

where thermocouple data have been recorded was reviewed.

To achieve adequate thermal protection and successful operation of the first development motor, the initial insulation design was conservative. The necessary thicknesses were determined by a direct linear scale-up of the JPL *SYNCOM* apogee motor insulation configuration. The first motor was considered quite conservative since actual insulation thicknesses are less than a direct linear scale-up and the chamber was a heavy wall unit. However, this approach assured that a layer of virgin material would remain in the chamber. Therefore, upon completion of the test, it was possible to determine the insulation surface regression and char depth. The insulation system design was based on surface regression and char-depth measurements from the first heavy-wall development test. Also considered in the initial design were the current state-of-the-art fabrication techniques and the availability of Gen-Gard V-52 in limited thicknesses.

To demonstrate the second design requirement of maintaining the chamber temperature below 700°F during the postfire heat-soak period, thermocouples were installed on the external surface of the chamber on several units fired in the motor development and qualification phases. As a result of these tests, it was evident that the initial insulation configuration was sufficient to protect the spacecraft from the postfire heat soak.

The final design constraint was to establish an insulation configuration that did not develop excessive postfire imbalance. To meet this requirement, it was necessary to design the insulation thickness beyond the required amount for thermal protection of the chamber. Based on *SYNCOM* experience, the increased insulation thickness results in a layer of virgin material intact after the postfire heat-soak period. Therefore, the insulation material adheres to the chamber symmetrically and assists in maintaining motor balance after firing.

This balance requirement is extremely difficult to demonstrate, since motor imbalance cannot be determined under simulated flight conditions. Normally it is not desirable to determine the imbalance of a motor fired at ambient conditions because the hot insulation together with ambient air sustain postfire burning of the insulation material during the heat-soak period. As the material burns and the motor heat soaks, the charred and weakened insulation drops from the top side of the motor. Of course, this results in an unrealistic and large amount of motor imbalance. When the unit is fired under simulated altitude conditions this does not occur, but the situation arises in which, during the normal course of removing the motor from the test stand and shipping the unit from Arnold Engineering Development Center, Tullahoma, Tenn., the charred and virgin insulation material is disturbed from its initial postfire condition. The disturbed material accumulates at the bottom of the chamber and must be removed prior to the balance test.

It is obvious that the disturbed insulation material or the removal of loose insulation invalidates the actual postfire imbalance condition. However, four units have been balanced under the above conditions, with 5 lb of loose insulation removed from one unit and 3 lb from each of the remaining three motors. The latter three units, which were fired in the motor qualification phase, met the postfire imbalance requirements. However, the single unit that did not meet postfire imbalance requirements consisted of a 410 steel chamber with 10.5 lb of insulation as compared to the flight titanium chamber with 12.5 lb of insulation. The steel chamber with the lighter insulation was used in the early portion of the motor development phase. The lighter insulation configuration chars completely during postfire heat soak. Therefore, larger random pieces of charred insulation fell from the wall of the chamber, thereby contributing to the larger imbalance of this unit. As a result of this design deficiency, it was necessary to add additional insulation in the chamber dome sections.

At the initiation of the motor development program at JPL the material selection for the chamber was based on a performance vs cost relationship, which resulted in a choice of 410 chromium steel as the chamber material. After the motor development program was well underway the purpose of the satellite was changed from communications to communications and scientific experiments. As a result of this decision a requirement was imposed upon JPL to use a nonmagnetic chamber material. Therefore, 6AL-4V titanium alloy was chosen for the chamber.

Since the yield strength of 6AL-4V titanium alloy rapidly decreases at elevated temperature, when compared to 410 chromium steel, it became necessary to redesign the insulation system for use in the titanium chamber. Because the same operating stresses are imposed during motor operation in both units (steel and titanium), the rapid decrease in titanium yield strength at elevated temperature invalidates the margin of safety in the insulation design. To achieve an adequate margin of safety in the titanium chamber, two additional 0.030-in. layers (see Fig. A-1; items 15–18) of insulation were added in the dome sections to decrease the average temperature at peak operating stress from 350°F to below 200°F. Additional insulation was not required in the chamber cylindrical section since the propellant acts as an adequate insulator until the flame front reaches this area at the end of the motor operation.

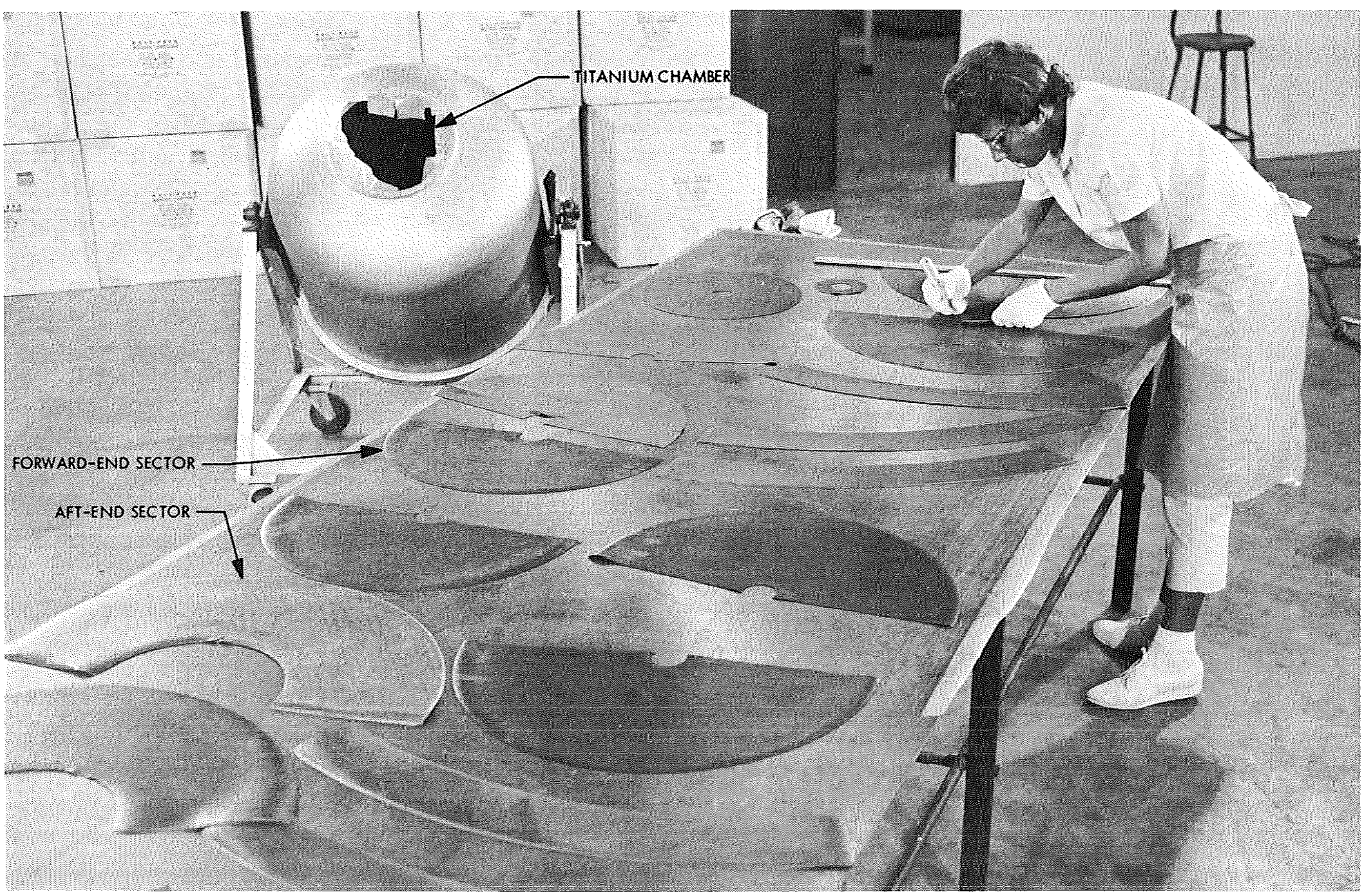


Fig. 7. Fabrication of *ATS* chamber insulation

The final insulation design for the 410 chromium steel chamber (see Fig. A-2) has an average weight of approximately 10.5 lb, while the flight configuration for the titanium chamber (see Fig. A-1) weighs approximately 12.5 lb. The two additional pounds of Gen-Gard V-52 were added in approximately equal proportions for thermal protection and improving the postfire imbalance.

C. Configuration

The insulation configuration of the flight titanium chamber consists of a varying number of layers of Gen-Gard V-52 vulcanized to each other and the internal surface of the chamber. The insulation configuration drawing (see Fig. A-1) shows that the thickness at the nozzle and igniter opening begins at 0.200 in. and tapers to 0.080 in. where the dome section joins the case cylindrical section. The required thickness is achieved at the openings by a buildup of five layers of insulation; one 0.080-in. layer and four 0.030-in. layers. Each layer continues from the opening, down the dome section, toward the cylindrical section, to a specified position. The cylindrical section, which is protected by the propellant from the hot combustion gases during motor operation, is insulated with a single layer of 0.030-in. insulation.

Each layer of insulation in the dome sections is comprised of hollow circles or a sector of hollow circles. These sectors of insulation are positioned into the chamber by a hand lay-up method. The one layer of insulation in the cylindrical section is rectangular and is also layed-up by hand into the chamber, prior to the vulcanization cycle. Figure 7 shows cut sectors before they are positioned in the chamber.

As shown in Fig. A-1, the insulation system is 100% bonded to the chamber wall. The propellant, in turn, is 100% bonded to the insulation without a liner interface. As a result of excellent propellant physical properties, the case-bonded configuration functions without the aid of insulation release boots.

D. Material

The material used in the chamber insulation system is designated NBR Gen-Gard V-52 and produced by the General Tire and Rubber Company at Akron, Ohio. Although the detailed formulation of Gen-Gard V-52 is considered proprietary, the basic ingredients are polybutadiene-acrylonitrile rubber, hydrated silica, asbestos fiber, reinforcing resin, plasticizer, antioxidant, and processing and vulcanizing agents. Table 1 lists the physical characteristics of NBR Gen-Gard V-52. The values are for information purposes only and should not be used for precise design calculations, since several parameters vary with cure conditions and the amount of insulation.

The insulation material, which is designated NBR Gen-Gard V-52, is produced under strict quality control specifications. At each step in the cycle, applicable tests are conducted to assure that only acceptable material is used in subsequent operations. Material certifications are supplied that certify the material was produced to the applicable specifications and that indicate the test data obtained from representative samples.

The unvulcanized material may be stored in its shipping container in a cool location (less than 100°F) out of direct sunlight for a recommended shelf life of 6 mo. As with most partially cured material, lower storage temperatures (to 40°F) and darkness will increase the shelf life. At present, a test method is not available to adequately determine the physical condition of the unvulcanized insulation after 6 mo of storage. However,

Table 1. Physical properties of cured Gen-Gard V-52[a]

Property	Values	Test method
Hardness, Shore-A	84 ±7	ASTM[b] D 676
Aged hardness, Shore-A	87 ±7	ASTM[b] D 676
Specific gravity	1.335 ±0.015	G-GTS[c] 1763
Parallel tensile, psi	1100 min	ASTM D 412
Perpendicular tensile, psi	600 min	ASTM D 412
Aged parallel tensile, psi	1400 min	ASTM D 412
Parallel elongation, %	25 min	ASTM D 412
Perpendicular elongation, %	225 min	ASTM D 412
Aged parallel elongation, %	25 min	ASTM D 412
Nitrogen permeation, $ft^3/ft^2/24\ h/0.001\ in./psi$	5.0×10^{-4} max	G-GTS 1766
Water absorption (wet), %	0.75 max	G-GTS 1767
Water absorption (dry), %	0.10 max	G-GTS 1767
Shrinkage (parallel), %	0.2 + 0.6 −0.2	G-GTS 1636
Shrinkage (perpendicular), %	1.9 ±0.6	G-GTS 1636

[a]These data, as listed in the Gen-Gard Insulation handbook, were obtained from test specimens vulcanized for 120 min at 308°F in two-plate, flash type compression molds at a minimum molding pressure of 500 psi.

[b]ASTM test method specifications may be obtained from American Society for Testing and Materials, 1916 Race St., Philadelphia 3, Pa.

[c]Copies of Gen-Gard V-52 test specifications (G-GTS) are available from the General Tire and Rubber Company, 1708 Englewood Ave., Akron, O., 44309

the General Tire and Rubber Company states that vulcanized products have been made with Gen-Gard V-52 that is more than 1 yr old and no adverse effects were noted in the fabrication process or in the end use of the product. As Gen-Gard V-52 ages in the unvulcanized stage, the hardness increases, the flexibility decreases, and the exposed surface (i.e., the one not protected by the polyethylene packaging liner) oxidizes. If the degradation of physical properties can be tolerated in the fabrication process and in the end environment, the material can be used beyond the recommended 6-mo shelf life. Unvulcanized Gen-Gard V-52 that was 10 mo old was used in an *ATS* apogee motor insulation system after the oxidation was thoroughly removed. No adverse effects, as a result of the aged material, were noticed during the fabrication process or in the end use of the insulation system.

