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REINFORCED PLASTIC CONSTRUCTION METHODS FOR LARGE ROCKET MOTOR CASE

VOLUME I PROGRAM SURVEY

FINAL TECHNICAL ENGINEERING REPORT
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FINAL TECHNICAL ENGINEERING REPORT

REINFORCED PLASTIC CONSTRUCTION METHODS FOR LARGE ROCKET MOTOR CASE

VOLUME I - PROGRAM SURVEY

W. G. Morse
F. W. Dallon

THIOKOL CHEMICAL CORPORATION
WASATCH DIVISION

Contract AF 33(600)-42511
Project 7-858

ABSTRACT

The objective of the program was the development of designs, fabrication processes, techniques and equipment for manufacture of fiberglass plastic rocket motor cases. Under Thiokol guidance, case designs and manufacturing methods were established for both monolithic and modular construction of large (44- and 65-in. dia) plastic cases. Design included derivation of dome contours, stress analysis of case assemblies and components, and specification of fiberglass, resin systems, case liners, hardware, and mandrels. Winding patterns and wrapping angles were evaluated using computer programs. Two cases of each design were fabricated, at least one of which was subjected to hydroburst testing. The TU-226A (Lamtex) 65-in. dia case withstood design pressure (1113 psig design; 1164 burst). The TU-227A (Allison) and TU-227B (Brunswick) 44 in. dia cases withstood design pressure (794 psig design; 1185 and 1188 psig burst) with high stress (300,000 psi). Failures due to causes other than case rupture (forward skirt failure; aft cover plate failure) prevented attainment of case rupture for cases fabricated by Black, Sivalls & Bryson (TU-226B-65 in. dia) and Brunswick Corporation (TU-227B-44 in. dia). Hydroburst tests on small diameter (18 in. dia) TU-228 cases (1113 psig design; 1595 and 1800 psig burst) proved the feasibility of modular construction of fiberglass cases. While a large TU-228 case (65 in. dia) ruptured below the design proof value (890 psig design; 840 psig burst) failure was attributed to module misalignment rather than to design defect. The hydroburst test of TU-290 case No. 3 (379,000 psi hoop stress at 750 psig) successfully culminated progressive development of the TU-290 single nozzle case design. The delivery, after fabrication, of a fixed, recessed, conical nozzle for each of two TU-290 hydroproof tested cases which were delivered to the Air Force, concluded the Reinforced Plastic Construction Methods for Large Rocket Motor Case Program.

Chemical Processing Branch
Manufacturing Technology Division
Air Force Materials Laboratory
Research and Technology Division
Air Force Systems Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

Publications No. 664-3312

FOREWORD

This Final Technical Documentary Report covers all work performed under Contract AF33(600)-42511 from 5 March 1961 to 15 November 1963. The manuscript was released by the author on 16 December 1963 for publication as an ASD Technical Engineering Report.

This contract with the Wasatch Division of Thiokol Chemical Corporation was initiated under Manufacturing Methods Project 7-858, "Reinforced Plastic Construction Methods for Large Rocket Motor Case". It was accomplished under the technical direction of Mr. Charles Tanis of the Chemical Processing Branch (MATC), Manufacturing Technology Division, AF Materials Laboratory, Wright-Patterson Air Force Base, Ohio.

Mr. William G. Morse was the Program Manager. Mr. Morse was assisted by Mr. Frank Dallon as Program Manager. Those assisting in the program were Mr. C. J. North, Project Engineer, Mr. Vern Burton and Mr. Neil Visser, Contract Administrators, Mr. C. A. Thierry, Senior Buyer, Mr. Harold M. Lee, Manufacturing Engineer, and Mr. W. M. Horton, Test Engineer. Design and analysis effort was accomplished under Mr. C. R. Bratton and Mr. John Hinchman, with stress analyses on case and nozzle designs by Mr. W. D. Humphrey, Mr. Dale Abildskov, Mr. R. L. Webster, Mr. J. Daines, Mr. James L. Crandell, Mr. Alex Brinchman, Mr. Claire Williams, Mr. John Kapp, and Mr. John Wilson. Technical writing was completed by Mr. R. McKnight.

This project has been accomplished as a part of the Air Force Manufacturing Methods Program, the primary objective of which is to develop, on a timely basis, manufacturing processes, techniques and equipment for use in economical production of USAF materials and components. The program encompasses the following technical areas:

Metallurgy - Rolling, Forging, Extruding, Casting, Fiber, Powder.
Chemical - Propellant, Coating, Ceramic, Graphite, Nonmetallics.
Electronic - Solid State, Materials and Special Techniques, Thermionics.
Fabrication - Forming, Material Removal, Joining, Components.

Suggestions concerning additional Manufacturing Methods development required on this or other subjects will be appreciated.

ABSTRACT

REINFORCED PLASTIC CONSTRUCTION METHODS FOR LARGE ROCKET MOTOR CASE (VOLUME I PROGRAM SURVEY)

W. G. Morse
F. W. Dallon

Thiokol Chemical Corporation
Wasatch Division

The objective of the program was the development of designs, fabrication processes, techniques and equipment for manufacture of fiberglass plastic rocket motor cases. Under Thiokol guidance, case designs and manufacturing methods were established for both monolithic and modular construction of large (44- and 65-in. dia) plastic cases. Design included derivation of dome contours, stress analysis of case assemblies and components, and specification of fiberglass, resin systems, case liners, hardware, and mandrels. Winding patterns and wrapping angles were evaluated using computer programs. Two cases of each design were fabricated, at least one of which was subjected to hydroburst testing. The TU-226A (Lamtex) 65 in. dia case withstood design pressure (1113 psig design; 1164 burst). The TU-227A (Allison) and TU-227B (Brunswick) 44 in. dia cases withstood design pressure (794 psig design; 1185 and 1188 psig burst) with high stress (300,000 psi). Failures due to causes other than case rupture (forward skirt failure; aft cover plate failure) prevented attainment of case rupture for cases fabricated by Black, Sivalls & Bryson (TU-226B-65 in. dia) and Brunswick Corporation (TU-227B-44 in. dia). Hydroburst tests on small diameter (18 in. dia) TU-228 cases (1113 psig design; 1595 and 1800 psig burst) proved the feasibility of modular construction of fiberglass cases. While a large TU-228 case (65 in. dia) ruptured below the design proof value (890 psig design; 840 psig burst) failure was attributed to module misalignment rather than to design defect. The hydroburst test of TU-290 case No. 3 (379,000 psi hoop stress at 750 psig) successfully culminated progressive development of the TU-290 single nozzle case design. The delivery, after fabrication, of a fixed, recessed, conical nozzle for each of two TU-290 hydroproof tested cases which were delivered to the Air Force, concluded the Reinforced Plastic Construction Methods for Large Rocket Motor Case Program.

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PUBLICATION REVIEW

This volume has been reviewed and is approved.

FOR THE DIRECTOR:

Melvin E. Fields
MELVIN E. FIELDS
Colonel, USAF
Chief, Manufacturing Technology Division
AF Materials Laboratory

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VOLUME ONE - PROGRAM SURVEY

I. INTRODUCTION

A. PROGRAM SCOPE

The Wasatch Division of Thiokol Chemical Corporation began work on Air Force Contract AF 33(600)-42511, "Large Plastic Rocket Motor Cases," on 5 Mar 1961. The program was planned in four phases, (I) Design Study, (II) Case Fabrication and Hydrostatic Testing, (III) Flight Loads Testing, and (IV) Static Firing. Subsequently, the program was redirected to emphasize advancement of fiberglass technology, rather than firing of rocket motors. The original Phases III and IV were deleted and a new Phase III, requiring the development of single (rather than a four) nozzle rocket motor, was substituted by supplemental agreement to the contract. Prior to the conclusion of the program, due to retitling of contract projects, this program was designated, "Reinforced Plastic Construction Methods for Large Rocket Motor Case".

This final report consists of six volumes. Volume I, "Program Survey", describes the program scope and objectives, the case designs, and the monolithic and modular construction concepts for fiberglass plastic cases. Volume II, "Case Designs and Fabrication", describes the design, fabrication and hydrotest for monolithic case construction (TU-226 and TU-227 case types). Volume III, "TU-228 Case Design and Fabrication", contains information parallel to that of Volume II for modular construction of cases, as does Volume IV, "TU-290 Case Design and Fabrication", for a monolithic case constructed during the redirected Phase III of the contract. Volume V, "Mandrels", describes the design, construction and use of mandrels for case fabrication. Volume VI, "Stress Analysis", contains stress analyses applicable to various facets of case design. Each volume contains an abbreviated table of contents of the entire report.

B. PROGRAM OBJECTIVE AND PROGRAM DESCRIPTION

The primary objective of the Reinforced Plastic Construction Methods for Large Rocket Motor Case Program was the development of manufacturing methods, control, processes, and equipment that can be used to fabricate large (65 in. dia or larger) fiberglass rocket motor cases. The objective included the advancement of the state-of-the-art of fiberglass use and the development of a high performance rocket motor. After work had begun, the program was redirected to emphasize advancement of the state-of-the-art of fiberglass use. The loading of propellant into cases, and the firing of motors, were deleted from the program.

The redirected program is described by phases as follows.

1. Phase I - Design Study

Thiokol prepared preliminary specification drawings for a monolithic and for a modular construction of fiberglass cases. Two types of case (TU-226 and TU-227; Figures 1 and 2), were to be constructed monolithically of fiberglass and a resin system. The TU-226 cases were to be 64.88 in. ID by 257 in. long; the TU-227 cases were to be 44.03 in. ID by 132.4 in. long. The TU-226 and TU-227 case types were to be fabricated by two methods (TU-226A and B designs; TU-227A and B designs). A case of modular design (TU-228, Figure 3; 65.90 in. ID by 258 in. long) was also to be constructed of fiberglass and a resin system. Requests for proposal to build one of the case designs were submitted to each of 19 vendors. After evaluation of proposals, Thiokol recommended a vendor to fabricate a case of each design to the Air Force procuring agency for approval, before contracts were awarded and before Phase II was started.

2. Phase II - Case Fabrication and Hydrostatic Testing

Following bench and laboratory tests (required to establish design concepts fundamental to fabrication) the fabrication and hydrotest of two cases of each design were planned for Phase II. Two cases of the best design of each type (TU-226 or TU-228, and TU-227 types) would be fabricated. These cases would be loaded with inert material simulating propellant in Phase III. Three additional cases of the best TU-227 design would be loaded with live propellant and tested in Phase IV. One case of modular design would also be loaded with live propellant and tested. When the program was redirected during Phase II, Phases III and IV were deleted, and a new Phase III substituted. In Phase II, therefore, only two cases of each design (TU-226, TU-227) and one TU-228 case were fabricated and hydrotested.

3. Phase III - TU-290 Case Design, Fabrication, Test, and Delivery

Three cases (TU-290, Figure 4), each approximately 44 in. in dia and 11 ft long, were designed, fabricated and tested. Fabrication of the second case followed hydroburst test of the first, to permit analysis of test results to be incorporated into design of the second case. Fabrication of the third case followed hydrotest of the second, with similar reasoning. Two additional cases were then fabricated following hydrotest of (and according to the design of) the third case. These latter two cases were insulated, and hydrotested to design limit pressure, before delivery to the Air Force.

A nozzle assembly was designed for use with the TU-290 motor. Two assemblies were fabricated and delivered to the Air Force.

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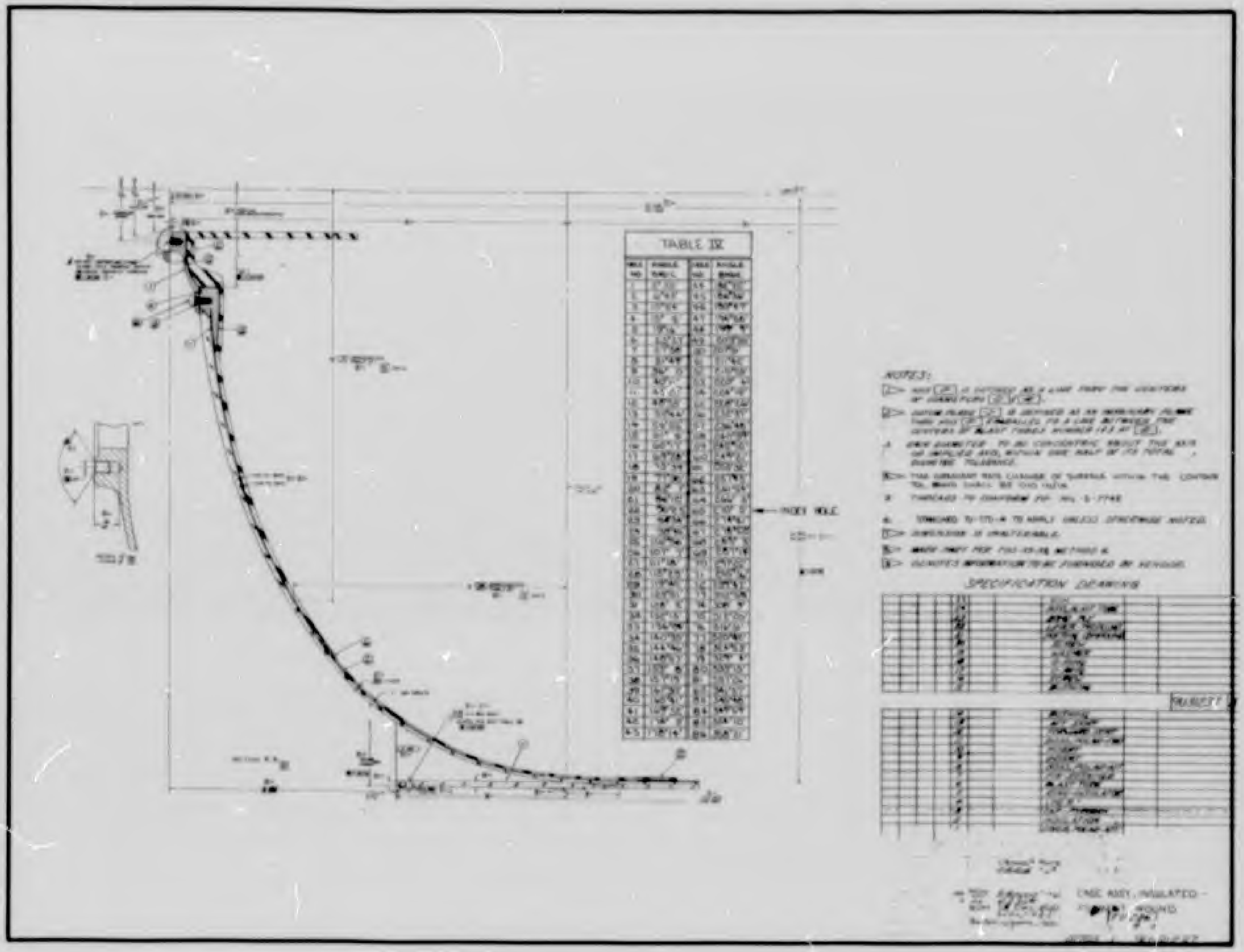


Figure 1. TU-226 Monolithic Fiberglass Plastic Case Drawing 9U31237 (Page 1 of 3)

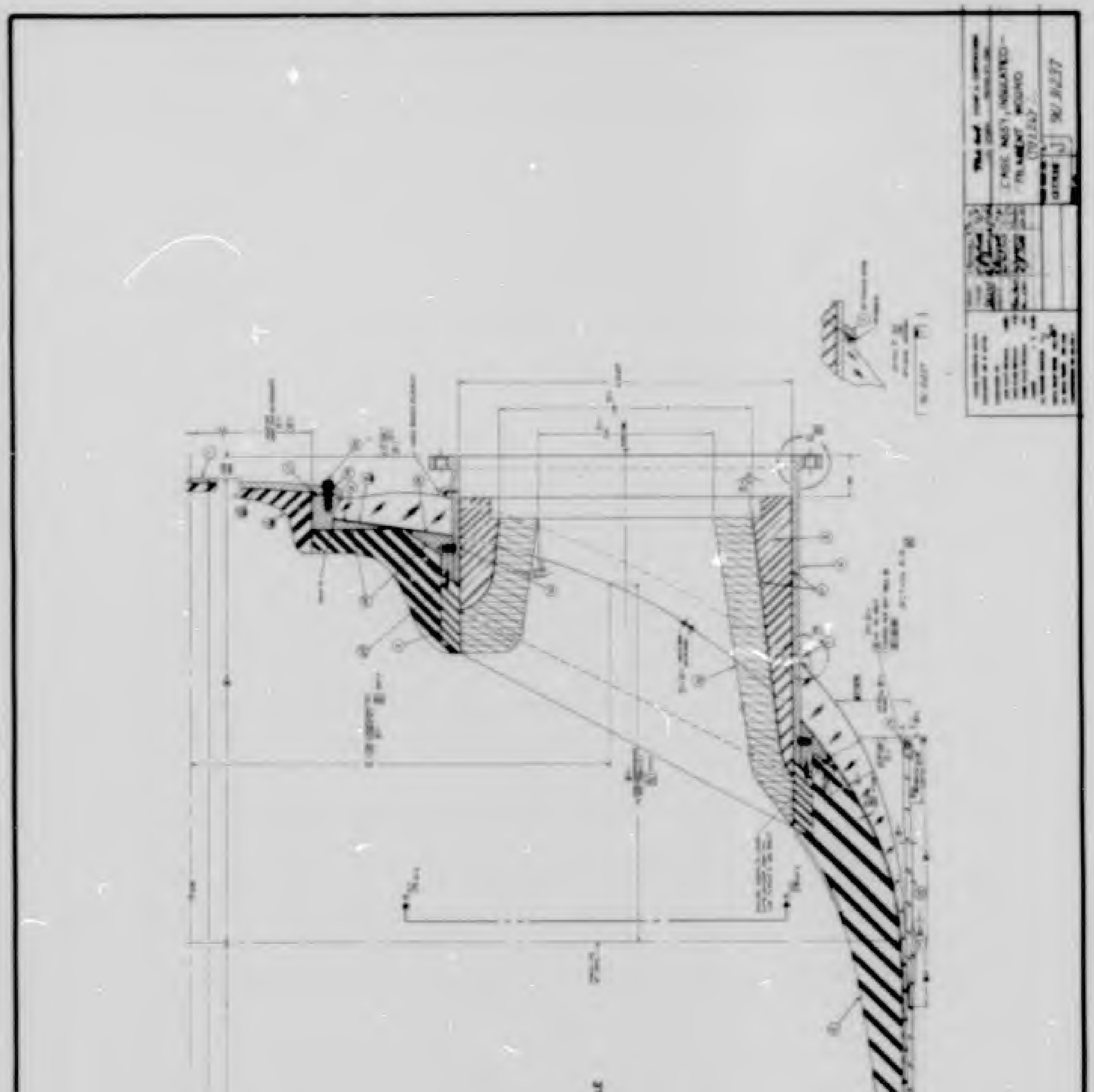


Figure 1. TU-226 Monolithic Fiberglass Plastic Case Drawing 9U31237 (Page 2 of 3)

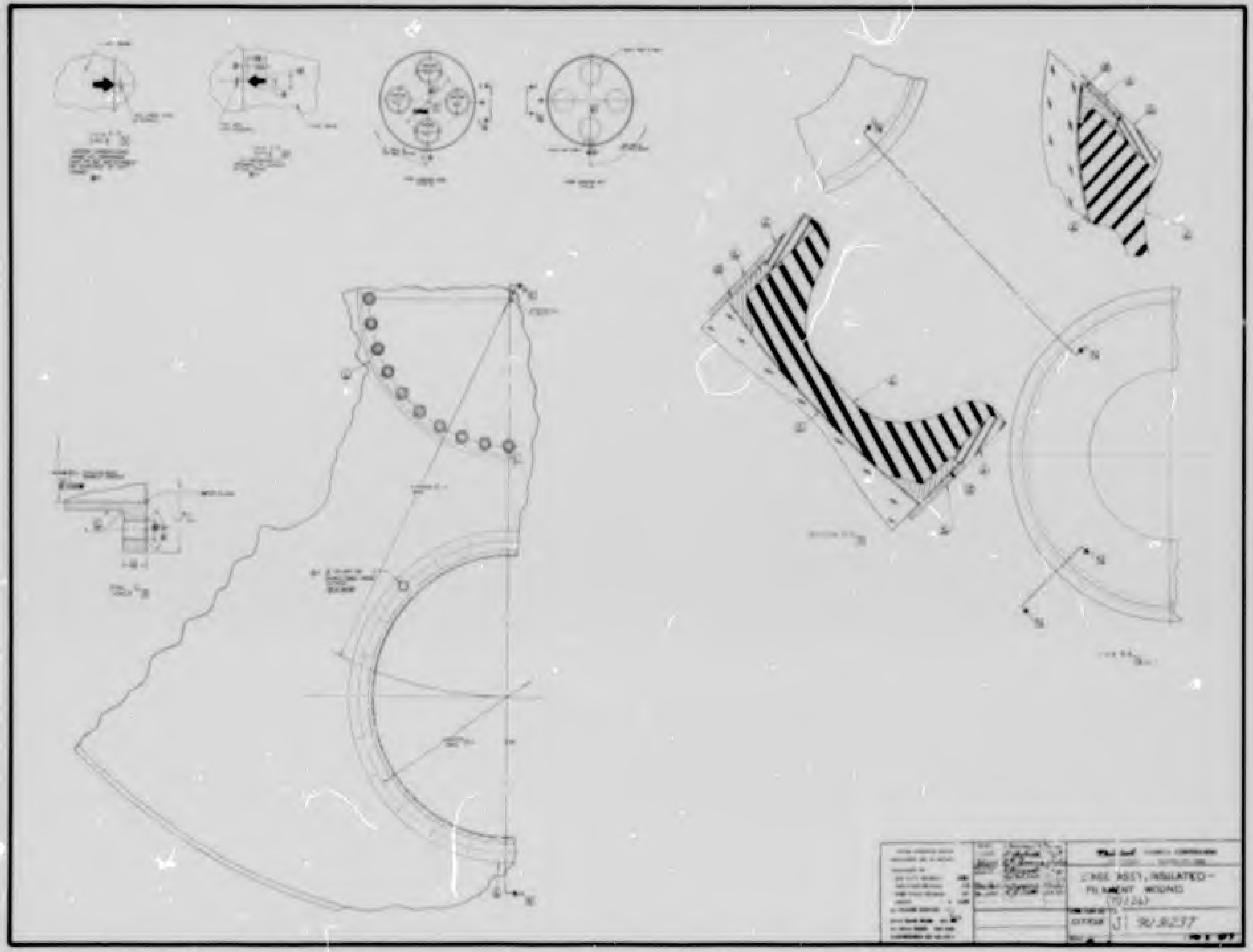


Figure 1. TU-226 Monolithic Fiberglass Plastic Case Drawing 9U31237 (Page 3 of 3)

