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260-SL-3 MOTOR PROGRAM

VOLUME I: 260-SL-3 Motor Internal Insulation System

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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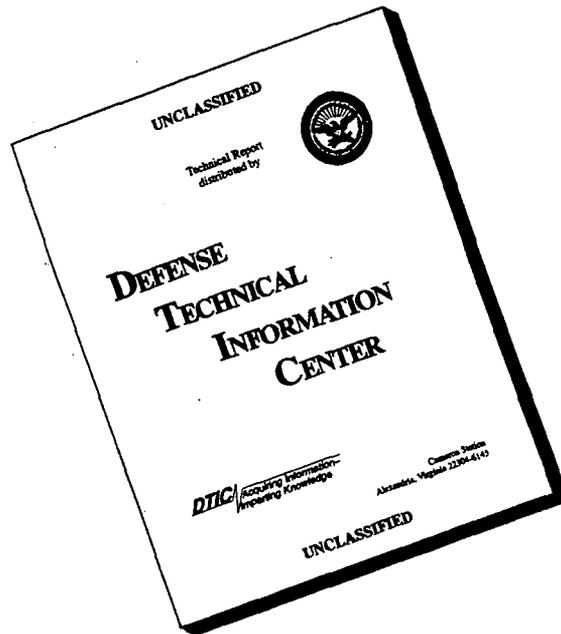
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FINAL PHASE REPORT

260-SL-3 MOTOR PROGRAM

VOLUME I

260-SL-3 MOTOR INTERNAL INSULATION

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

28 April 1967

Contract No. NAS3-7998

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AEROJET-GENERAL CORPORATION
A SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY

ABSTRACT

Motor 260-SL-3 was insulated with Gen-Gard V-44 rubber. The design configuration was based on the V-44 rubber thickness-loss-rate data obtained during the 120-SS-1, 260-SL-1, and -2 motor static test firings. Previously fired and rehabilitated forward and aft insulation from motor case, S/N 001 (motor 260-SL-1), were used in motor 260-SL-3. Unusable cylindrical-section rubber and damaged forward- and aft-head insulation were removed from the case. New cylindrical-section insulation, propellant boot, and aft-boot extension components were fabricated by layup of unvulcanized V-44 (or V-45) on a mandrel and cure in an autoclave. Repair of existing insulation and installation of new insulation components were accomplished by Aerojet personnel at the Aerojet-Dade Division (A-DD), Homestead, Florida. Insulation of motor 260-SL-3 was completed on 9 January 1967.

Report NASA CR-72228

TABLE OF CONTENTS

	<u>Page</u>
I. Summary	1
II. Introduction	2
A. Purpose of Report	2
B. Scope of Report	2
C. Program Status	2
III. Insulation Design	3
A. Requirements	3
B. Design Thickness	3
C. Insulation Plan	6
D. Insulation Design Description	7
IV. Process Evaluation	8
A. Effect of Rubber Surface Condition	11
B. Primer Condition	12
C. V-61/V-44 Bond Strength	12
D. Peel Strength	13
V. Rehabilitation of Existing Insulation	13
A. Prehydrotest Operations	13
B. Posthydrotest Operations	15
VI. Insulation Fabrication	16
A. Forward Insulation	16
B. Aft Insulation	16
C. Cylindrical-Section Insulation	17
D. Propellant Boots and Boot Extension	18
E. Firing Cap Insulation	18
VII. Component Installation	18
A. Replacement Aft Insulation Segment	19
B. Installation of V-61 into Insulation V-Grooves	19
C. Cylindrical-Section Insulation	21
D. Repair of Existing Forward and Aft Insulation	22
E. Reinstallation of V-61 into Insulation V-Grooves	22

TABLE OF CONTENTS (cont.)

	<u>Page</u>
F. Boot Installation	23
G. Seaming of Propellant Boots	23
H. Boot-Extension Installation	25
I. Final Operations	26
VIII. Conclusions	28
References	29

APPENDIX A

BOND STRENGTH EVALUATION PROCEDURES AND FLOW SHEET

FIGURE LIST

Figure

- 1 Gen-Gard V-44 Thickness Loss Rate Versus Gas Flow Mach Number
- 2 260-SL-3 Motor Chamber Insulation Design Thickness Contour
- 3 260-SL-3 Insulated Motor Chamber
- 4 Effect of Rubber Surface Condition
- 5 Plot of Epon 948.2 Adhesive Bond Strength as a Function of Fired Rubber Surface Thickness Removed
- 6 Plot of SD-850-2 Liner Bond Strength as a Function of Fired Rubber Surface Thickness Removed
- 7 Fuller 162-Y-22 Primer-to-Gen-Gard V-44 Epoxy Bond Strength and Gen-Gard V-61 to Gen-Gard V-44 Bond Strength Test Data Sheet
- 8 Gen-Gard V-44-to-Gen-Gard V-45 Epoxy Bond Peel Strength Test Data Sheet
- 9 Rehabilitated 260-SL Motor Case (S/N 001) for Motor 260-SL-3
- 10 Forward Insulation V-Grooves After V-61 Removal
- 11 Forward Insulation V-Grooves After V-61 Removal
- 12 Final 260-SL-3 Rehabilitated Forward Insulation Contour
- 13 Final 260-SL-3 Rehabilitated Aft Insulation Contour
- 14 Replacement Aft Insulation Segment Under Vacuum Cure
- 15 Aft Step-Joint Build-Up with V-61 Potting Insulation
- 16 Adhesive Application to Cylindrical Section Rubber Strip
- 17 Installation of Cylindrical Section Rubber Strip
- 18 Stitching Cylindrical Section Insulation Strip
- 19 Revised Aft Propellant Boot Extension Configuration

I. SUMMARY

The insulation effort in the 260-SL-3 motor program was directed toward applying the rubber fabrication and installation methods previously demonstrated in 260-SL motors to the insulation system for motor 260-SL-3.

The chamber was insulated with Gen-Gard V-44, an acrylonitrile butadiene, asbestos-fiber-filled rubber. The insulation configuration is based on V-44 rubber thickness-loss-rate data accumulated from the insulation performance observed during static test firings of 100-, 120-, and 260-in.-dia motors. To reduce program costs, the previously fired motor case, S/N 001 (formerly motor 260-SL-1), including the existing forward and aft insulation, was used for motor 260-SL-3. Unusable cylindrical section insulation and areas of damaged forward and aft-head rubber were removed.

The 260-SL-3 chamber insulation configuration is similar to that of the 260-SL-1 configuration. Damaged areas in the existing forward and aft insulation sections were repaired with cured V-44 rubber sheets, secondarily bonded in place. The eroded portion of the aft insulation at the step-joint was built up to its original configuration with Gen-Gard V-61 rubber potting insulation. The chamber cylindrical section was insulated with 0.20-in.-thick sheets of vulcanized V-44 rubber, secondarily bonded into the chamber with Epon 948.2 adhesive. The longitudinal and circumferential V-grooves between rubber strips were filled with V-61 material. The propellant boots are identical to the configuration used in the previous 260-SL motors.

New cylindrical-section insulation, propellant boots, and aft boot extension components were fabricated by the Goodyear Tire and Rubber Co., Akron, Ohio. Fabrication of these components employed the layup and autoclave cure technique previously demonstrated for the 260-SL motors.

I, Summary (cont.)

Installation of the new rubber components and rehabilitation of the existing insulation in the chamber were accomplished by Aerojet personnel at the Aerojet-Dade Division, Homestead, Florida. Insulation of motor 260-SL-3 was completed on 9 January 1967.

II. INTRODUCTION

A. PURPOSE OF REPORT

This is the first in a series of final phase reports to be issued as major phases of the 260-SL-3 motor program are completed.

B. SCOPE OF REPORT

This report summarizes the design, rehabilitation, fabrication and installation of the 260-SL-3 motor chamber insulation. The following program tasks are included:

1. Establishment of requirements for the internal insulation.
2. Description of the motor insulation design.
3. Completion of process evaluation test program and analysis of results.
4. Description of the rubber-component fabrication.
5. Description of the residual rubber rehabilitation.
6. Description of the rubber-component installation and residual rubber repair.
7. Conclusions

C. PROGRAM STATUS

Operations involved in insulating motor 260-SL-3 were completed on 9 January 1967. The motor is scheduled to be test fired in late June 1967.

III. INSULATION DESIGN

A. REQUIREMENTS

The 260-SL-3 motor-chamber internal-insulation system is required to provide thermal protection to the motor during web burning, tailoff, and afterburn prior to quench. State-of-the-art insulation materials were to be used.

B. DESIGN THICKNESS

The 260-SL-3 chamber-insulation design is based on data obtained from the 44-in.-dia, 120-in.-dia, and 260-SL-1 and -2 motor static firings. The development history, processing, and performance of the insulation system in these motors are fully documented in Reference (1). The measured Gen-Gard V-44 rubber erosion data from these motors and motor 100-FW-2 (Reference (2)) are summarized in Figure 1; the observed rubber thickness loss rates (TLR) are plotted as functions of gas flow Mach numbers for various locations (area ratios) in each motor. The performance of Gen-Gard V-44 is quite consistent at the lower Mach numbers (<0.25) while at higher Mach numbers some data scatter is experienced. A nominal or average V-44 rubber TLR versus Mach number line was constructed from the available data and is included in Figure 1. This "design line" then was used to determine the rubber thickness requirements for motor 260-SL-3.

The insulation design thickness requirements were calculated as the product of thickness loss rate at full and reduced operating pressure, exposure time at full and reduced operating pressure, and a 2.0 safety factor, as shown below:

$$t = \text{S.F.} \left[(\theta_1)(\text{TLR}_1) + (\theta_2)(\text{TLR}_2) \right]$$

III, B, Design Thickness (cont.)

- where: t is design thickness, in.
 S.F. is safety factor, 2.0
 θ_1 is exposure time to full motor operating pressure
 (web burning time), sec
 TLR_1 is thickness loss rate at the Mach number of a
 local area ratio, in./sec
 θ_2 is exposure time at reduced pressure during tailoff
 and afterburn, sec
 TLR_2 is thickness loss rate at reduced pressure during
 tailoff and afterburn.

The exposure time is a function of web burning duration, propellant grain configuration, and propellant burning rate. Because the TLR is a function of motor operating pressure and gas velocity, each area of the motor was analysed separately to determine the local conditions to which the rubber was exposed. A summary of the internal chamber insulation design thicknesses is presented in Figure 2.

1. Forward-Head Insulation

Since a forward boot is used to reduce propellant grain stress, it must be assumed that the forward-head insulation is exposed to hot gases and flame throughout motor operation. However, gas velocity is very low in this area, such that the forward head insulation is subjected primarily to thermal degradation rather than erosion. The observed TLR of V-44 in this essentially stagnant region is 0.005 in./sec at full operating pressure and 0.0035 in./sec at reduced pressure. For a web duration of 75 sec, a 2.0 safety factor, and a tailoff/afterburn duration of 20 sec (tailoff duration reduced in 260-SL-3 due to utilization of inert slivers), the required forward rubber thickness is calculated as follows:

$$t_{fh} = 2.0 \left[(0.005)(75) + (0.0035)(20) \right] = 0.90 \text{ in.}$$

III, B, Design Thickness (cont.)

2. Cylindrical-Section Insulation

The cylindrical-section rubber is exposed only during tailoff and afterburn periods. Using the V-44 TLR observed in previous tests and a 20-sec tailoff/afterburn exposure time, the required thickness is determined as follows:

$$t_{cs} = 2.0 \left[(0.0035) (20) \right] = 0.14 \text{ in.}$$

3. Aft-Head Insulation

The determination of aft-head insulation thickness is more complex because of high-velocity gas flow, changes in contour of the exposed surfaces during motor operation, and varying exposure times. The design aft-head insulation thicknesses, summarized in Figure 2, are calculated as follows:

a. Diameters

Aft stations are established at convenient incremental diameters between the aft step-joint and the cylindrical section of the motor. Diametral increments of 10 in. were selected from the 170.0-in.-dia step-joint to the 260-in. diameter.

b. Area Ratio and Mach Number

After the flow area at each incremental diameter is determined, the local ratio of flow area to nozzle throat area (A/A^*) then is calculated. The average 260-SL-3 motor throat area during web action time was used ($A^* = 6295 \text{ sq in.}$). The local Mach number is obtained from compressible-flow tables for subsonic flow.

III, B, Design Thickness (cont.)

c. Thickness Loss Rate

Thickness loss rates corresponding to the computed local Mach numbers are obtained from Figure 1. Since the nominal operating pressure for motor 260-SL-3 is not significantly different from the operating pressures of the motors used to obtain the data in Figure 1, no correction factors are required.

d. Exposure Time

The exposure times at the local area ratios are shown in Figure 2.

e. Rubber Thickness

The design rubber thickness is calculated as the sum of the thickness required for both nominal and reduced pressure exposure times multiplied by the 2.0 safety factor, shown in Figure 2.

4. Propellant Boots

The propellant boots, manufactured from Gen-Gard V-45 rubber, are designed for exposure throughout the web burning duration. Since the web burning duration of motor 260-SL-3 is less than the previous 260-SL motors, the 0.25-in. boot thickness was not changed.

C. INSULATION PLAN

The 260-SL-3 motor-chamber internal-insulation plan is outlined in Reference (3). To minimize insulation costs for this motor, an initial

III, C, Insulation Plan (cont.)

decision was made to reuse the forward and aft insulation from motor 260-SL-2. However, because of a long afterburn and heat-soak following the 260-SL-2 motor static test, the forward insulation in this motor was heat-degraded throughout the entire rubber thickness (Reference (1), Section XI.A.1.) and was unusable as motor insulation. Consequently, the S/N 001 chamber from motor 260-SL-1 was selected as the 260-SL-3 motor chamber. The plan was to rehabilitate and repair the existing forward and aft insulation in the chamber; the cylindrical section insulation was to be removed and replaced with new V-44 rubber.

D. INSULATION DESIGN DESCRIPTION

The chamber internal-insulation design configuration is shown in Figure 3. The 260-SL-3 motor insulation configuration is similar to that of motor 260-SL-1, which is described in detail in Reference (1).

1. Forward-Head Insulation

The forward-head insulation for motor 260-SL-3 consists of residual forward-head rubber from motor 260-SL-1. As reported in Reference (1), approximately 0.25 in. of material was eroded during the 260-SL-1 motor test firing, so that 0.95 to 1.05 in. of usable insulation remained. The existing insulation thickness in the chamber is greater than the 0.90-in. required minimum design thickness.