The material supplier warrants that the cumulative area of unvulcanized calendered material in any roll with defects such as wrinkles, internal voids, delaminations, contamination, etc., shall not exceed 10% of the net area of the material in the roll. The thickness tolerances are not applicable to material within 2 yd of each end and within 5% of the width of each edge of the roll.

The thickness tolerances on Gen-Gard V-52 are of some concern, since it is desirable to maintain control of the weight variation of the insulation system. On all NBR Gen-Gard V-52, the tolerances are warranted to be within certain limits and on most rolls of material are well within the limits. However, the tolerances are not identical on all gauges of material. Of the two thicknesses used in the program, the tolerance on the 0.030-in. material is ± 0.005 in., or a 33% range, while the tolerance on the 0.080-in. material is $\pm 10\%$. If the system is extremely weight sensitive, it is obvious that these thickness tolerances directly affect the weight and thickness of the end product, if the part is fabricated with a specified number of layers. This is predominantly evident on units fabricated from different rolls, since the actual tolerance within a roll is considerably less than the maximum allowable. Experience has shown that a large percentage of a roll is on the low side of the thickness tolerance while another roll of material is on the high side of the tolerance. Based on the results of the weight data collected on the *ATS* insulation system, the total weight variation of the titanium chamber insulation configuration has been minimal, as shown in Table 2.

III. Fabrication

A. Background

Fifty chamber insulation systems were fabricated and used in the motor development, qualification, and flight phases. Of the 50 units fabricated, 4 were for the heavy wall motor firings, 23 were for the chromium steel chambers, designated configuration number 1 (Fig. A-2), and 23 were for the 6AL-4V titanium chamber, designated configuration 2 (Fig. A-1).

The following discussion describes the fabrication process of configuration 2, which was used in all flight units. Each unit was fabricated to JPL drawing J3901797A (Fig. A-1) and JPL specification GMO-50363-GEN-1 (Appendix B). The insulation material was purchased by JPL to the specification provided by General Tire and Rubber Company and then the material was supplied to the fabrication vendor, Haveg Industries, Inc., Reinhold Aerospace Division, Santa Fe Springs, Calif.

Fabrication of the insulation system is comprised of three major operations that are performed by two different contractors. Preparing the inside surface of the chamber to remove any contaminants and enhance the bonding characteristics of the insulation to the chamber is the initial processing operation. The remaining tasks, performed by a second vendor, are the installation of the unvulcanized insulation into the chamber and the subsequent curing of the material.

Vulcanized insulation components may be made by several conventional fabrication procedures. One method considered was to use matched metal compression mold dies to form the insulation configuration, after which the components would be bonded to the chamber with common adhesion procedures. The second approach was to hand lay-up the insulation into the chamber and then to vulcanize and bond the components to the chamber simultaneously.

The hand lay-up procedure was chosen as the method for fabricating the chamber insulation system. The reasons for choosing this method were that this approach is primarily less expensive overall and is also more adaptable to immediate changes, which are prevalent in a development program. In addition, it was necessary to consider the quantity of parts to be produced, the dimensional tolerances required of the end product, and the time available for fabrication.

Table 2. Summary of insulation weights

Chamber serial number	Code	Configuration J3901797	Lot	Total weight, lb	Weight of Gen-Gard V-52, lb	Adhesive weight,[a] lb
P-21	—	N/C[b]	A	11.31	9.89	1.42
P-22	C-7	N/C	A	11.35	9.05	1.30
P-23	F-3	N/C	A	11.37	9.88	1.49
P-24	C-6	N/C	A	11.21	9.66	1.55
T-2	D-5T	N/C	A	11.38	10.26	1.12
P-32	F-2	N/C	B	10.57	9.45	1.12
P-34	F-3	N/C	B	10.98	9.57	1.41
T-3	D-2T	N/C	B	10.74	9.44	1.30
T-4	G-8T	A	B	11.80	10.81	0.99
T-6	G-9T	A	B	12.08	10.97	1.11
T-7	Q-1T	A	B	12.37	10.95	1.42
T-8	Q-2T	A	B	12.18	11.06	1.12
T-9	Q-3T	A	C	12.40	11.29	1.11
T-10	Q-4T	A	C	12.42	11.33	1.09
T-11	Q-5T	A	C	12.39	11.35	1.04
T-12	Q-6T	A	C	12.57	11.42	1.15
T-13	Q-7T	A	C	12.35	11.26	1.09
T-14	Q-8T	A	C	12.50	11.32	1.18
T-15	Z-1	A	C	12.49	11.39	1.10
T-16	Z-2	A	C	12.70	11.56	1.14
T-17	Z-3	A	C	12.47	11.43	1.04
T-18	Q-9T	A	C	12.55	11.48	1.07
T-19	Z-4	A	C	12.48	11.39	1.09
T-20	E-3T	A	C	12.62	11.52	1.10
T-21	Z-5	A	C	12.33	11.29	1.04
T-22	Z-6	A	C	12.39	11.26	1.13
T-23	Z-7	A	C	12.31	11.19	1.12

[a]Adhesive weight includes two coats of Thixon P-4 primer and one coat of Thixon 1209 adhesive.
[b]N/C = no change.

If the size of each chamber dome section is considered, a preformed insulation boot would require two sets of large, expensive matched metal dies, one for each chamber dome section. Based on the fact that a limited number of units would be fabricated, the cost incurred by two sets of dies and a large compression molding press could not be amortized into the total system cost and would not result in a lower cost than the hand lay-up technique. This fact is more evident if consideration is given to the fact that the initial insulation system would be subjected to design changes, which in turn require modification to the matched metal dies or fabrication of new dies. In addition, the hand lay-up technique allows for complete freedom for immediate changes in thicknesses, by the addition or removal of a layer of insulation. Of course, with matched metal dies, a configuration change normally requires a lengthy delay to modify the dies or fabricate new molds.

There are several disadvantages associated with a hand lay-up technique. Tolerances for this method must be large since the skill of the technician determines the dimension of the finished part. Also, a precise value of the end product thickness is difficult to achieve for two reasons. First, the insulation material, NBR Gen-Gard V-52, is only available in stock sizes of 0.010, 0.030, and 0.080 in. Secondly, these sizes may have relatively large tolerances; i.e., beyond 10%, as previously mentioned.

B. Process

The initial operation in the insulation fabrication process is to chemically clean the inside surface of the chamber to achieve optimum bonding conditions. A contaminated surface could result in a chamber-to-insulation bond failure or a subsequent failure during high stress loading conditions.

After the chamber is constructed, the internal surface is given a solvent wipe, then bead-blasted to roughen the surface. Next, the unit is prepared for chemical cleaning by Cromer Processing, Inc., of Los Angeles, Calif. The internal and external surfaces are wiped with a warm sodium hydroxide alkaline solution to remove most contaminants. Then an etch solution is applied to both chamber openings to expose an optimum bonding surface free of contaminants and oxidation.

The etch solution is formulated with 7.8 parts water, 2.0 parts nitric acid, and 0.2 parts hydrofluoric acid; it is subsequently tested to ensure its potency. Normally, two test samples, 1 $\times$ 6 in., taken from the cylindrical section of a hydroburst chamber are used to ensure the correct potency of the etch solution. The samples are prepared in the identical manner as the chamber is prepared for chemical cleaning. The sample is wiped with warm sodium hydroxide, water-rinsed and air-dried, then etched with the nitric acid/hydrofluoric acid solution. The sample thicknesses are measured before and after to determine the surface regression. If the etch solution removes less than 0.0005 in. during the 3-min wipe period, it is acceptable for use on the chamber.

Before the etch solution is applied, the chamber is wiped with a sodium hydroxide alkaline solution on the internal surface to remove any contaminants. The outside surface is also wiped to improve the esthetic value of the unit. Both the internal and external surfaces are rinsed with clean water to remove any traces of the sodium hydroxide solution and then the surfaces are dried with low-pressure air. A polyethylene bag is placed over the chamber, with an opening at the nozzle end, to protect the unit from any nitric acid/hydrofluoric acid drippings. The unit is then ready for chemical etching.

Since the primary purpose of the etch process is to improve the bonding characteristics of the chamber–insulation interface at the openings, only this area is etched. This includes the surface from the inside diameter of the opening to a point 1.5 in. beyond at the forward end and 0.5 in. beyond at the aft opening as shown in Fig. 8. The etch solution is applied, neutralized with clean water, and allowed to evaporate; any excess solution is removed with clean, low-pressure, dry air.

After a fresh surface is exposed by the etch solution, the surface is again susceptible to oxidation, which impairs the optimum bonding properties of the surface. Therefore, to protect the surface and achieve the desired bonding characteristics, the etched surface is painted with the insulation primer within 4 h after the etch solution is applied.

The chemical cleaning process was initiated after numerous motor development units incurred insulation-to-chamber bond failures at the openings during insulation fabrication or after propellant loading. Of course, the defects were repaired prior to static testing to avoid a possible motor failure. There were two reasons for modifying the insulation process to achieve an acceptable bond between the chamber/insulation interface at the forward and aft openings.

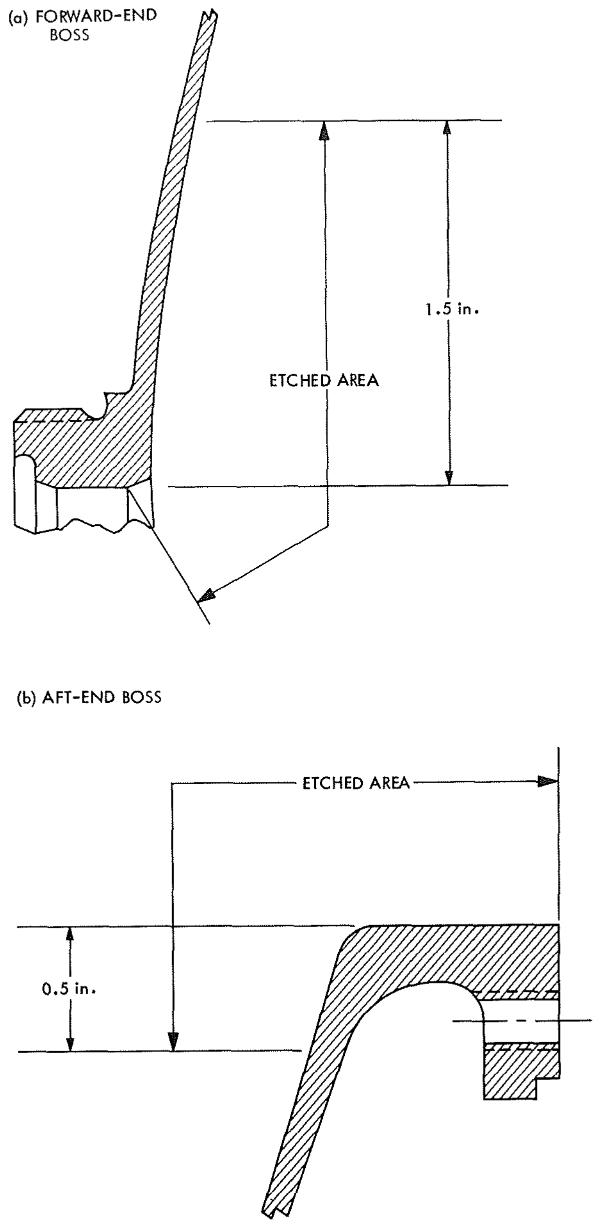


Fig. 8. *ATS* motor chamber etching details

First, it was believed that the bond was marginal since the failures occurred on random units. Therefore, although all bond failures existed either after insulation fabrication or propellant loading, it was probable that a failure could occur during environmental or static testing. During these tests the bond line is highly stressed. If a bond failure occurred during environmental testing, the test would be considered a failure, since the separation would require repair prior to static test. Also, if a bond failure occurred during the environmental tests, the insulation system would require redesign and demonstration of a successful fix prior to completion of the motor development program. This "wait-and-see" method, which is considered an unprofessional approach to the problem, could jeopardize the overall program if the random failure occurred in the motor qualification phase.

Secondly, the task of repairing a defective insulation bond after fabrication or propellant loading would be time consuming and inconvenient.

After chemical cleaning and etching, the chamber is ready for installation of the insulation system. To achieve the bond between the insulation and the chamber wall it is necessary to prime the surface of the case with an adhesion medium. Under normal circumstances, one coat of bonding cement is sufficient, but with a highly stressed insulation bond a two-coat system is necessary to achieve a high-strength quality bond. On the basis of the insulation configuration and the fact that the propellant is entirely case-bonded to the insulation, it was decided to use a two-coat cement system.