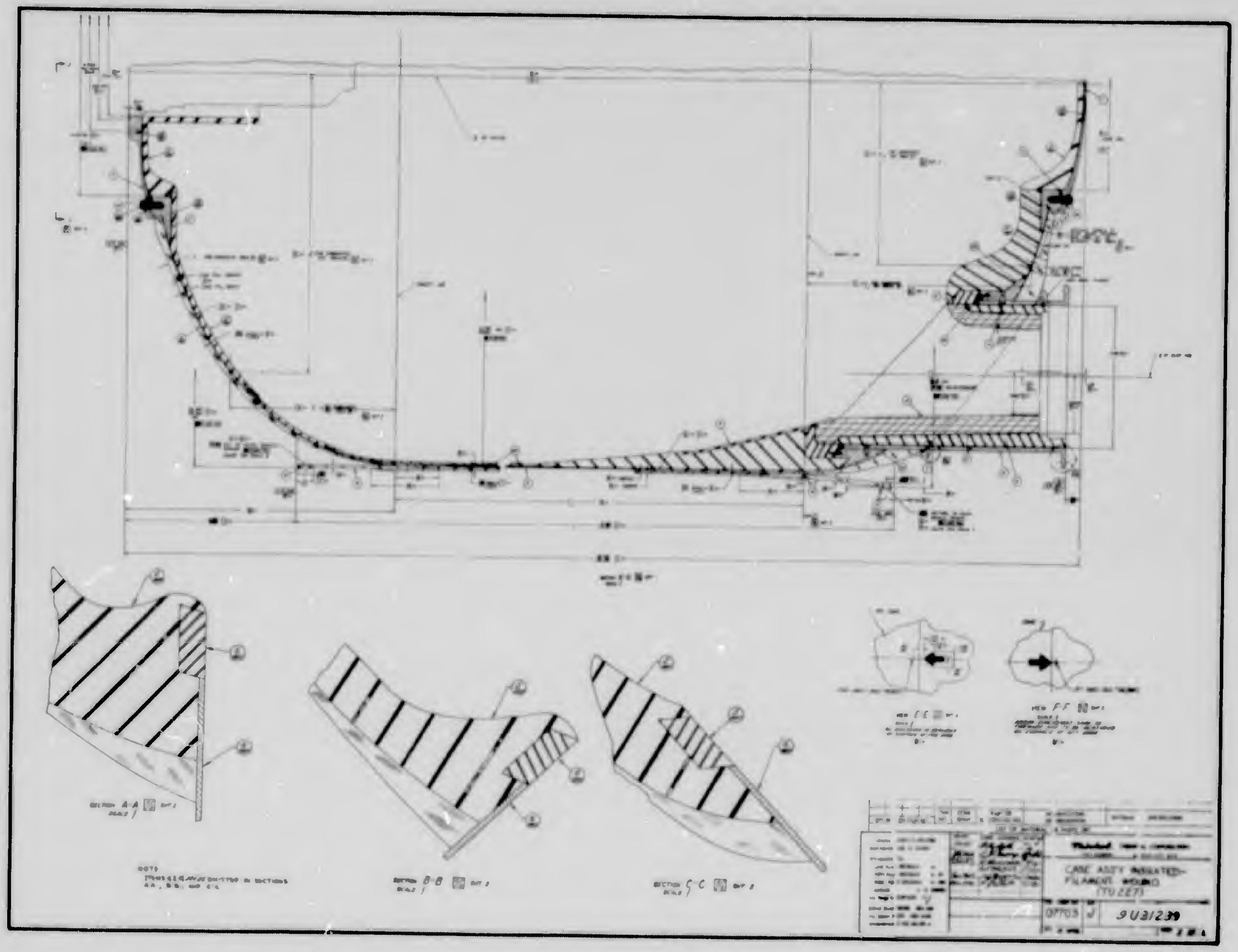


Figure 2. TU-227 Monolithic Fiberglass Plastic Case Drawing 9U31239 (Page 1 of 3)

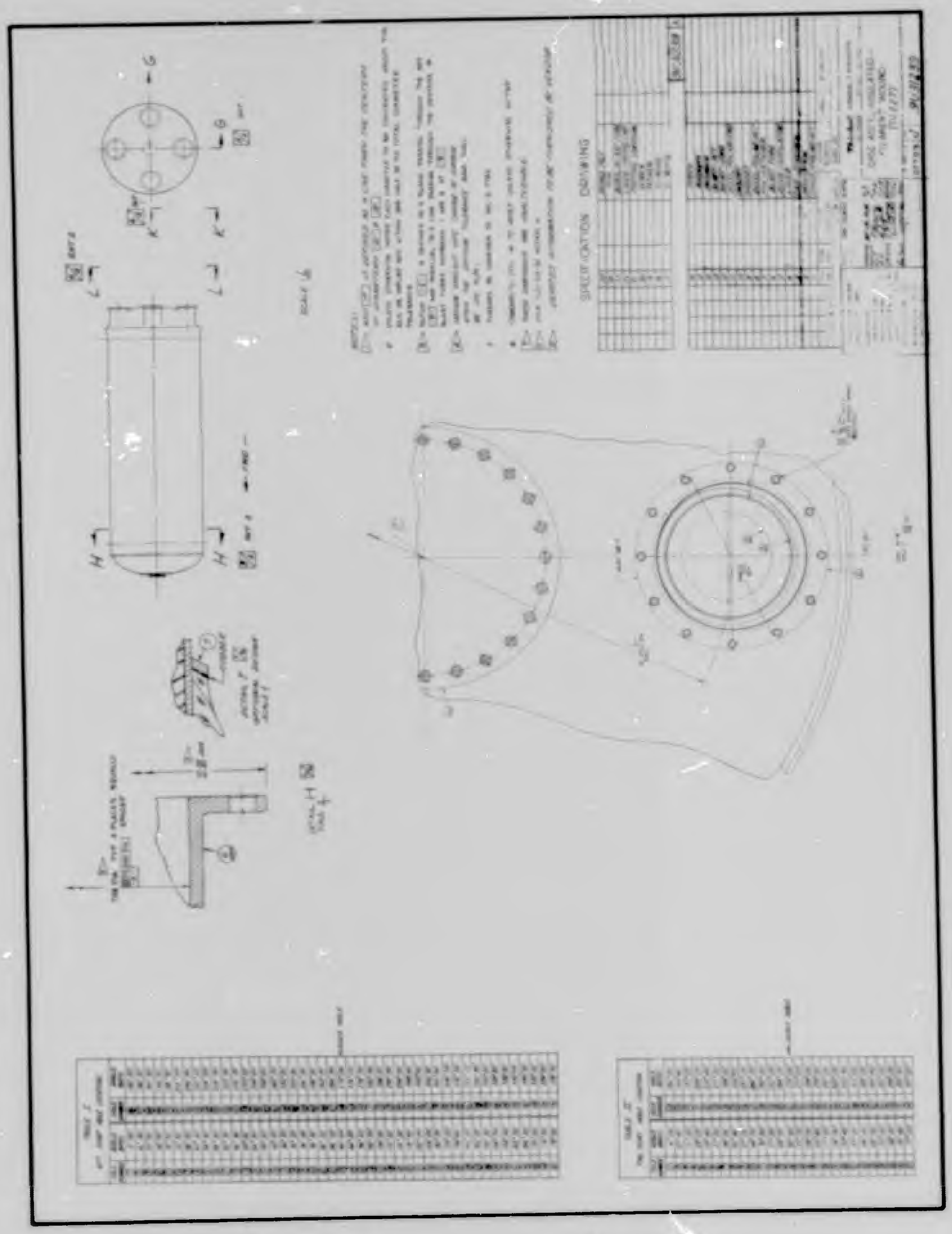


Figure 2. TU-227 Monolithic Fiberglass Plastic Case Drawing 9U31239 (Page 2 of 3)

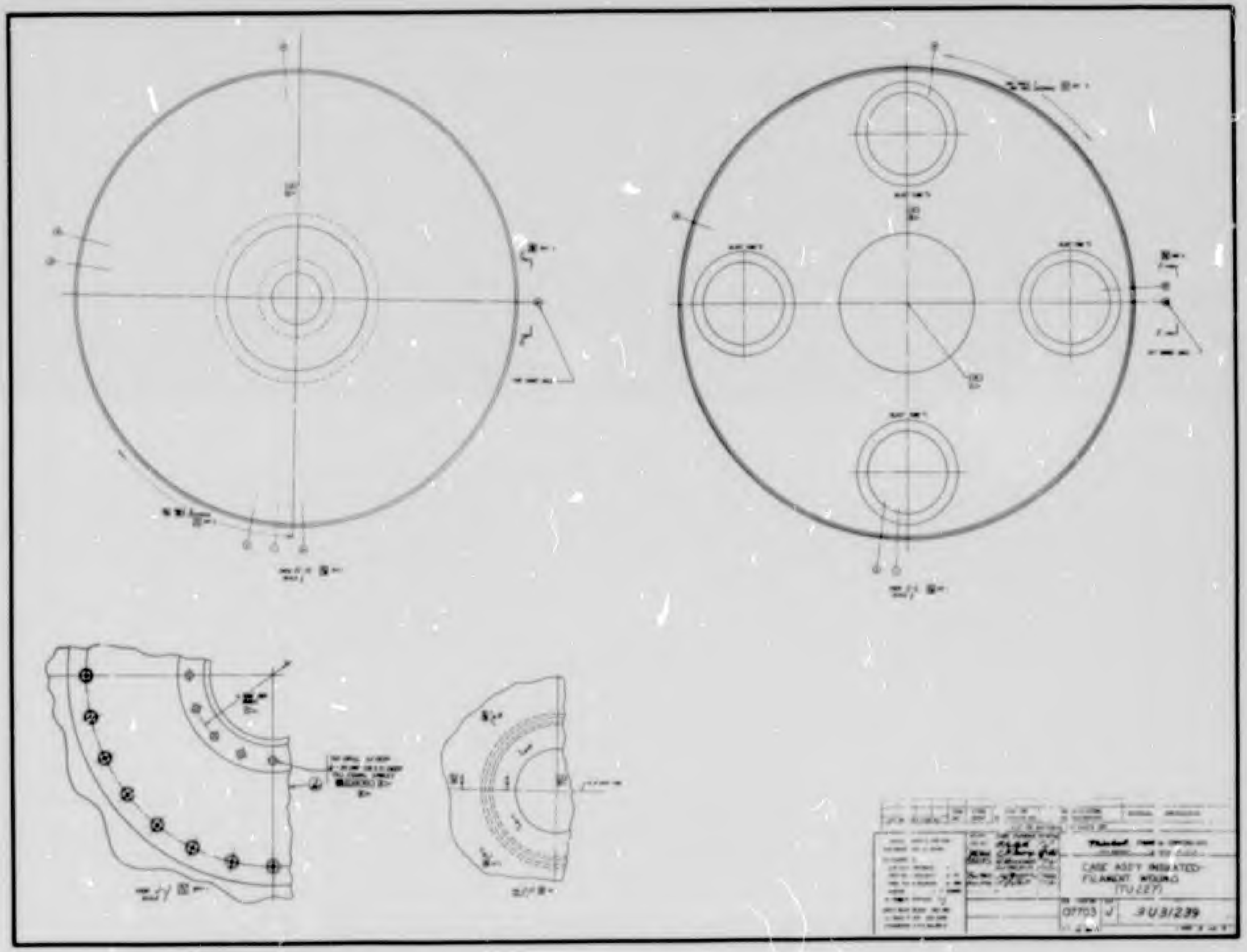


Figure 2. TU-227 Monolithic Fiberglass Plartic Case Drawing 9U31239 (Page 3 of 3)

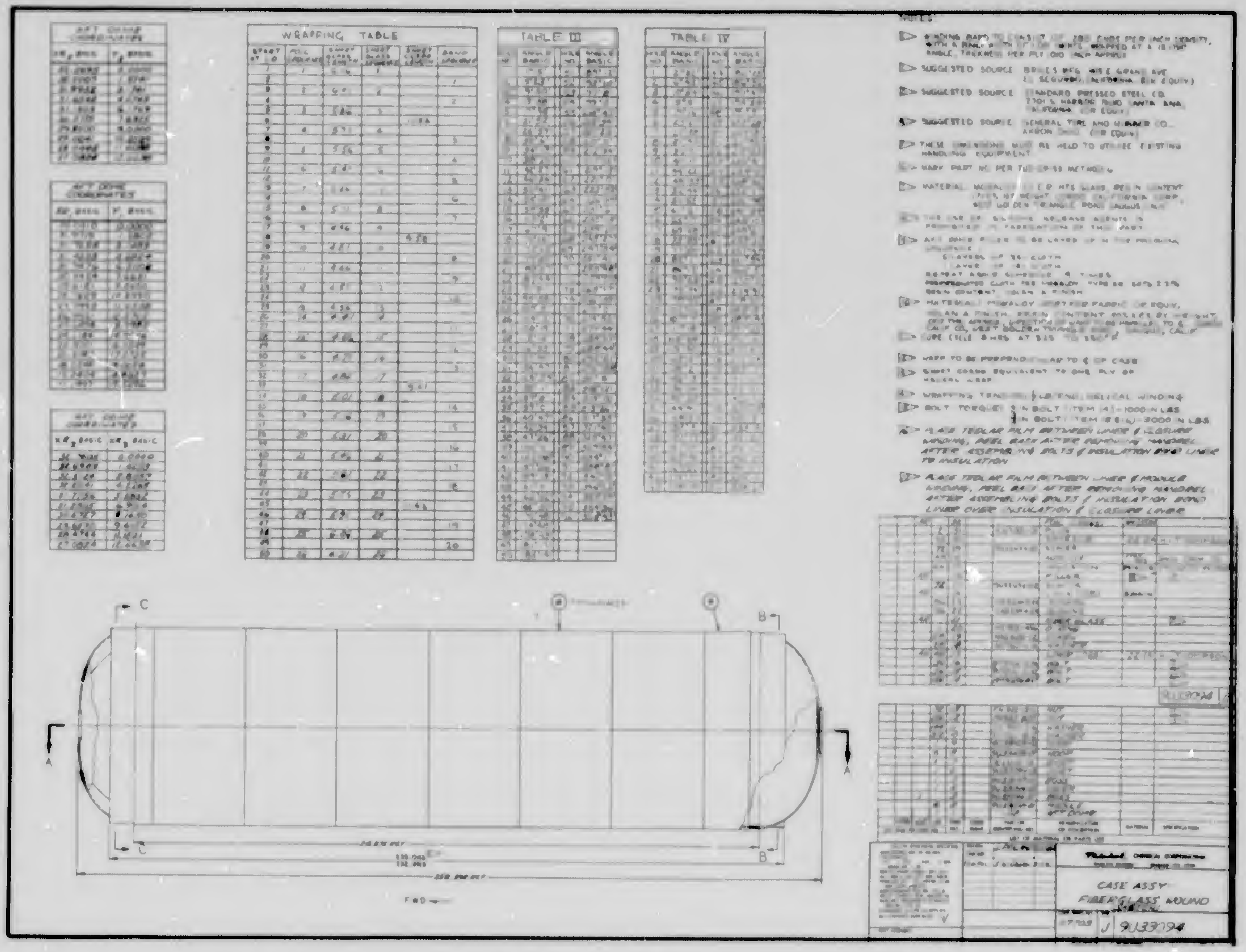


Figure 3. TU-228 Modular Fiberglass Plastic Case Drawing 9U33094 (Page 1 of 2)

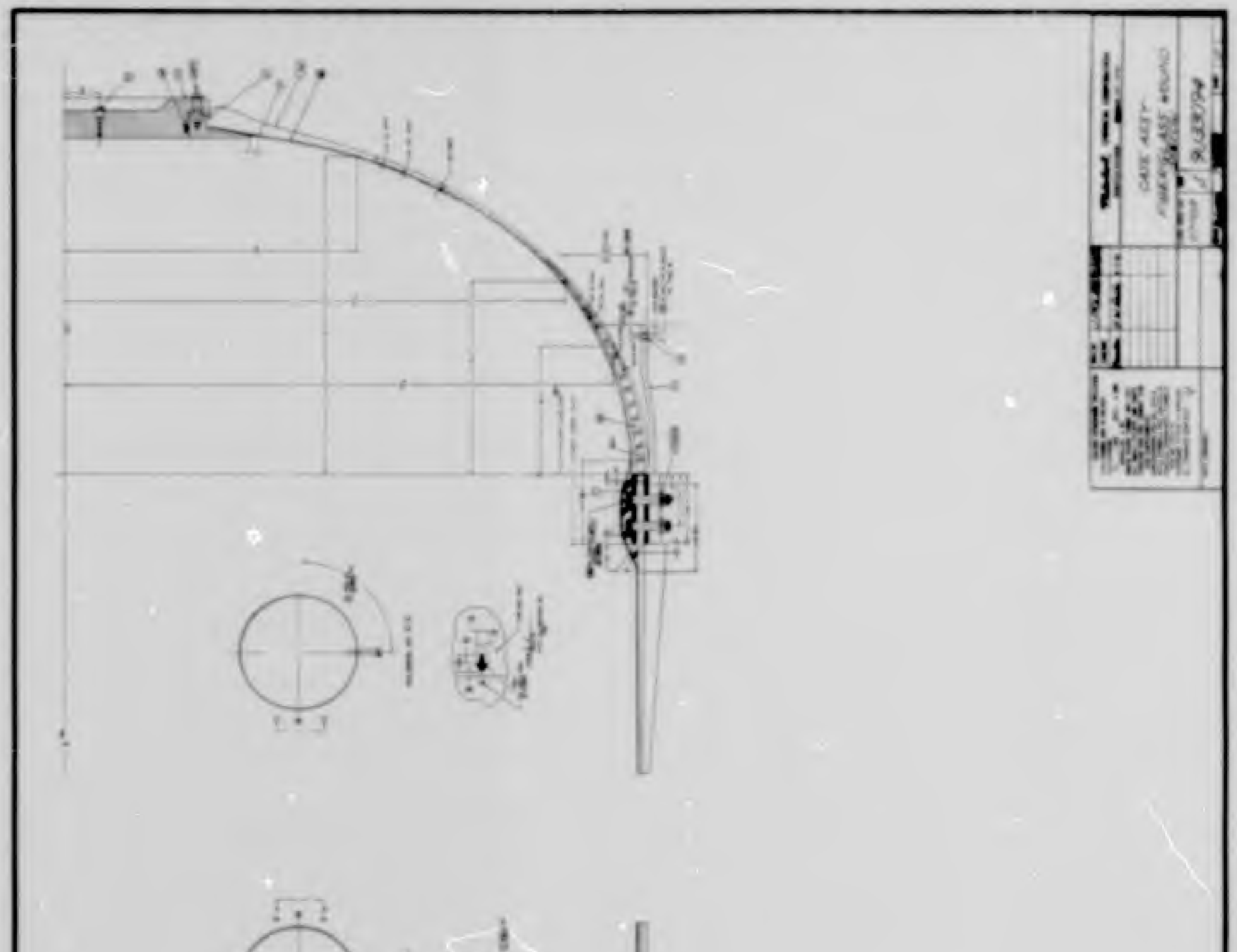


Figure 3. TU-228 Modular Fiberglass Plastic Case Drawing 9U33094 (Page 2 of 2)

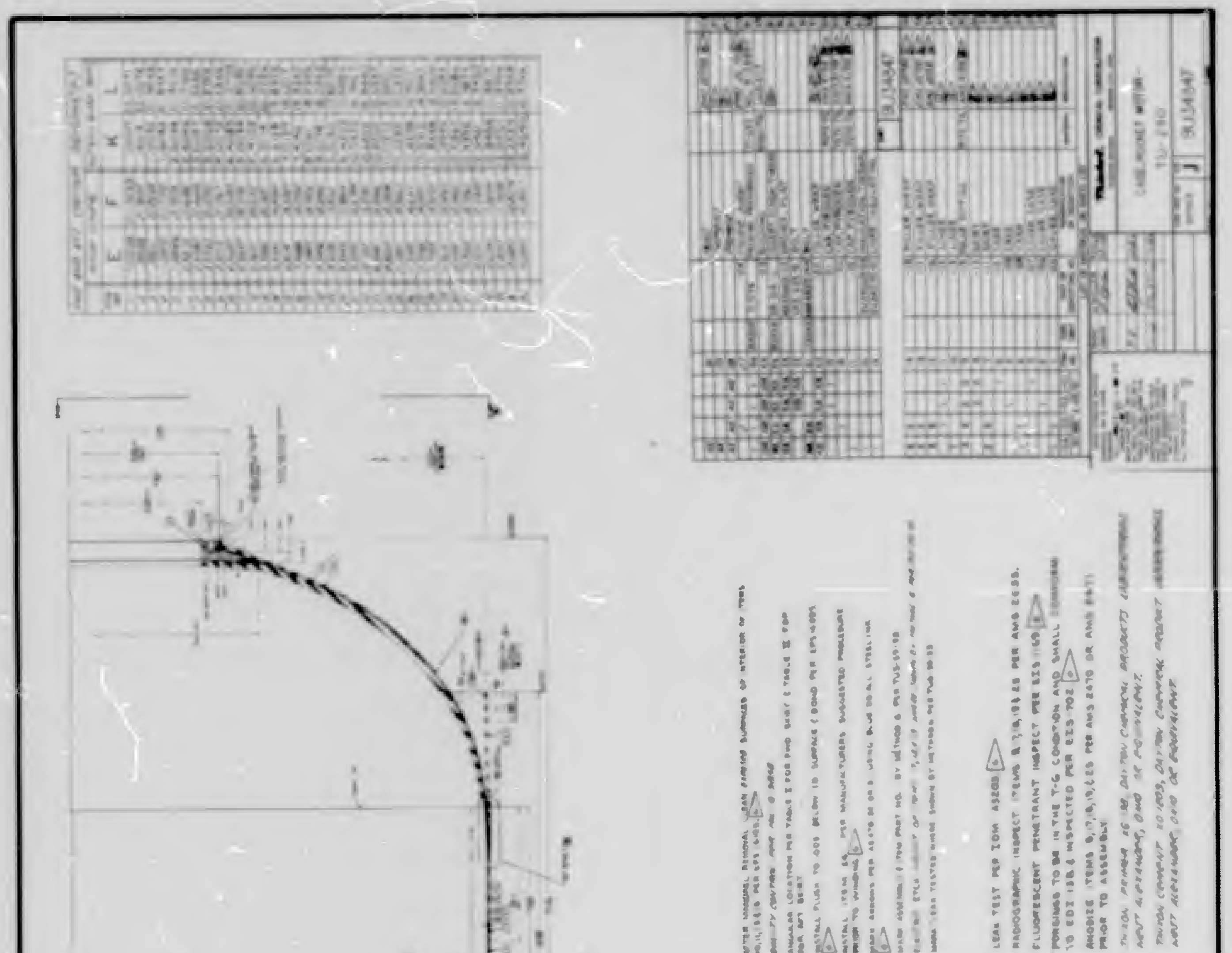


Figure 4. TU-290 Monolithic Fiberglass Plastic Case Drawing 9U34847 (Page 1 of 2)