2. Cylindrical-Section Insulation

The chamber cylindrical section was insulated with 32.5-in.-wide strips of 0.20-in.-thick autoclave-cured V-44 rubber, which were secondarily bonded longitudinally into the chamber with Epon 948.2 adhesive. The longitudinal and circumferential V-groove joints between the strips were filled with V-61 potting insulation.

III, D, Insulation Design Description (cont.)

3. Aft-Head Insulation

The aft-head insulation for motor 260-SL-3 consists of residual aft-head rubber from motor 260-SL-1. As reported in Reference (1), only the insulation near and at the aft step-joint was eroded during the firing. The eroded area was built up with V-61 material to the original 260-SL-1 configuration, which is 4.26-in. thick at the step-joint. The minimum required thickness for the 260-SL-3 motor at the step-joint is 4.10 in.

4. Propellant Boot

The forward and aft propellant boots are identical in thickness and configuration to the 260-SL-1 and -2 motor boots. Manufactured from V-45 rubber, the 0.25-in.-thick boots were secondarily bonded to the insulation with Epon 948.2 adhesive; the V-grooves between the boot segments were filled with Germax-cure-accelerated V-45 seam stock.

IV. PROCESS EVALUATION

No new materials or processes were used for the 260-SL-3 motor insulation system. Results from previous material and process tests reported in Reference (1) were applied to this program.

The current program called for rehydrotest of the chamber prior to processing. As a result, the existing forward and aft insulation was subjected to water absorption during hydrotest. Subsequently, the chamber interior was dried at $165 + 5^{\circ}\text{F}$ for 15 days. In an effort to evaluate the effectiveness of the planned post-hydrotest drying cycle, the Goodyear Tire and Rubber Company was directed to fabricate eight 6.0-in.-square, 2.0-in.-thick samples of Gen-Gard V-44 rubber. The sample blocks were laid up and autoclave cured in accordance with Aerojet specification AGC-36420; the completed sample block weights were

IV, Process Evaluation (cont.)

the same within ± 0.1 lb. The sample blocks were delivered to the A-DD quality control laboratory, dried, and initial weights were obtained. Prior to hydrotest, six of the sample blocks were attached to the hydrotest plug splash plate and suspended inside the 260-SL-3 motor case. After hydrotest, the blocks were returned to the quality control laboratory and "wet weights" were obtained. Three of the samples were returned to the chamber, and remained in the chamber during post hydrotest operations and the 15 day, $160 \pm 5^\circ\text{F}$ drying cycle. The remaining three samples, which were used as controls, were placed in the 180°F oven in the quality control laboratory. Following the 15-day drying cycle, the test and control samples were wrapped in moisture-proof polyethylene bags, cooled to ambient temperature, and weighed. The results were as follows:

<u>Sample No.</u>	<u>Initial Weight, gm</u>	<u>"Wet" Weight After Hydrotest, gm</u>	<u>Weight After Drying, gm</u>	<u>Percent Moisture Removed</u>
070 (Test)	2200.5	2207.8	2198.7	75
071 (Test)	2201.3	2208.8	2198.8	85
072 (Test)	2203.5	2210.1	2200.9	80
067 (Control)	2197.7	2205.0	2192.8	*
068 (Control)	2190.5	2199.0	2185.7	*
069 (Control)	2194.6	2201.1	1289.7	*

* Average of control samples assumed to be 100% moisture removal.

The weight loss of the samples exposed to the chamber drying cycle was to be 85% of the weight loss observed in the control samples. As shown in the foregoing table, two samples exhibited less than 85% moisture removal. However, all of the sample weights after drying were less than the initial weight, indicating that volatile material in the rubber was being removed along with moisture. It was apparent that any further drying would tend only to remove more volatile material from the rubber, and little, if any, further moisture removal would be achieved.

IV, Process Evaluation (cont.)

Prior to initiation of rubber component installation, it was necessary to evaluate:

A. The effect of the fired-insulation surface condition on liner and adhesive bond strength. The purpose was to determine the amount of residual rubber surface abrasion necessary during insulation rehabilitation.

B. The ability of Epon 948.2 adhesive to bond to Fuller 162-Y-22 primed steel after exposure to hydrotest fluid and to the 15-day drying cycle. The purpose was to determine whether sandblasting and repriming of chamber interior after hydrotest was necessary to achieve adequate bond strength between the primed chamber and the rubber insulation components.

C. The ability of V-61 potting insulation to bond to fired V-44 rubber after exposure to hydrotest fluid and to the 15-day drying cycle. The purpose was to determine whether other than normal rubber surface preparation was required to achieve an adequate bond between the V-61 seam material and the V-44 insulation.

D. The ability of Epon 948.2 adhesive to bond to fired V-44 rubber after exposure to hydrotest fluid and to the drying cycle. The purpose was to determine that an adequate bond could be achieved between the V-45 propellant boots and fired V-44 insulation.

In all tests, control specimens with unfired, unexposed material were prepared to provide a data-evaluation baseline.

Fired V-44 rubber was obtained from the S/N 002 chamber (motor 260-SL-2). Rubber samples were cut to the required size and subjected to hydrotest fluid at the pressure and for the duration expected during the actual motor chamber hydrotest cycle. The samples were then dried at $165 \pm 5^{\circ}\text{F}$ for 15 days.

IV, Process Evaluation (cont.)

Fuller 162-Y-22 primed steel plates were also exposed to hydrotest fluid and dried. The specified number of peel and double plate test (DPT) specimens were prepared for testing. The detailed procedures for preparation and testing of the specimens and the task flow sheet are presented in Appendix A.

A. EFFECT OF RUBBER SURFACE CONDITION

The first series of tests was made to determine the thickness of the fired rubber surface that must be removed to provide a bonding surface equivalent to the conditions experienced with new abraded rubber. A controlled amount of the fired rubber surface was removed; DPT specimens then were prepared, using both Epon 948.2 adhesive and SD 850-2 liner as the bonding materials. The detailed test results are shown in Figure 4. Plots of adhesive and liner bond strength as a function of the surface depth removed are presented in Figures 5 and 6, respectively. Although some data scatter was experienced, which is normal for DPT tests, the data trend was apparent and showed that 0.06 to 0.10 in. of fired rubber surface must be removed to obtain bond strength values equivalent to values exhibited by unfired rubber in previous tests. The type of specimen failure also indicated the necessity of surface removal. When the rubber surface was merely cleaned and abraded, failure occurred directly at the rubber-to-adhesive (or liner) interface. When the abrasion depth was 0.06 in. or greater, failure occurred in the rubber (with Epon 948.2) or in the liner material. The 0.06/0.10-in. rubber surface abrasion depth was incorporated into the procedure for rehabilitation of the residual insulation in the motor chamber.

As shown in Figures 5 and 6, the Epon 948.2 bond-strength values for the control samples were unusually low (319 to 407 psi), and were not significantly greater than the values obtained with the essentially unabraded fired rubber specimens. However, the control samples failed in the rubber and not at the rubber-to-adhesive interface, indicating the possibility that the rubber used in the control samples tended to delaminate during the DPT test. Unfired rubber samples were obtained from the warehouse at A-DD. As a result, the

IV, A, Effect of Rubber Surface Condition (cont.)

quality or previous use of the material could not be established. Fresh V-44 rubber sample material could not be obtained in time to complete the tests prior to the required processing date.

Bond strength values measured during tests previously conducted by Goodyear ranged from 450 to 600 psi. As a result, the Goodyear test results were used as an evaluation baseline for Epon 948.2 instead of the control sample data.

B. PRIMER CONDITION

Specimens were prepared and tested to evaluate the bond strength of Epon 948.2 to Fuller 162-Y-22 primed steel after exposure to hydrotest fluid and to the 15-day drying cycle. The test data are shown in Figure 7; the results indicate that no appreciable deterioration was exhibited in the ability of Epon 948.2 to bond to the exposed primer. The specimen failures for the most part occurred in the rubber. As noted in Figure 7, three failures occurred at the bondline between the primer and adhesive. However, in every instance, this type of failure was accompanied by evidence of a void or bubble in the epoxy. In specimen No. 053, visual inspection showed that approximately 0.18 sq in. of the surface was unbonded. The low strength value was due to the smaller effective bond area and the resulting uneven pull on the specimen during test.

The process planning specified use of the prehydrotest primed surface; based on the above test results, this plan appeared valid.

C. V-61/V-44 BOND STRENGTH

Specimens were prepared and tested to evaluate the ability of V-61 potting insulation to bond to fired V-44 rubber after exposure to hydrotest

IV, C, V-61/V-44 Bond Strength (cont.)

fluid and to the drying cycle. These test results are included in Figure 7. The data show no deterioration in the bond strength of V-61 to the fired V-44 rubber; failure of two control specimens and all of the test specimens occurred in the V-61. As noted in Figure 7, control specimen No. 056 failed at the V-61-to-V-44 interface, resulting in an abnormally low bond-strength value. This type of failure was indicative of either improper cleaning of the rubber surface or insufficient initial wetting of the rubber surface with V-61, which showed the necessity for rigid process control and surveillance during operations involving the use of V-61 material.

D. PEEL STRENGTH

Specimens were prepared to evaluate the peel strength of Epon 948.2 between new V-45 rubber sheet and fired, exposed V-44. The test data presented in Figure 8 showed no degradation in the peel strength. The ability to bond the V-45 propellant boots to the residual V-44 rubber insulation was adequately demonstrated.

V. REHABILITATION OF EXISTING INSULATION

The requirements for rehabilitation of the S/N 001 motor chamber for use in motor 260-SL-3 are shown in Figure 9. These requirements were translated into operating procedures, References (4) and (5).

A. PREHYDROTEST OPERATIONS

Prior to installing new rubber components, it was necessary to remove the unusable rubber and to clean the surfaces of the residual insulation.

V, A, Prehydrotest Operations (cont.)

The first step was to remove the remaining cylindrical-section insulation, epoxy adhesive, and primer. Removal was accomplished by placing a local heat source on the outside of the chamber. As the Epon 948 adhesive softened, the rubber and adhesive were scraped off to the primed surface with aluminum chisels. This operation was repeated until the entire cylindrical section was free of adhesive and rubber. The heat source consisted of six 1600-watt floor heaters mounted in a plywood shroud. Thermocouples were mounted on the chamber and used to limit the temperature to 250°F at the chamber wall.

Some rubber removal tests had been conducted on the existing forward and aft insulation in the S/N 001 chamber shortly after the 260-SL-1 motor test firing. These tests were conducted before the decision was made to use this chamber for motor 260-SL-3. Since some mechanical and chemical damage was incurred, it was necessary to remove approximately one full aft-insulation segment. In addition, two smaller sections in the forward and aft rubber were removed as a result of test damage. The previously described technique was employed to remove these sections of damaged forward- and aft-head insulation, except that hand rounters were used to cut grooves in the rubber to reduce the thickness and facilitate removal.

After rubber removal, the exposed chamber surfaces were gritblasted with MS-MH Type B glass beads. The nozzle was maintained at 90 degrees to the chamber with the tip 6 in. from the wall and was moved continuously at a uniform rate. At no time was the nozzle stopped while the gritblaster was operating. Also, the high-pressure hose was attached to the lighting and suspension truss approximately 4 ft from the chamber wall to prevent serious material removal in the event that the hose should break. Following extensive cleaning, including numerous solvent wash-downs, the metal was sprayed with Fuller 162-Y-22 epoxy primer.

V, A, Prehydrotest Operations (cont.)

After priming, the chamber was moved to the CCT facility and hydrostatically proof tested.

B. POSTHYDROTEST OPERATIONS

The first operation after the chamber was returned to the General Processing area was to remove the V-61 potting insulation from the forward and aft insulation segment V-grooves. This proved to be the most difficult operation. To use routers would be time consuming, and the use of electric saws presented the hazard of inadvertently contacting the metal surface. Hence, the material was manually removed by using rubber mallets and aluminum chisels. This technique resulted in cuts and gouges in the sides of the rubber V-groove, and total removal of the V-61 was not possible. A power sander was equipped with an aluminum saddle, extending approximately 0.13-in. beyond the abrasive wheel. The aluminum saddle was indexed on the chamber wall at the base of the V-groove and prevented the abrasive wheel from contacting the metal surface. This method was successful in removing almost all of the V-61 in the grooves. In inaccessible areas close to the chamber wall or where the V-groove base was narrow, traces of V-61 remained. Completed forward V-grooves are shown in Figures 10 and 11. After acceptance of V-61 removal, the metal at the base of the V-grooves was gritblasted to remove the primer, cleaned, and reprimed with Fuller 162-Y-22. In this limited access area, the primer was brush-applied to prevent contamination of the adjacent rubber.

Inspection of the primed metal surface in the chamber cylindrical section revealed several rust pockets where hydrotest instrumentation had been secured with Dow-Corning sealant (WS-1076). As hand-sanding proved to be ineffective in removing these rust pockets, these areas were gritblasted, cleaned, and reprimed.

V, B, Posthydrotest Operations (cont.)

The forward insulation surface from the boot-bond area to the cylindrical-section joint was abraded, using a power sander with a No. 80 grit abrasive wheel, with 0.06 to 0.10 in. of the surface removed. The surface of the forward insulation forward of the boot bond area was cleaned by wire brushing. The eroded section of the aft step-joint was ground to a smooth contour, using a power sander with a No. 36 grit abrasive wheel. The measured forward and aft insulation contours following rehabilitation operations are shown in Figures 12 and 13, respectively.

VI. INSULATION FABRICATION

Manufacture of the cylindrical-section insulation, propellant boots, aft-boot extension, forward insulation-joint doubler, and firing-cap insulation was accomplished by Goodyear, using the same fabrication techniques that were used for components of motors 260-SL-1 and -2. Since these fabrication techniques were defined in Reference (1), only changes or problem areas significant to the 260-SL-3 insulation-component manufacture are discussed.

A. FORWARD INSULATION

No forward insulation components were fabricated.

B. AFT INSULATION

No new aft insulation components were manufactured for this motor. However, since a section of aft rubber approaching the size of an aft segment had been removed, it was necessary to provide a method of insulating this area.

A review of insulation component records from the previous program revealed that an extra aft insulation segment had been manufactured for motor 260-SL-1. This segment, P/N 600307-15, S/N 260A-6, was fabricated to the

VI, B, Aft Insulation (cont.)

original or thin configuration (2.76-in. thick at the step-joint) used in motor 260-SL-2. The existing aft insulation in the S/N 001 chamber was 4.26-in. thick at the step-joint. Since the step-joint of the existing insulation was to be built-up to the original thickness with V-61, the decision was made to use the available aft segment as a replacement and to build-up its contour with V-61 material.