Thixon P-4*, a one-coat cement for bonding nitrile rubber, is used as the primer coat. To improve the bonding characteristics, two coats of Thixon P-4 are applied. First, the chamber is painted with a brush coat of primer and allowed to dry until all solvents have evaporated. Next, a second brush coat is applied at right angles to the first coat and allowed to dry.

The cement coat over the primer, Thixon-1209*, is applied with a brush and allowed to dry until all solvents have evaporated. The application of both the primer and cement are accomplished within 24 h prior to the installation of the unvulcanized insulation to ensure adequate bonding characteristics.

Next, the unvulcanized insulation is prepared for the hand lay-up method of fabrication. Generally, this technique can be described as follows: sheet stock material is cut in specified patterns and applied by hand in a particular series to build up a number of layers on the inside surface of the chamber. Under heat and pressure, the material is then cured and vulcanized to the chamber wall.

The quality of a hand lay-up insulation component is a direct function of the abilities of the technician performing the various operations. Therefore, it is necessary

*Thixon is a product of Dayton Chemical Co., Dayton, Ohio.

to maintain tight controls over the quality of application as well as the amount of vulcanizing primer and cement brushed on the chamber wall. Also, it is necessary to ensure that each patterned piece is accurately oriented in the chamber. Since the system is near optimum, it is mandatory that the layers extend accurately to the required radius to avoid major variations in chamber temperature between units.

Each sector of insulation, 31 pieces in all, is cut from a roll of Gen-Gard V-52. Cutting is accomplished with precision metal templates to maintain accurate geometry control on each pattern. The pattern pieces are cut within 48 h prior to use to avoid any significant shrinkage effects. All patterned pieces are then scrubbed with methyl ethyl ketone (MEK) to soften the surface and provide a tacky interface between the layers of the adhesion cement. Next, the layers are placed into the chamber in sequence, a bleeder cloth is applied to the outermost layer, then the chamber is encapsulated in a vacuum bag.

For a minimum of 2 h, a vacuum of 24 in. of mercury is applied to the unvulcanized lay-up to remove any entrapped air prior to curing the insulation. Any entrapped air between the layers of insulation will result in delaminations between layers, which are detrimental to the performance of the insulation system.

Vulcanization of the insulation is accomplished in a high-strength pressure vessel (autoclave) capable of tolerating the required pressure and temperature. A minimum pressure of 100 lb/in.^{2} is maintained on the unit throughout the entire vulcanizing cycle. In addition, a minimum vacuum of 24 in. of mercury is also maintained on the vacuum bag. Figure 9 shows the vulcanization cycle.

After the motor chamber has cooled to ambient temperature and the vulcanization pressure released, the vacuum bag and the bleeder cloth are removed. Next, the excess insulation is removed from each chamber opening and the exposed internal surface of the insulation is sandblasted to improve the propellant bonding characteristics.

Prior to accepting the insulated chamber, it is visually inspected for general workmanship. Also, a Shore-A hardness test is performed to ensure that the value lies between 84 ± 7. The most crucial requirement is a thorough inspection of the chamber openings to ensure that there are no insulation delaminations and unbonded or

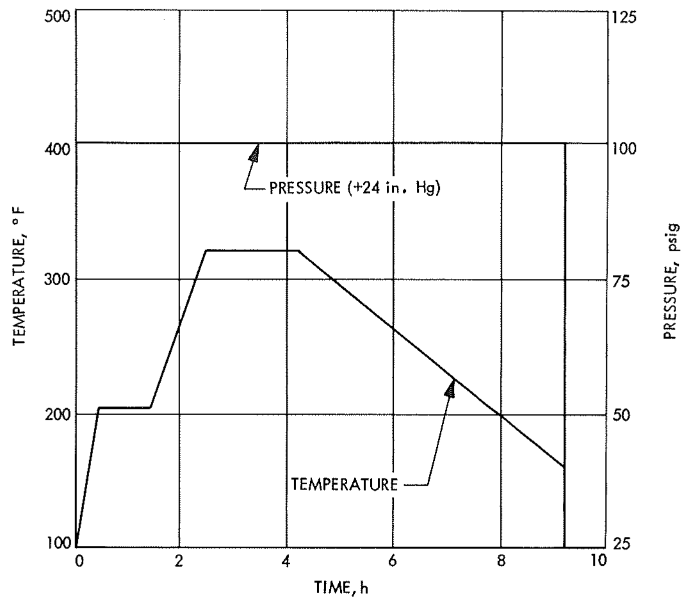


Fig. 9. Insulation cure cycle

weakly bonded areas at these openings. The inspector then attempts to push the insulation away from the openings using medium pressure on a screwdriver. If the insulation bond at both openings is adequate, an extreme amount of force may be applied to the insulation, since the insulation will fail before the bond line. The force that can be generated by the screwdriver test, and its resulting stress on the insulation bond line, far exceeds any stresses that occur during motor operation. If the above inspections are accomplished without major deviation and the process documentation and material certifications are complete, the unit is accepted by JPL.

A final operation performed at JPL consists of trimming the aft opening insulation to allow for a clearance of 0.015 in. between the nozzle assembly and the insulation. Minimum clearance between the insulation and the nozzle decreases the circumferential gap for hot combustion gases to gain access to the aluminum nozzle attachment ring.

As a result of the case-bonded propellant–insulation configuration, relatively high stress loadings occur between insulation and propellant. Therefore, to prevent a separation between propellant and insulation, a strong bond must be achieved at the interface. To acquire a reliable high-strength chemical bond between the two materials, the insulation is treated with a solution of

75% methylene chloride and 25% toluene diisocyanate (TDI) prior to propellant casting. Methylene chloride, which is caustic, attacks the insulation and allows the TDI to penetrate the insulation surface. The insulation surface is exposed to this solution for a 3-min period. Next, the methylene chloride solution remaining on the surface is removed by oven drying overnight at 160°F, which leaves only the curing agent, TDI. The propellant also employs TDI, which is its curing agent; therefore, during propellant curing, an effective chemical bond between propellant and insulation is achieved. Peel tests have shown that the propellant–insulation bond strength is greater than the strength of the cured propellant.

The average weight of the insulation configuration for the titanium chamber is 12.5 lb; the weight of the 410 chromium steel chamber is 10.5 lb. Table 2 lists the weights of the rubber, primer, and vulcanizing cement for the titanium chamber insulation configuration.

IV. Performance

Ten static tests in the motor development and qualification phases have been conducted with chambers instrumented with thermocouples on the external surface. This was accomplished to determine chamber temperatures during and after the test and, therefore, to verify the insulation design. Five of the units were static tested under simulated altitude conditions at Arnold Engineering Development Center (AEDC), Tullahoma, Tennessee. The remaining five tests were conducted at ambient conditions at the JPL–Edwards Test Station (ETS) facility.

On each instrumented chamber, the thermocouples were located just below the end of a layer of insulation rather than slightly above so that a higher temperature would be recorded during the test run. Figure 10 shows a typical thermocouple layout. In addition, three thermocouples were positioned in the chamber cylindrical section to confirm a uniform propellant burnout. If the web burnout was not uniform, one of three thermocouples would respond to the resulting temperature sooner than the other two thermocouples. The insulation thickness (0.030 in.) in this area is not sufficient to thermally protect the chamber from the combustion gases.

Four steel motor chambers (two fired at JPL–ETS at ambient conditions and two fired at AEDC under simulated altitude conditions) were instrumented with ther-

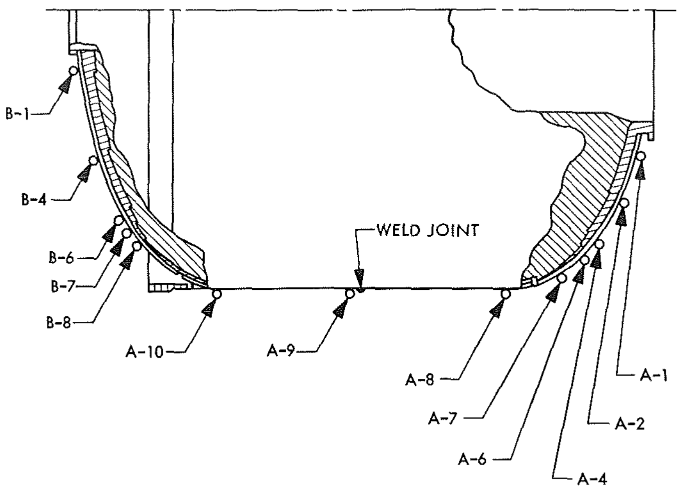


Fig. 10. Thermocouple layout for qualification motors Q-5T and Q-8T

mocouples located on the external surface of the chamber. Figure A-2 shows the insulation configurations. Figures C-1 and C-2 show the thermocouple positions and the temperature–time history of motor E-1 fired at AEDC. The maximum temperatures recorded during the test occurred approximately 90 s after motor tailoff. The maximum motor temperature of 700°F occurs in the elliptical dome section of the chamber.

The flight insulation design, configuration 2 (Fig. A-1), was evaluated in six motor tests. Two steel chambers were instrumented with thermocouples, prior to the availability of the titanium chamber, and fired at the JPL–ETS site at ambient conditions to develop the design. Two motors with titanium chambers were also fired at ambient conditions during the later environmental test phase.

Final demonstration and confirmation of the flight insulation design occurred in the motor qualification phase during which two motors were instrumented and fired at AEDC under altitude conditions. Figure 10 shows the thermocouple positions; Table 3 shows the temperature–time profile during motor burn for qualification motors, Q-5T and Q-8T, fired at 40 and 100°F, respectively.

Figure 11 shows temperature data recorded during the test of qualification motor Q-5T for 300 s following ignition. As shown in Fig. 11, the external chamber temperature during motor operation was below 200°F, and the maximum temperatures were below 700°F.

Table 3. Chamber temperature profile for qualification motors Q-5T and Q-8T

Burn time,[a] s	Temperature at thermocouple position[b]												
	A-1	A-2	A-4	A-6	A-7	A-8	A-9	A-10	B-1	B-4	B-6	B-7	B-8
	Motor Q-5T												
0	40	39	37	40	41	44	49	44	30	34	35	33	36
5	40	39	38	41	42	44	48	44	30	33	35	33	36
10	40	40	42	45	42	44	49	44	29	33	35	33	35
15	42	42	47	51	44	45	49	44	29	33	35	33	35
20	43	45	54	58	46	46	49	45	31	33	35	33	35
25	47	49	60	65	49	47	50	45	36	36	34	33	36
30	57	57	68	72	51	48	50	45	47	51	35	33	36
35	75	75	74	78	54	50	51	46	64	79	43	40	44
40	97	104	91	102	56	51	52	47	86	118	75	82	107
45	127	137	132	237	60	55	54	46	114	161	123	151	197
	Motor Q-8T												
0	93	96	93	96	95	93	88	86	83	85	87	86	87
5	94	97	95	97	99	94	88	86	82	84	86	86	86
10	96	101	99	102	108	95	89	87	82	84	86	86	86
15	100	108	105	108	117	97	91	87	82	84	87	86	87
20	103	114	111	114	123	98	91	88	83	84	87	86	87
25	109	119	115	118	127	99	92	88	85	86	87	86	87
30	120	128	120	123	132	100	92	89	93	99	87	87	87
35	137	148	126	128	137	101	93	89	106	124	89	95	100
40	156	177	146	163	140	102	94	89	125	160	108	150	201
45	199	246	229	308	260	126	143	157	152	207	156	231	327

[a]Primary burn time: 43.3 s for motor Q-5T and 41.9 s for motor Q-8T.

[b]See Fig. 10 for thermocouple layout.

Table 4. Summary of prefire and postfire insulation weights

Item	Qualification motor code							
	Q-1T	Q-2T	Q-3T	Q-4T	Q-5T	Q-6T	Q-7T	Q-8T
Insulation, lb	12.37	12.18	12.40	12.42	12.39	12.57	12.35	12.50
TDI,[a] lb	0.39	0.35	0.36	0.34	0.44	0.38	0.34	0.41
Total insulation, lb	12.76	12.53	12.76	12.76	12.83	12.95	12.69	12.91
Chamber assembly (prefire), lb	36.65	36.98	36.91	37.28	37.66	37.60	37.75	37.34
Chamber assembly (postfire), lb	33.44	33.49	33.55	33.80	34.35	34.10	34.03	33.63
Total insulation loss, lb	3.21	3.49	3.36	3.48	3.31	3.50	3.22	3.71
Insulation loss, %	25	28	26	27	26	27	25	29

[a]Toluene diisocyanate (TDI) is the insulation rinse solution absorbed prior to propellant loading.