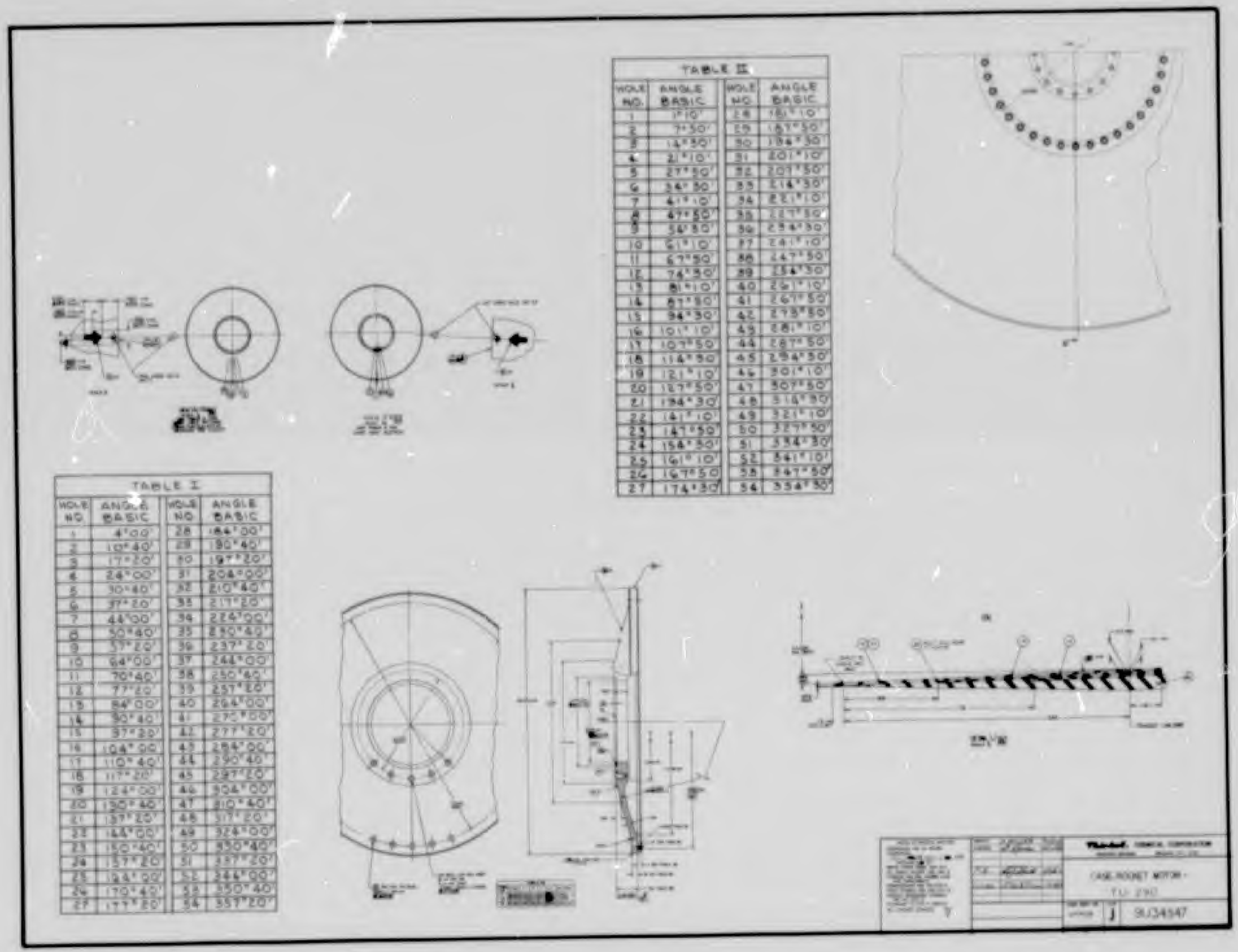


TABLE I

HOLE NO	ANGLE BASIC	HOLE NO	ANGLE BASIC
1	4°00'	28	184°00'
2	10°40'	29	190°40'
3	17°20'	30	197°20'
4	24°00'	31	204°00'
5	30°40'	32	210°40'
6	37°20'	33	217°20'
7	44°00'	34	224°00'
8	50°40'	35	230°40'
9	57°20'	36	237°20'
10	64°00'	37	244°00'
11	70°40'	38	250°40'
12	77°20'	39	257°20'
13	84°00'	40	264°00'
14	90°40'	41	270°00'
15	97°20'	42	277°20'
16	104°00'	43	284°00'
17	110°40'	44	290°40'
18	117°20'	45	297°20'
19	124°00'	46	304°00'
20	130°40'	47	310°40'
21	137°20'	48	317°20'
22	144°00'	49	324°00'
23	150°40'	50	330°40'
24	157°20'	51	337°20'
25	164°00'	52	344°00'
26	170°40'	53	350°40'
27	177°20'	54	357°20'

TABLE II

HOLE NO.	ANGLE BASIC	HOLE NO.	ANGLE BASIC
1	1°10'	28	181°10'
2	7°50'	29	187°50'
3	14°30'	30	194°30'
4	21°10'	31	201°10'
5	27°50'	32	207°50'
6	34°30'	33	214°30'
7	41°10'	34	221°10'
8	47°50'	35	227°50'
9	54°30'	36	234°30'
10	61°10'	37	241°10'
11	67°50'	38	247°50'
12	74°30'	39	254°30'
13	81°10'	40	261°10'
14	87°50'	41	267°50'
15	94°30'	42	274°30'
16	101°10'	43	281°10'
17	107°50'	44	287°50'
18	114°30'	45	294°30'
19	121°10'	46	301°10'
20	127°50'	47	307°50'
21	134°30'	48	314°30'
22	141°10'	49	321°10'
23	147°50'	50	327°50'
24	154°30'	51	334°30'
25	161°10'	52	341°10'
26	167°50'	53	347°50'
27	174°30'	54	354°30'

Figure 4. TU-290 Monolithic Fiberglass Plastic Case Drawing 9U34847 (Page 2 of 2)

C. DESIGN AND FABRICATION REQUIREMENTS

The purpose of this program was to develop manufacturing methods for the fabrication of large (65 in. dia and larger) fiberglass reinforced plastic rocket motor cases. Designs were prepared for the monolithic and modular cases to be fabricated under the development portion of the program (Phases II and III). Performance requirements were the same as required for Stage I and II MINUTEMAN motors. Each fabricator selected to work on this program was allowed to use, to a great extent, a general fabrication process which had been developed for smaller cases. Case designs were expected to be consistent with the successful experience of each fabricator, where the fabricator would use basic winding equipment available and a fiberglass and resin system which would, according to his experience provide the highest strength levels. Consequently, the fabrication processes varied widely and included helical and polar winding, interspersed hoop and helical winding, noninterspersed hoop and helical winding, pressurized and nonpressurized mandrels, mandrels of segmented aluminum extrusion, of cast sand and resin, of soluble or breakout plaster construction, and both prefabricated and integrally wound skirts of fiberglass, or fiberglass and aluminum, construction. Lamtex selected single end E-HTS fiberglass roving for case manufacture, and 168-end E-HTS fiberglass for skirt fabrication. BS & used 20-end E-801 fiberglass for helical case wrapping and 30-end E-801 fiberglass for hoop wrapping. Allison selected 12-end E-HTS fiberglass for both helical and hoop wrapping. Brunswick chose 12-end E-HTS fiberglass for polar, and 20-end E-HTS fiberglass for hoop wrapping. Hitco used 20-end E-HTS fiberglass for fabrication of modules of the case.

Periodic progress reports from each fabricator were also required, as well as descriptions of fabrication processes, techniques, and procedures, inspection reports and test reports.

II. DISCUSSION

A. PHASE I - DESIGN AND STUDY

Thiokol began work on this phase of the contract on 5 Mar 1961. The objectives of this phase were:

1. To study basic design concepts, component materials, design parameters, glass-resin combinations, winding techniques, and dome port reinforcing methods for fiberglass plastic motor cases;
2. To design fiberglass plastic motor cases of large (44 to 65 in. or larger) diameters;
3. To investigate propellant loading and case handling techniques for large fiberglass plastic motor cases, to prepare tentative loading procedures, and to estimate tool and equipment requirements and costs for various grain configurations;
4. To complete preliminary case and ballistic design drawings, case weight calculations, and component tolerance studies before the selection of vendors;
5. To evaluate subcontractor proposals for case fabrication.

Phase I effort was completed by May 1961, following a project progress conference at Manufacturing Methods Division, AMC, Aeronautical Systems Center, Wright-Patterson, Ohio. The accomplishments of Phase I are discussed below.

1. Component Design and Materials Evaluation

a. Skirts

Thiokol originally planned to design skirts for fiberglass plastic motor cases to meet handling requirements of MINUTEMAN cases, because tooling for this case size was available. Also, since strength in the attachment area was a basic consideration, steel was first considered for the skirt material. Skirts made of steel can be made having a shorter width than skirts of other materials, because of inherent strength. For a given skirt-to-skirt length, a shorter skirt width permits greater case volume, a greater volume of propellant, and a higher motor mass fraction.

Skirts made of other materials (Figure 5) also considered were:

1. An all metal, nonferrous skirt;
2. A skirt laminated of metal and fiberglass;
3. A fiberglass skirt with metal bushings at attachment points.

The skirt designs were evaluated using these criteria:

1. Structural integrity and reliability;
2. Compatibility between skirt and case expansion rates under stress;
3. Cost;
4. Ease of fabrication.

The all metal steel skirt design was rejected because the difference in expansion rates between steel and fiberglass compromised structural integrity. The all metal, nonferrous skirt design was rejected for the same reason.

A fiberglass skirt having steel strips in the region of attachment laminated between layers of fiberglass was designed. The design is superior to all metal designs in strain compatibility. Machining difficulties and tolerance considerations are eliminated. The design permits a fiberglass-to-fiberglass bond in the attachment area, which contributes to structural reliability.

Continued investigation revealed that an all fiberglass designed skirt with metal bushings could be fabricated which would meet all loading requirements. With only a minor modification to the case handling harness, a tension load on the skirt (and thereby, an increase in skirt length) would be eliminated. The fiberglass skirt design costs less to fabricate and permitted better structural integrity since plastic to metal compatibility problems were not involved. To prevent damage to attachment holes in the skirt during case handling, protective metal bushings were inserted in each hole. These bushings also reduced bearing stress on the fiberglass. The length of the skirt had to be increased to compensate for expansion of the case dome while allowing adequate clearance for attachment bolts.

This skirt design also permitted prefabrication of a skirt, which could be slipped over the case during the wrapping operation and secured by hoop windings. This skirt design was selected for use with TU-226A, TU-226B, TU-227A and TU-228 case designs.

The metal and fiberglass laminated skirt design was modified for use on the TU-227B case design. An aluminum ring was designed, through which skirt attachment bolt holes could be drilled, but which had a thin, peripheral extension to which the layers of fiberglass were bonded. The method of fabrication permitted the fiberglass of the skirt to be bonded to the fiberglass of the case.

b. Insulation

Designs for internal case insulation were prepared using the latest state-of-the-art advancements of the solid propellant industry. A rigid or semirigid insulation was selected initially, but was replaced by an elastomeric insulation when newly developed methods for application of insulation became available. The basic high elongation properties and excellent impermeability characteristics of elastomers, together with the high erosion resistance of silicone and asbestos fiber fillers, provided a superior insulation. The new insulation materials reduced fabrication and tooling costs, and eliminated sealing (and cracking) problems encountered with rigid insulation materials. An inexpensive female mold could be used to form and place elastomeric materials instead of the costly, matched compression tooling required for rigid insulation. The most important advantage of elastomeric insulation for use with fiberglass cases was high elasticity, because of the high elongation of fiberglass cases under stress.

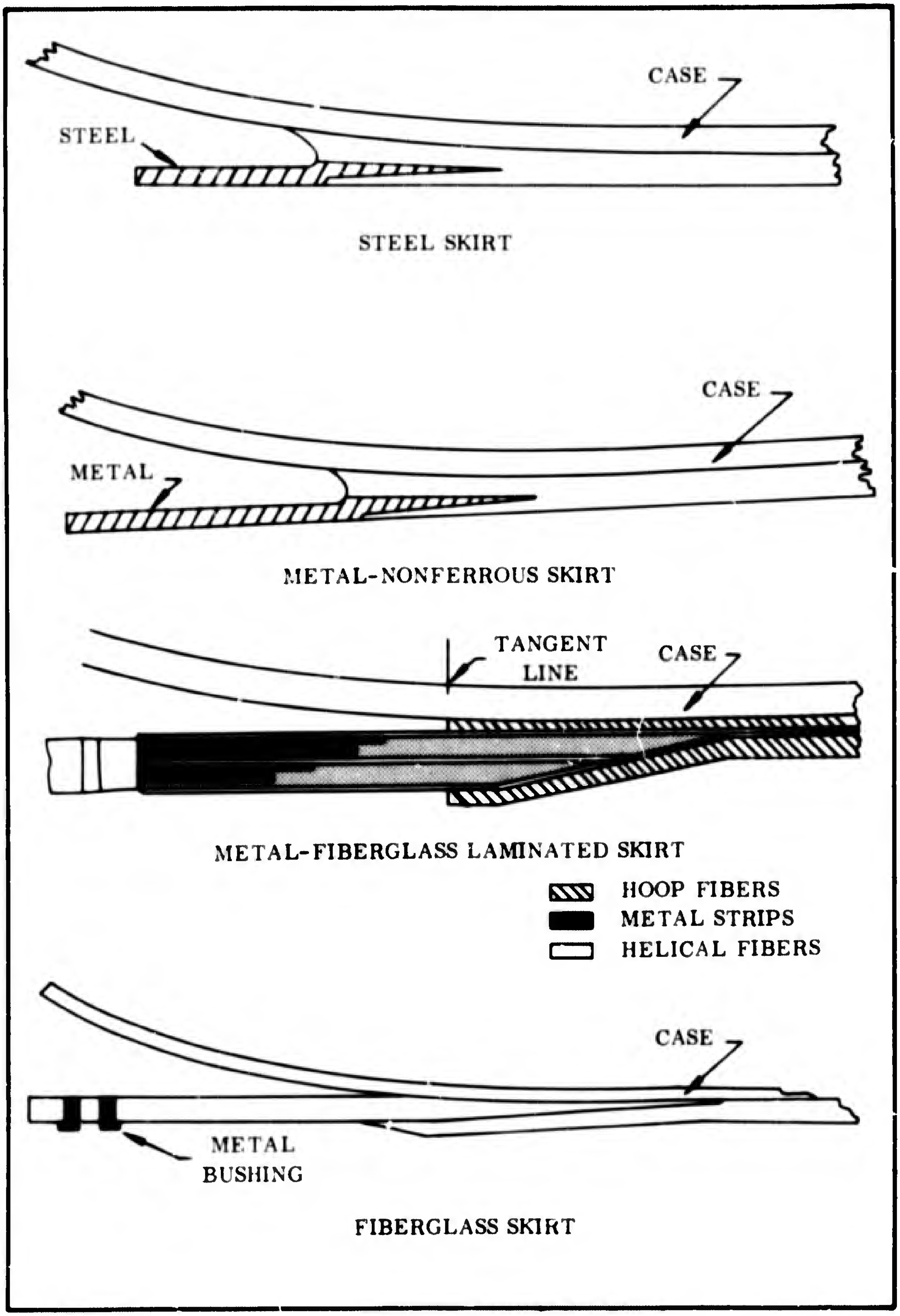
In the case insulation design, a rubber layer, impermeable to gas, was bonded to the external surface of the insulation. It consisted of two layers of uncured Buna-N rubber, vulcanized to form a single, fused layer 0.060 in. thick.

At each nozzle port, a graphite-phenolic insulator ring, molded into the insulation, was used as a thermal insulating barrier between the nozzle throat and the ablative elastomeric insulation. The barrier would prevent material degradation and subsequent gas flow behind the graphite. In addition to serving as a heat barrier, the graphite-phenolic ring would serve as a structural member supporting the elastomeric insulation, as a close tolerance joining surface for blast tube inserts, and as an intermediate, heat dissipating, agent.

The insulation would be premolded and assembled on the case mandrel before fiberglass winding operations. The technique permits all bosses and attachment hardware to be molded into the insulation and provides a leakproof, gas-tight seal inside the completed chamber.

c. Fore and Aft Dome Ports

Case openings were designed originally for removable fore and aft dome closures because large openings would be required to insert a metal mandrel for propellant loading. This approach to case design was rejected early in Phase I because too many difficulties were encountered in the development of case design.



STEEL SKIRT

METAL-NONFERROUS SKIRT

METAL-FIBERGLASS LAMINATED SKIRT

FIBERGLASS SKIRT

Figure 5. Skirt Designs Considered - Phase I

The loading technique was modified to permit use of a collapsible (or frangible, or soluble) mandrel instead of a solid mandrel. This change eliminated the need for large fore and aft ports in the case. Structural advantages were realized with smaller fore and aft ports of equal (or nearly equal) size, and stresses were alleviated in these critical regions. A stable winding angle for application of glass fibers could be used, and the load on the polar cap was reduced. The reduction of the load on the polar cap permitted use of a lightweight port cap design.

d. Blast Tubes

The originally proposed design had blast tubes bolted directly to the fiberglass. A new design was developed after investigation and analytical study, which permitted construction of a case easier to build and having greater structural integrity. The blast tubes would be installed before propellant was loaded. However, to prevent damage to blast tube insulation during propellant loading, the insulation would have to be attached after loading, a slight disadvantage relative to the original design.

Blast tube attachment methods (Figures 6 and 7) investigated during Phase I included:

1. Bolting directly to the fiberglass;
2. Bolting parallel to the motor case centerline into the steel blast tube flange;
3. Bolting radially to the blast tube ring;
4. Attaching by breechlock arrangement to the blast tube flange;
5. Attaching with a snap ring on a modification of a snap ring;
6. Using a one piece fiberglass blast tube;
7. Incorporating a one piece fiberglass blast tube and blast tube ring.

A one piece blast tube and blast tube attachment collar would provide the highest structural efficiency, but motor fabrication and assembly requirements precluded use of the design. Other design considerations (excessive machining cost, problems in sealing against pressure leakage, excessive weight, undesirable assembly procedures, excessive nozzle and insulation development) negated advantages of many attachment methods considered.

In the final design, the blast tube attachment collar was embedded in the closure insulation. After the case was wrapped and cured, nozzle ports were cut

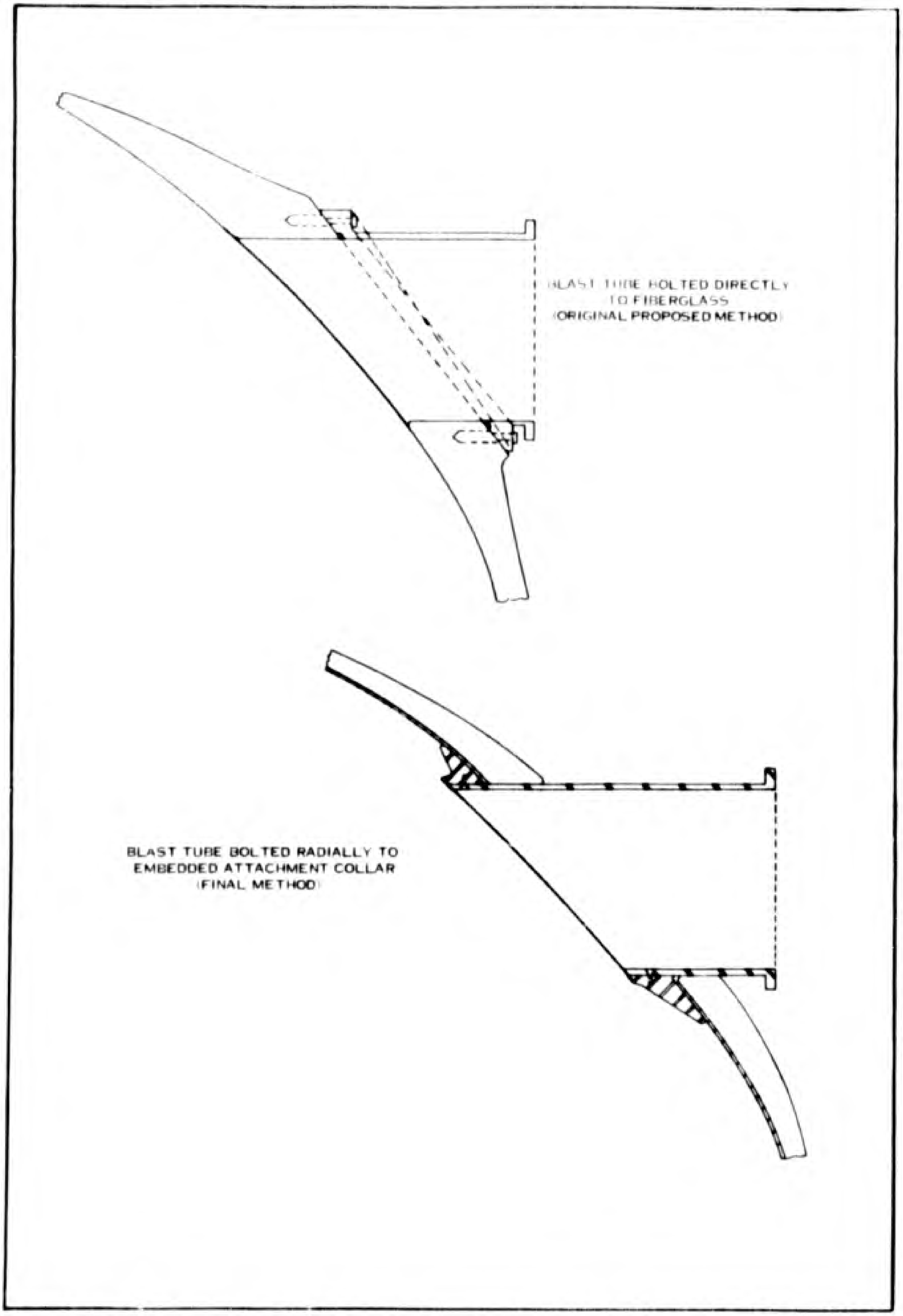


Figure 6. Original and Final Blast Tube Attachment Methods

into the case so the blast tube could be inserted in the port and bolted to the attachment collar. The collar is embedded in a rubber type insulation which permits shear deformation in the insulation between the collar and the fiberglass closure rather than in the fiberglass. The rubber also eliminated the need to connect blast tube attachment collars. The radial load component of the nozzle thrust is transferred from the blast tube collar to the fiberglass. Bolting the blast tube to the attachment collar provided a desirable distribution of loads. The design in this respect is more efficient structurally than that of snap ring designs.

e. Nozzle Port Reinforcement

Necessary openings in a fiberglass case can be formed during case fabrication or cut into the domes later. Openings can be cut through glass filaments after the case is wound, but reinforcement is required to strengthen the case when basic fibers are cut. Fore and aft dome polar openings are made as the filaments pass around the mandrel shaft during winding. Glass strand, however, which accumulates around the periphery with this pattern, can unduly increase case weight. Several methods for strengthening regions of high stress were investigated. Patterns for primary and secondary load reinforcements (Figure 8) were developed using glass filaments and a resin system, glass cloth and glass tape section (fabricated in a mold shaped to the contour of the dome), or combinations of such patterns and materials.

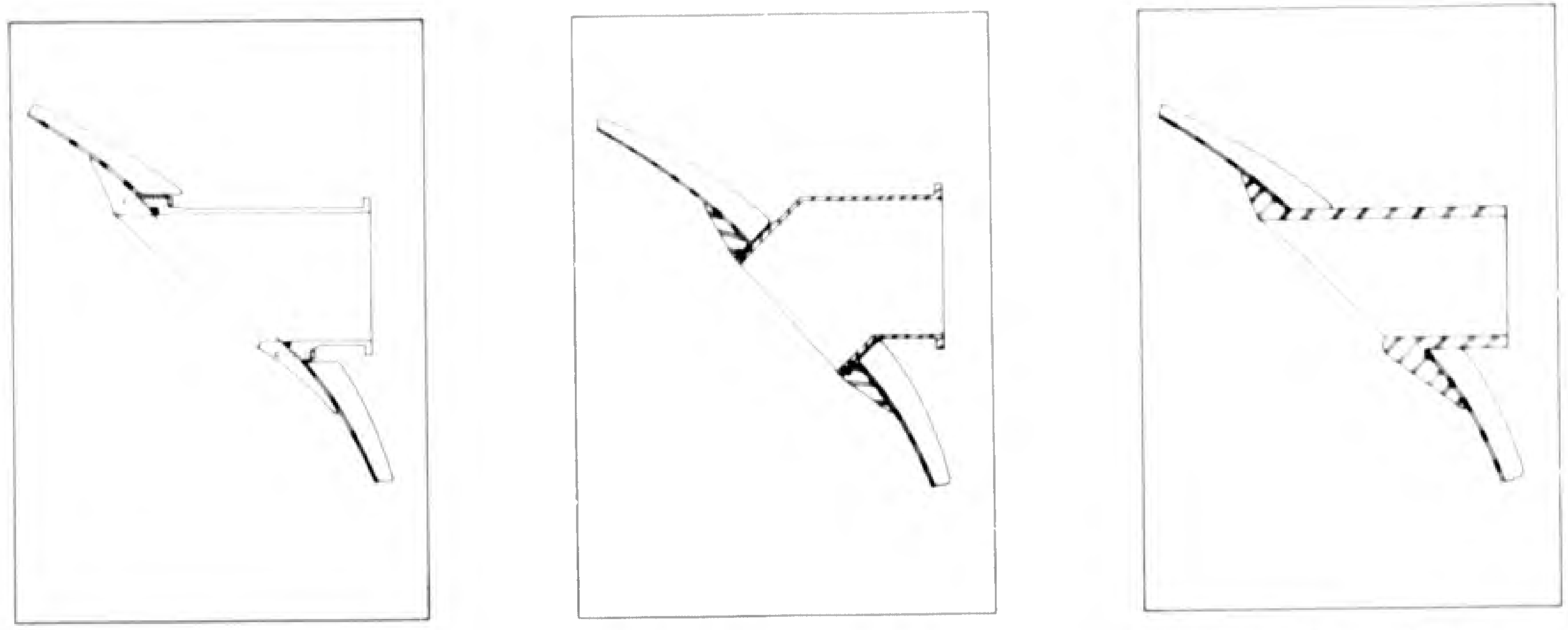
Annular ring (or modified annular ring) reinforcements were selected to carry primary loads imposed on fibers cut for blast tube openings. Dome section reinforcements were used to carry the secondary membrane loads which develop as blast tube and dome regions deflect while the case is pressurized. Over each area where a hole was to be cut, reinforcements were placed between helically wound layers as the case was wrapped.

f. Case Materials

During Phase I, Thiokol and a number of vendors evaluated materials for the fiberglass reinforced plastic motor cases. Final selection of materials was made after case designs were completed (Phase II).