The segment had been in storage at Goodyear for about one year. The Shore A cure hardness at the time of manufacture was 78; the hardness after storage ranged from 80 to 83, indicating no significant deterioration had been experienced by the rubber. The segment was cleaned, buffed, dried, and shipped to A-DD for installation.

C. CYLINDRICAL-SECTION INSULATION

The cylindrical-section insulation was fabricated from V-44, calendered to a 0.100 ± 0.010 -in. thickness. The uncured stock was laminated to obtain 0.200-in.-thick strips. Three 256-in.-long and three 312-in.-long unvulcanized laminated strips were alternately wrapped on a cure mandrel, with a nylon separator between each strip. Three such wraps were made on each curing mandrel, so that nine 256-in.-long and nine 312-in.-long strips were obtained from each curing mandrel. The entire mandrel was encased in a blanket, and a vacuum was applied. The mandrel was placed in an autoclave, and the insulation was vulcanized at 310°F maximum. After cure, the vulcanized material was unrolled, visually inspected, spark-tested, and abraded. The strips were trimmed to obtain a 32.5 ± 0.12 in. width; the longitudinal edges then were machine-skived to 45 degrees. One 256- and one 312-in.-long strip were wrapped in a black polyethylene bag and packed in a shipping crate. A total of 26 crates, each containing a matched 256- and a 312-in.-long strip, were shipped to A-DD for installation.

VI, Insulation Fabrication (cont.)

D. PROPELLANT BOOTS AND BOOT EXTENSION

The forward and aft propellant boots were fabricated by laying up unvulcanized V-45 stock directly to a released mandrel surface. Four boots were laid up and cured at one time on one mandrel; nylon separator plies were used between each boot. This method was effective in reducing the cost and time required for boot fabrication.

Fabrication of the propellant boots and boot extension was complicated by the unexpected high shrinkage experienced during cure of the unvulcanized V-45 material. The measured shrinkage was as high as 10%, as compared with 2 to 4% shrinkage on previous components. As a result, a number of repairs were required, particularly in the boot extension. The excessive shrinkage was apparently the result of winding the unvulcanized V-45 stock too tightly on the shipping drum. To reduce shrinkage, the uncured stock was unrolled and allowed to relax for several days prior to layup. This condition did not affect the quality of these components, but did cause a delay in fabrication and necessitate an order for additional material.

E. FIRING CAP INSULATION

Fabrication and assembly of the forward firing cap insulation was conducted exactly as described in Reference (1).

VII. COMPONENT INSTALLATION

Installation requirements for the 260-SL-3 motor insulation are included in Figure 3. The operational procedure, Reference (6), was prepared to reflect the installation requirements. Installation of the 260-SL-3 motor insulation components was accomplished by Aerojet personnel at A-DD.

VII, Component Installation (cont.)

A. REPLACEMENT AFT INSULATION SEGMENT

Installation of the replacement segment, S/N 260A-6, was accomplished as planned. A heavy-gage aluminum-foil template was laid up in the area where the segment was to be installed. The template was removed, placed over the replacement aft insulation segment, and the segment was trimmed to the template configuration. The trimmed segment was moved into the chamber and checked for final fit. The sides of the segment were retrimmed where necessary, skived to 30 degrees using a power sander, and the bonding surface was abraded. Fifty lb of Epon 948.2 was mixed and applied to both the segment and chamber bonding surfaces. No. 1502 cotton bleeder cloth was applied to the chamber epoxy surface, and the segment was installed. Blankets were installed and dealed around the periphery, and vacuum was drawn. The adhesive was cured for 12 hr under 25-in.-Hg vacuum, as shown in Figure 14.

B. INSTALLATION OF V-61 INTO INSULATION V-GROOVES

The following four lots of V-61 material were procured for 260-SL-3 motor insulation operations:

<u>Lot No.</u>	<u>Quantity, lb</u>
<u>Component 1/Component 2</u>	
2618/2619	240
2440/2441	160
2568/2569	48
2620/2621	464*

*272 lb were ordered to replace the material lost because of improper cure.

It was decided to use lot No. 2618/2619 to fill the forward and aft insulation V-grooves, lot No. 2440/2441 to build up the aft step-joint, and lot No. 2620/2621

Report NASA CR-72228

VII, B, Installation of V-61 into Insulation V-Grooves (cont.)

to fill the cylindrical-section insulation V-grooves. Lot No. 2568/2569 was to be reserved for small repairs. Lot No. 2618/2619 material was mixed in 10-lb batches in the Semco mixer, using the required 60 strokes. Prior to weigh-out, the component 1 material was premixed. The mix pot was cleaned after each 10-lb batch was mixed; the dasher plate was cleaned after each third batch. The mixed material was dispensed from the mix pot into Semco cartridges under pressure, and then injected into the forward and aft insulation V-grooves with an air-powered caulking gun. As shown in Figure 15, the material was troweled into place to accomplish the aft step-joint buildup. Approximately 24 hr after completion of V-61 installation, it became evident that the material was not going to cure properly. The V-61 material normally attains about 85% of its final cure hardness 24 hr after mixing, although a 7-day cure is allowed. This lot of material still was soft to the touch 3 days after cure. Up to this point, 39 batches of material had been mixed and installed; the lot number, quantity, location, and hardness are summarized below.

<u>Lot No.</u>	<u>Quantity Mixed, lb</u>	<u>Location</u>	<u>7-Day Shore D Hardness</u>
2618/2619	230	Forward/aft V-groove and aft segment buildup	24 to 35
2568/2569	24	3 forward seams	41 to 55
2440/2441	140.0	Step-joint buildup	42 to 50

Since none of the lot No. 2618/2619 material cured properly, while all of lots No. 2440/2441 and 2568/2569 material did cure properly, it was evident that the problem was related to the material rather than the processing procedure. The material in the V-grooves and replacement aft-insulation segment buildup was rejected and removed.

VII, Component Installation (cont.)

C. CYLINDRICAL-SECTION INSULATION

Immediately after chamber hydrotest and drying, cursory visual and tape-test inspections were conducted to evaluate the condition of the cylindrical-section primed metal surface. The results indicated that no primer-to-case bond deterioration had occurred, which substantiated the results of the process evaluation test discussed in Section IV,B, of this report. However, several months later, and just prior to initiating the installation of cylindrical section insulation components, the surface was again inspected and tape-tested. The visual inspection revealed the presence of several areas where the primer was pitted. Further probing in these areas revealed a rust colored appearance, which indicated the beginning of possible corrosion under the primer. Small flecks of primer also were pulled off with the tape during the tape test, an abnormal amount for such a test. It was apparent that a time dependent factor, possibly related to the hydrotest, had caused a deterioration of the primer-to-metal bond. The decision was made to resandblast and reprime the chamber cylindrical section; these operations were accomplished as previously described, except that zirconium oxide was used as the abrasive medium instead of glass beads.

The first strip of the cylindrical-section insulation was aligned by using the longitudinal weld beads in the forward and aft cylindrical courses as an index. When the longitudinal guide line was established, aluminum straight edges were installed to provide a guide edge for installation of the first strip. The rubber strips were moved into the chamber, the skived edges were aligned along the aluminum straight edge, and the strips were trimmed to fit in place. After trimming, the strips were turned over, the epoxy adhesive was applied, and the strips then were installed, as shown in Figures 16 and 17. The strips were pressed into contact with the chamber by 4-in.-wide rollers as shown in Figure 18, while removing entrapped air in the process. Twenty-four full-width longitudinal strips were installed; the final strip was trimmed longitudinally

VII, C, Cylindrical-Section Insulation (cont.)

to a 20-in. width prior to installation. The gap at the base of the longitudinal and circumferential V-grooves was 0.13 to 0.50 in. to facilitate installation of the V-61 material.

D. REPAIR OF EXISTING FORWARD AND AFT INSULATION

The areas in the forward and aft insulation where damaged rubber had been removed were repaired with V-44 strips. Residual cylindrical-section strips were cut to the required dimensions and bonded into the areas with Epon 948.2 adhesive. Additional insulation sheets were bonded over the initial layer until the area being repaired was built up flush with the adjacent insulation surfaces. The laminated steps were buffed to eliminate sharp corners and smooth out the contour. A router was used to grind out the surface defects in the aft insulation.

E. REINSTALLATION OF V-61 INTO INSULATION V-GROOVES

The V-grooves in the insulation of the forward, aft, and cylindrical sections were filled with V-61, using the process previously described. Several days prior to the V-61 seaming operation, 200-gram batches of V-61 were mixed from each lot of material on hand to ensure that an acceptable cure would be attained. All samples tested attained acceptable cure level. All V-grooves and the replacement aft-insulation segment were filled with material from lot No. 2620/2621. Future procedures involving the use of V-61 material will include an initial test sample to verify that each lot of material to be used exhibits adequate cure.

The instrumentation probe holes and the ground-out area in the aft insulation were also filled with V-61 material. Also, additional V-61 material was installed around the circumference of the aft step-joint buildup to obtain a slight overbuild and facilitate machining this area to final contour.

VII, Component Installation (cont.)

F. BOOT INSTALLATION

Installation of the forward and aft propellant boots was accomplished much easier and faster than originally anticipated. First, one forward boot was trimmed and skived to a set of calculated dimensions. The vacuum handling fixture then was installed, the boot was moved into the chamber, and the outline of this boot was laid out and marked on the forward insulation in eight places. From the layout, it was evident that the calculated boot dimensions were reasonably accurate. The first trimmed boot was installed into position, using double-backed tape to hold it in place. The second boot then was laid in position adjacent to the first boot, using the marked outline to ensure correct alignment. The edge of the second boot adjacent to the first boot then was marked to obtain a 0.25- to 0.50-in.-wide gap at the base of the V-groove. The second boot was removed from the chamber and trimmed.

Epon 948.2 was applied to the bond surface on the boot and insulation, and the surfaces were pressed together using 4-in. rollers. When the adhesive sample became tacky, vacuum was applied behind the boot to hold it in place during subsequent operations. This procedure was repeated until all forward and aft boots were installed.

G. SEAMING OF PROPELLANT BOOTS

Prior to seaming the propellant boots, operating personnel were required to prepare test seams for qualification in accordance with the instructions presented in Reference (7). Before operator qualification, the process engineers prepared test seams to exhibit some degree of proficiency in order to instruct the operating personnel. The practice seams prepared by the process engineers did not attain the 800-psi tensile strength requirement; test values ranged from 300 to 600 psi. Assistance was obtained from Goodyear personnel.

VII, G, Seaming of Propellant Boots (cont.)

experienced in boot seaming operations to make the process engineers more qualified to train operating personnel. The Goodyear representative found that approximately half of the Germax-cure accelerated V-45 "hot stock" had reached an advanced state of cure, and was unusable for boot seaming. The reason for the advanced cure state of the material was unknown. After manufacture at Goodyear, the material was stored at 0°F to arrest cure; the V-45 stock sheets were packaged in dry ice prior to shipment, at which time the material was acceptable. The packaged material was air-freighted to Miami, picked up immediately, and stored in the freezer at the General Processing building. New material was procured to replace the rejected stock.

Qualification of the operating personnel for boot seaming was successfully completed. At the start of each shift, a demonstration on boot seaming was given by the shift engineer. During demonstration, each operator was given an opportunity to handle the tools and material. Then, using V-45 rubber sheets procured specifically for qualification, each operator laid up and cured a 36-in.-long seam. Twelve Instron specimens were cut and tested, and the 10 best tensile strength values obtained from the specimens were used to determine qualification. During his next shift, each operator was given an opportunity to review sections of the seam he had prepared the previous day. Then each operator laid up and cured a second 36-in.-long seam. The test procedure for the second layup was the same as for the first test seam. Four operators from each shift attempted to qualify; only two from each shift prepared acceptable seams. The qualification criteria required that the average tensile strength of 10 specimens be 800 psi or greater, and that no specimen exhibit a tensile strength less than 500 psi. The six qualified operators prepared seams that exhibited average tensile strength values ranging from 974 to 1186 psi; these values were higher than those reported by Goodyear.

VII, G, Seaming of Propellant Boots (cont.)

Seaming of the forward and aft propellant boost was accomplished successfully. When vacuum was released behind the boots, the underneath side of the seams was inspected. The cured seam stock was well knitted to the boot rubber, and only minor, isolated defects were detected. These minor defects were caused either by wrinkles in the boot, which created a small gap between the boot and the back-up tape, or by wrinkles in the back-up tape. The defects were only 0.01- to 0.06-in.-deep and were considered to be acceptable without repair.

H. BOOT-EXTENSION INSTALLATION

Assembly of the boot-extension fixture and installation of the boot extension into the motor were conducted without major problems. The most difficult task was getting the aft boot back into position and applying a vacuum. The 3M EC-1202 double-backed tape did not have sufficient adhesive strength to hold the boot in position until vacuum could be applied. All other mechanical methods of holding the boot in place were unsuccessful. As a result, it was necessary to apply 1746C temporary cement (natural rubber dissolved in naphtha and toluene) behind the aft boot to hold it in place until vacuum was applied.

Coupled with the problem encountered in getting the aft boot back into position was the problem of a mismatch between the boot and insulation contour, which resulted in small wrinkles and gaps around the full circumference of the aft edge of the aft boot. It appeared that a more reliable joint could be achieved by lapping the boot extension over the aft boot and bonding the components together rather than by attempting to seam the components together with the Germax cure-accelerated material. This type of bonded lap joint would be structurally adequate, more easily installed, and more easily repaired, if necessary. The original 260-SL-1 and -2 motor boot extension

III, H, Boot-Extension Installation (cont.)

and the revised configuration for motor 260-SL-3 are shown in Figure 19. The aft boot-to-boot joint actually carries no significant load and is essentially required only to provide a vacuum seal during subsequent motor propellant loading operations. It is apparent that this type of bonded lap joint would be incorporated in future motor designs.

As shown in Figure 19, the boot extension was lapped over the boot and bonded with Epon 948.2. A bond width of 3.75 to 5 in. was obtained. After the adhesive was applied, the surfaces were pressed together, a vacuum blanket was installed over the joint, and the adhesive was cured under vacuum.

When the vacuum blanket was removed after cure, there were several areas where the extension had pulled away from the boot, leaving a 0.18- to 0.25-in. gap. These bond defects were repaired by sanding off the cured epoxy, cleaning the area, and injecting fresh Epon 948.2 into the unbonded area. A vacuum blanket then was installed over the area, and the repair was cured under vacuum.