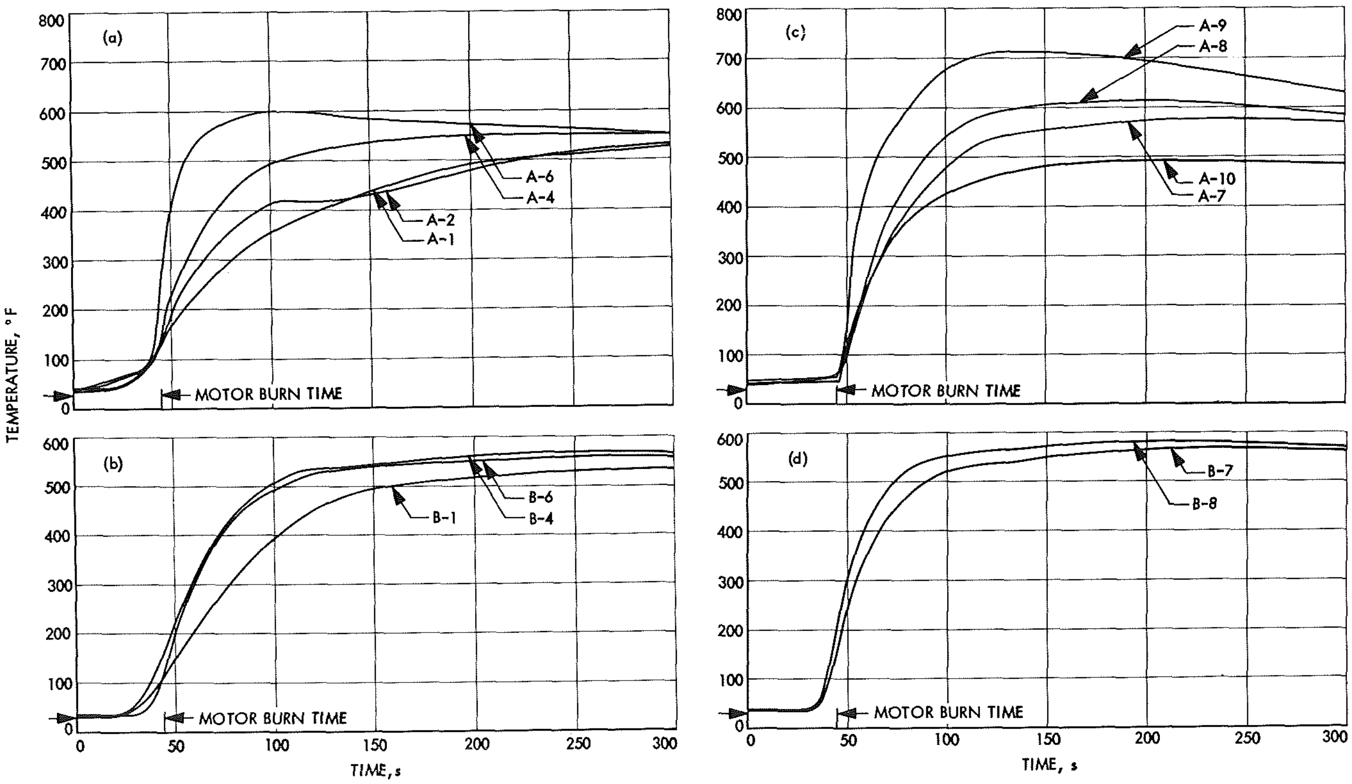


Fig. 11. Comparison of thermocouple data at 40°F for qualification motor Q-5T

Figure 12 presents a comparison of temperature data for the critical thermocouples A-6 and B-8 on qualification motors, Q-5T and Q-8T, fired at 40 and 100°F.

An additional quantity of insulation in the titanium chamber dome sections is required to reduce case temperatures during motor operation. The yield strength of 6AL-4V titanium decreases rapidly at elevated temperatures and is also initially lower (150,000 vs 180,000 psi) than 410 steel.

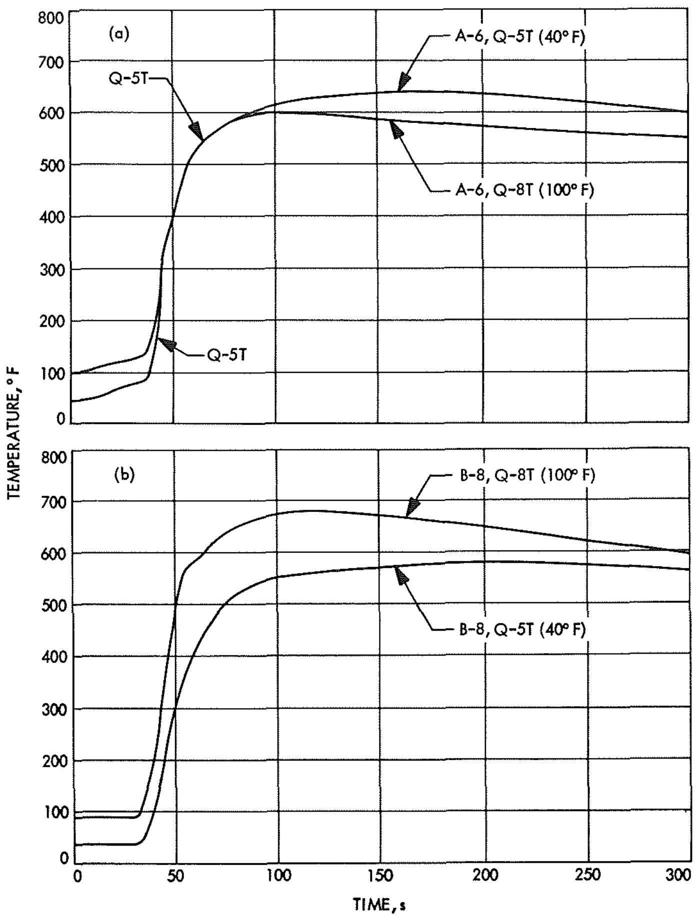


Fig. 12. Comparison of thermocouple data for qualification motors Q-5T and Q-8T

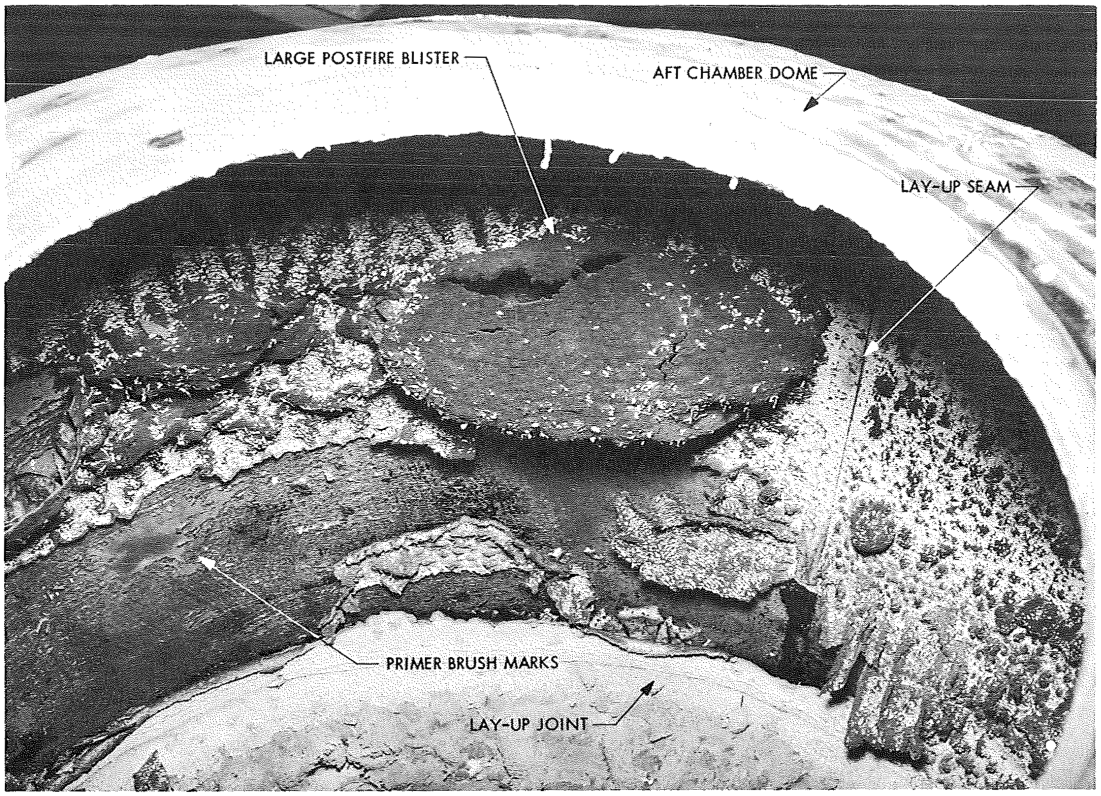
The stress in the titanium chamber at peak motor operating pressure would approach the elevated temperature yield strength of titanium if the unit were allowed to reach the same temperature (350°F) as the steel case. The criterion for evaluating this insulation design is based on the margin of safety between the actual working stress in the chamber and the titanium yield strength at the operating temperature. Figure 6 depicts a typical burn-time curve. This figure shows that the insulation of configuration 2 provides adequate chamber temperature control during the motor burning phase.

The additional insulation required for the titanium chamber helps to maintain postfire dynamic balance requirements, since some virgin insulation material remains and tends to adhere symmetrically to the chamber surface. Configuration 2 was used for all qualification and flight units.

After firing one of the motor qualification units at AEDC under spin and altitude environments, the nozzle was removed to examine the insulation. The insulation was charred along with evidence of large insulation blisters. The majority of the material was intact except for a small quantity that had fallen from the wall after cooldown. Figures 13–15 show the condition of this particular unit.

After static test at AEDC, each unit was weighed to determine the amount of insulation lost during motor operation. Table 4 summarizes the prefire and postfire chamber weights and the resulting loss in insulation weight.