(1) Resin Systems--Several resin systems were analyzed and found to be superior to others on the basis of Naval Ordnance Laboratory (NOL) tests; each system has been used previously for full scale rocket motor case fabrication. These systems include:

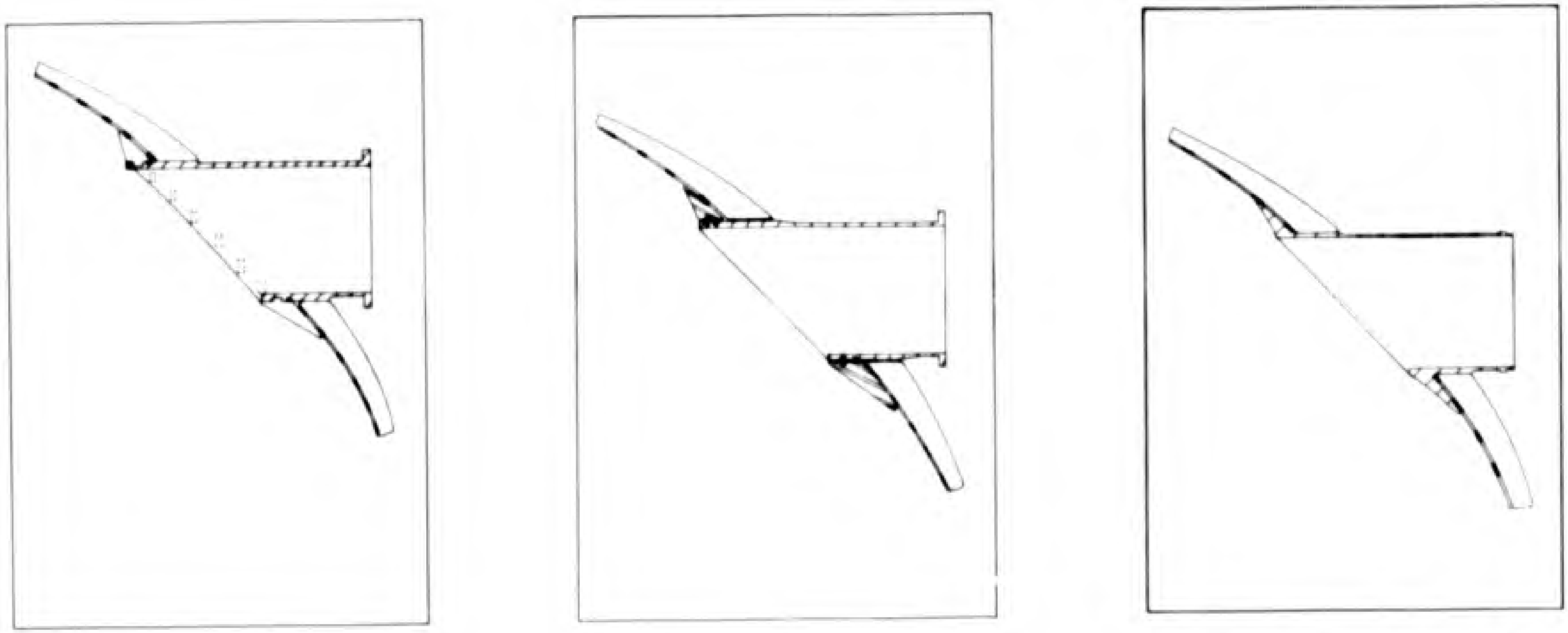
1. CIBA 6005 with methyl-nadic-anhydride hardener;
2. EPIREZ 510 with methyl-nadic-anhydride; benzyl-dimethyl-anhydride hardener;



Blast tube bolted into flange

Blast tube with snap ring attachment

One-piece fiberglass blast tube



Blast tube with breechlock attachment

Blast tube with modified snap ring attachment

Integral blast tube and blast tube flange

Figure 7. Alternate Blast Tube Attachment Methods

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3. EPON 828 with methyl-nadic-anhydride; benzyl-dimethyl anhydride hardener;
4. EPON 828 with meta-phenylene-diamine hardener;
5. EPON 826 with para-phenylene-diamine hardener.

Epoxy compounds using methyl-nadic-anhydride and benzyl-dimethyl-anhydride hardener were relatively stable with respect to viscosity during a given interval, important for control of resin content in the final product. Above ambient temperatures, epoxy compounds using the meta-phenylene-diamine hardener were considerably less stable than the first named groups because the resin viscosity increases rapidly. For all systems, pot life of the resin system must be monitored closely, and proper processing techniques used. Each resin system evaluated was within tolerances of acceptable fabrication criteria when proper processing parameters were not exceeded.

Studies of resin (viscosity, pot life, gel time) and fiberglass finishes also were initiated during Phase I. For the highest glass-resin composite strength, complete coating of glass fibers is necessary. Normally complete coverage of the fiberglass surface cannot be obtained with a highly viscous resin; consequently a strain of dry glass may occur in the structure. Conversely, glass fibers cannot retain a sufficient amount of resin where the viscosity of the resin is too low. Viscosity must be controlled between these limits.

The viscosity of some epoxy resins may be controlled by the quantity of hardening agents. Dow Epon 828, for example, upon the addition of methyl-nadic-anhydride and benzyl-dimethyl-amine, has an initial viscosity of 2,000 cp, which increases to 5,000 cp after 40 hr at 70 to 80°F. The viscosity of other epoxy resin systems can be controlled with thixotropic agents. An agent such as butyl-glycidal-ether reduces viscosity 200 to 300 percent and increases pot life 150 to 200 percent for some dry phenolic resin. The viscosity of wet phenolic resins may be controlled by solvents, but solvents must be removed from the resin prior to curing. During solvent removal, microvoids are produced in polyesters, phenolics, or epoxy compounds, resulting in a detrimentally porous structure. A minimum amount of solvent which will properly control viscosity should be used with resin systems.

Resin pot life must be adequate for the winding time required. If resin, applied to the mandrel during the winding process, begins to gel, resin migration is retarded due to winding tension and resin-rich strata results. Hardening agents and resins must be chosen after the total process time is known, to properly select a resin system having desirable physical properties over the full processing interval. For an example of possible control limits in the use of epoxy resin systems, pyromellitic dianhydride (PMDA) will provide a usable pot life of nine hours at ambient temperature, but only 20 minutes at 150°F; benzyl-dimethyl-amine (BDMA) and methyl-nadic-anhydride (MNA) will provide a usable pot life of as much as three

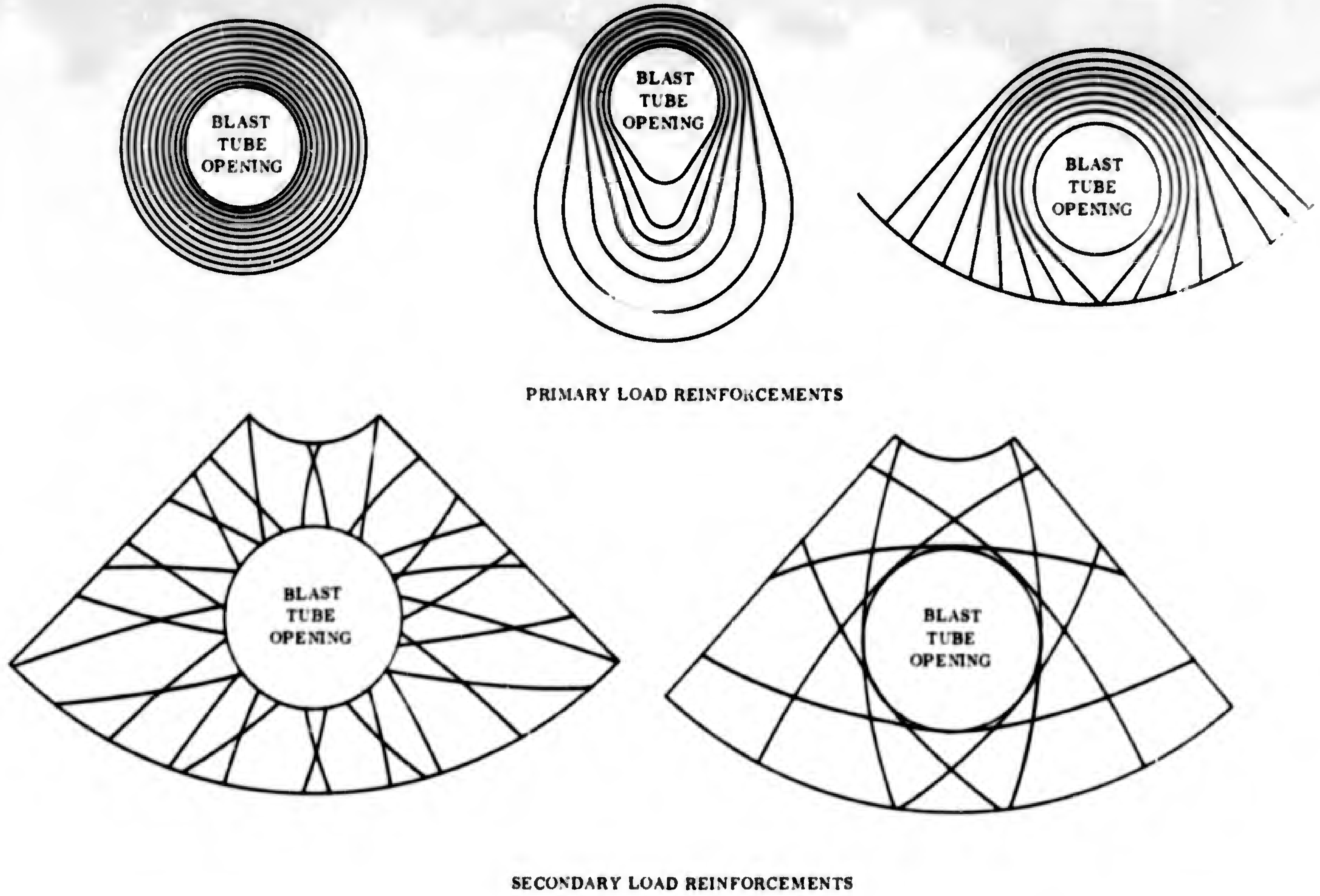

Figure 8. Nozzle Port Reinforcement Patterns

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days at ambient temperature; Epon 828 with meta-phenylene diamine has a pot life of from four to six hours at 70°F.

(2) Fiberglass--Fiberglass widely used in the industry in 1960-62 was electrical (E) glass. For high strength in rocket motor cases, however, a newer, high tensile strength (HTS) finish was used, which has approximately 15 percent greater strength than other glass fibers used. The fiberglass formulation is E glass, with a protective epoxy coating applied to the fibers. The new finish permitted a greater portion of the potential glass strength to be realized.

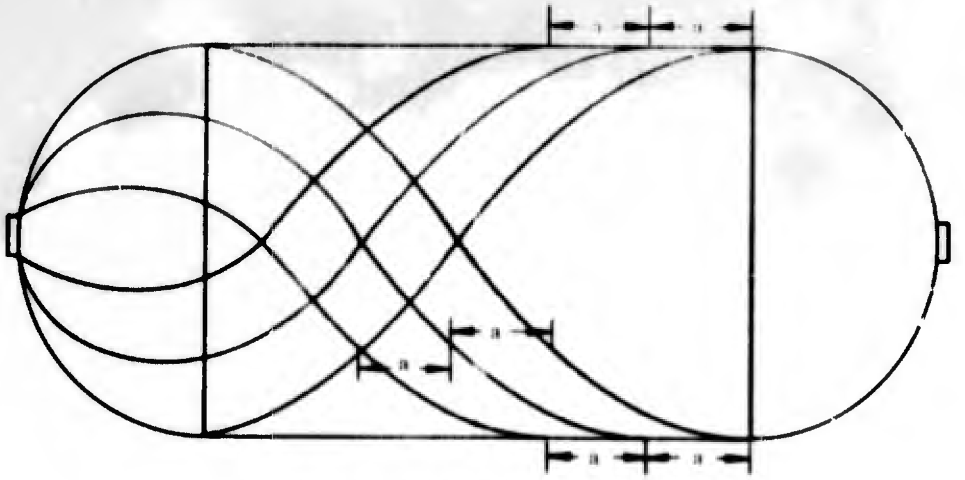
Continuous end roving is available with a wide range in the number of ends per roving. Single end roving seems to yield better results than multiple end roving because more precise control over winding operations is possible. Precise control over strand placement permits the highest strength possible to be developed in the case.

(3) Winding Patterns--For the most effective use of glass fibers in the case, the internal pressure within a fiberglass plastic case must be counteracted, without side deflection, by tension loads in the fibers. Complete uniformity of wall thickness must be maintained; otherwise, either locally thin sections transmit a part of the pressure load to neighboring thick sections by transverse shear in the fibers, or excessive membrane stress results. Either condition causes premature case failure. Filaments must be positioned so the tensile strength of glass fibers is most effectively used to counteract loads resulting from internal pressure.

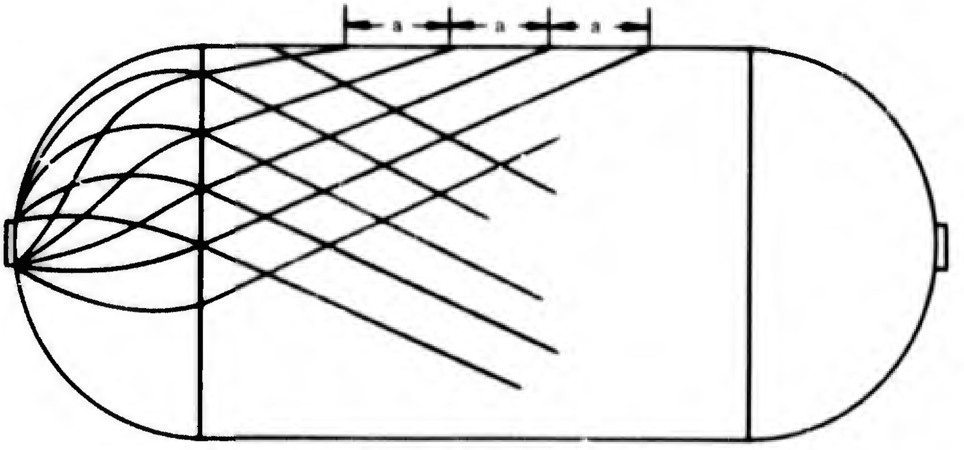
Fibers are positioned so friction or resin tackiness is not required to prevent fibers from slipping on the mandrel. If the equipment used to wind the vessel places the strand on the mandrel accurately, a uniform wall thickness can be developed. Proper dome contours can be wrapped regardless of the size or configuration of the dome port opening or other structural (nozzle) openings. Either wet, or preimpregnated, fiberglass can be applied.

Using a helical pattern, however, (Figure 9) the effective tensile strength of fibers is reduced, because fibers cross over one another in the cylindrical section. The fibers are not straight; consequently, some bending is introduced. Further, complex machinery is required to maintain proper filament placement and tolerance control.

A polar (biaxial) pattern eliminates the crossing of one fiber over another on the cylindrical section and permits potentially higher strength levels. The low wrapping angle orients fibers nearly parallel to the centerline, and keeps the number of longitudinal fibers to a minimum.



REVERSE HELICAL WINDING PATTERN



POLAR (BIAXIAL) WINDING PATTERN

Figure 9. Winding Patterns

Control of filament tension is important for either pattern, to assure uniform tension on fibers, and to obtain a uniform distribution of glass with a desired resin content. Tension may vary from 0.25 to 1.0 lb per end depending on resin viscosity, desired resin content, mandrel diameter, and wrapping pattern.

2. Ballistic Grain Configuration and Loading Procedure

Preliminary evaluations of the ballistic grain configuration (of a conventional type) were completed by 31 May 1961. Preliminary design information indicated that a motor having a fiberglass case would contain less propellant than a corresponding steel case having the same outside case diameter. Design data indicated that the thicker wall of the fiberglass case would reduce the outside diameter of the propellant charge; however, the inert material weight would also be reduced. Ballistic performance of fiberglass would be comparable to that of steel case designs. Design studies indicated further that additional propellant weight could be added by changing aft end grain designs. Later, ballistic performance of the plastic case design was shown to be slightly better than that of a steel case design, when ballistic data from static tests on motors with steel cases was compared with theoretical ballistic values for motors with plastic cases.

Because the ballistic design of the motor was not completed sufficiently during Phase I to establish propellant loading techniques, investigations dealt with propellant loading methods only, on an assumption that propellant would be cast under vacuum through the aft end of the case.

The preliminary ballistic design (based upon a case design having removable domes) required propellant to be cast into the aft closure. Depending upon the type of propellant used, the aft closure might have to be cast after the propellant in the case was cured. However, if the same propellant was used in case and closure, both case and closure could be cast simultaneously but independently. The final decision regarding the loading technique to be used was postponed. Late in Phase II, a decision was made to delete all propellant loading work from the contract (Supplemental Agreement No. 4).

3. Subcontractor Evaluation

Nineteen filament winding vendors were invited to submit proposals for the design and fabrication of fiberglass reinforced plastic rocket motor cases. These vendors were: Aerojet-General Corp; Black, Sivalls and Bryson, Inc; Boeing Airplane Co; Brunswick Corp; Douglas Aircraft Corp, Eldon Industries; B. F. Goodrich Corp; Goodyear Aircraft Corp; Hercules Powder Co, Rocky Hill Division; Lamtex Industries, Inc; Lockheed Aircraft; Narmco; Rocketdyne Division, North American Aviation, Inc; Rohr Aircraft Co; U.S. Rubber Co; Thompson Ramo Wooldridge, Inc; Walter Kidde and Co; and Zenith Plastics Co. Of these, Lockheed Aircraft, Narmco, and Walter Kidde and Co chose not to submit a proposal. Later, because of the Zenith Plastics Company transfer to H. I. Thompson Company,

H. I. Thompson Company's acceptance of Zenith Plastics Company proposal involved it as a vendor. A team of representatives from Procurement, Program Management, Development Engineering, Test Engineering, and Quality Control at the Thiokol Wasatch Division conducted plant surveys to evaluate subcontractor facilities, tooling, direct and indirect experience, and management. Thiokol then submitted a technical and cost evaluation on the proposals and recommended subcontractors to the Manufacturing Technology Laboratory. A mutual agreement was reached by the Manufacturing Technology Laboratory and Thiokol for subcontract work as follows:

Monolithic Case Construction

1. TU-226A--Lamtex Industries, Inc.
2. TU-226B--Black, Sivalls and Bryson, Inc.
3. TU-227A--Allison Division of General Motors Corp.
4. TU-227B--Brunswick Corp.

Modular Case Construction

1. TU-228--Zenith Plastics Co (H. I. Thompson Co).

4. Drawings and Specifications

Thiokol specification drawings 9U31237 and 9U31239 (Figures 1 and 2) were prepared for the TU-226 and TU-227 motor cases, respectively, to define case requirements for subcontractors. Thiokol specifications TWS-EQ-35 and TWS-EQ-36, (Appendices A and B, Volume II) were also prepared.

B. PHASE II CASE FABRICATION AND HYDROSTATIC TESTING

Before the start of Phase II, ownership of Zenith Plastics Co was transferred from Minnesota Mining and Manufacturing Co, Minneapolis, Minnesota to the H. I. Thompson Fiber Glass Co, Los Angeles, California. The new owner accepted the terms of, and assumed responsibility for, the subcontract entered into by Zenith Plastics Co.

Phase II effort began on 25 Sep 1961 with preliminary work by the subcontractors to modify case designs to permit fabrication at their plants. Final designs for monolithic cases were completed by subcontractor representatives at the Wasatch Division beginning 11 Oct 1961. Design of a case of modular design was begun in October 1961, following preliminary bench tests on materials.

1. Monolithic Construction of Fiberglass Plastic Cases

a. Case Design and Component Fabrication

(1) Drawings--Fabrication techniques for four monolithic case designs were developed by Thiokol and the responsible subcontractors selected after industrial survey and analytical study. The following case designs were developed:

1. TU-226A (Figure 10, Drawing No. 9U30765) fabricated by Lamtex Industries, Inc (Lamtex), Farmingdale, Long Island, New York;
2. TU-226B (Figure 11, Drawing No. 9U30782) fabricated by Black, Sivalls and Bryson Inc (BS&B), Ardmore, Oklahoma;
3. TU-227A (Figure 12, Drawing No. 9U33846) fabricated by Allison Division of General Motors Corp (Allison), Cleveland, Ohio;
4. TU-227B (Figure 13, Drawing No. 9U30750) fabricated by Brunswick Corp (Brunswick), Marion, Virginia.

(2) Case Design Criteria--The characteristics of the winding machine used by the subcontractor and the subcontractor's experience in fabrication of fiberglass products governed, to a great extent, the selection of wrapping angles and winding patterns. The availability of resin compounds, the subcontractor's experience with particular resin compounds, and the density of the case wall controlled selection of the resin system. Design requirements (Table I) were established for each contractor based upon the above factors.