I. FINAL OPERATIONS

After the double-backed tape and 1746C cement were cleaned out from behind the aft and forward boots, a thorough inspection was conducted of the entire insulation surface. Several defect areas were observed in the V-61 seams. Material in the area adjacent or around the defects was removed with aluminum chisels until the base of any crack or void was exposed. The area then was sanded, cleaned, and filled with new V-61.

During the final inspection, nine areas in the cylindrical section insulation were found to contain pockets of trapped air; these air pockets ranged in diameter from 4 to 12 in. These defects were repaired as follows:

III, I, Final Operations (cont.)

1. The rubber at the approximate center of the air pocket was cut, exposing the primed steel underneath.
2. Newly mixed Epon 948.2 was loaded into a Semco cartridge.
3. The adhesive was injected into the exposed pocket.
4. A small roller was used to press the rubber into contact with the chamber; all pressure was applied in a direction toward the slit in the rubber to remove the entrapped air.
5. A small doubler of V-44 rubber, 1-in.-wide by 0.20-in.-thick (residual cylindrical-section insulation), was bonded over the cut made in the rubber; after cure, the doubler was trimmed long enough to overlap the edge of the slit approximately 0.5 in.
6. After cure, the doubler was ground down to an approximately 0.1- to 0.05-in. thickness, and the edges were skived to eliminate sharp surface discontinuities.

When all repairs were completed, the aft boot was assembled to the casting adapter. A vacuum was applied, and the air behind the aft boot was evacuated. When the boot began to pull down, the vacuum valve was turned off and an ammonia supply was turned on. Ammonia was allowed to flow into the volume behind the boot until evidence of pressure was obtained. As the chamber was being rotated, phenolphthalein-soaked cloths were placed over the seams, the boot bondline, and the boot-to-boot extension bondline. Three small leaks in the boot-to-boot extension bondline were clearly detected. The cloth over the leak immediately turned pink, indicating the presence of ammonia. No leaks were detected in the seams or through the boot bond area.

III, I, Final Operations (cont.)

Vacuum was again applied and the aft boot was pulled down tight against the insulation. The noted leaks were sanded, cleaned, and filled with fresh Epon 948.2 adhesive injected through a Semco cartridge. As the epoxy was being installed, the vacuum behind the boot pulled the adhesive into the void areas.

This method of leak detection proved to be more effective than spark-testing, leak-checking with soap solution, or using halogen sniffers. The leaks not only were immediately detected, but their exact location was clearly evident. In future motors, this detection method can be expanded to include a check of the forward propellant boot integrity.

VIII. CONCLUSIONS

The fabrication and installation of the 260-SL-3 motor insulation system met the design requirements. The insulation performance in previous 260-SL motor static test firings demonstrated that the methods used to design, fabricate, and install chamber insulation components were satisfactory. The 260-SL-3 motor insulation system is similar to the 260-SL-1 configuration, although the web action time of motor 260-SL-3 is 40 to 50 sec shorter than that of motor 260-SL-1. The only new concepts in the 260-SL-3 motor insulation system are the use of previously fired, rehabilitated insulation and the use of single-ply rubber strips for cylindrical-section insulation with V-61-filled V-grooves between strips. Insofar as can be determined from documentation review, direct engineering surveillance, and current inspection techniques, there are no suspect or questionable areas in the 260-SL-3 chamber internal-insulation system.

Report NASA CR-72228

LIST OF REFERENCES

1. Aerojet-General Corp. Report No. NASA CR-54930, 260-In.-Dia Motor Feasibility Demonstration Program, Volume V: 260-SL Motor Internal Insulation System, Contract No. NAS3-6284, dated 8 April 1966.
2. Aerojet-General Corp. Report No. 0434-01S15-T6, 100FW-2 Motor Firing Report, Large Solid Rocket Program, Contract No. AF 04(611)-6094, dated April 1962.
3. Project Directive No. 116, Revision 1, 260-SL-3 Motor Insulation (This document covers plan and the tasks required to complete the motor insulation program.)
4. Process and Inspection Summary 260A-45, Prepare 260-SL-1 Chamber for Hydrotest (This document provides the processing procedures and inspection for rehabilitation of the S/N 001 chamber prior to hydrotest.)
5. Process and Inspection Summary 260A-55, Prepare 260-SL-1 Chamber for Insulation (This document provides the processing procedures and inspection for rehabilitation for the S/N 001 chamber prior to insulation.)
6. Process and Inspection Summary 260A-57, Insulate 260-SL-3 Chamber (This document provides the processing instructions and the inspection for motor chamber insulation.)
7. Process and Inspection Summary TU-30, Qualification and Training - Propellant Boot Seaming (This document provides the process and test procedures for qualification of operators for the boot-seaming operation.)

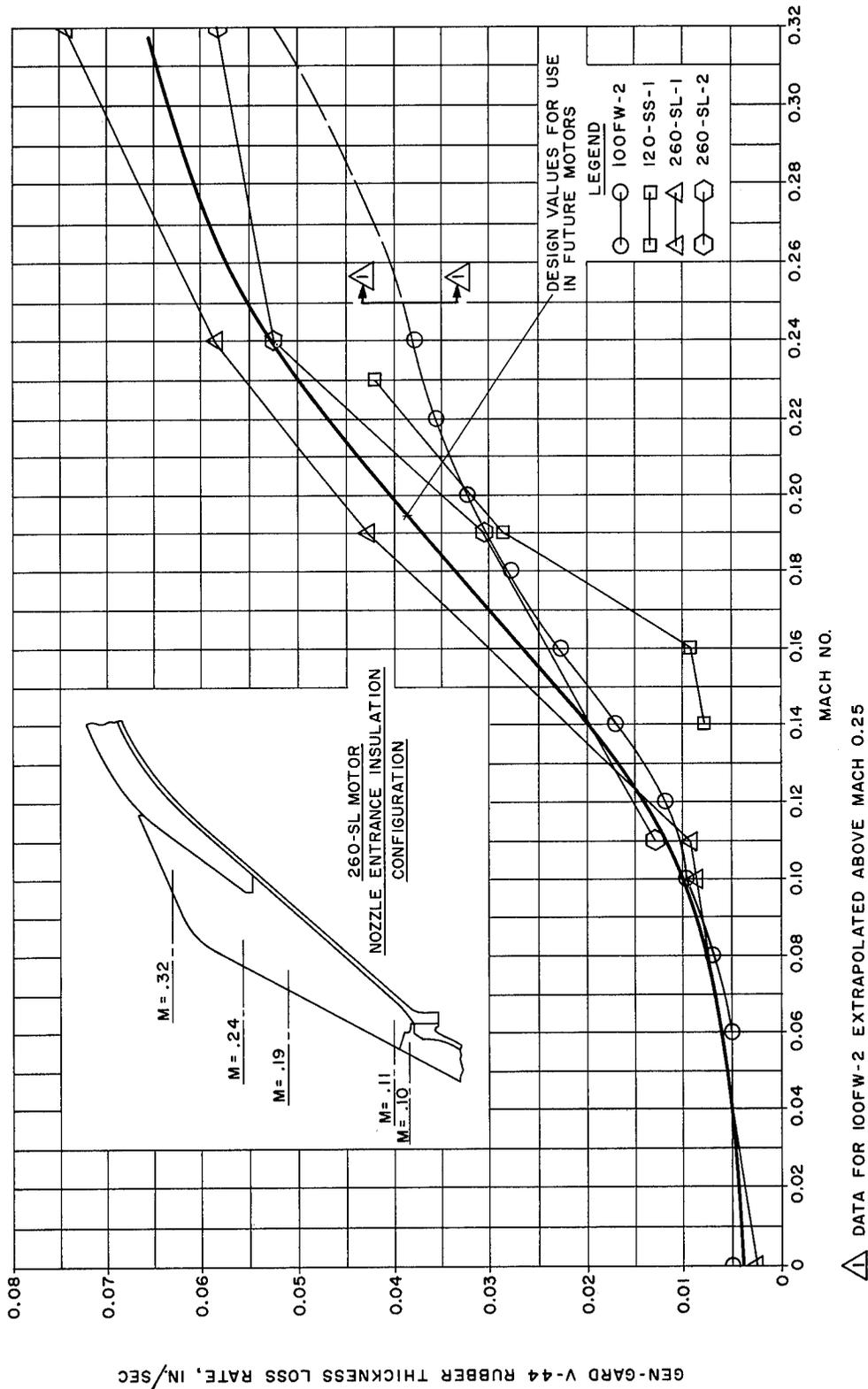


Figure 1

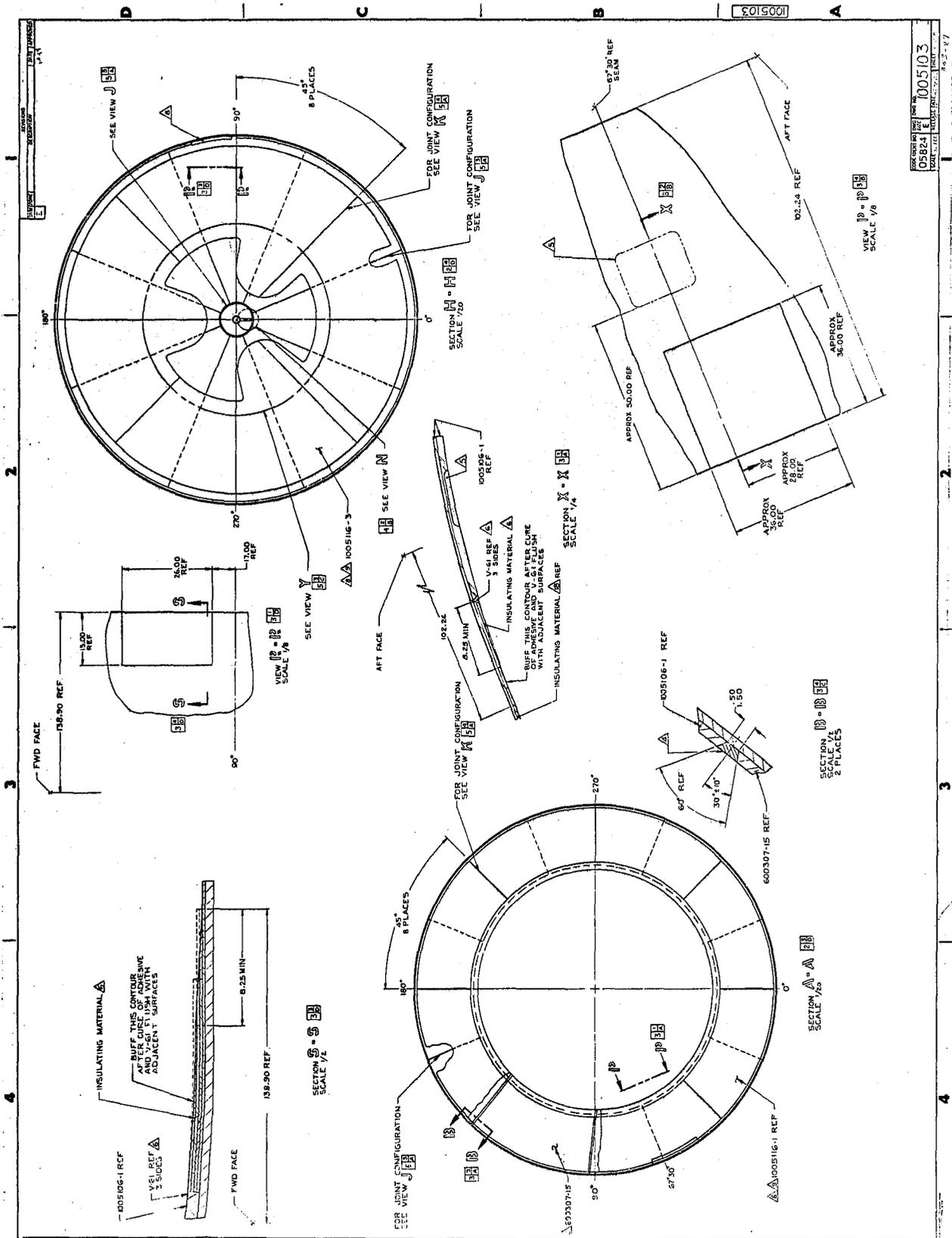
Gen-Gard V-44 Thickness Loss Rate Versus Gas Flow Mach Number

Diameter, in.	Flow Area, sq in.	Area Ratio, A/A^* (1)	Mach No.	Exposure Time, sec (2)	Thickness Loss Rate, in./sec	Thickness, in.	Design Thickness, in. (3) $260-SL-3$	Design Thickness, in. (4) $260-SL-1$
<u>Aft Insulation</u>								
170 (Step joint)	22698	3.61	0.17	75/20	0.026/0.005	2.05	4.10	4.26
180	25447	4.05	0.15	75/20	0.0198/0.005	1.59	3.18	--
190	28353	4.51	0.14	65/20	0.0168/0.005	1.19	2.38	4.06
200	31416	5.0	0.12	54/20	0.012/0.005	0.78	1.56	2.21
210	34636	5.5	0.11	42/20	0.0105/0.005	0.55	1.10	1.37
220	38013	6.04	0.10	29/20	0.0095/0.005	0.38	0.76	1.10
230	41548	6.6	0.09	21/20	0.0083/0.005	0.27	0.54	1.00
240	45239	7.2	0.08	14/20	0.0073/0.005	0.20	0.40	0.90
250	49087	7.8	0.08	7/20	0.0073/0.005	0.15	0.30	0.80
260	53903	8.4	0.07	0/20	-/0.005	0.10	0.20	0.20
<u>Cylindrical Section</u>								
<u>Forward Insulation</u>								
				20	0.0035	0.007	0.14	0.20
				75/20	0.005/0.0035	0.45	0.95 to 1.05 (5)	1.25

- (1) A^* , Average motor throat area during web burning time, 6295 sq in.
- (2) Direct impingement/tailliff and afterburn.
- (3) Thickness x 2.0 safety factor.
- (4) Thickness dimensions reflect smooth contour (Reference 600307-9).
- (5) Existing measured thickness of residual rubber in forward head of 260-SL-1 motor chamber.