TOP VIEW



BOTTOM VIEW

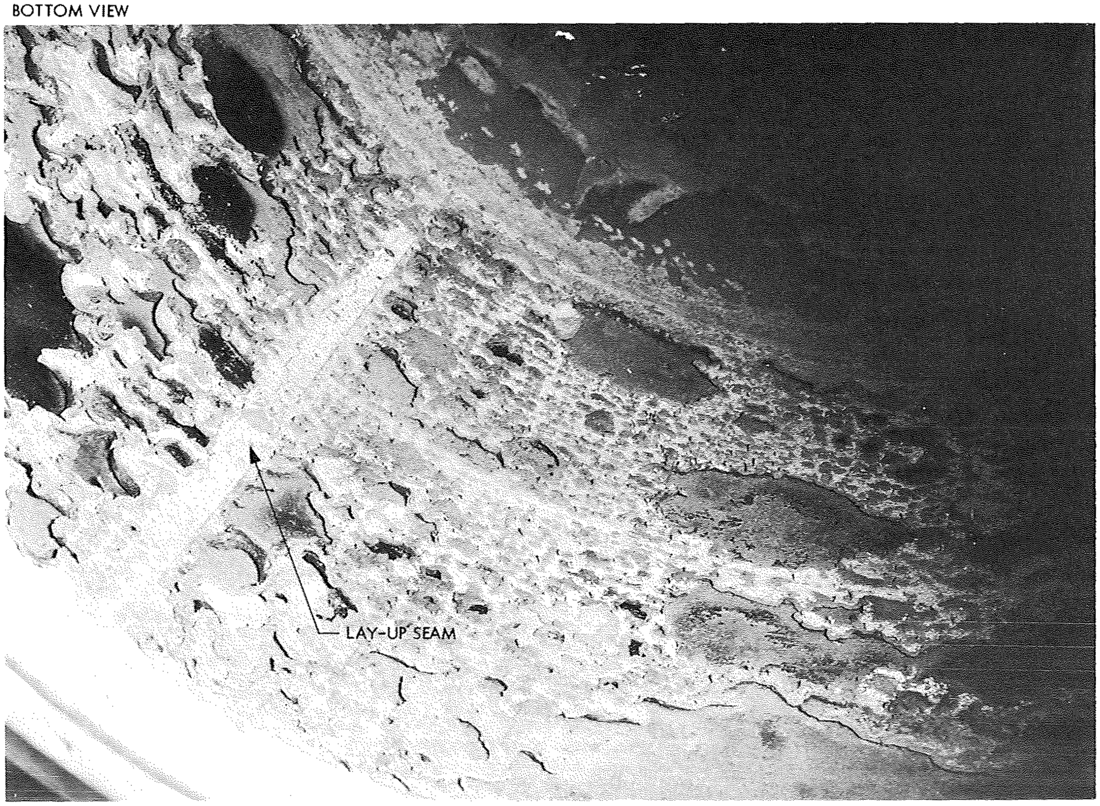


Fig. 13. Postfire condition of insulation, cylindrical section

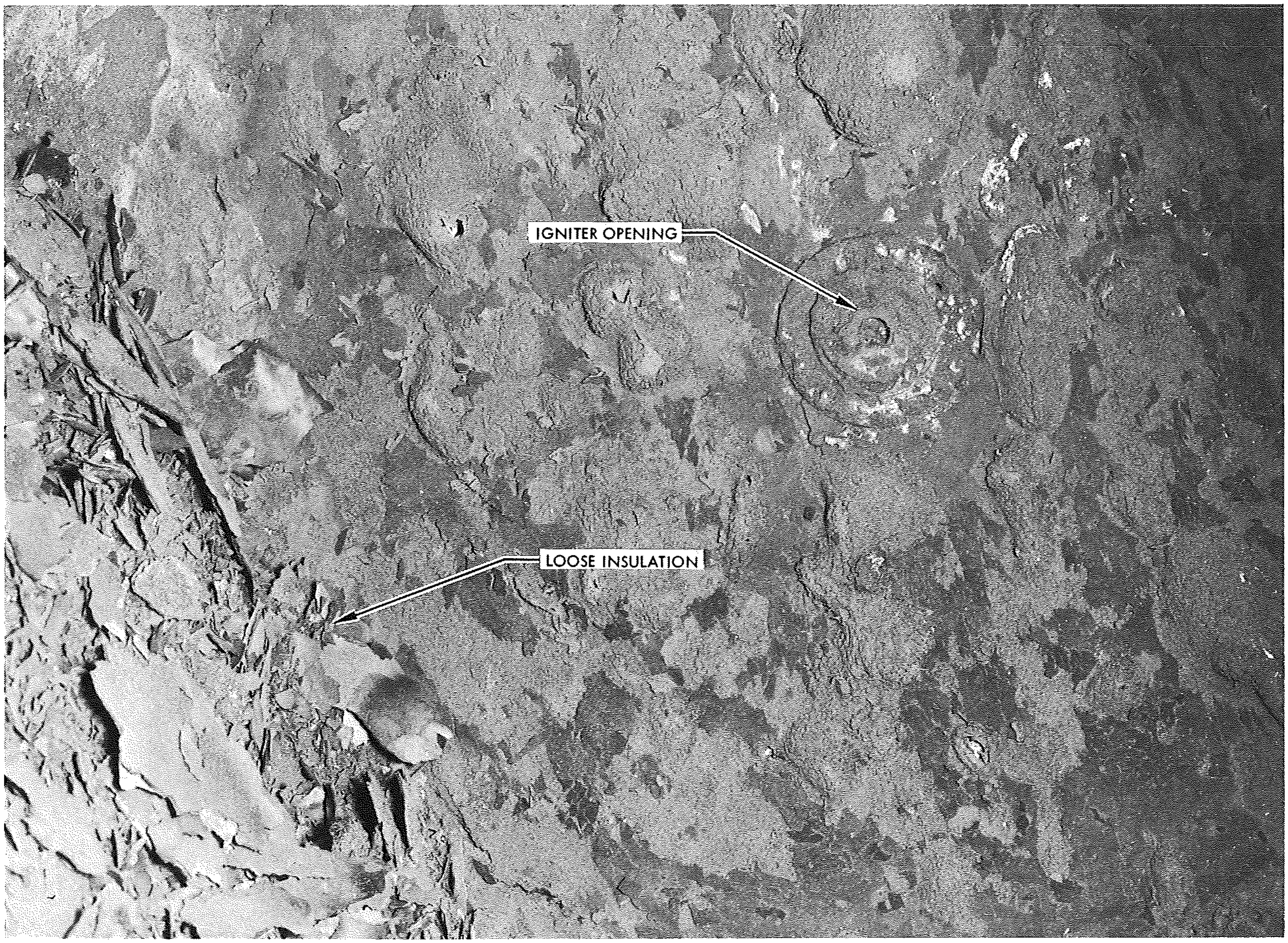


Fig. 14. Postfire condition of insulation, forward-end dome

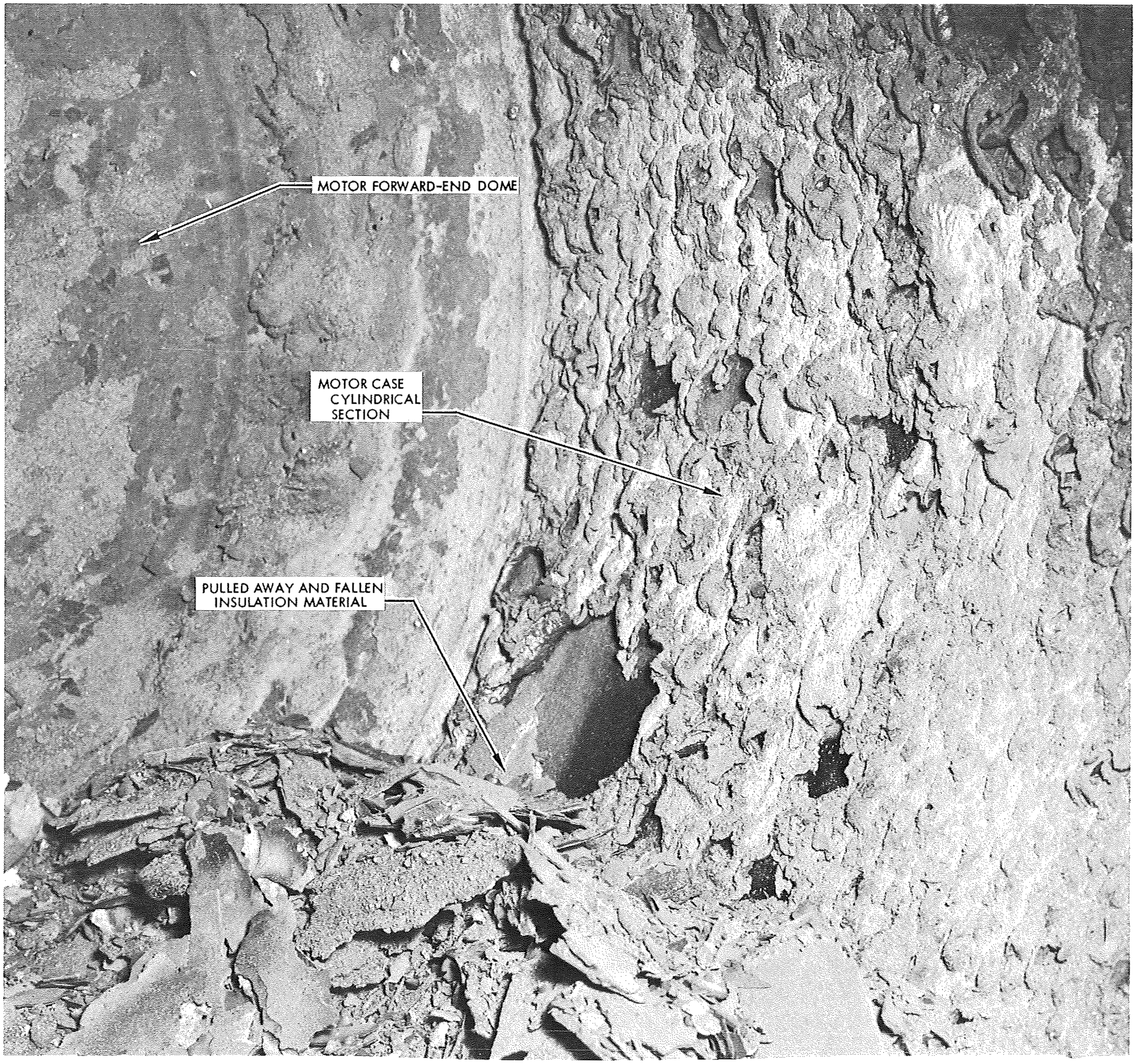
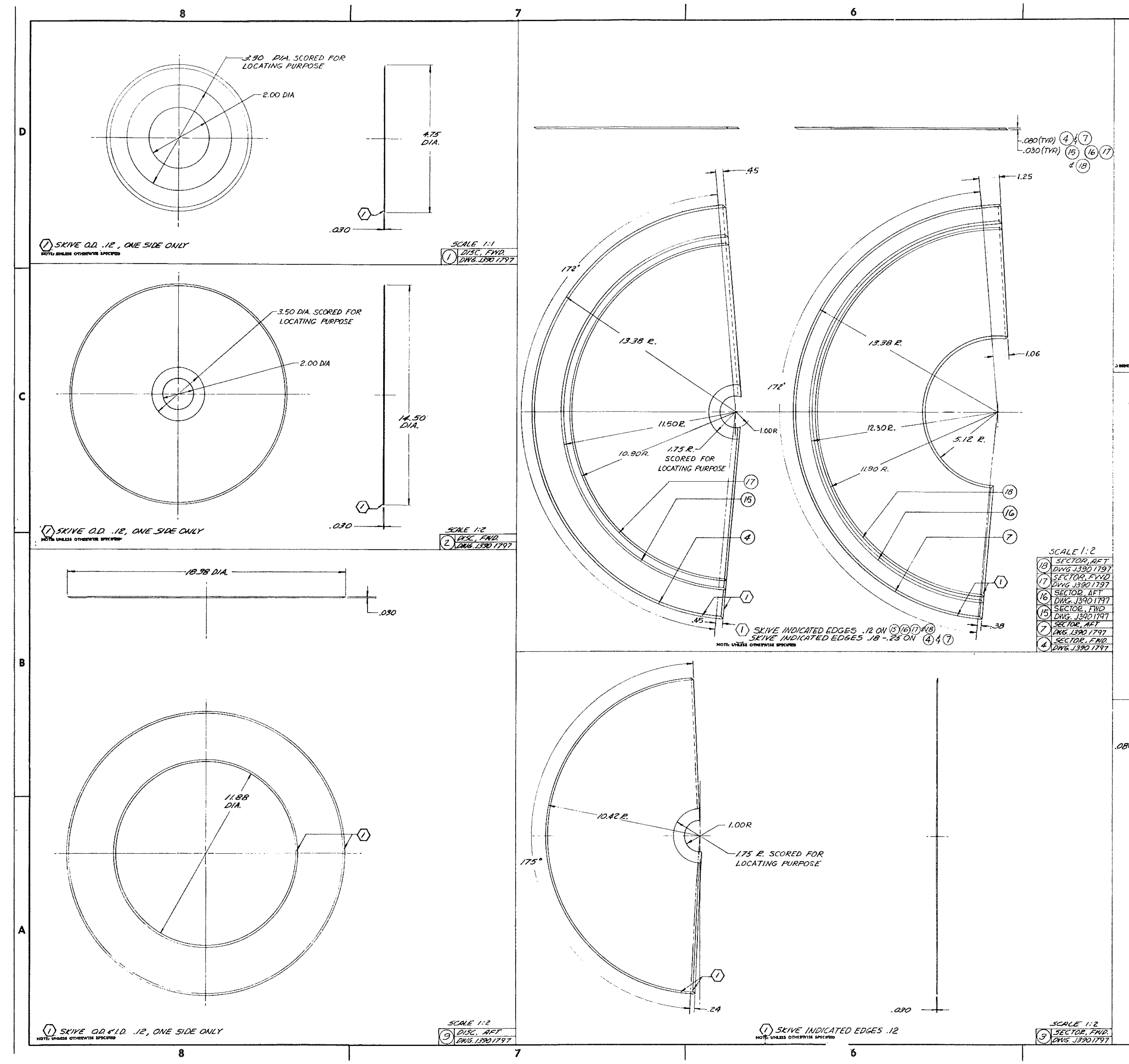


Fig. 15. Postfire condition of motor case insulation

Appendix A
Chamber Insulation Design Drawings


3.50 DIA. SCORED FOR LOCATING PURPOSE
2.00 DIA
4.75 DIA.
.030
SKIVE O.D. .12, ONE SIDE ONLY
NOTE: UNLESS OTHERWISE SPECIFIED
SCALE 1:1
1 DISC, FWD. DWG. J390 1797
3.50 DIA. SCORED FOR LOCATING PURPOSE
2.00 DIA
14.50 DIA.
.030
SKIVE O.D. .12, ONE SIDE ONLY
SCALE 1:2
2 DISC, FWD. DWG. J390 1797
18.38 DIA.
.030
11.88 DIA.
SKIVE O.D. & I.D. .12, ONE SIDE ONLY
SCALE 1:2
9 DISC, AFT DWG. J390 1797
.45
1.25
.080 (TYP) 4 & 7
.030 (TYP) 15 16 17 & 18
172°
13.38 R.
11.50 R.
10.90 R.
1.00 R
1.75 R. SCORED FOR LOCATING PURPOSE
17
15
4
1
.45
13.38 R.
1.06
12.30 R.
5.12 R.
11.90 R.
18
16
7
.38
SKIVE INDICATED EDGES .12 ON 15 16 17 & 18
SKIVE INDICATED EDGES .18 - .25 ON 4 & 7
SCALE 1:2
18 SECTOR, AFT DWG. J390 1797
17 SECTOR, FWD. DWG. J390 1797
16 SECTOR, AFT DWG. J390 1797
15 SECTOR, FWD. DWG. J390 1797
7 SECTOR, AFT DWG. J390 1797
4 SECTOR, FWD. DWG. J390 1797
10.42 R.
175°
1.00 R
1.75 R. SCORED FOR LOCATING PURPOSE
.24
.030
SKIVE INDICATED EDGES .12
SCALE 1:2
3 SECTOR, FWD. DWG. J390 1797
.080
8
7
6
D
C
B
A