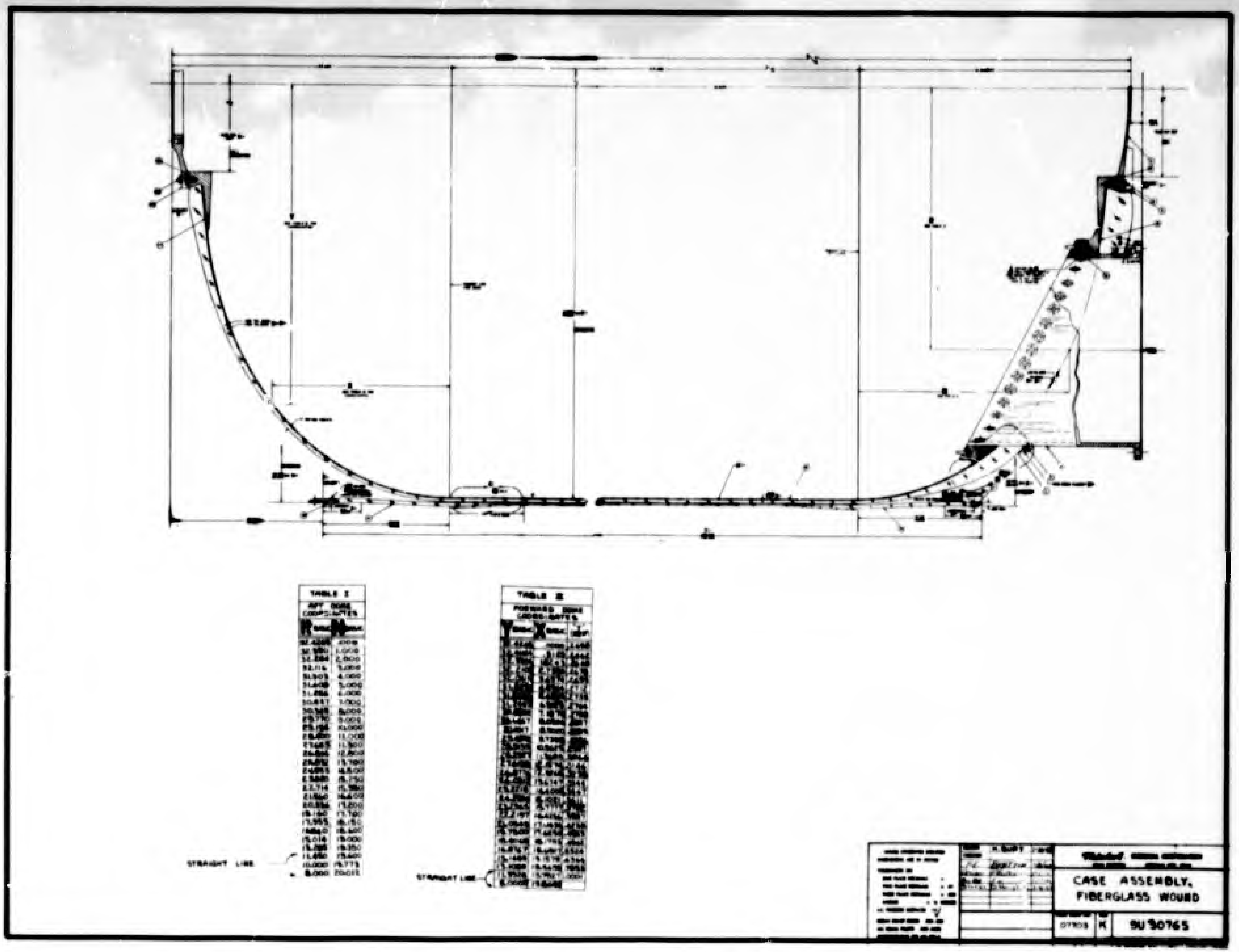


Figure 10. TU-226A Monolithic Fiberglass Plastic Case Drawing 9U30765 (Page 1 of 5)

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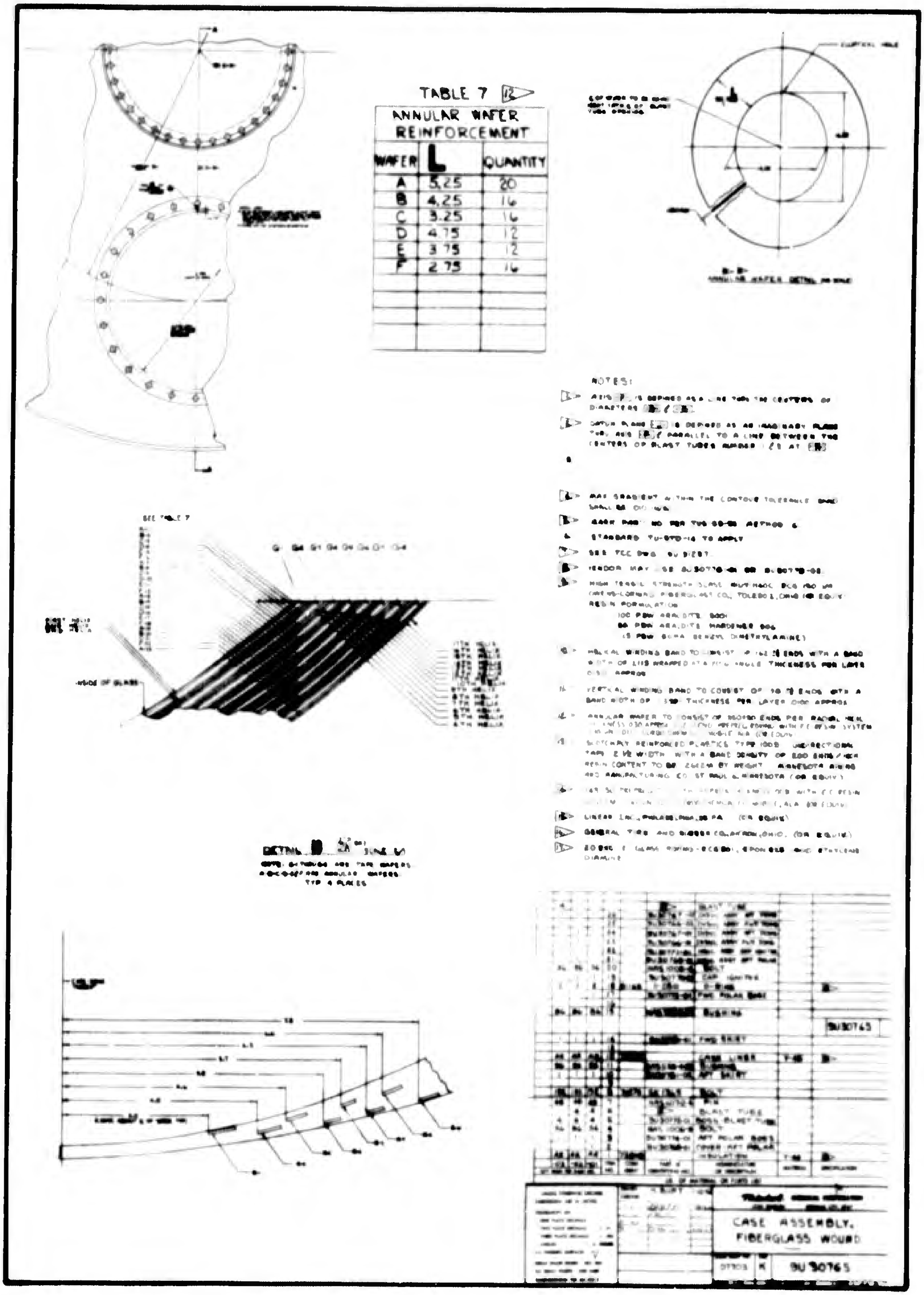


TABLE 7

ANNULAR WAFER REINFORCEMENT		
WAFER	L	QUANTITY
A	5.25	20
B	4.25	16
C	3.25	16
D	4.75	12
E	3.75	12
F	2.75	16

Figure 10. TU-226A Monolithic Fiberglass Plastic Case Drawing 9U30765 (Page 2 of 5)

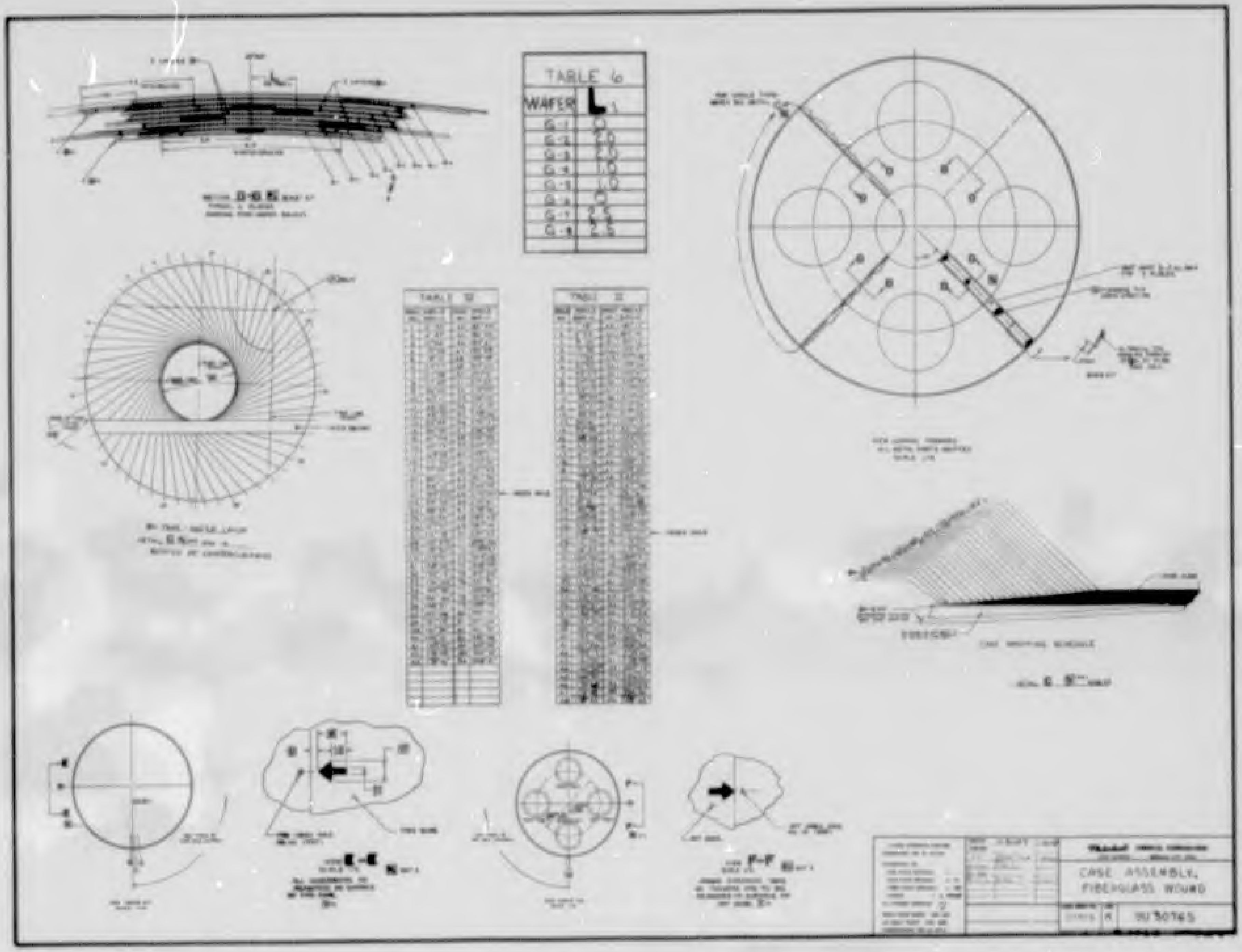


Figure 10. TU-226A Monolithic Fiberglass Plastic Case Drawing 9U30765 (Page 3 of 5)

Figure 10. TU-226A Monolithic Fiberglass Plastic Case Drawing 9U30765 (Page 4 of 5)

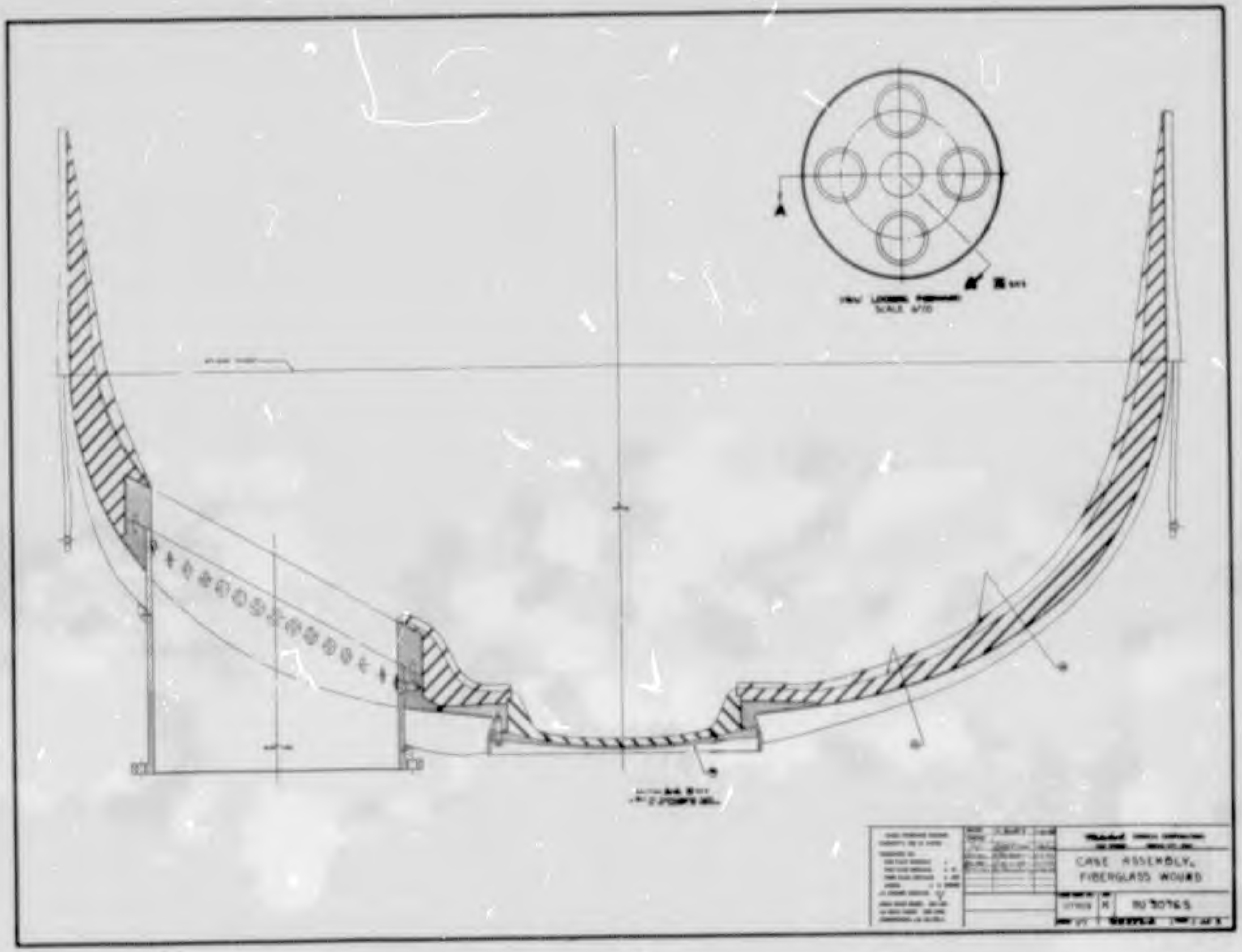


Figure 10. TU-226A Monolithic Fiberglass Plastic Case Drawing 9U30765 (Page 5 of 5)

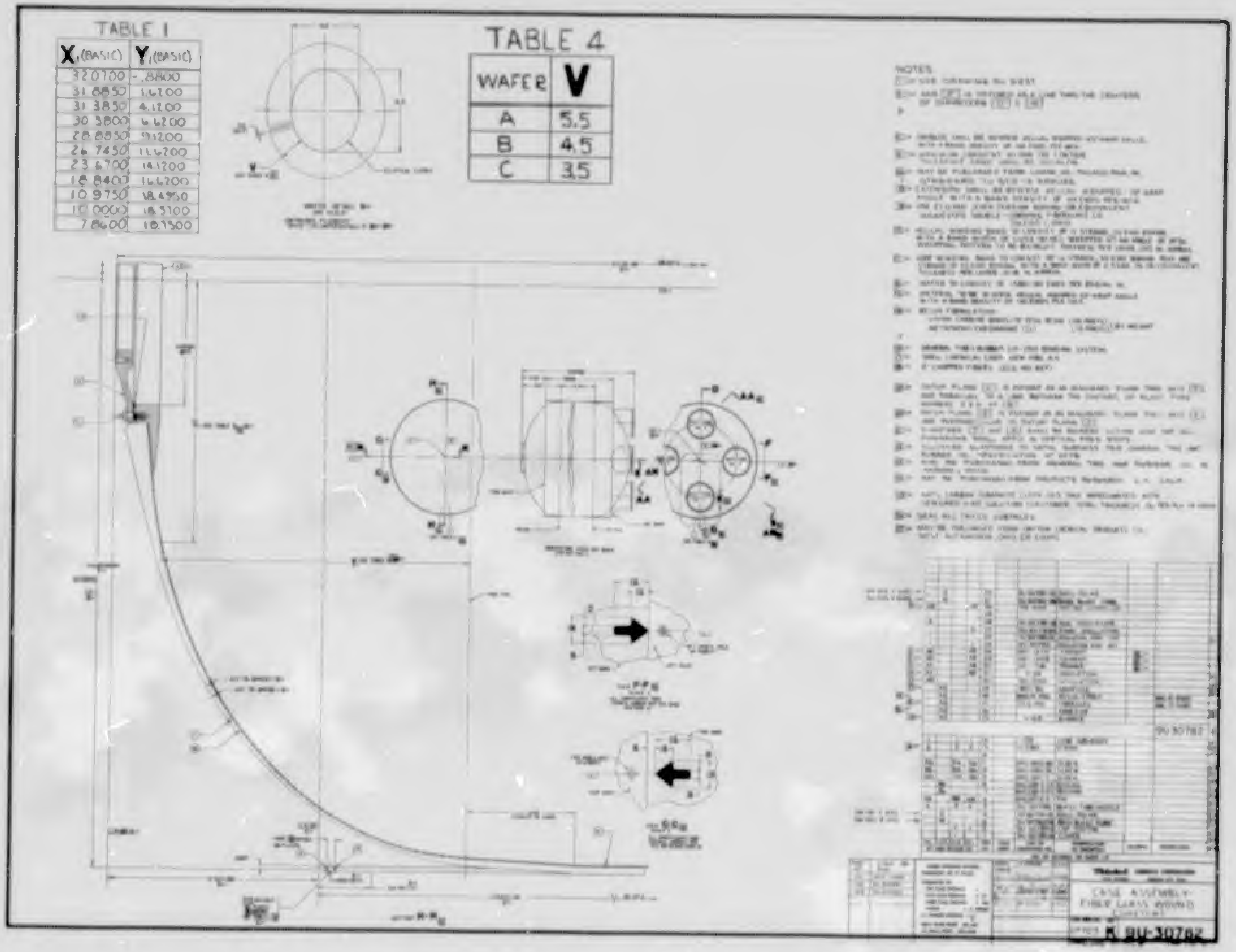


TABLE 1

X₁ (BASIC)	Y₁ (BASIC)
32.0700	-.8800
31.8850	1.6200
31.3850	4.1200
30.3800	6.6200
28.8850	9.1200
26.7450	11.6200
23.6700	14.1200
18.8400	16.6200
10.9750	18.4950
10.0000	18.5100
7.8600	18.1500

TABLE 4

WAFER	V
A	5.5
B	4.5
C	3.5

Figure 11. TU-226B Monolithic Fiberglass Plastic Case Drawing 9U30782 (Page 1 of 6)

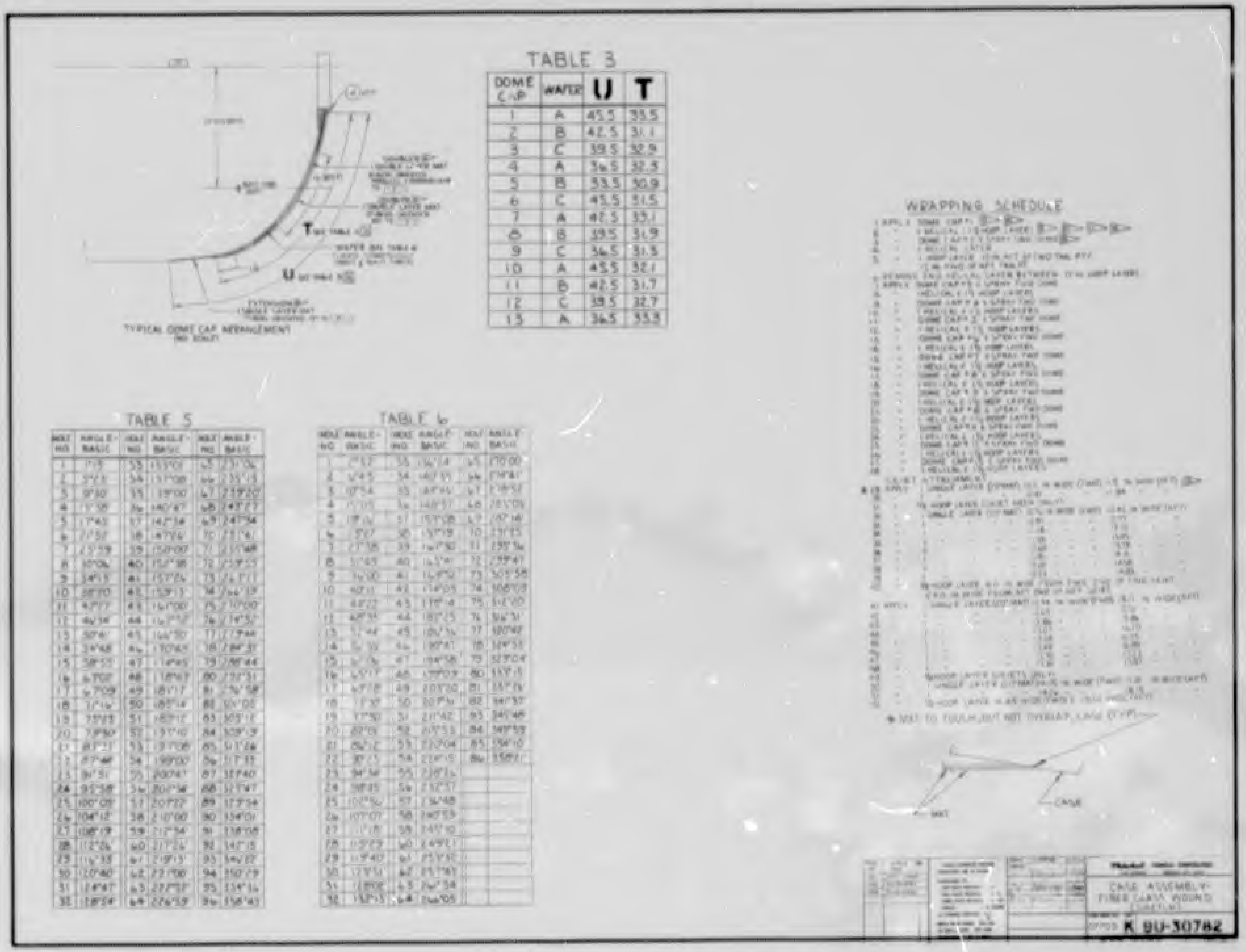


TABLE 3

DOME CAP	WAFER	U	T
1	A	45.5	33.5
2	B	42.5	31.1
3	C	39.5	32.9
4	A	36.5	32.3
5	B	33.5	30.9
6	C	45.5	31.5
7	A	42.5	33.1
8	B	39.5	31.9
9	C	36.5	31.3
10	A	45.5	32.1
11	B	42.5	31.7
12	C	39.5	32.7
13	A	36.5	33.3

Figure 11. TU-226B Monolithic Fiberglass Plastic Case Drawing 9U30782 (Page 2 of 6)

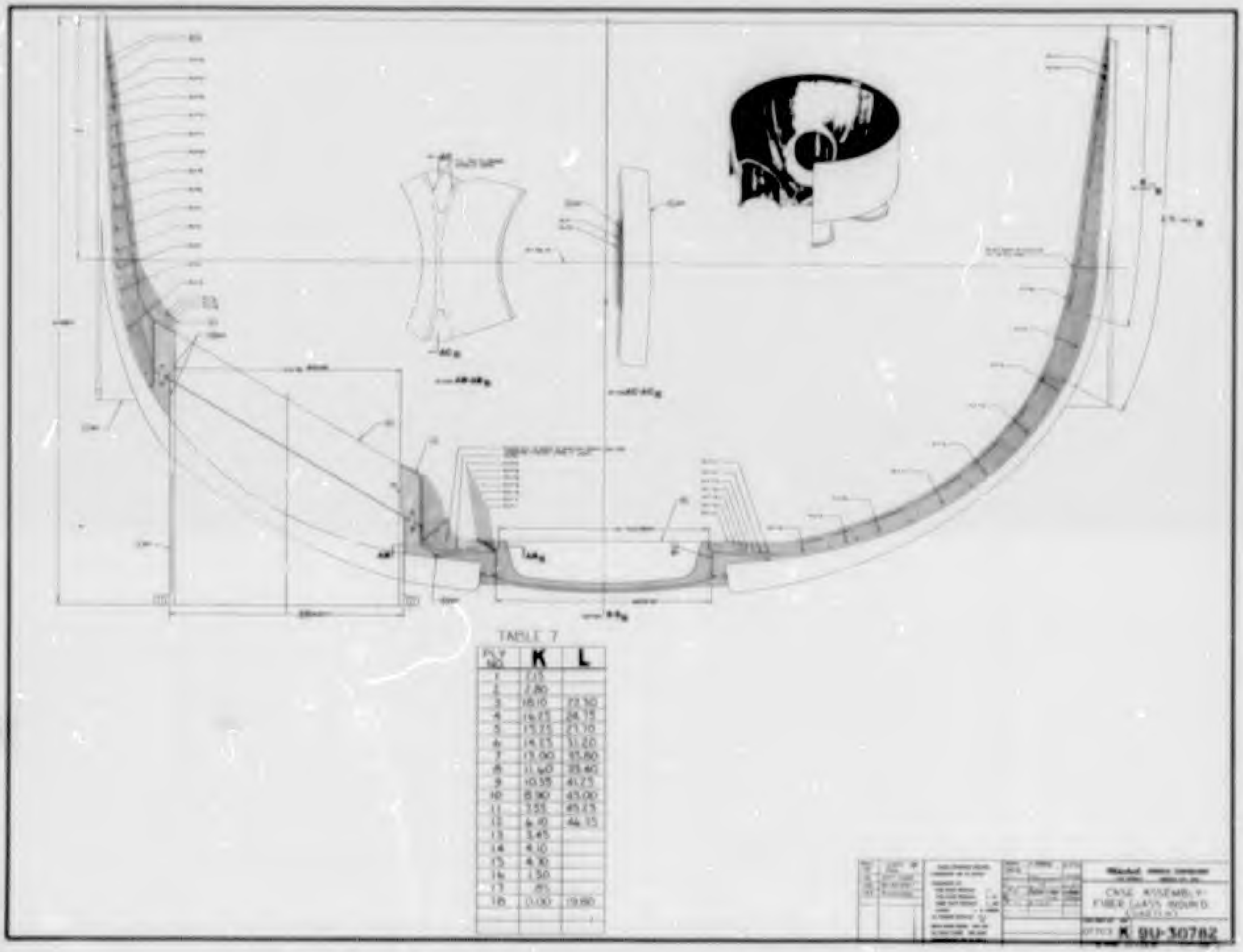


Figure 11. TU-226B Monolithic Fiberglass Plastic Case Drawing 9U30782 (Page 3 of 6)