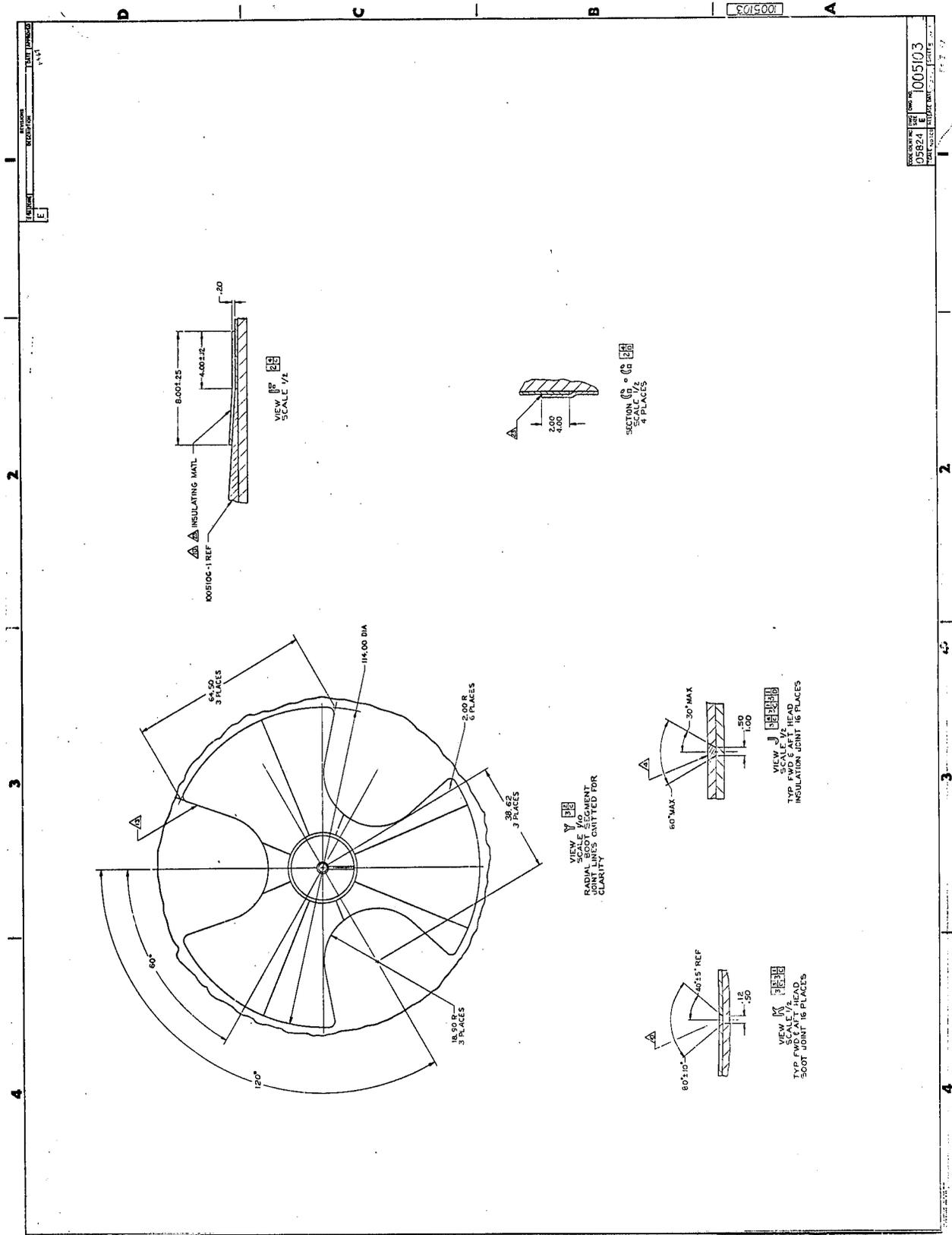
260-SL-3 Motor Chamber Insulation Design Thickness Contour

Figure 2



260-SL-3 Insulated Motor Chamber

Figure 3, Sheet 3 of 5



260-SL-3 Insulated Motor Chamber

Figure 3, Sheet 5 of 5

Report NASA CR-72228

Sample No.	Initial Thickness, in.	Sand to Remove, in.	Final Thickness, in.	Fed. Std. Color No.	Shore A Hardness	Tensile Strength, psi SD850-2	Epon 948.2	Type of Failure
001	.746			34086	72,72,71	392		In liner
002	.704				69,72,71	433		In liner
003	.776				74,72,73	440		In liner
004	.768				70,70,70		319	In rubber
005	.810				71,70,73		364	In rubber
006	.710				66,68,68		407	In rubber
007	.728			30099	76,75,75	299		Rubber-to-liner interface
008	.769				75,76,75	325		Rubber-to-liner interface
009	.782				64,72,65	251		Rubber-to-liner interface
010	.769				70,74,75		280	Rubber-to-epoxy interface
011	.822				72,74,72		325	Rubber-to-epoxy interface
012	.792				68,70,74		302	Rubber-to-epoxy interface
013	.773	.03	.742	30099/ 30118	66,67,64	324		In liner, near interface
014	.812	.03	.783	30099/ 30118	76,75,75	422		In liner, near interface
015	.806	.03	.776	30099/ 30118	76,78,76	436		In liner, near interface
016	.801	.03	.771	30099	73,71,74		437	In rubber
017	.828	.03	.797	30099/ 30118	74,72,69		429	In rubber
018	.728	.03	.698	30099/ 30118	75,74,75		466	In rubber
019	.822	.06	.761	30118	73,73,72	435		In liner
020	.734	.06	.673	30118	74,71,74	427		In liner
021	.728	.06	.669	30118	72,74,72	402		In liner
022	.815	.06	.755	30118	75,75,74		426	In rubber
023	.755	.06	.694	30118	71,73,72		449	In rubber
024	.798	.06	.738	30118	71,72,72		536	In rubber

Instron, Model 1M Settings:

Chart Speed: .10 in./min.
Test Date: 9-8-66

Crosshead Speed: 5 in./min.
Test Temperature: 77°F

Scale: 100
% RH: 34

Effect of Rubber Surface Condition

Figure 4, Sheet 1 of 2

Report NASA CR-72228

Sample No.	Initial Thickness, in.	Sand to Remove, in.	Final Thickness, in.	Fed. Std. Color No.	Shore A Hardness	Tensile Strength, psi		Type of Failure
						SD850-2	Epon 948.2	
025	.740	.10	.640	30219	71,73,73	442		In liner
026	.767	.10	.667	30219	72,73,72	441		In liner
027	.788	.10	.688	30219	74,73,74	447		In liner
028	.748	.10	.647	30219	72,73,72		543	In rubber
029	.779	.10	.680	30219	74,73,73		607	In rubber
030	.785	.10	.685	30219	69,71,69		630	In rubber
031	.820	.13	.690	30219	73,73,72	463		In liner
032	.727	.13	.596	30219	74,75,75	471		In liner
033	.808	.13	.678	30219	74,73,73	418		In liner
034	.760	.13	.629	30219	72,73,74		427	In rubber
035	.825	.13	.694	30219	75,73,73		474	In rubber
036	.766	.13	.636	30219	71,72,72		542	In rubber
037	.765	.19	.575	30118/ 30219	70,69,71	440		In liner
038	.745	.19	.555	30118/ 30219	73,73,74	446		In liner
039	.742	.19	.552	30118/ 30219	72,73,71	459		In liner
040	.780	.19	.589	30118/ 30219	75,75,73		674	In rubber
041	.790	.19	.599	30118/ 30219	74,74,75		587	In rubber
042	.763	.19	.573	30118/ 30219	70,69,69 70,69,69		489 489	In rubber In rubber
043	.747	.25	.497	30118/ 30219	69,70,72	495		In liner
044	.810	.25	.559	30118/ 30219	70,72,71	490		In liner
045	.800	.25	.549	30118/ 30219	73,72,72	433		In liner
046	.767	.25	.517	30118/ 30219	73,73,73		511	In rubber
047	.749	.25	.500	30118/ 30219	65,67,67		573	In rubber
048	.732	.25	.482	30118/ 30219	71,70,71		483	In rubber

Instron, Model TM Settings:

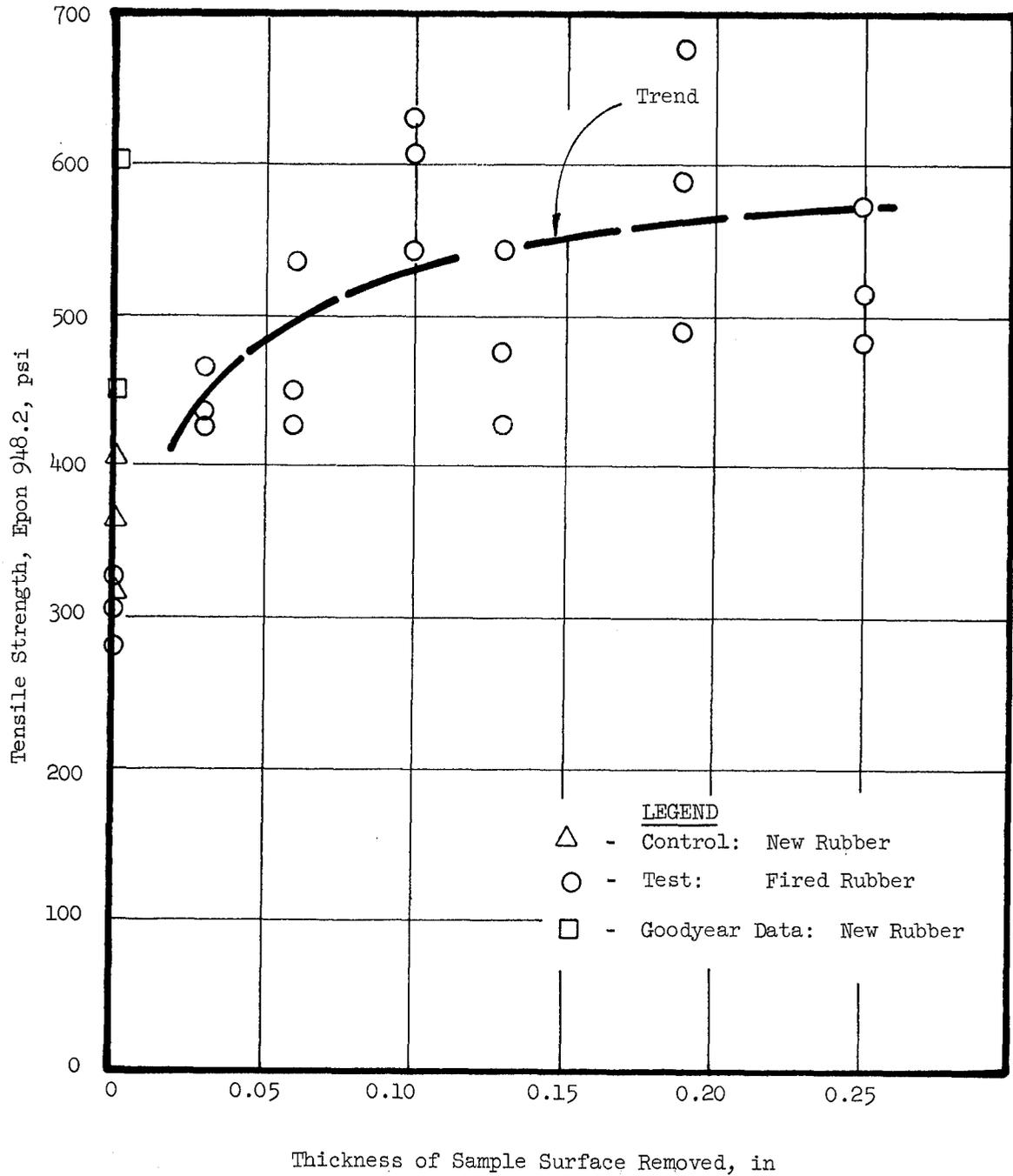
Chart Speed: 10 in./min.
Test Date: 9-8-66

Crosshead Speed: 5 in./min.
Test Temperature: 77°F

Scale: 100
% RH: 34

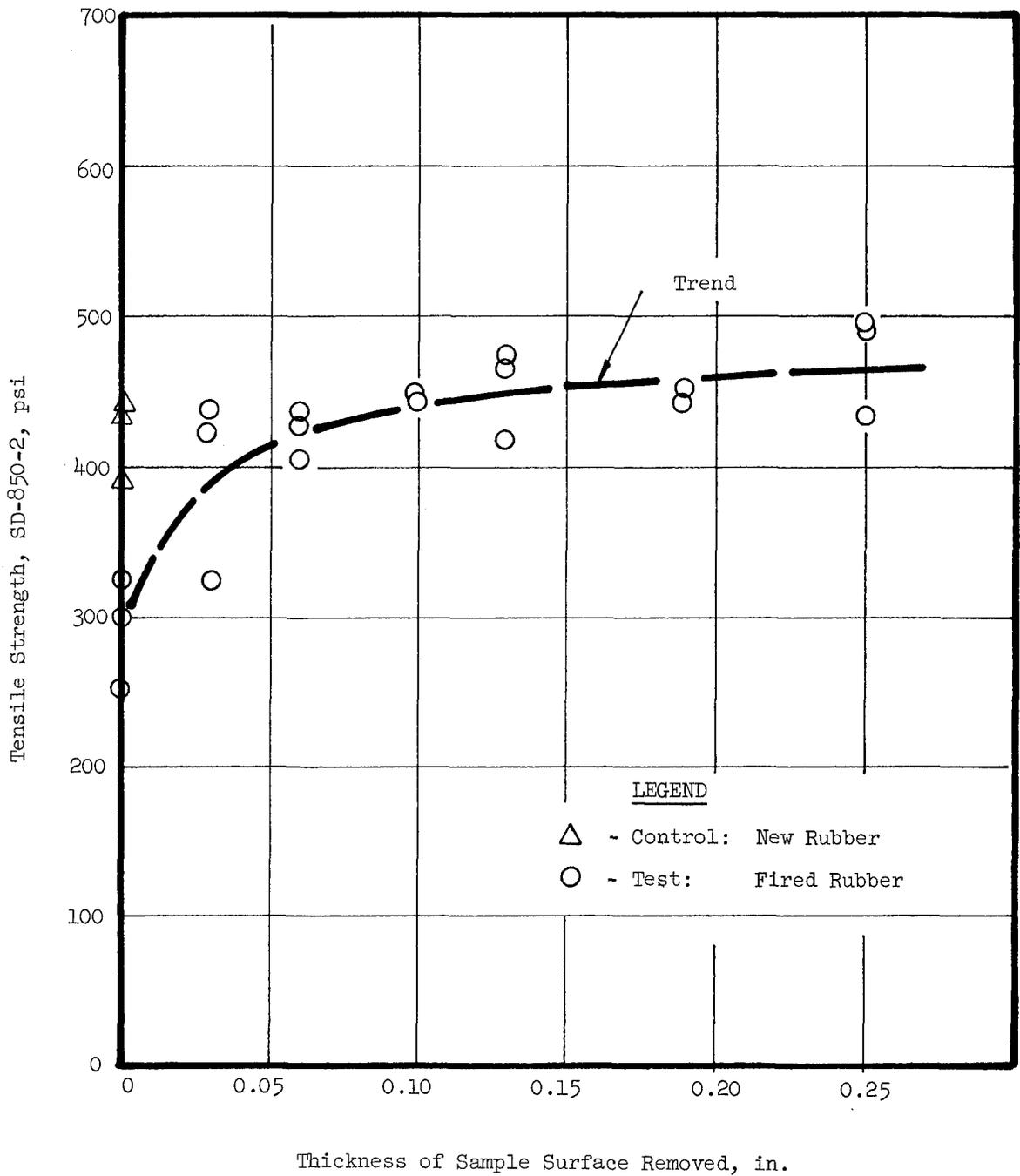
Effect of Rubber Surface Condition

Figure 4, Sheet 2 of 2



Plot of Epon 948.2 Adhesive Bond Strength as a Function of Fired Rubber Surface Thickness Removed

Figure 5



Plot of SD-850-2 Liner Bond Strength as a Function of
Fired Rubber Surface Thickness Removed

Figure 6

Report NASA CR-72228

Primer Bond Strength Data Sheet

<u>Sample No.</u>	<u>Tensile Strength, psi</u>	<u>Type of Failure</u>
049 Control	861	Partially in rubber and partially in primer-to-epoxy interface
050 Control	512	In rubber
051 Control	629	In rubber
052 Test	579	In rubber
053 Test	380	Epoxy-to-primer interface*
054 Test	913	Partially in rubber and partially in primer-to-epoxy interface

Instron, Model TM Settings:

Chart Speed: 10 in./min.	Crosshead Speed: 5 in./min.	Scale: 1000
Test Date: 9-8-66	Test Temperature: 75°F	% RH: 34

*Approximately 0.2-in.-wide by 0.9-in.-long portion of surface unbonded.