- 2 -

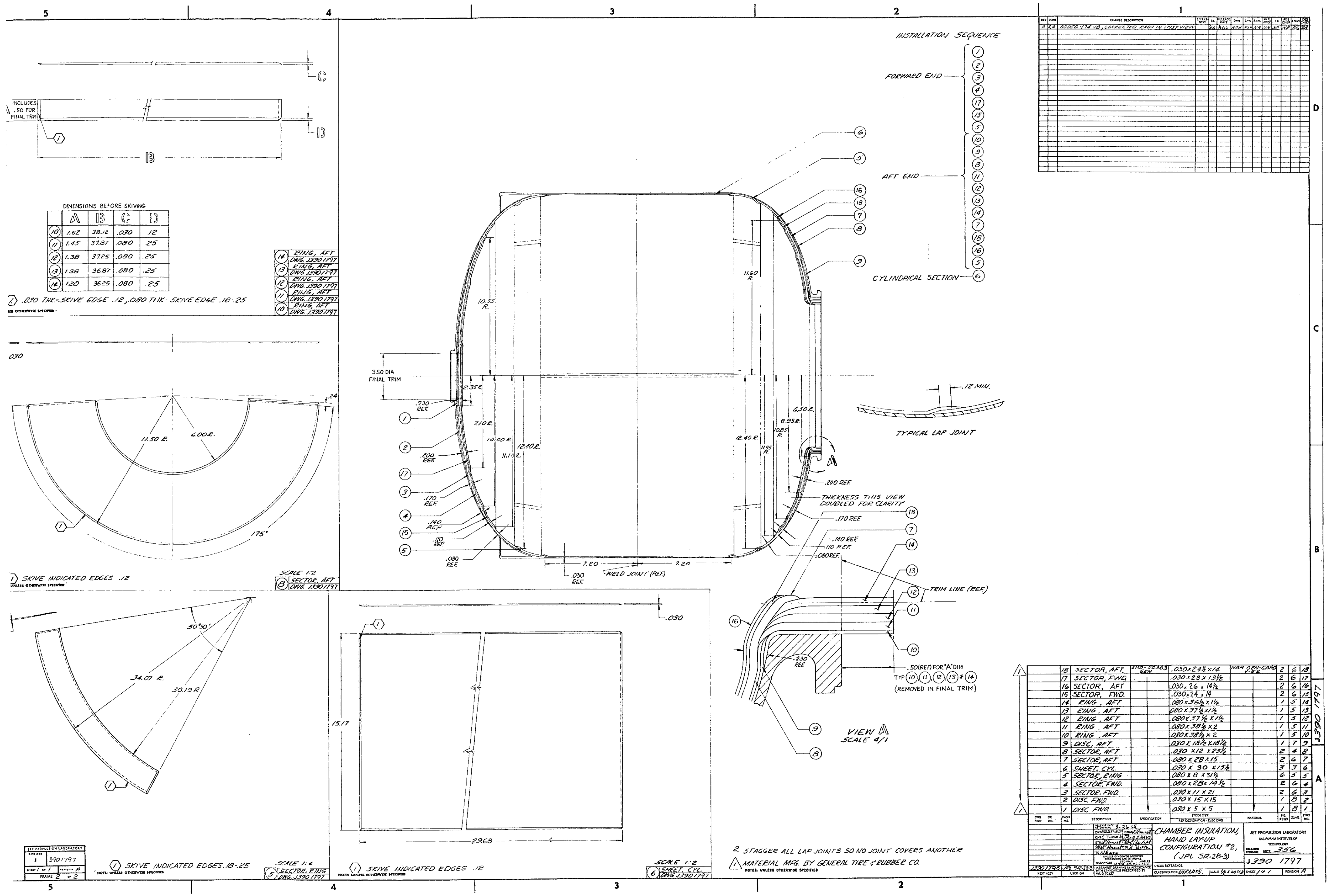


Fig. A-1. Insulation configuration number 2

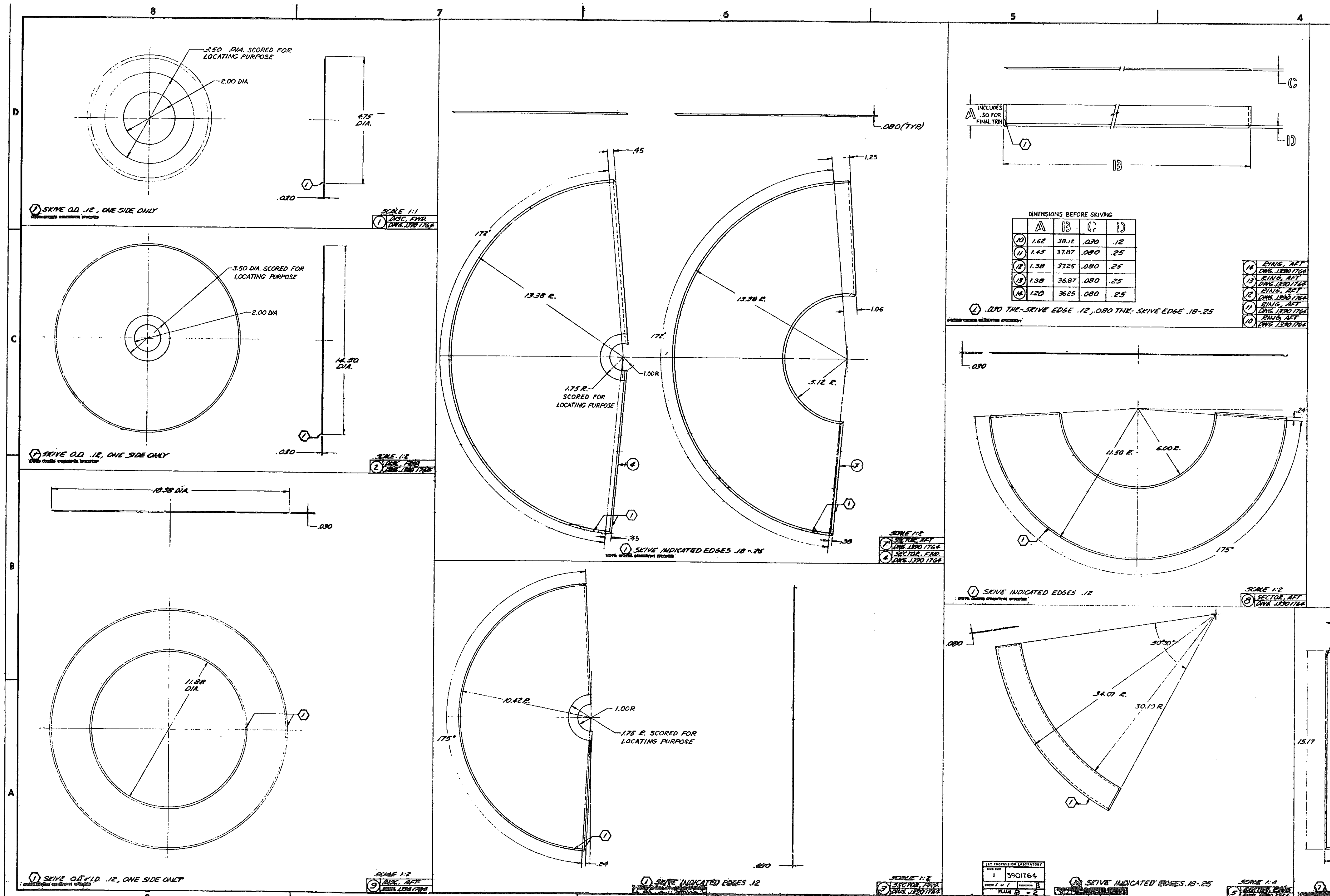
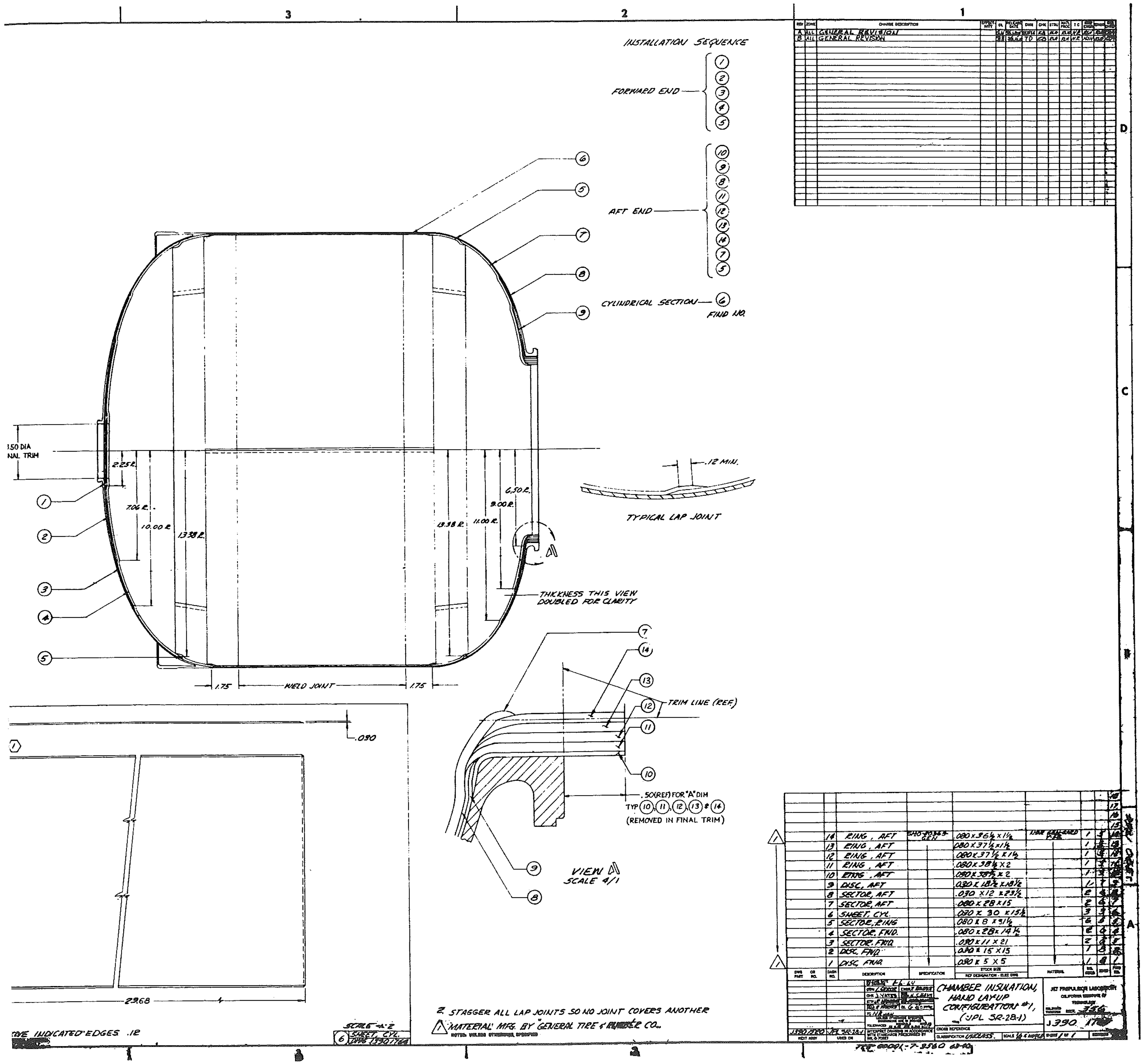


Fig. A-2. Insulation configuration number 1

-2-


INSTALLATION SEQUENCE
FORWARD END
AFT END
CYLINDRICAL SECTION
FIND NO.
TYPICAL LAP JOINT
.12 MIN.
THICKNESS THIS VIEW DOUBLED FOR CLARITY
WELD JOINT
TRIM LINE (REF)
.50(REF) FOR "A" DIM
TYP (10) (11) (12) (13) & (14)
(REMOVED IN FINAL TRIM)
VIEW A
SCALE 4/1
2. STAGGER ALL LAP JOINTS SO NO JOINT COVERS ANOTHER
MATERIAL MFG. BY GENERAL TIRE & RUBBER CO.
14 RING, AFT .080 x 36¼ x 1½
13 RING, AFT .080 x 37¼ x 1½
12 RING, AFT .080 x 37½ x 1½
11 RING, AFT .080 x 38¼ x 2
10 RING, AFT .080 x 38¾ x 2
9 DISC, AFT .030 x 18½ x 18½
8 SECTOR, AFT .030 x 12 x 23½
7 SECTOR, AFT .080 x 28 x 15
6 SHEET, CYL .080 x 30 x 15½
5 SECTOR, RING .080 x 8 x 9½
4 SECTOR, FWD. .080 x 28 x 14½
3 SECTOR, FWD. .030 x 11 x 21
2 DISC, FWD. .030 x 15 x 15
1 DISC, FWD. .030 x 5 x 5
CHAMBER INSULATION, HAND LAYUP CONFIGURATION #1, (JPL SR-28-1)
JET PROPULSION LABORATORY
GENERAL REVISION

Appendix B
Chamber Insulation Specification

SPECIFICATION AMENDMENT

JET PROPULSION LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY • PASADENA, CALIFORNIA

GENERAL SPECIFICATION
INSULATION OF METAL ROCKET MOTOR CHAMBERS
USING NBR GEN-GARD MATERIALS
(HAND LAY-UP, CURE IN-PLACE METHOD)

JPL SPEC GMO-50363-GEN

AMENDMENT 1

DATE: 19 November 1964

PAGE 1 OF 1 PAGES

1) Change page 10, paragraph 4.1, to read as follows:

"4.1 In-process inspection. The contractor shall be responsible for maintaining all records and performing all necessary quality control inspections of the finished assembly and during the manufacture of the unit to assure compliance with all requirements specified herein. All materials, subassemblies or assemblies which deviate from the requirements of this specification shall be submitted to JPL for acceptance or rejection. The JPL source inspector shall make in-process inspections as necessary to verify that proper quality assurance measures are being taken."