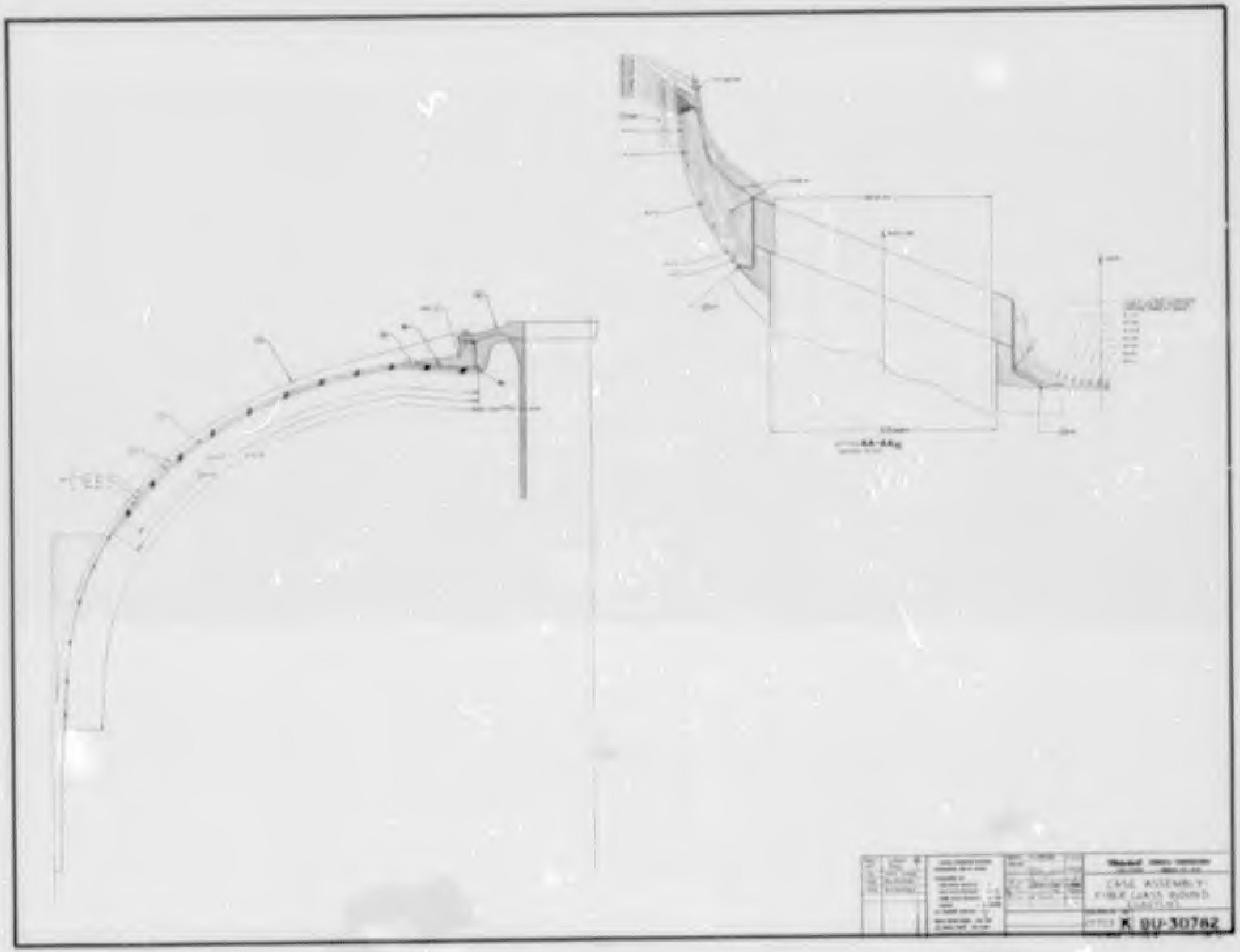


Figure 11. TU-226B Monolithic Fiberglass Plastic Case Drawing 9U30782 (Page 4 of 6)

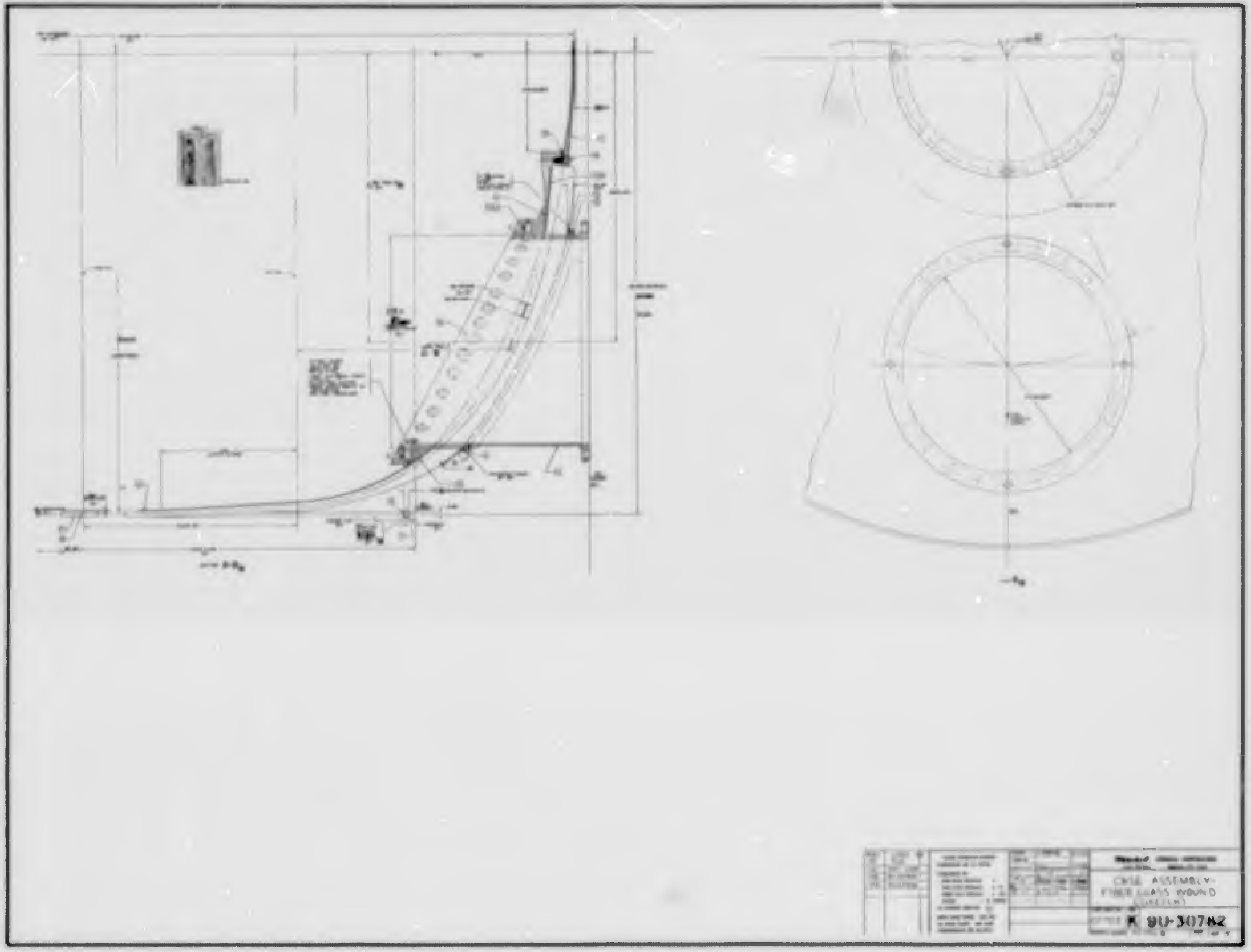


Figure 11. TU-226B Monolithic Fiberglass Plastic Case Drawing 9U30782 (Page 5 of 6)

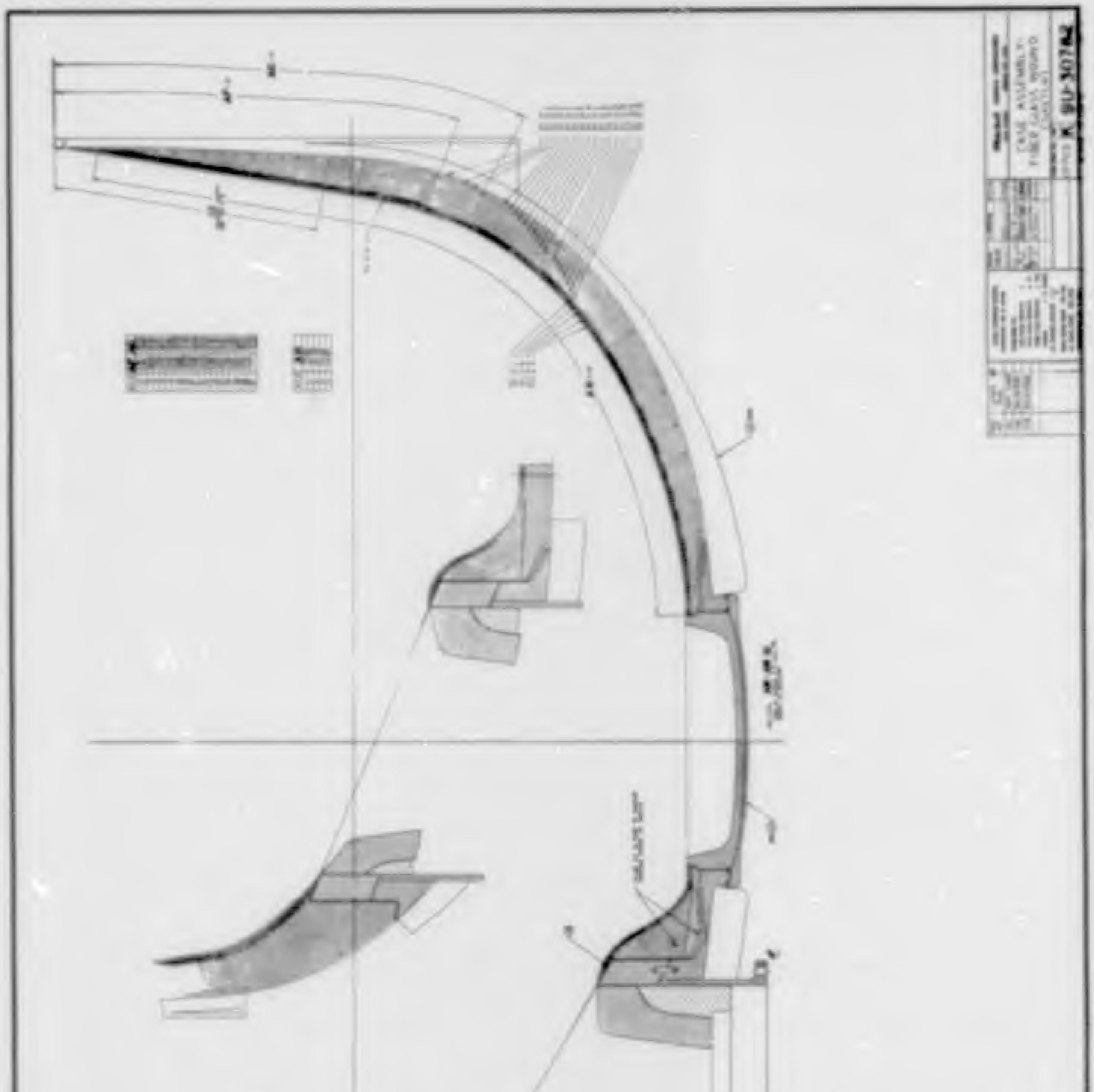


Figure 11. TU-226B Monolithic Fiberglass Plastic Case Drawing 9U30782 (Page 6 of 6)

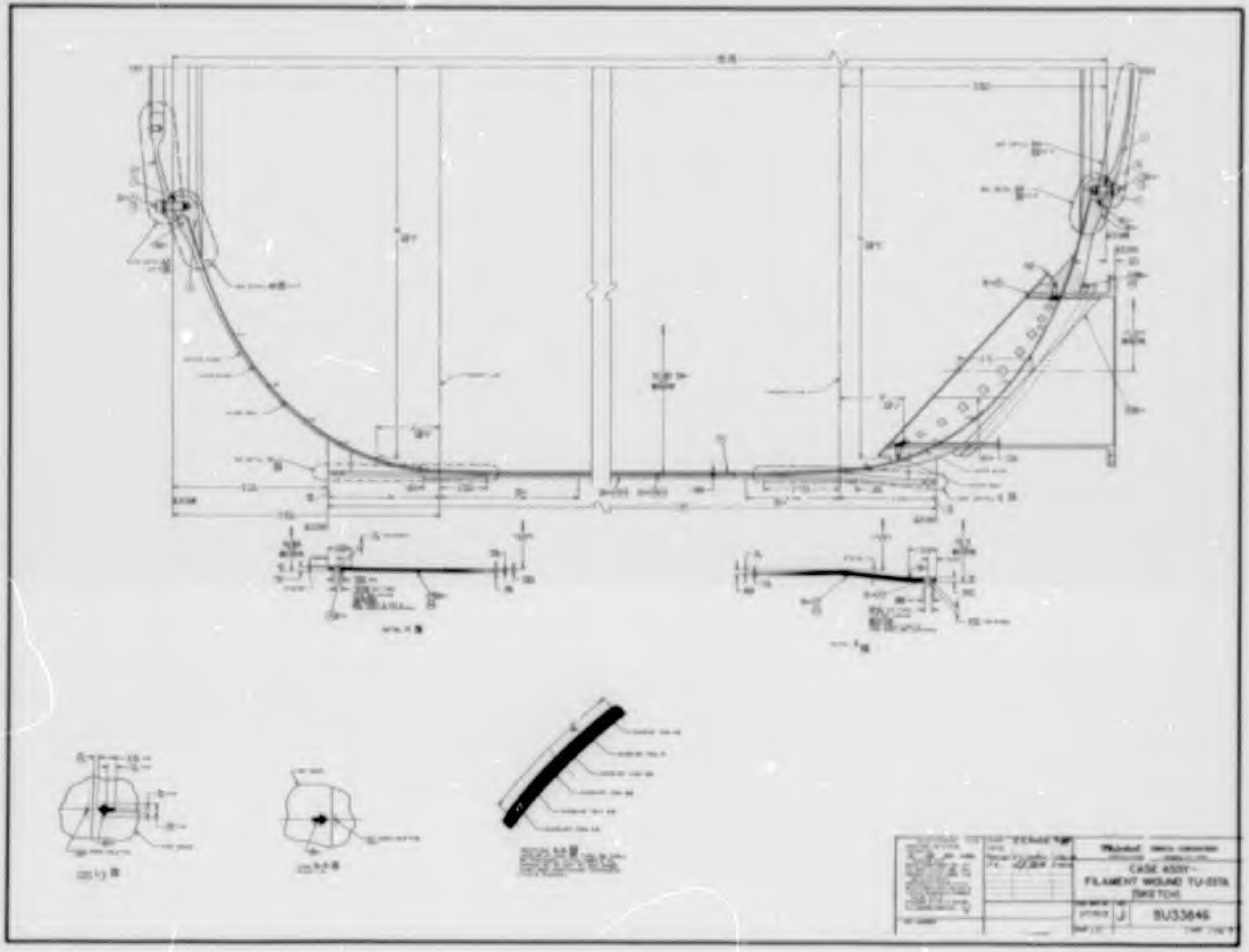


Figure 12. TU-227A Monolithic Fiberglass Plastic Case Drawing 9U33846 (Page 1 of 4)

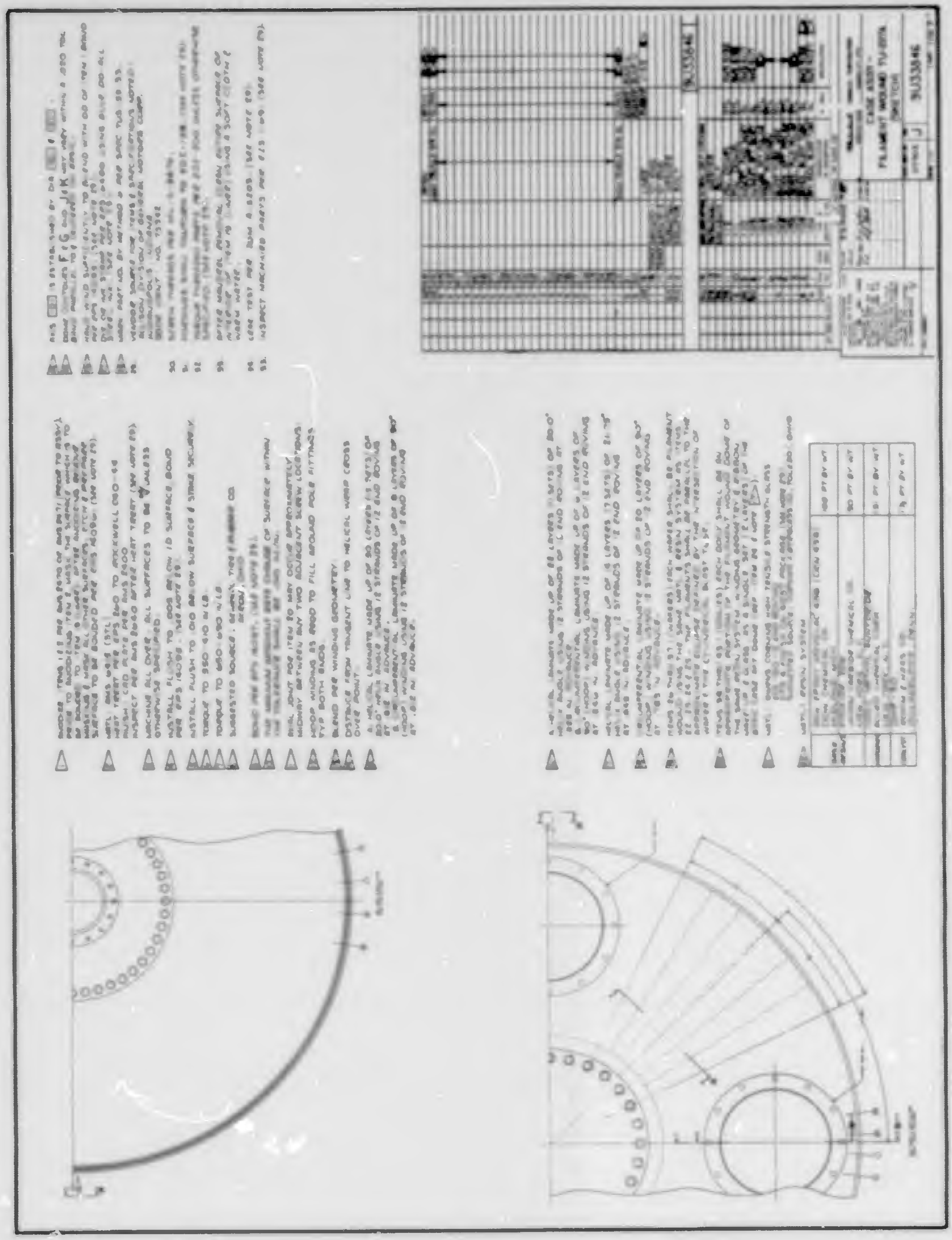
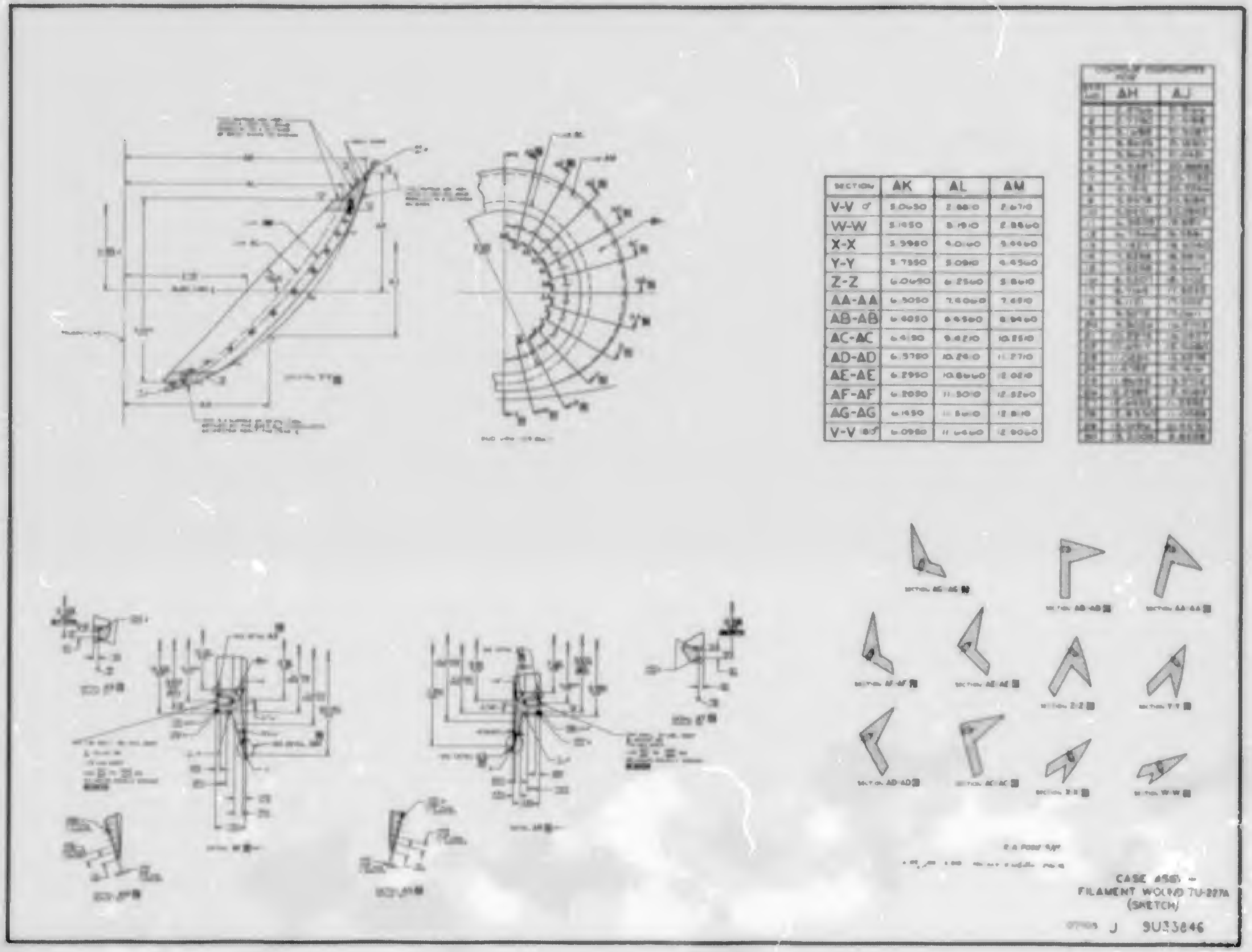