V-61** Bond Strength Data Sheet

<u>Sample No.</u>	<u>Tensile Strength, psi</u>	<u>Type of Failure</u>
055 Control	419	In V-61
056 Control	226	V-61 to V-44 interface
057 Control	445	In V-61
058 Test	357	In V-61
059 Test	440	In V-61
060 Test	429	In V-61

Instron, Model TM Settings:

Chart Speed: 10 in./min.	Crosshead Speed: 5 in./min.	Scale: 500
Test Date: 9-8-66	Test Temperature: 75°F	% RH: 34

**GenGard V-61 Data: Component 1 - Lot S/N 2153 V-61-1P, dated 2-12-65
 Component 2 - Lot S/N 2152 V-61-2P, dated 2-10-65
 Mixed 8-26-66

Fuller 162-Y-22 Primer-to-Gen-Gard V-44 Epoxy Bond Strength and
 Gen-Gard V-61 to Gen-Gard V-44 Bond Strength Test Data Sheet

Figure 7

Report NASA CR-72228

<u>Sample No.</u>	<u>Tensile Strength, psi</u>			<u>Type of Failure</u>
	<u>Minimum</u>	<u>Maximum</u>	<u>Average</u>	
061 Control	55.7	81.5	66.6	In rubber
062 Control	79.2	92.2	84.2	In rubber
063 Control	79.5	91.5	84.5	In rubber
064 Test	76.5	88.9	78.8	In rubber
065 Test	79.4	84.5	81.5	In rubber
066 Test	67.7	90.5	78.6	In rubber

Instron, Model TM Settings:

Chart Speed: 10 in./min. Crosshead Speed: 12 in./min. Scale: 200
Test Date: 9-8-66 Test Temperature: 75°F % RH: 34

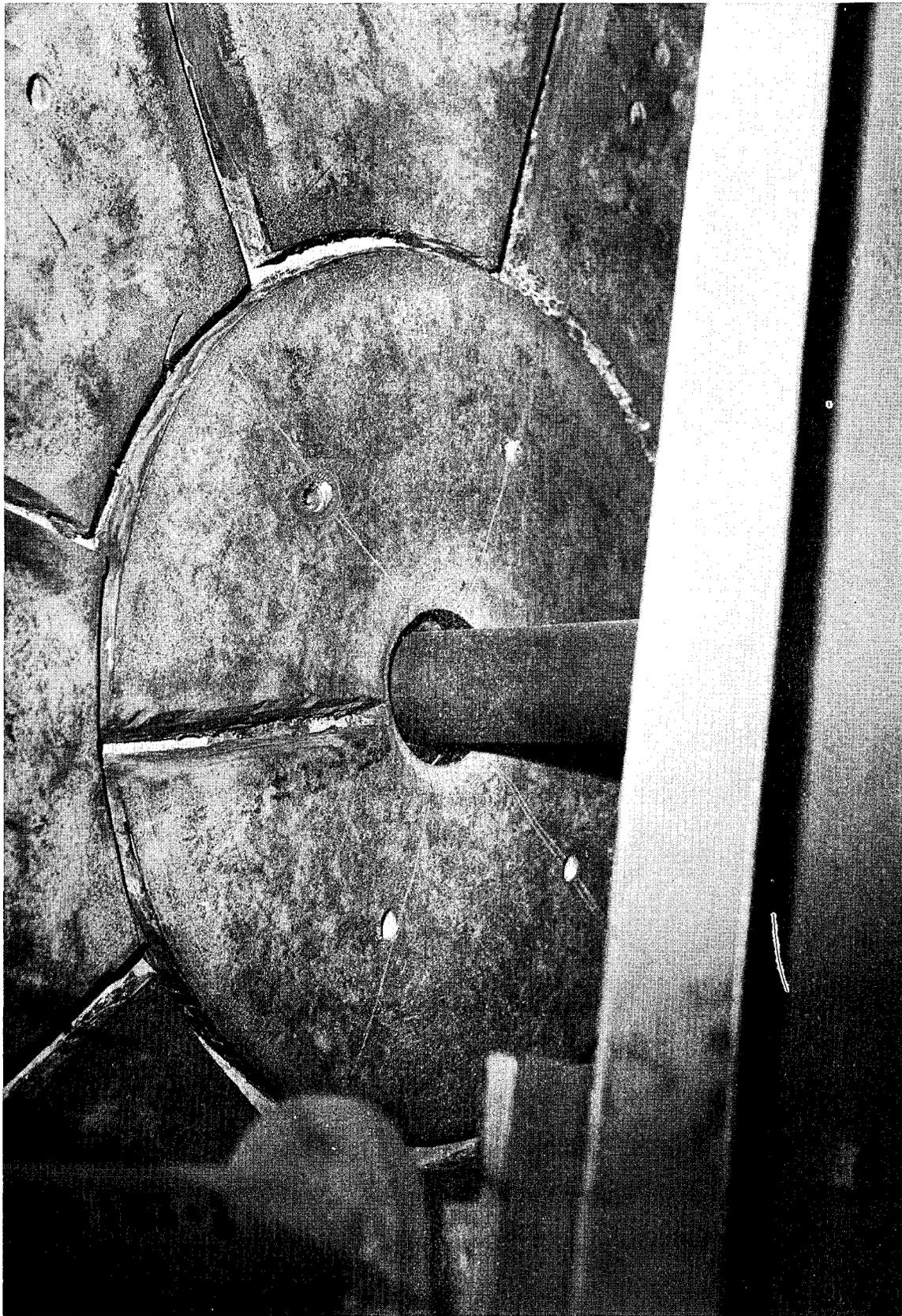
Gen-Gard V-44-to-Gen-Gard V-45 Epoxy Bond Peel Strength
Test Data Sheet

Figure 8



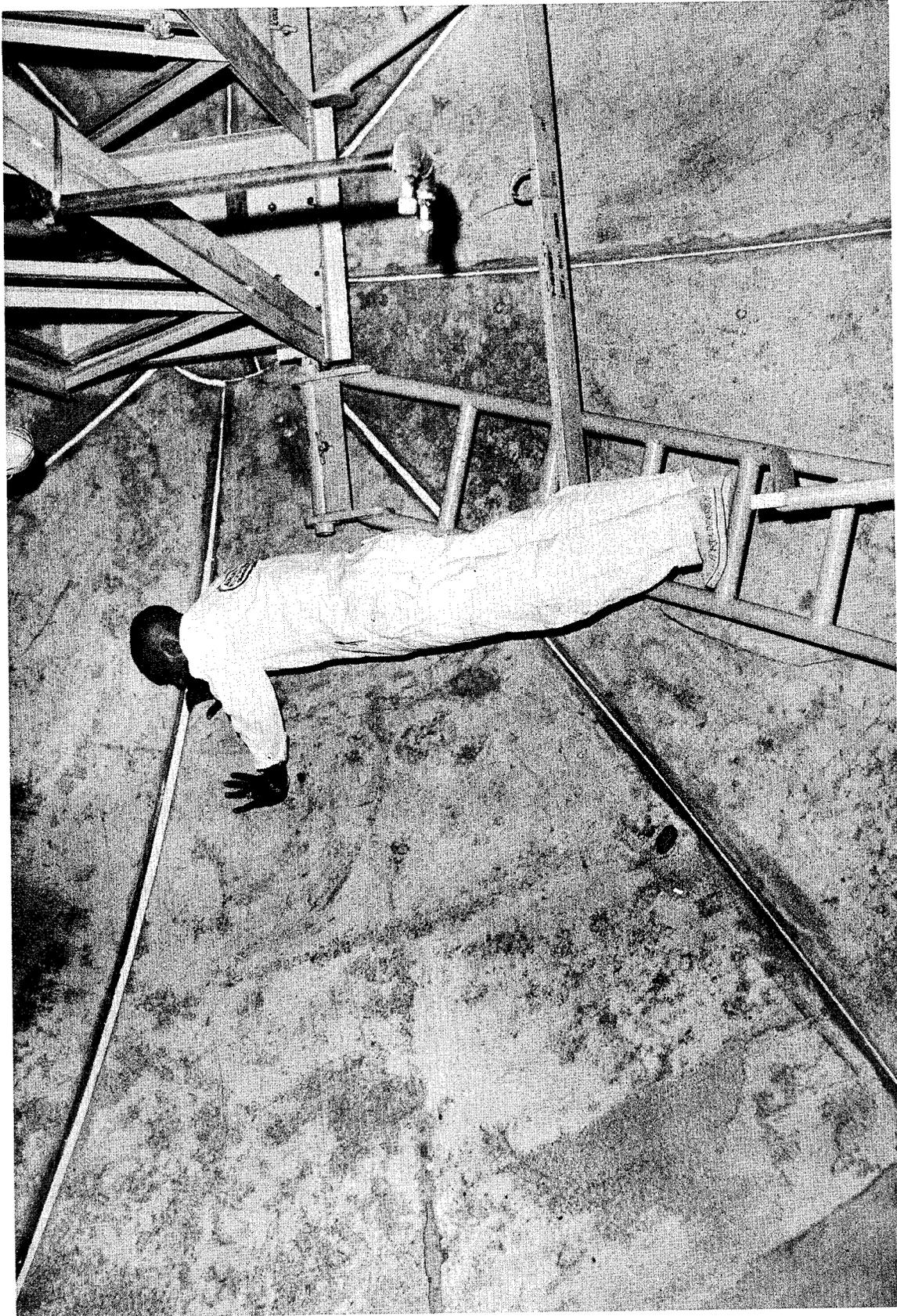
Rehabilitated 260-SL Motor Case (S/N 001) for Motor 260-SL-3

Figure 9, Sheet 1 of 4



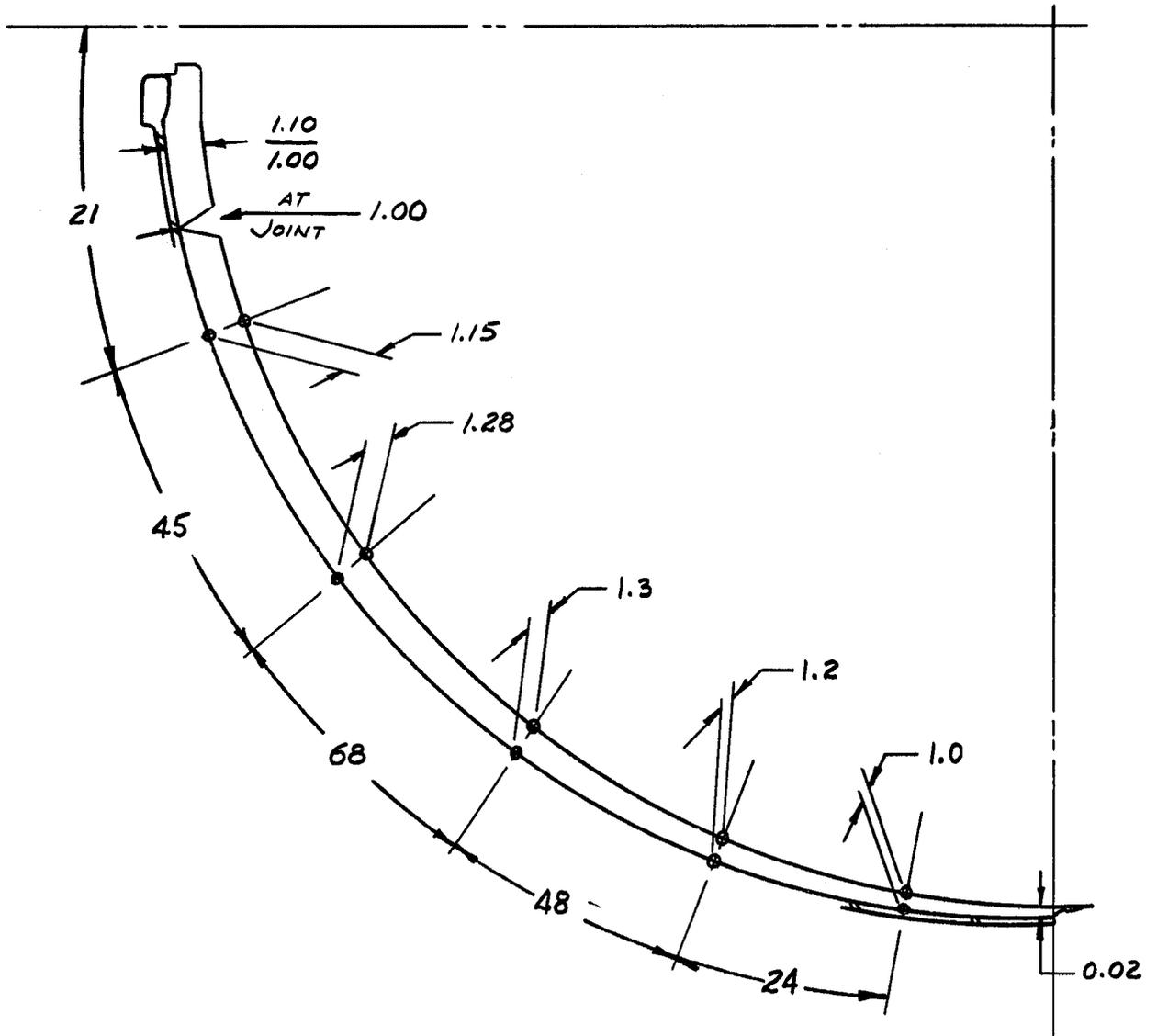
Forward Insulation V-Grooves After V-61 Removal