2) Change page 10, paragraph 4.2, to read as follows:

"4.2 Final inspection. The contractor shall perform a final inspection of each unit and a review of in-process data in the presence of the JPL source inspector to assure compliance with the requirements of this specification."

REMARKS:

RELEASE:	APPROVED:	APPROVED:	PREPARED BY:
G. Inouye			Richard L Haserot
G. Inouye			R. L. Haserot

JPL SPEC GMO-50363-GEN

DATE: 7 October 1964

ENGINEER: Richard L Haserot
R. L. Haserot

RELEASE: J. Ryciak
J. Ryciak

GENERAL SPECIFICATION
INSULATION OF METAL ROCKET MOTOR CHAMBERS
USING NBR GEN-GARD MATERIALS
(HAND LAY-UP, CURE IN-PLACE METHOD)

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

PAGE 1 OF 11 PAGES

1. SCOPE

1.1 Scope. This specification describes the process for the insulation of metal rocket motor chambers by the hand lay-up and cure in-place method using unvulcanized calandered NBR GEN-GARD materials.

1.2 Description. NBR GEN-GARD materials are butadiene-acrylonitrile rubber base products manufactured by the General Tire and Rubber Company, Akron 9, Ohio.

2. APPLICABLE DOCUMENTS

2.1 The following documents, of the issue in effect on the date of invitation for bids, form a part of this specification to the extent specified herein:

SPECIFICATIONS

General Tire and Rubber Company

1627	NBR GEN-GARD V-44
1628	NBR GEN-GARD V-45
1990	NBR GEN-GARD V-52

American Society for Testing and Materials

ASTM D676

DRAWINGS

(Applicable drawings showing insulation configuration and details will be specified for each type chamber to be insulated and will be listed in other appropriate documents.)

3. REQUIREMENTS

3.1 General.

3.1.1 Conflicting requirements. Any conflicting requirements arising between this specification and any specification or document listed herein shall be referred in writing to the Jet Propulsion Laboratory (JPL) for interpretation and clarification.

3.1.2 Requests for deviation. Any deviation from the requirements of this specification or from the drawings, specifications, publications, materials and processes specified herein shall be considered a change or deviation and shall not be allowed except by written authorization from JPL.

3.1.3 Parts, equipment and processes. Parts, equipment and processes employed shall conform to the documents specified herein. When a definite part, equipment or process is not specified, the selection for each application shall be suitable for the intended use.

3.1.4 Materials. All materials shall conform to the requirements of the applicable material specification listed herein.

3.1.4.1 Quality and condition of materials. All materials shall be sound, of uniform quality and condition. Insulation material shall be free of voids, cracks, and delaminations which might harmfully effect the strength, endurance or wear of the finished product. No uncalandered GEN-GARD material shall be used which has been unrolled for more than 24 hours.

3.1.4.2 Material shelf life. No material shall be used which has a shelf life greater than that specified in the applicable material specification.

3.1.4.3 Material certification. No roll of material shall be used until an appropriate certification of conformance for the specific roll of material has been received from the material supplier.

3.1.5 Damage to chamber. Any damage to any portion of the chamber such as cracks, dents, scratches or any other condition which might cause rejection of the assembly for its intended use must be reported immediately to JPL. All insulation work on the chamber shall cease and the unit shall be placed in bonded storage until dispostion is received from JPL.

3.2 Insulation process.

3.2.1 Chamber cleaning. The inside surfaces of the chamber to which the insulation material will be applied, shall be thoroughly cleaned and degreased. This operation will be performed at JPL. The chamber will arrive at the insulating facility cleaned and ready for priming and packaged in a polyethylene bag.

Note: To prevent contamination, the chamber shall not be removed from the protective plastic bag until immediately prior to priming.

3.2.2 Preparation of metal surface for bonding. The metal surface shall be prepared in the following manner:

a. Apply one uniform brush coat of Thixon P-4 primer to the clean metal surfaces and allow it to dry for 30 minutes at ambient conditions or until all the solvent has evaporated. Thixon P-4 primer should be applied with a minimum thickness of 0.003 inches.

Notes:
1. Thixon primers and cements are manufactured by the Dayton Chemical Products Company, West Alexandria, Ohio.
2. Mix the primer thoroughly before applying.
3. It may be necessary to increase the 30 minute drying periods mentioned above and in subsequent paragraphs when the relative humidity is high, or when excessive amounts of primer, cement, or solvents have been used, or when the ambient temperature is below 70°F.

b. Apply a second uniform brush coat of Thixon P-4 primer, brushing at right angles to the first coat, and allow it to dry for 30 minutes at ambient conditions or until all the solvent has evaporated.

c. Apply one uniform brush coat of Thixon XO-1209 cement over the primer coats and allow it to dry for 30 minutes at ambient conditions or until all the solvent has evaporated.

d. For the above operations weigh the primer and cement can plus the brush before and after the operation to determine the exact amount of material applied to the chamber.

e. The above operations shall take place not more than 24 hours prior to installation of the unvulcanized material.

3.2.3 Preparation of unvulcanized material. Patterned pieces for the lay-up should be cut from the appropriate unvulcanized GEN-GARD material according to the applicable drawings. The patterned pieces should be cut from material that is free of all defects such as wrinkles, voids, delaminations, foreign matter, etc.

3.2.3.1 Scrubbing. All surfaces and edges of the unvulcanized patterned pieces, that are to be bonded to metal or mated to other pieces of material in the lay-up, should be scrubbed with clean cloths that are wet but not dripping with methyl ethyl ketone (MEK), and simultaneously or immediately thereafter scrubbed with a brush.

Notes:

1. MEK may be purchased from any supplier of solvents. Commercial grade MEK is satisfactory as long as no trace quantities of impurities are left after evaporation. Safety precautions applicable to inflammable solvents like MEK should be observed.
2. Examples of acceptable brushes for the scrubbing operation are:
   (a) Hand Type Wire Brush #4768 made by Fuller Brush Company.
   (b) Shoe Handle Brush #418, Catalogue 60, with 0.022 inch diameter nylon bristles made by The Manufacturers Brush Company.

Notes: 3. Care shall be exercised in all subsequent operations to prevent contamination of the scrubbed edges and surfaces because of possible adverse effects on adhesion.

3.2.4 Lay-up technique for unvulcanized material. The technique is as follows:

a. The scrubbed patterned pieces should be used in the lay-up within four hours, but not until after all traces of MEK have evaporated.

Note: Approximately 30 minutes at ambient temperature and relative humidity are usually sufficient for all drying operations.

b. The scrubbed patterned pieces should be assembled together carefully to insure that all air is expelled from between the mating surfaces and edges. The pieces should be thoroughly stitched together with appropriate rubber-working tools.

c. The patterned pieces should be placed on the structure or substrate in such a manner that the largest patterned pieces will be the first pieces exposed to the end environment in the finished article or as specified in applicable drawings.

d. The edges of the patterned pieces should be skived or scarfed at a low angle, approximately 45°, or as indicated in applicable drawings.

e. The edges of the patterned pieces in any one layer should overlap a minimum of 1/4-inch, or as indicated on applicable drawings.

f. The workability of the unvulcanized material may be increased by heating to 100°F. The material may be held at this temperature for several hours with no detrimental effects.

3.2.5 Bleeder ply. The outermost ply of the lay-up should be completely covered with a bleeder cloth ply. The bleeder material should be cut in patterned pieces and placed over the lay-up in such a manner that there are no wrinkles which would leave impressions in the finished part. The cloth should be treated with a noncontaminating release agent such as teflon or soap solution. Silicone containing release agents shall not be used.

Note: "Quilon" C and "Quilon" M treating solution have been found to be effective noncontaminating bleeder cloth release agents which permit the bleeder cloth to be reused numerous times without further treatment. "Quilon" C and "Quilon" M are products of the E. I. DuPont DeNemours and Company, Wilmington, Delaware. Consult DuPont Products Information Bulletin A 29486 for details.

3.2.6 Vacuum bag. The lay-up and the bleeder ply should be completely encapsulated in a vacuum bag using standard vacuum bagging technique. A minimum of one vacuum port should be installed in the vacuum blanket. It should be so located and constructed that the bleeder cloth and unvulcanized GEN-GARD material will not be drawn into the port opening. The purpose or effectiveness for the vacuum port will be negated if the port is blocked.

3.2.7 Evacuation. A vacuum of a minimum of 24 inches mercury should be applied at room temperature to the vulcanized lay-up for a minimum of two hours before vulcanization. The longer the vacuum is held, prior to vulcanization, the better are the chances that all residual air will be removed from the lay-up and the better are the chances of producing a nondelaminating part.

3.2.8 Vulcanization. Vulcanization may be accomplished in any vessel capable of tolerating the required pressure and temperature. Steam or electrically heated autoclaves are acceptable. In addition, the following shall be observed:

a. A minimum pressure of 100 psi shall be maintained on the part throughout the entire vulcanization cycle. In addition, a vacuum of a minimum 24 inches mercury shall also be maintained on the vacuum bag.

b. The temperature at the center of the autoclave shall be raised to 205 ±10°F and held at this temperature for a minimum of 1 hour.

c. After one hour at 205°F, the temperature of the autoclave shall be increased to 325 ±5°F and held at this temperature for 90 to 105 minutes.

d. The 100 psi minimum vulcanization pressure shall be maintained until the bond line has cooled to below 150°F.

3.2.9 Clean up, trimming and surface preparation. After the chamber has cooled to ambient temperature and the vulcanization pressure released, the vacuum bag and bleeder cloth should be removed and the following steps taken:

a. Remove excess cured insulation material from around chamber openings. Trim the insulation to final configuration as shown on applicable drawings. Knives or grinding tools may be used for this operation. However, extreme care shall be taken to avoid scratching or otherwise damaging the chamber surfaces.

b. The inside surface of the insulation shall be cleaned and free from all bleeder cloth, dirt or other contaminants.

c. The inside surface of the insulation shall be roughened thoroughly by sandblasting. During the sandblast operation the surfaces of the chamber openings shall be protected by masking.

d. The inside surface of the sandblasted insulation shall be scrubbed clean with acetone to remove all evidence of sand or other contaminants.

3.2.10 Precautions. The following precautions shall be observed:

a. The chamber is a highly stressed pressure vessel. Do not use sharp instruments on the chamber metal.

b. Do not rest the chamber on any surface which might scratch, dent or otherwise cause damage.

c. After the patterned pieces of unvulcanized insulation material have been scrubbed clean with MEK extreme care shall be taken so that they are not subsequently contaminated by dirt, grease or fingerprints. Clean, lint-free gloves shall be worn whenever handling the insulating material.

d. Whenever the cleaned chamber is out of the protective plastic bag the chamber openings must be covered as much as is practical to prevent contamination of the cleaned surface. Aluminum foil taped in place is an adequate cover.

e. The primed chamber shall be protected from contamination by covering the chamber openings as much as possible. During the drying operations the openings must be left uncovered.

f. Compounds containing silicone shall not be used for, or during, any operation covered in this specification. In addition, these compounds shall not be used in any work area where units are manufactured to meet the requirements for this specification.

g. The metal-insulation interface at the chamber openings shall be 100 percent firmly bonded.

3.3 Repairs and rework. Repairs or rework of any item in process or completed shall not be made without prior approval of JPL. Any item suggesting repair or rework shall be thoroughly documented for evaluation by JPL.

3.4 Identification. The identification of the completed insulation shall carry the same serial number as the chamber into which it was installed.

3.5 Records. It shall be the responsibility of the contractor to prepare and maintain all records necessary to insure compliance with this specification and the applicable drawings and a copy of these records shall be presented to JPL. These records shall include, but shall not be limited to, the following:

a. Material supplier certifications for all insulation materials, primers and cements.
b. Identification of all material used by type, roll, run, lot container number and shelf life expiration date as applicable.
c. Date and time data for all time dependent operations such as primer and cement application and drying time and evacuation time.
d. Vulcanization temperatures, times, and pressures.
e. All data obtained under the quality assurance provisions herein.