Figure 12. TU-227A Monolithic Fiberglass Plastic Case Drawing 9U33846 (Page 2 of 4)



SECTION	AK	AL	AM
V-V 0°	5.0650	2.8810	2.6710
W-W	5.1450	3.1910	2.8860
X-X	5.5950	4.0160	3.4460
Y-Y	5.7350	5.0810	4.4560
Z-Z	6.0650	6.2560	5.8610
AA-AA	6.3050	7.4060	7.6810
AB-AB	6.4050	8.4560	8.9460
AC-AC	6.4190	9.4210	10.2510
AD-AD	6.3780	10.2410	11.2710
AE-AE	6.2950	10.8660	12.0210
AF-AF	6.2030	11.3010	12.5260
AG-AG	6.1450	11.5610	12.8110
V-V 85°	6.0980	11.6460	12.9060

Figure 12. TU-227A Monolithic Fiberglass Plastic Case Drawing 9U33846 (Page 3 of 4)

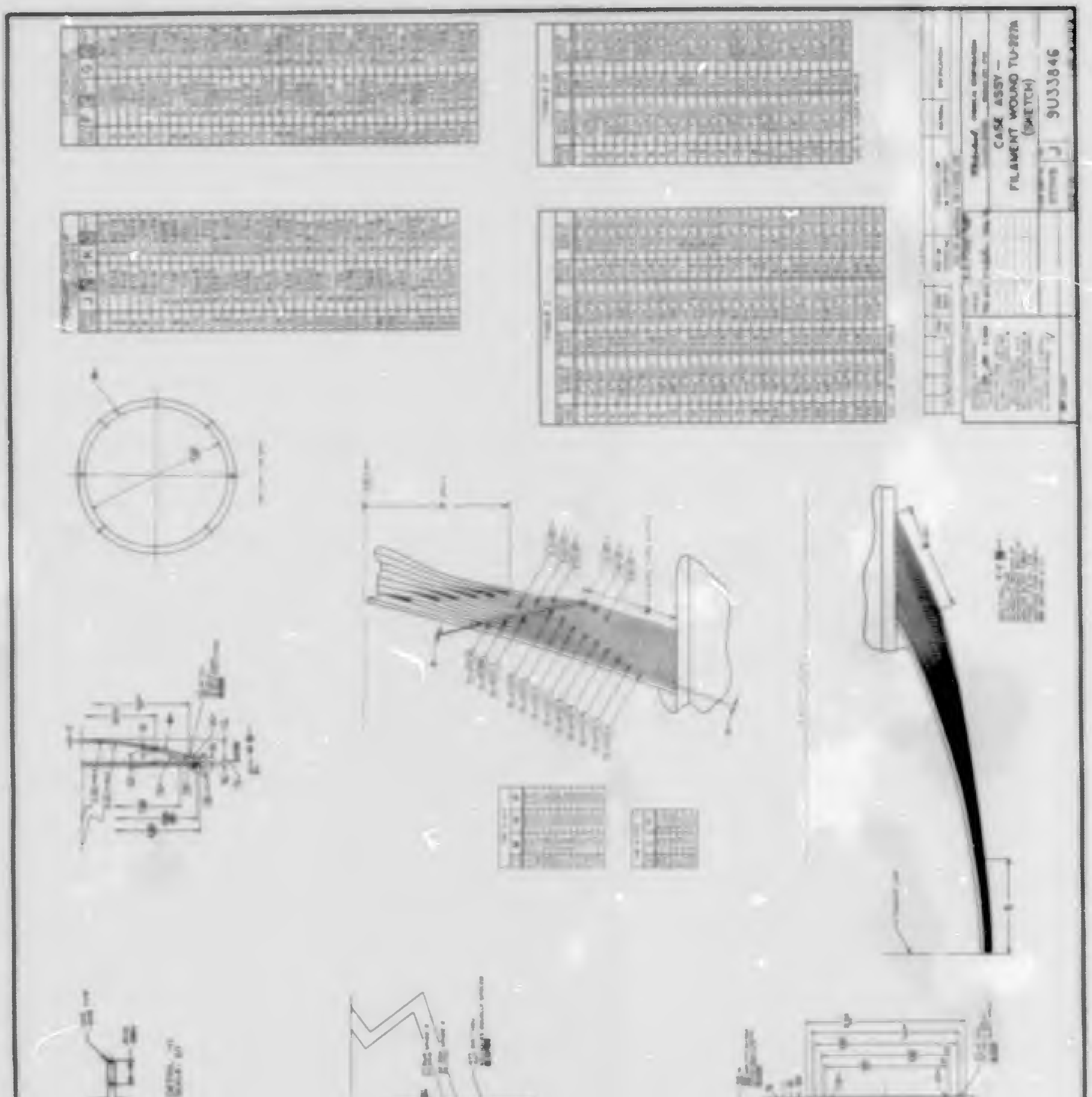


Figure 12. TU-227A Monolithic Fiberglass Plastic Case Drawing 9U33846 (Page 4 of 4)

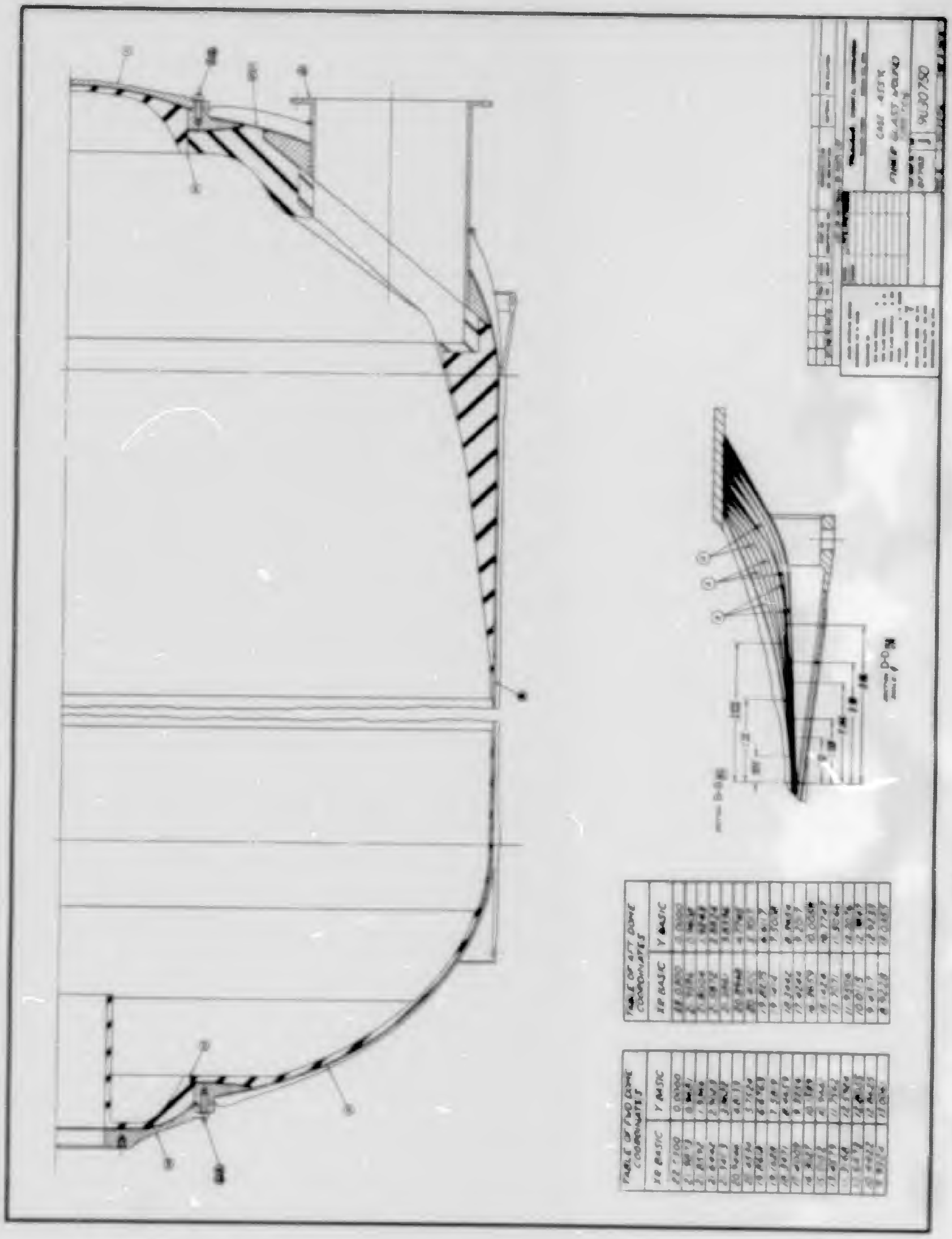


Figure 13. TU-227B Monolithic Fiberglass Plastic Case Drawing 9U30750 (Page 1 of 3)

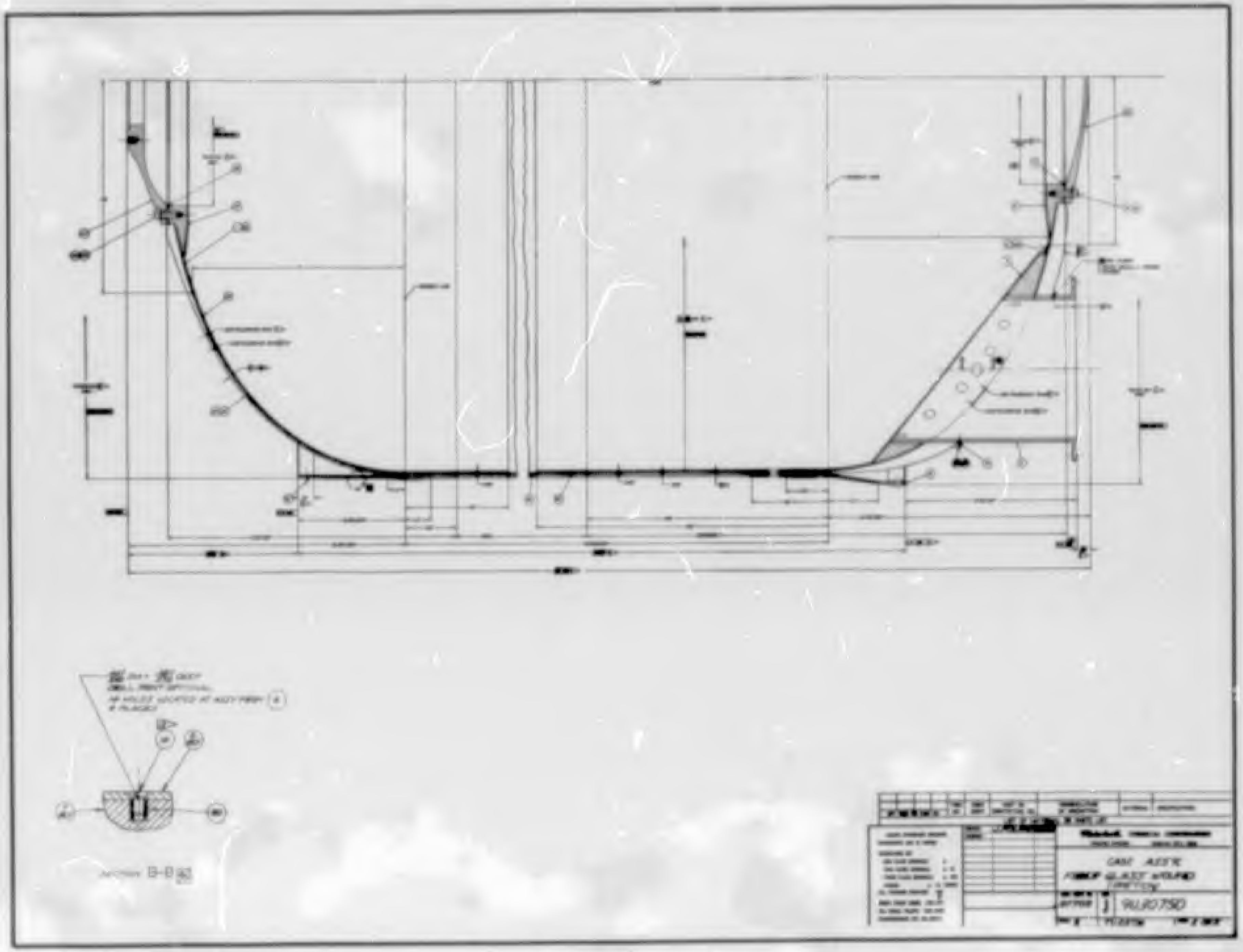


Figure 13. TU-227B Monolithic Fiberglass Plastic Case Drawing 9U30750 (Page 2 of 3)

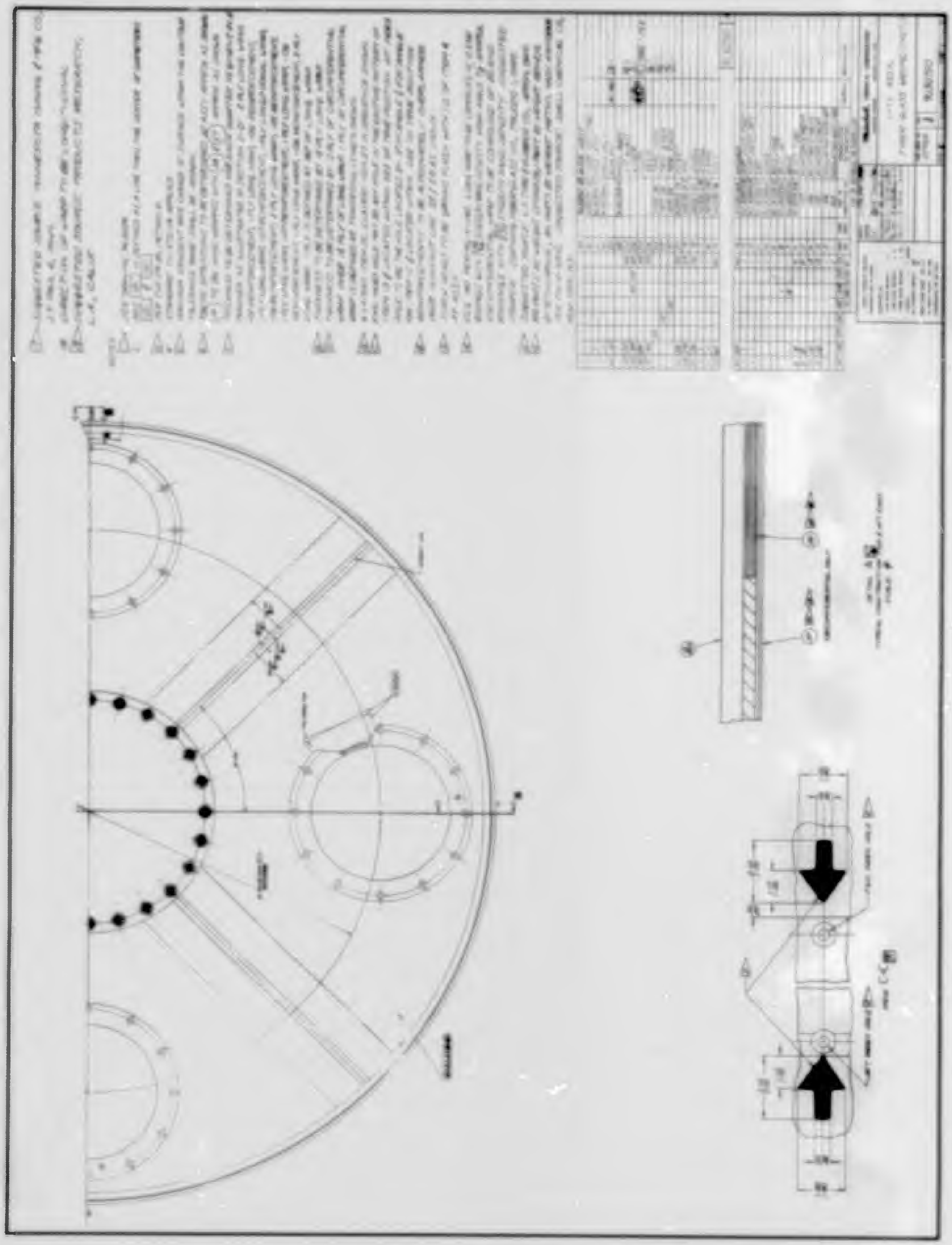


Figure 13. TU-227B Monolithic Fiberglass Plastic Case Drawing 9U30750 (Page 3 of 3)

TABLE I

TU-226 AND TU-227 CASE DESIGN PARAMETER SUMMARY

	LAMTEX TU-226A	BS&B TU-226B	ALLISON TU-227A	BRUNSWICK TU-227B
Wrapping Pattern	Reverse Helical	Reverse Helical	Reverse Helical	Polar
Wrap Angle (deg)	20° 16'	15° 06'	21° 20'	7° 7.5'
Band Density	142 Hoop 145 Helical	195 Hoop 206 Helical	203 Hoop 214 Helical	300 Hoop 216 Helical
Design Wall Thickness, (in.)	0.4921	0.3924	0.2188	0.2688
Actual Wall Thickness, (in.)	0.3605	0.4130	0.207	0.222
Wrapping Tension, (lb/end)	0.50	0.75	0.5	0.33
Stress Ratio (helical/hoop)	0.7526	0.7917	0.8961	0.7110
Density, (lb/cu in.)	0.068	0.073	0.074	0.073
Resin Content, (percent by wt)	Araldite 9001 NMA-BDMA 23.7	ERL 2256 CL 20.94	DEN 438 EPOXIDE 206 MNA-DPM	EPON 828 NMA-BDMA 19.69

(3) Case Mandrels--Fabrication techniques for, and stress analyses of, mandrels for large fiberglass plastic cases are described in Volume V of this report. The mandrel used by Lamtex to wind the TU-226A case (Figure 14) was fabricated of plaster reinforced with jute. Plaster bulkheads were mounted to a shaft on 16 in. centers to provide support for the cylindrical section of the mandrel. Tubular steel members were mounted longitudinally along the outer periphery of the cylindrical section for reinforcement. End domes were of reinforced plaster. A layer of plaster was applied over the structure and the outer surface was machined to required dimensions.

The mandrel used by BS&B to wind the TU-226B case was fabricated of longitudinal extruded aluminum alloy sections (Figure 15) fastened with internal clips. The BS&B segmented mandrel had a driveshaft which was an 8 in. dia heavy duty steel tube attached to the mandrel shell by three drive spokes. The spoke assemblies were attached to the driveshaft and to the mandrel shell at the two case to dome tangent points and at the center of the case. Nineteen extruded aluminum stringers (slats; leaves), extending from dome to dome, were clipped together over seven tee-frames to form the shell of the mandrel. Three of the tee-frames were attached to the spoke assemblies. Domes of reinforced plaster were contoured to the desired shape, and the entire outer surface of the mandrel was machined to the proper diameter for the case. A case liner placed over the contoured domes and cylinder formed the completed mandrel.

Mandrel construction is unique in that the case liner is inflated with air during case winding. The compressive load developed by overwrapping fiberglass is, essentially, balanced by internal mandrel pressure using the rubber case liner as a bladder. The first layers of glass fiber are wound over the mandrel, and air pressure is introduced to the case liner. As subsequent layers of glass are added, air pressure is increased to maintain a constant inside diameter, as indicated by zero indications on dial indicators. An adequate pressure maintained at the surface of the mandrel counteracts the effects of winding tension, which might otherwise deform the mandrel during winding. In addition to maintaining case concentricity and a constant inside case diameter, pressure aids control of tension in inner layers of glass as winding progresses. If the liner were not pressurized, the addition of successive layers of glass would compress the mandrel slightly causing a loss of tension in inner layers. The applied pressure varied from 0 psi (after the third helical layer was wrapped) to 95 psi (when case curing was started). Mandrel deformation under load was measured by gages applied to the interior of the mandrel surface underneath the bladder. Pressure application was as follows:

Operation	Internal Pressure (psi)
Finish of 3rd helical layer	0
First pass of 4th helical layer	14
Finish of 4th helical layer	16
Finish of 5th helical layer	20

APPLICATION OF PLASTER OVER STEEL REINFORCING TUBES

COMPLETED LAMTEX MANDREL BEFORE APPLICATION OF MOLD RELEASE AGENT AND RUBBER CASE LINER

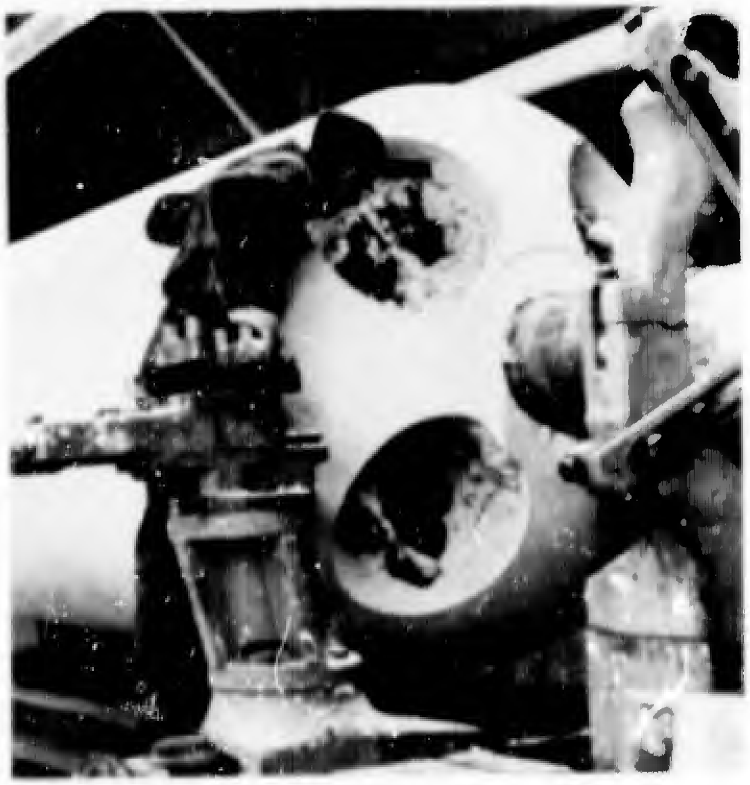


Figure 14. TU-226A Case Mandrel

Operation	Internal Pressure (psi)
First pass of 6th helical layer	24
Finish of 7th helical layer	24
Finish of 8th helical layer	34
First pass of 9th helical layer	40
First pass of 10th helical layer	50
First pass of 11th helical layer	64
Finish of 11th helical layer	80
Before 12th helical layer	75
Finish of 12th helical layer	90
Before 13th helical layer	95
Finish of 13th helical layer	91
Start of skirt winding	92
After skirt winding	94
Beginning of case cure	95
During case cure	87
After case cure	90

A segmented plywood structure with a swept and machined plaster shell (Figures 16 and 17) was used by Allison to wind the TU-227A case. Bulkheads fabricated of radially segmented plywood pieces were bolted together and spaced at 20 in. intervals on a tubular steel main shaft. In the cylindrical section, bulkheads were covered with longitudinal plywood slats held in place with steel bands. A 0.5 in. layer of plaster was applied to the outside of the plywood surface and machined to the required dimensions. The mandrel was sprayed with sealant and the case liner applied to the mandrel surface.