Figure 10



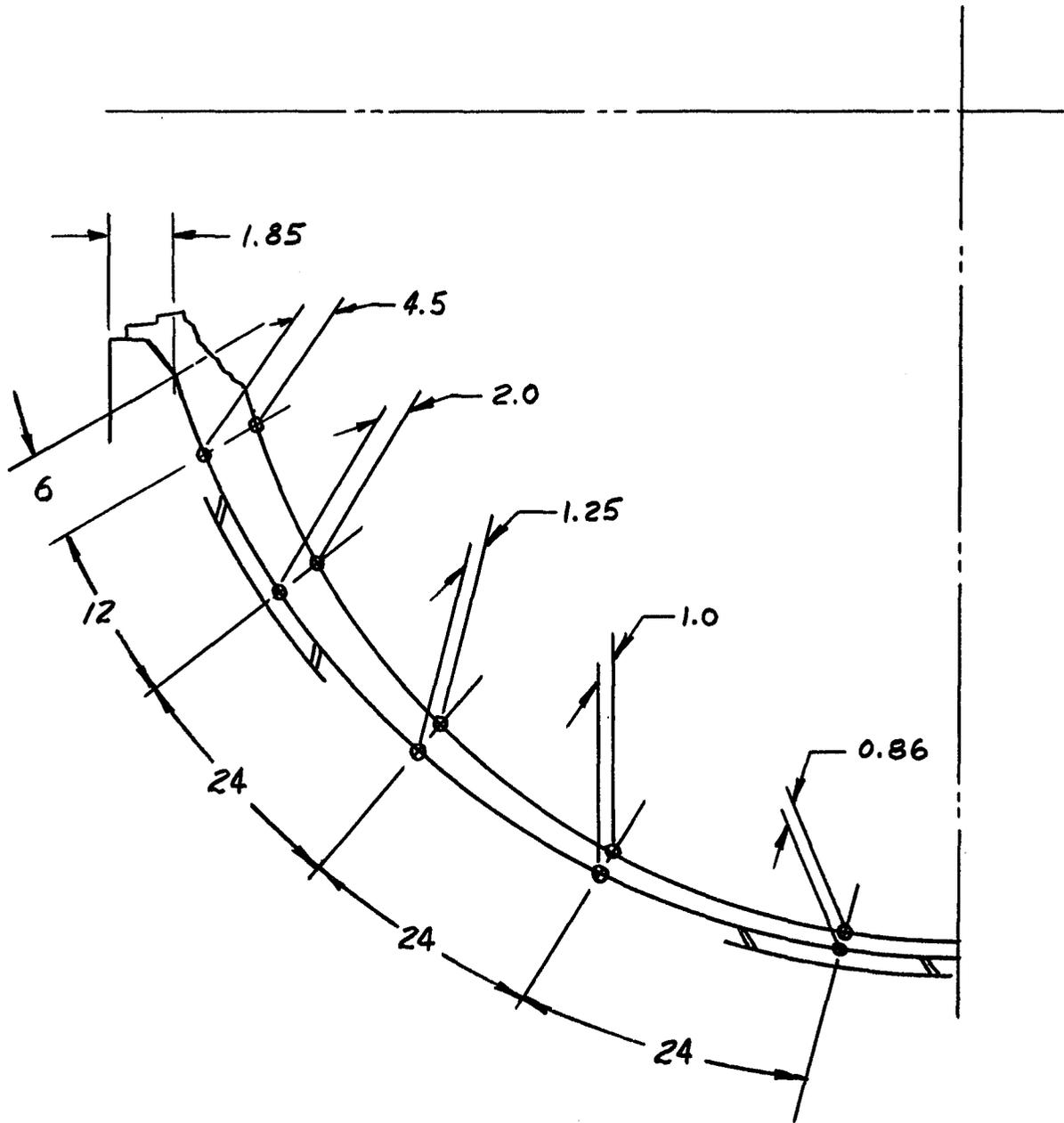
Forward Insulation V-Grooves After V-61 Removal

Figure 11



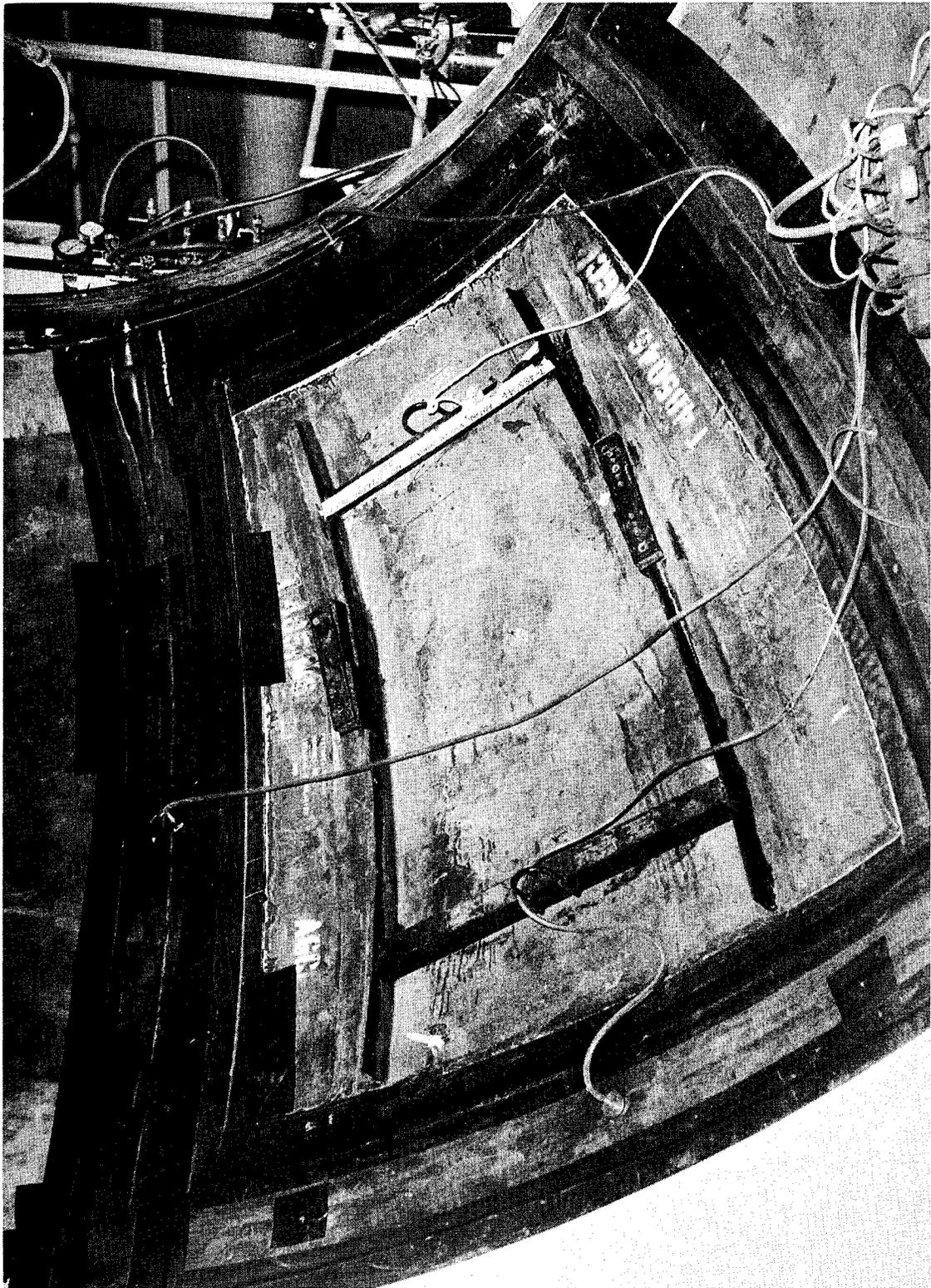
Final 260-SL-3 Rehabilitated Forward Insulation Contour

Figure 12



Final 260-SL-3 Rehabilitated After Insulation Contour

Figure 13



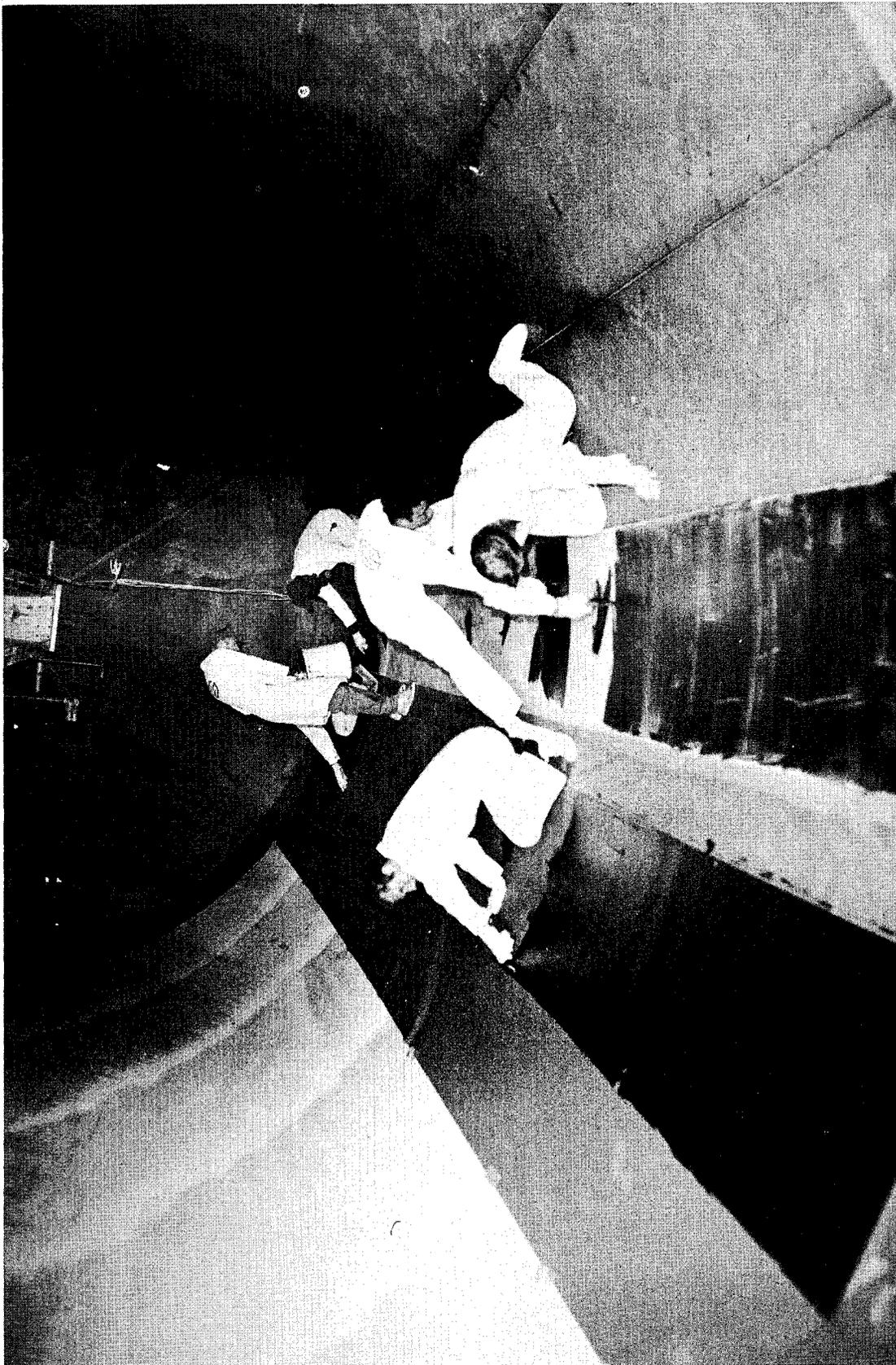
Replacement Aft Insulation Segment Under Vacuum Cure

Figure 14



Aft Step-Joint Build-Up with V-61 Potting Insulation

Figure 15



Adhesive Application to Cylindrical Section Rubber Strip

Figure 16



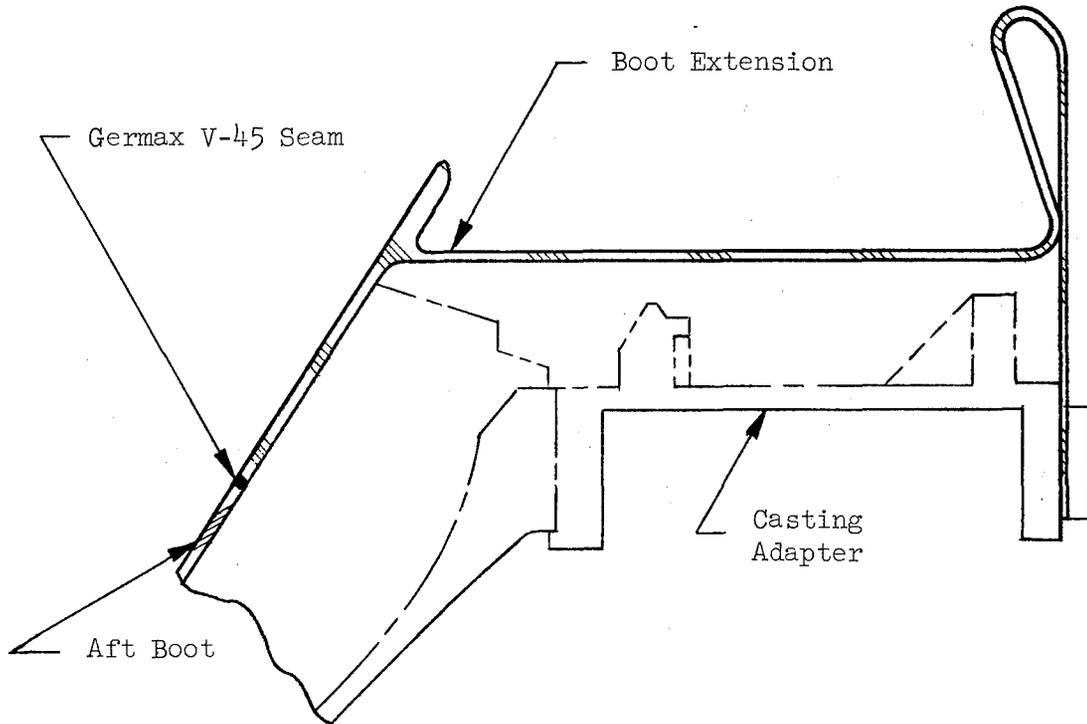
Installation of Cylindrical Section Rubber Strip