3.6 Workmanship. Each unit and corresponding records shall be examined to determine conformance with this specification, and to verify that the materials, manufacture, identification and records are suitable for the purpose intended and have been completed in a thorough and workmanlike manner.

4. QUALITY ASSURANCE PROVISIONS

4.1 Contractor responsibilities. The contractor shall be responsible for maintaining all records and performing all necessary quality control inspections of the finished assembly and during the manufacture of the item to insure compliance with all requirements specified herein. All materials, subassemblies or assemblies which deviate from the requirements of this specification shall be submitted to JPL for acceptance or rejection.

4.2 Final inspection. The contractor shall perform a final inspection of the item and a review of in-process data to insure compliance with the requirements of this specification.

4.2.1 Visual inspection. A visual inspection shall be made of the general workmanship of the completed insulation. Particular attention shall be paid to the inside surface of the insulation to assure that the surface is evenly roughened by sandblasting and that there are no splits, cracks or delaminations in the material or at the material seams or overlaps.

4.2.2 Chamber openings. A thorough inspection of the chamber openings shall be made to assure that there are no insulation separations, unbonded or weakly bonded areas at these openings. An attempt shall be made to push the insulation away from the metal using hand and finger pressure. Any indication of unbondedness in these areas shall be cause for rejection by JPL.

4.2.3 Shore A hardness test. The contractor shall perform a Shore A hardness test on the completed unit in accordance with ASTM test method D676. The acceptable range for Shore A hardness is 84 ±7. The test shall be made at all chamber openings, as practical.

4.3 Process and test equipment. Process and test equipment used shall be of sufficient quality and accuracy to permit conformance to the requirements of this specification. The contractor shall maintain adequate calibration of test equipment.

5. PREPARATION FOR DELIVERY

5.1 Serialization. Chamber insulation shall carry the same serial number as the chamber into which it is installed. The chamber serial number shall be assigned by JPL and will be firmly affixed to the chamber. This serial number shall be affixed to all records pertaining to the insulation.

5.2 Packaging. The completed insulated chamber shall be sealed in a plastic bag, and packaged in a suitable container which is strong enough to preclude damage during shipment.

6. NOTES

6.1 Intended use. It is intended that this insulation be used for internal thermal protection of solid propellant rocket motors.

Appendix C
Thermocouple Layout and Temperature Data

EXACT THERMOCOUPLE LOCATIONS ARE SHOWN ON JPL DRAWING J3901754

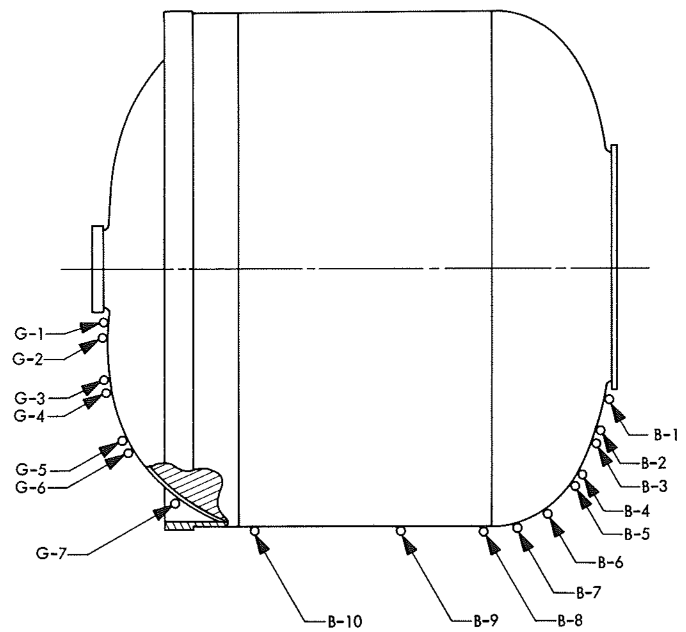


Fig. C-1. Thermocouple layout for qualification motor E-1 with 410 chromium steel chamber

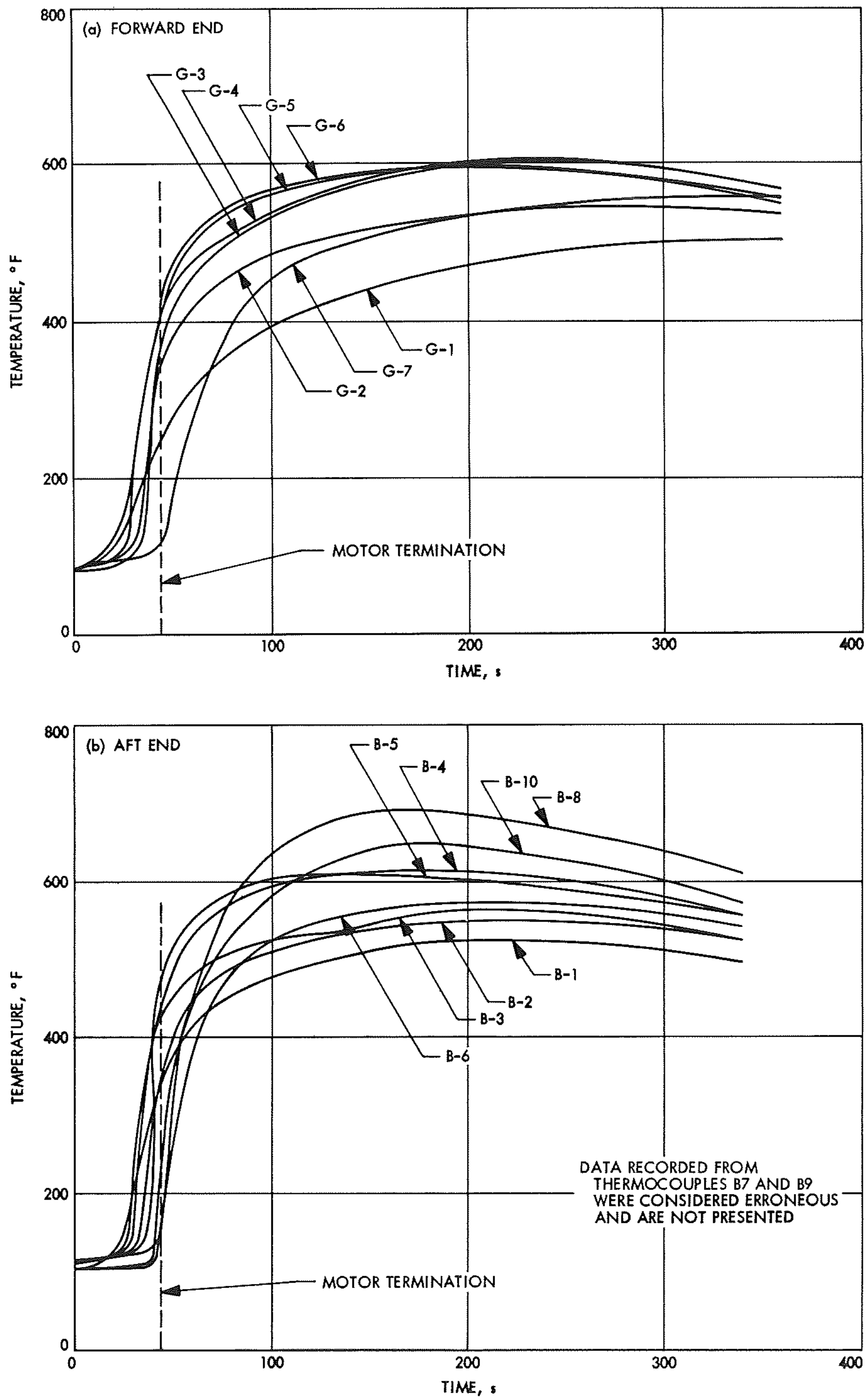


Fig. C-2. External case temperature for qualification motor E-1

Bibliography

Anderson, F. A., *Properties and Performance of JPL 540 Propellant,* Technical Memorandum 33-131. Jet Propulsion Laboratory, Pasadena, Calif., Apr. 30, 1963 (Confidential).

Anderson, R. G., *Applications Technology Satellite Apogee Motor (Description and Performance Characteristics),* Technical Memorandum 33-340. Jet Propulsion Laboratory, Pasadena, Calif., Jan. 1, 1968.

Anderson, R. G., Gin, W., and Kohorst, D. P., *The SYNCOM I JPL Apogee Rocket Motor,* Technical Memorandum 33-143, Revision 1. Jet Propulsion Laboratory, Pasadena, Calif., Sept. 16, 1963 (Confidential).

Cimino, A. A., and Stevenson, C. W., *Altitude Testing of a JPL-SR-28-1 Apogee Rocket Motor for the Advanced Technological Satellite Spacecraft (Preliminary Test Phase—Part II),* AEDC-TDR-64-259. Arnold Engineering Development Center, Arnold Air Force Station, Tenn., Dec. 1964.

Cimino, A. A., and Stevenson, C. W., *Results of the Qualification Test of Eight JPL SR-28-3 Rocket Motors at Simulated Altitude,* AEDC-TR-66-221. Arnold Engineering Development Center, Arnold Air Force Station, Tenn., Nov. 1966.

Domal, A. F., *Thermal and Dynamic Investigation of the Hughes ATS Spacecraft and Apogee Motor System at Simulated High Altitude (S/S Synchronous Spacecraft Thermal Model S/N T-4),* AEDC-TR-66-170. Arnold Engineering Development Center, Arnold Air Force Station, Tenn., Oct. 1966.

Fordyce, D. V., *Apogee Rocket Motor,* ATS No. S2-0153. Goddard Space Flight Center, Greenbelt, Md., June 10, 1965.

Frank, D. R., and Anderson, R. G., *Qualification Phase for the Applications Technology Satellite Apogee Rocket Motor,* Technical Memorandum 33-339. Jet Propulsion Laboratory, Pasadena, Calif., Sept. 15, 1967.

Grippi, R. A., *Design, Fabrication, and Testing of the Applications Technology Satellite Apogee Motor Nozzle,* Technical Memorandum 33-333. Jet Propulsion Laboratory, Pasadena, Calif., July 15, 1967.

Haserot, R. L., *SYNCOM Apogee Rocket Motor (Description and Performance Characteristics),* Technical Memorandum 33-176. Jet Propulsion Laboratory, Pasadena, Calif., July 1, 1964 (Confidential).

Lardenoit, V. F., Wada, B. K., and Kohorst, D. P., *Design, Fabrication, and Testing of the Applications Technology Satellite Apogee Motor Chamber,* Technical Memorandum 33-309. Jet Propulsion Laboratory, Pasadena, Calif., Nov. 1, 1966.

Lee, B. J., *Altitude Testing of a JPL-SR-28-1 Apogee Rocket Motor for the Advanced Technological Satellite Spacecraft (Preliminary Test Phase—Part I),* AEDC-TDR-64-207. Arnold Engineering Development Center, Arnold Air Force Station, Tenn., Oct. 1964.

Lee, T. P., *Handling Equipment for the Applications Technology Satellite (ATS) Rocket Motor,* Technical Memorandum 33-337. Jet Propulsion Laboratory, Pasadena, Calif., July 1, 1967.

Lee, T. P., *Ignition System for the ATS Rocket Motor,* Technical Memorandum 33-317. Jet Propulsion Laboratory, Pasadena, Calif., Feb. 1, 1967.

Bibliography (contd)

Stevenson, C. W., and Nelius, M. A., *Results of Testing Two JPL-SR-28-1 (S/Ns P-14 and P-15) Solid-Propellant Rocket Motors Under the Combined Effects of Simulated Altitude and Rotational Spin,* AEDC-TR-65-186. Arnold Engineering Development Center, Arnold Air Force Station, Tenn., Sept. 1965.

Supporting Research and Advanced Development, Space Programs Summaries 37-20 to 37-33, Vol. V. Jet Propulsion Laboratory, Pasadena, Calif., covering period of Feb. 1, 1963 to May 31, 1965 (Confidential).

Supporting Research and Advanced Development, Space Programs Summaries 37-34 to 37-41, Vol. IV. Jet Propulsion Laboratory, Pasadena, Calif., covering period of June 1, 1965 to Sept. 30, 1966.

Supporting Research and Advanced Development, Space Programs Summaries 37-43 to 37-45, Vol. IV. Jet Propulsion Laboratory, Pasadena, Calif., covering period of Dec. 1, 1966 to May 31, 1967.

Supporting Research and Advanced Development, Space Programs Summaries 37-47 to 37-49, Vol. III. Jet Propulsion Laboratory, Pasadena, Calif., covering period of Aug. 1, 1967 to Jan. 30, 1968.

Supporting Research and Advanced Development, Space Programs Summary 37-53, Vol. III. Jet Propulsion Laboratory, Pasadena, Calif., Oct. 31, 1968.

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