Figure 17

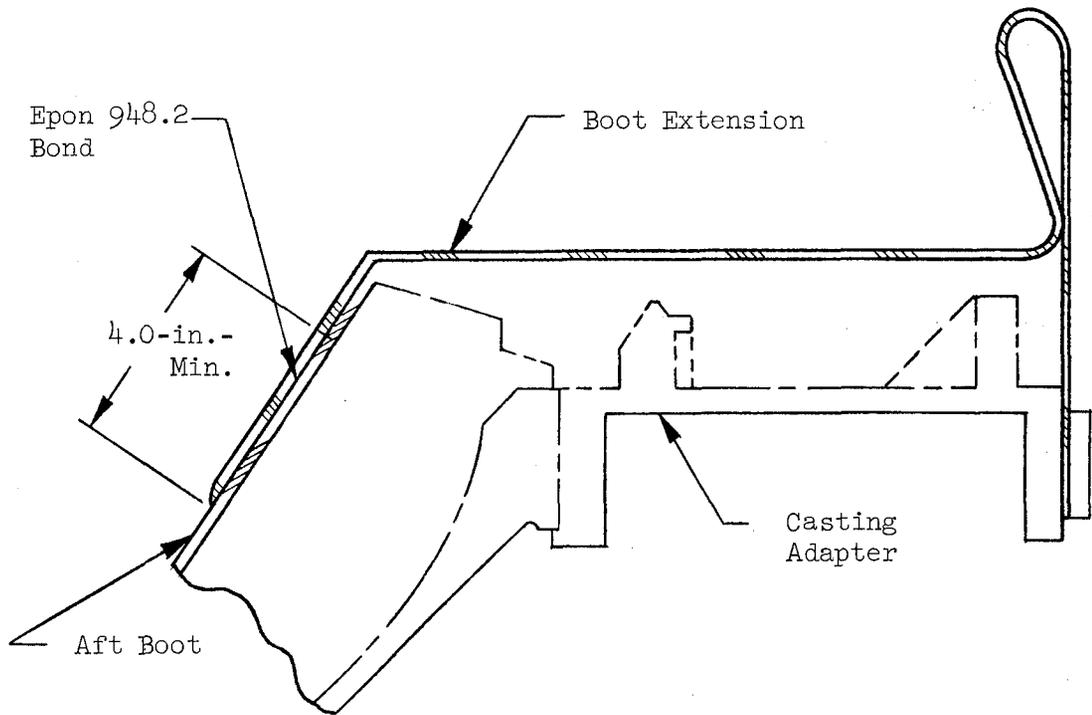


Stitching Cylindrical Section Insulation Strip

Figure 18



260-SL-1, -2 Configuration



260-SL-3 Configuration

Revised After Propellant Boot Extension Configuration

Figure 19

Report NASA CR-72228

APPENDIX A

BOND STRENGTH EVALUATION PROCEDURES AND FLOW SHEET

BOND STRENGTH EVALUATION PROCEDURES AND FLOW SHEET

1. Obtain the following materials before starting this bond strength study:

<u>MATERIAL</u>	<u>REMARKS</u>
A. V-44 Rubber, unfired	Cut to sizes specified in Task V
B. V-44 Rubber, fired	Cut to sizes specified in Task V
C. V-45 Rubber, unfired	Cut to sizes specified in Task XVII
D. EPON 948.2 Type IV	
E. V-61 Rubber	
F. Liner Raw Materials	Dry the Cab-O-Sil and Fe ₂ O ₃ at 180°F for 3 days before use.
G. Isol	Iso-propyl alcohol, lab stock.
H. Steel Plates	120 ea. 2-3/8 x 2-3/8 x 1/8 in. 6 ea. 1 x 8 x 1/8 in. 6 ea. 6 x 6-1/2 x 1/8 in. (hole drilled in two corners)

2. The Flow Sheet is used as follows:

Start under the Task Number I (Roman numeral) which has a quantity.

Continue from there to number one (Arabic number) under Roman Numeral II and then in numerical (Arabic) order complete each of the tasks to the end of the Flow Sheet. Procedures for accomplishing each task shown on the Flow Sheet are in Paragraph 4.

3. All rubber bonding surfaces will be abraded with -120 grit sandpaper and then cleaned with Isol (iso-propyl alcohol) prior to the bonding operation.

4. Bond strength evaluation procedures are as follows:

<u>TASK NO.</u>	<u>PROCEDURE</u>
I, II, & III	<u>STEEL PLATES</u> : All the steel plates will be sandblasted, cleaned and primed with Fuller Epoxy Primer 162-Y-22 according to AGC 364 by Dept. 3340. The primed steel plates will be cured for 6 hr at ambient and then delivered to the Q.C. Laboratory.

Report NASA CR-72228, Appendix A

TASK NO.

PROCEDURE

IV EPON 948.2, TYPE IV: Mix the Epon 948.2 according to AGC 34151 and apply a coat 0.010-0.020 inches thick to the bonding surfaces. The ultimate thickness of the Epon bond must be between 0.020 - 0.040 inches. Mate the bonding surfaces and remove any Epon that is squeezed out from between the bonding surfaces. The bonding surfaces must be kept aligned.

V. V-44 RUBBER: The quantity, size, type (unfired or fired rubber) and use of V-44 rubber as shown on the flow sheet are as follows:

<u>Quantity</u>	<u>Size (inches)</u>	<u>Type</u>	<u>Use on Flow Sheet</u>
6	1 x 1 x 0.5-0.7	Unfired	Liner and Adhesive Bond Strength
42	1 x 1 x 0.5-0.7	Fired	Liner and Adhesive Bond Strength
12	1 x 1 x 0.25	Fired*	Primer Bond Strength**
12	1 x 1 x 0.25	Fired*	V-61 Bond Strength
6	1 x 8 x 0.1	Unfired	Peel Bond Strength
6	6 x 6 x 2	Unfired	Chamber Drying Cycle

VI. CURE AT AMBIENT FOR 36 HOURS: Cure the Epon 948.2 for 36 hr at the Q.C. Laboratory's ambient conditions. 75°F ± 2 and 40% RH max.

*Charred; discolored surface removed completely.

TASK NO.

PROCEDURE

VII

SUBJECT SAMPLES TO HYDROTEST FLUID: The samples will be placed in a Crawford Bomb chamber filled with hydrotest fluid (sodium dichromate solution) and pressurized according to the following table:

<u>Step</u>	<u>Pressurize to</u>	<u>Rate of Pressurization</u>	<u>Duration at Pressure</u>
1	0 psig	-- psi/minute	48 hours
2	40	+ 50	1 minute
3	200	+ 50	1 minute
4	40	- 50	1 minute
5	200	+ 50	1 minute
6	40	- 50	1 minute
7	200	+ 50	1 minute
8	400	+ 50	1 minute
9	500	+ 50	1 minute
10	600	+ 50	1 minute
11	717 $\begin{matrix} + 5 \\ - 15 \end{matrix}$	+ 50	80 seconds
12	0	- 100 (max.)	24 hours

After the above cycling is complete, remove the samples from the Crawford Bomb chamber and rinse with tap water to remove the residual hydrotest fluid.

VIII

DRY AT 165 + 5°F FOR 15 DAYS: Dry the Test and Control samples at 165 \pm 5°F for 15 days in a forced draft oven. After 15 days remove the samples from the oven and allow to cool to room temperature.

TASK NO.

PROCEDURE

IX

SAND TO DEPTH INDICATED AND MEASURE COLOR AND SHORE A

HARDNESS: Samples 007 through 048 are to be sanded to the depths indicated on the Flow Sheet. The initial thickness of each sample will be measured with dial calipers to the nearest 0.001 inches. The samples will then be carefully sanded to their individual depths, checking periodically with the dial caliper to assure the correct sanding depths are obtained. The initial and final thickness of each sample will be recorded on the attached data sheet.

The surface color of all the samples will be measured using Federal Standard No. 595, Federal Color Standards. If an exact color match cannot be found, two colors can be used to bracket it. The number(s) below the color chips in the Federal Standard will be recorded on the attached data sheet.

The Shore A hardness of each sample will be taken according to AGC Standard 3003, Method 3404, except the equilibrium time will be 15 seconds. Three readings over the surface will be taken and recorded on the attached data sheet.

X

COAT WITH SD-850-2 LINER: SD-850-2 Liner will be prepared by the Q.C. Laboratory in accordance with AGC-36431. Apply a coat 0.010 - 0.020 inches thick to each of the surfaces that are to be bonded. The thickness of the liner bond must be between 0.020 - 0.040 inches. Remove any excess liner which may flow from between the bonding surfaces.

TASK NO.

PROCEDURE

- XI SANDWICH WITH STANDARD-HALF DPT: The standard-half DPT's prepared according to the Flow Sheet, Paragraph F.1, are bonded to samples 001 through 048 with Epon 948.2 or SD-850-2 as specified by the Flow Sheet.
- XII CURE 2 DAYS AT 80°F AND THEN 2 DAYS AT 135°F: The samples bonded together with SD-850-2 liner are cured at 80°F for two days and then 135°F for two days, in accordance with AGC 36431.
- XIII BOND SURFACES WITH V-61 RUBBER: The V-61 rubber will be prepared by Operations personnel, Dept. 3340, in the Model S-1378 SEMCO pressure mixer at 60 strokes per batch. A one-half gallon size batch will be prepared per agc 36335 and AGC drawing 1005103. A quart can, and one dispensing tube will be filled with the V-61 rubber. In addition, a top for the tube and an air operated dispensing gun will be supplied by Operations.

The V-61 bonding operation that follows will be accomplished immediately after the mixing operations. The pot life of this material is very short.

- A. Wet the rubber surfaces to be bonded with the V-61 in the quart can with a stiff brush. Place the test samples in one modified DPT mold and the control samples in another so the bonding surfaces face each other.

TASK NO.

PROCEDURE

- B. Fill the void between the bonding surfaces with V-61 material from the loaded tube using the air-operated gun and dispensing tip. The tip must be submerged during the filling operations to avoid air entrapment.
- C. Cure the samples for seven days at ambient laboratory conditions, $75^{\circ}\text{F} \pm 2^{\circ}\text{F}$ and 40% RH max. Shore D hardness after seven days shall be 38, minimum.

XIV

V-45 RUBBER, UNFIRED: The quantity, size and use of V-45 rubber as shown on the Flow Sheet are as follows:

<u>Quantity</u>	<u>Size (inches)</u>	<u>Use on Flow Sheet</u>
48	1 x 1 x 0.25	Liner and Adhesive Bond Strength
	1 x 12 x 0.25	Peel Bond Strength

XV

TEST FOR BOND STRENGTH: The double plate tests (DPT) will be tested using a Model TM Instron tester. AGC STD 3003, Method 3421, will be used as a procedure guide. The actual Instron settings and data will be recorded on the data sheet for the test being performed. The data sheets are attached.

The rubber peel samples will be tested according to ASTM D-903. All conditions and data required in ASTM D-903 will be recorded on the Rubber Peel Bond Strength data sheet.

Report NASA CR-72228, Appendix A

Sample Identification	Processing Tasks													Remarks			
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII		XIV	XV	
Effect of Rubber Condition on Liner and Adhesive Bond Strength	2 3/8 x 1/8"	Steel Plates	Sandblast & Clean with CH ₂ Cl ₂	Prime w/Primer 102-Y-22	Spun 946.2 Type IV	V-44 Rubber Tired, except as noted below	Cure at Ambient For 36 Hours	Subject to Hydratest Fluid	Dry at 165 ± 5°F for 15 days	Sand to Depth Indicated Below	Coat with SD 850-2 Liner	Standard-Half DPT	Cure 2 Days at 80°F	Bond Surfaces with V-61 Rubber	Untired	Test for Bond Strength	
	3 ea.		1	2	3	Untired 4	5 & 11	6	7	None	9	10	11		1x1x0.25"	12	
	3 ea.		1	3 & 9	3	Untired 4	5	6	7	None	8	9	10			12	
	3 ea.		1	3 & 9	3	Untired 4	5	6	7	None	8	9	10			12	
	3 ea.		1	2	3 & 9	4	5 & 11	6	7	None	8	9	10			12	
	3 ea.		1	2	3 & 9	4	5 & 11	6	7	0.03"	8	9	10			12	
	3 ea.		1	2	3 & 9	4	5 & 11	6	7	0.03"	8	9	10			12	
	3 ea.		1	2	3 & 9	4	5 & 11	6	7	0.06"	8	9	10			12	
	3 ea.		1	2	3 & 9	4	5 & 11	6	7	0.06"	8	9	10			12	
	3 ea.		1	2	3 & 9	4	5 & 11	6	7	0.10"	8	9	10			12	
	3 ea.		1	2	3 & 9	4	5 & 11	6	7	0.10"	8	9	10			12	
	3 ea.		1	2	3 & 9	4	5 & 11	6	7	0.13"	8	9	10			12	
	3 ea.		1	2	3 & 9	4	5 & 11	6	7	0.13"	8	9	10			12	
	3 ea.		1	2	3 & 9	4	5 & 11	6	7	0.25"	8	9	10			12	
	3 ea.		1	2	3 & 9	4	5 & 11	6	7	0.25"	8	9	10			12	
	48 ea		1	2	3			5									12
(Use with above samples in Task XI, Step 10)																	
Primer Bond Strength	2 3/8 x 1/8"																
	6 ea*		1	2	4	1x1x0.25"	6	3	4								
	6 ea*		1	2	5	Untired 4	7										7
*Number two steel plates with the same number																	
V-61 Bond Strength	2 3/8 x 1/8"																
	6 ea		1	2	3	1x1x0.25"	5	6	7								
	6 ea		1	2	3	Untired 4	5	6	7								8
V-44-V-45 Peel Bond Strength	1x8x1/8"																
	3 ea		1	2	3 & 7	1x8x0.1"	5 & 9	6	7								
	3 ea		1	2	3 & 8	Untired 4	5 & 10	6	7						1x1x0.25"	9	10
																	11