Brunswick fabricated a mandrel of sand and water-soluble resin (100 pbw sand; 3 pbw water; 1.5 pbw Gelvatol No. 30 Shawinigan Resins Corp, Springfield, Mass., 3.0 pbw denatured alcohol) for the TU-227B case. The steel mandrel shaft was mounted on a vertical axis for case winding. To minimize mandrel weight, sheet metal tubes were placed parallel to the axis of assembly (Figure 18), to reduce the volume of sand required. The forward dome, aft dome, and cylindrical sections of the mandrel were cast separately and joined with an adhesive in the final step of mandrel fabrication. The mandrel was cast in a mold, and no machining of outside contours was necessary.

(4) Ballistic Design and Process Tooling for Propellant Loading--At the beginning of the program, two TU-227 cases were to be loaded with live propellant after fabrication and, in Phase IV, tested statically. The case design was tailored for

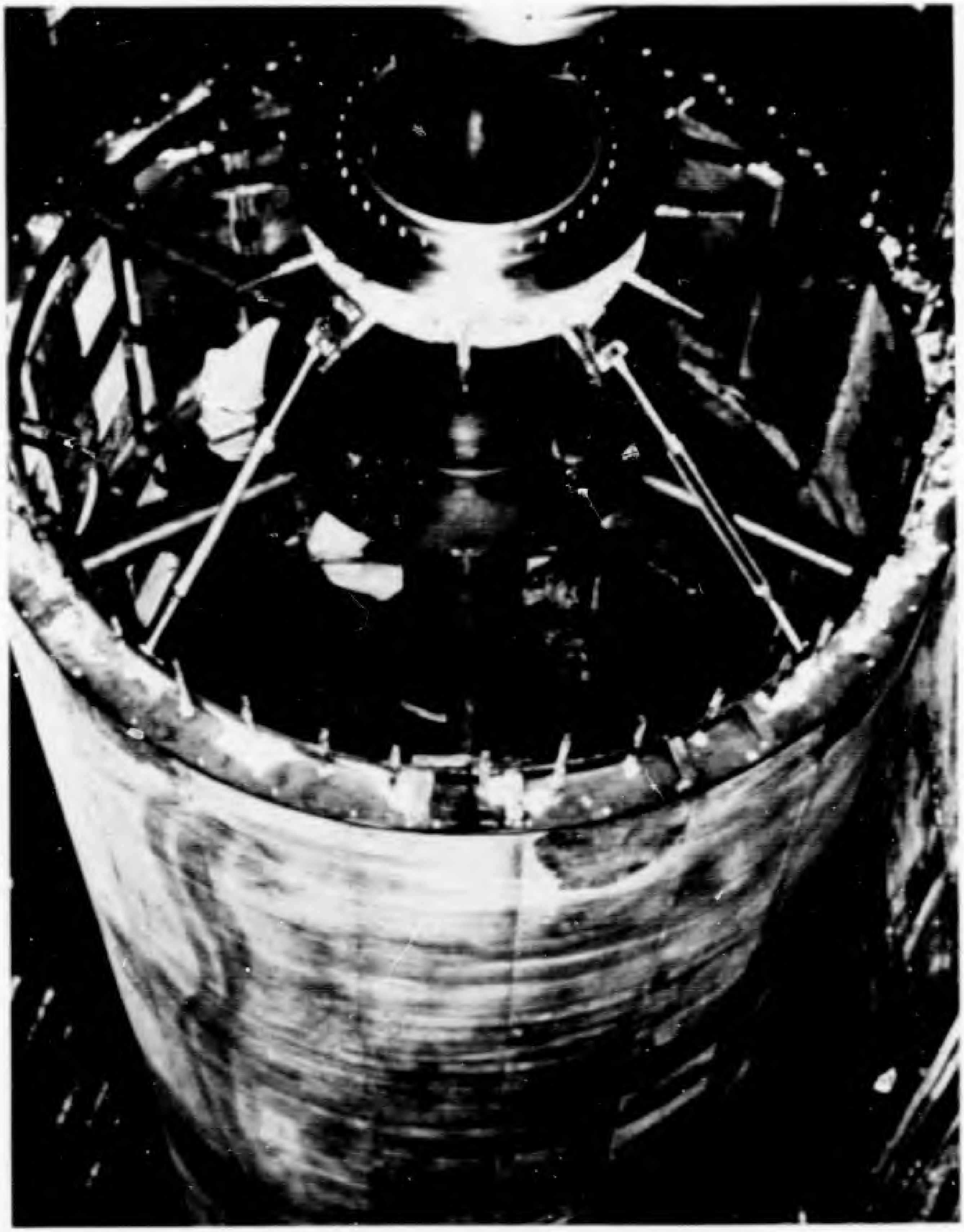


Figure 15. TU-226B Case Mandrel Section

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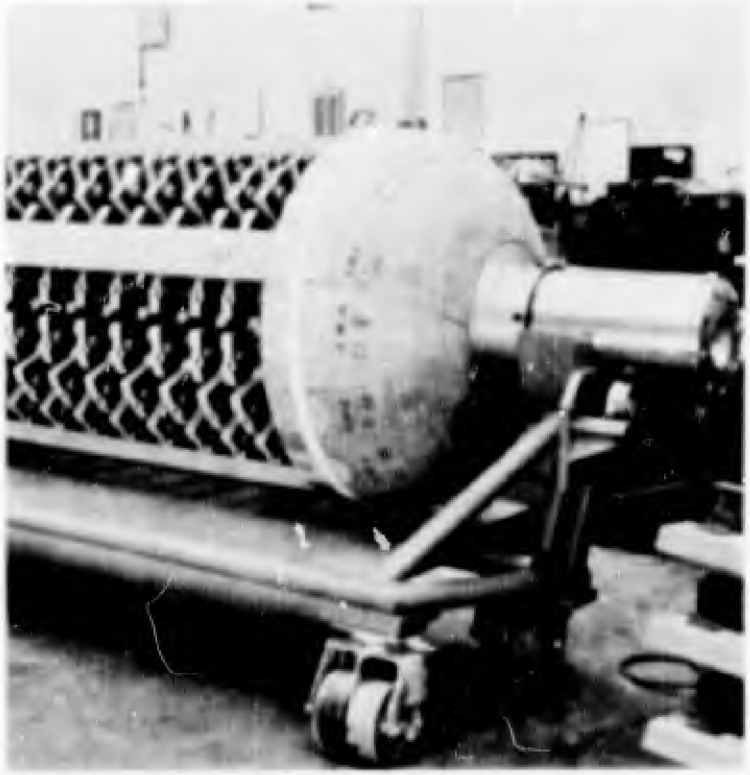
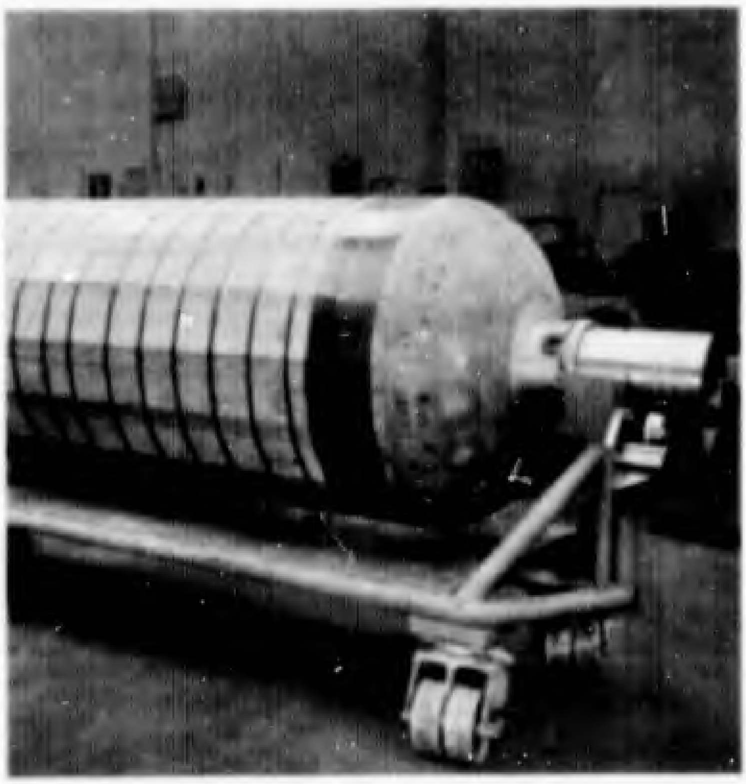
Wood substructure showing bulkheads and end domes

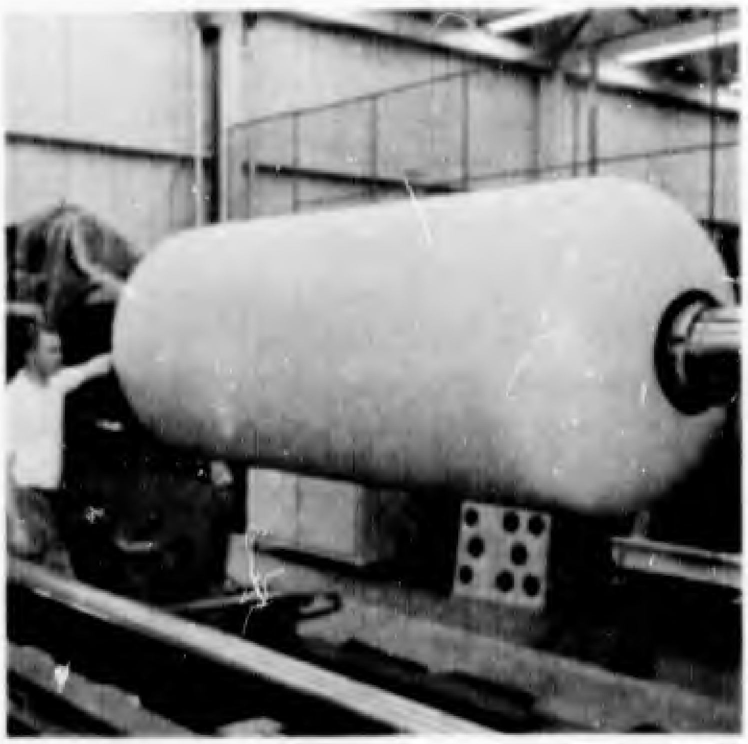


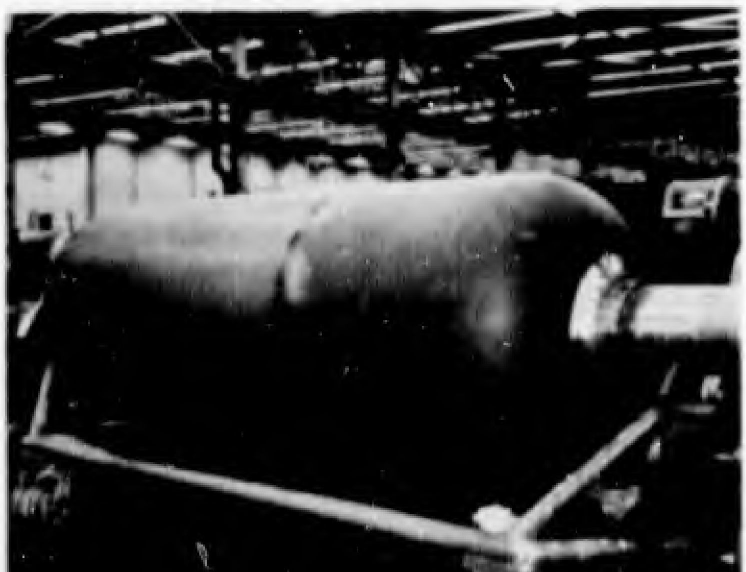


Completed wood substructure for Allison mandrel

Figure 16. TU-227A Case Mandrel Subsection

GEN-GARD V-57 SEALANT SPRAYED ON ALLISON MANDREL





V-45 LINER APPLICATION TO MANDREL

Figure 17. TU-227A Case Mandrel

this requirement and a ballistic design was produced. Drawings for process tooling were also prepared. Because of a long lead time required to fabricate insulation tooling needed in Phase IV, the insulation had to be designed in Phase II. Insulation drawings for both cases were sketched, and modified to incorporate each change in case design as changes developed. When, near the end of Phase II, following several redirections of effort, propellant loading and static testing were deleted from the program, all work on the insulation drawings was stopped with the drawing approximately 90% complete.

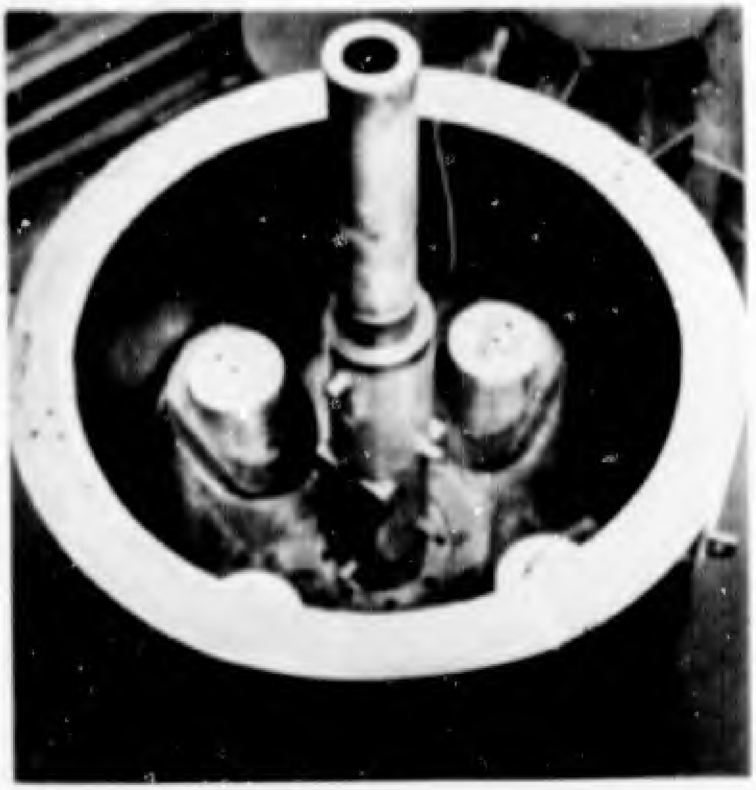
(5) Structural Loads Testing--Initially, five structural load tests were to be conducted in Phase III. Initial planning and preliminary procedures for this testing were initiated in Phase II. Because of the program redirection during Phase II, this effort was revised extensively and was finally deleted entirely from the contract. The planned tests are described in the Performance Test Sections of Thiokol Specifications TWS-EQ-35A and TWS-EQ-36A (Volume II, Appendices A and B).

(6) Case Pressure Test Tooling and Modification--Design of new tooling and modifications to existing tooling and equipment for burst testing of cases was started during Phase II. A new piston design was adapted (extension of bearing guides to allow for case expansion, and change of piston diameter to fit the blast tube configuration of the TU-226 and TU-227 case assemblies). Changes were made to permit use of water (rather than oil, which would contaminate plastic case liner-insulation) for pressure testing of cases (Figure 19). The existing pumping system was not able to deliver an adequate volume of water at the specified time. An accumulator system was designed, fabricated, and installed to supply a sufficient volume (Figure 20).

(7) Hydrotest Arrangement--The empty TU-226 and TU-227 cases were installed vertically in the hydrotest facility with the nozzle ports up (Figure 21). Floating pistons were placed in the four nozzle ports and the applied pressure was transmitted to the overhead beam of the hydrotest stand. By this arrangement, the pressure loads were transmitted from the blast tube area, through the hydrotest stand to the forward skirts, to simulate forward skirt loading. The forward polar opening was capped with a modified cover, to which hydrotest piping was attached.

(8) Processing Standards--Processing standards for loading of live propellant and inert formulation into the cases for Phases III and IV were started in Phase II. Effort on processing standards was cancelled when the loading requirements were deleted from the contract.

(9) Handling Tooling--Existing tooling developed for other contracts was modified to adapt it for use in handling TU-226 and TU-227 cases. It was functionally checked on a TU-226 case and found adequate. Because of contract redirection, the motor tooling was not needed, and functional checks were not performed.



AFT CLOSURE METAL MOLD FOR BRUNSWICK MANDREL

AFT CLOSURE METAL MOLD FILLED WITH SAND MATRIX

Figure 18. TU-227B Case Mandrel Section

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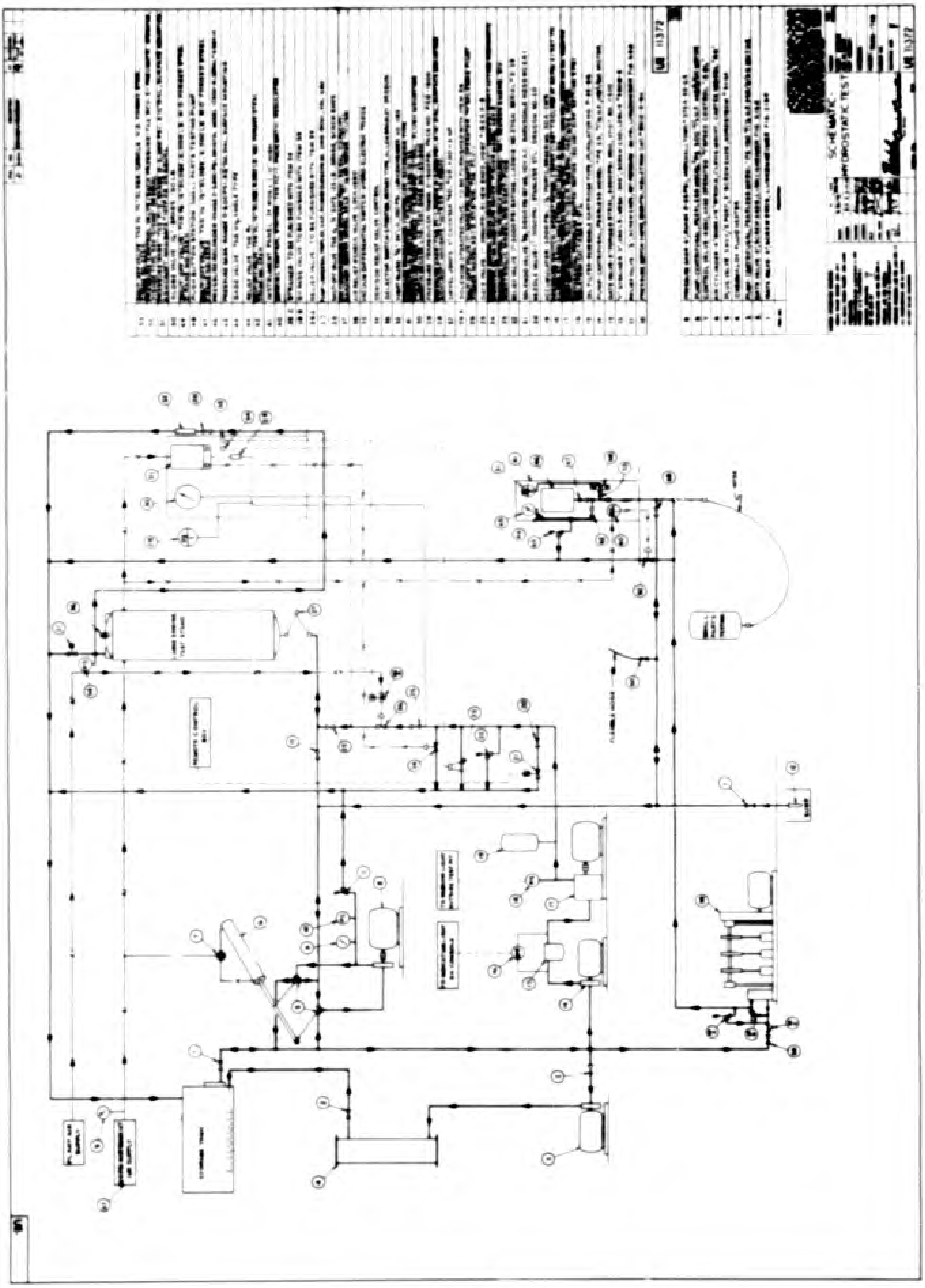

Figure 19. Case Pressure Test Schematic Diagram

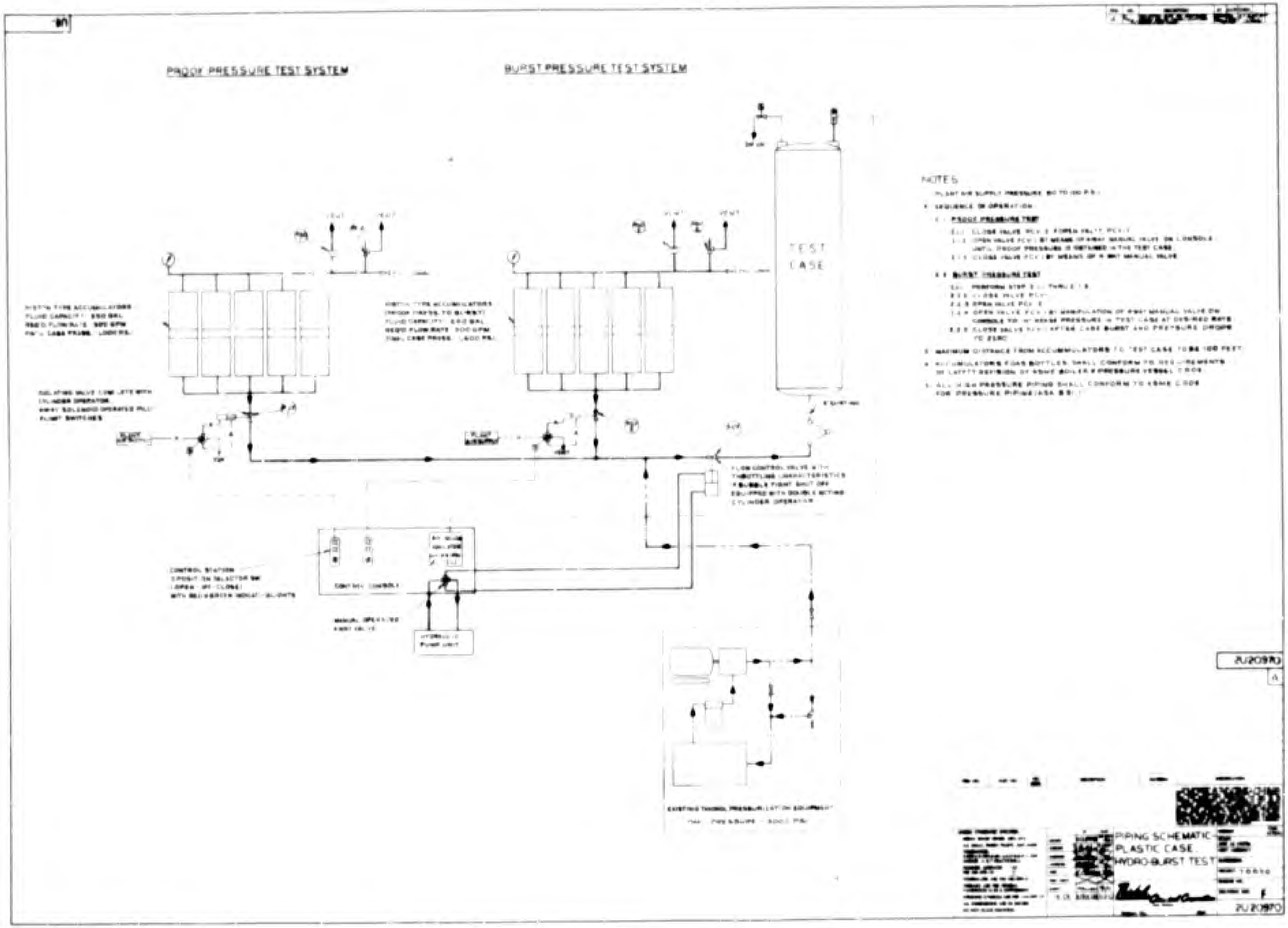

Figure 20. Case Pressure Test Accumulator Schematic Diagram

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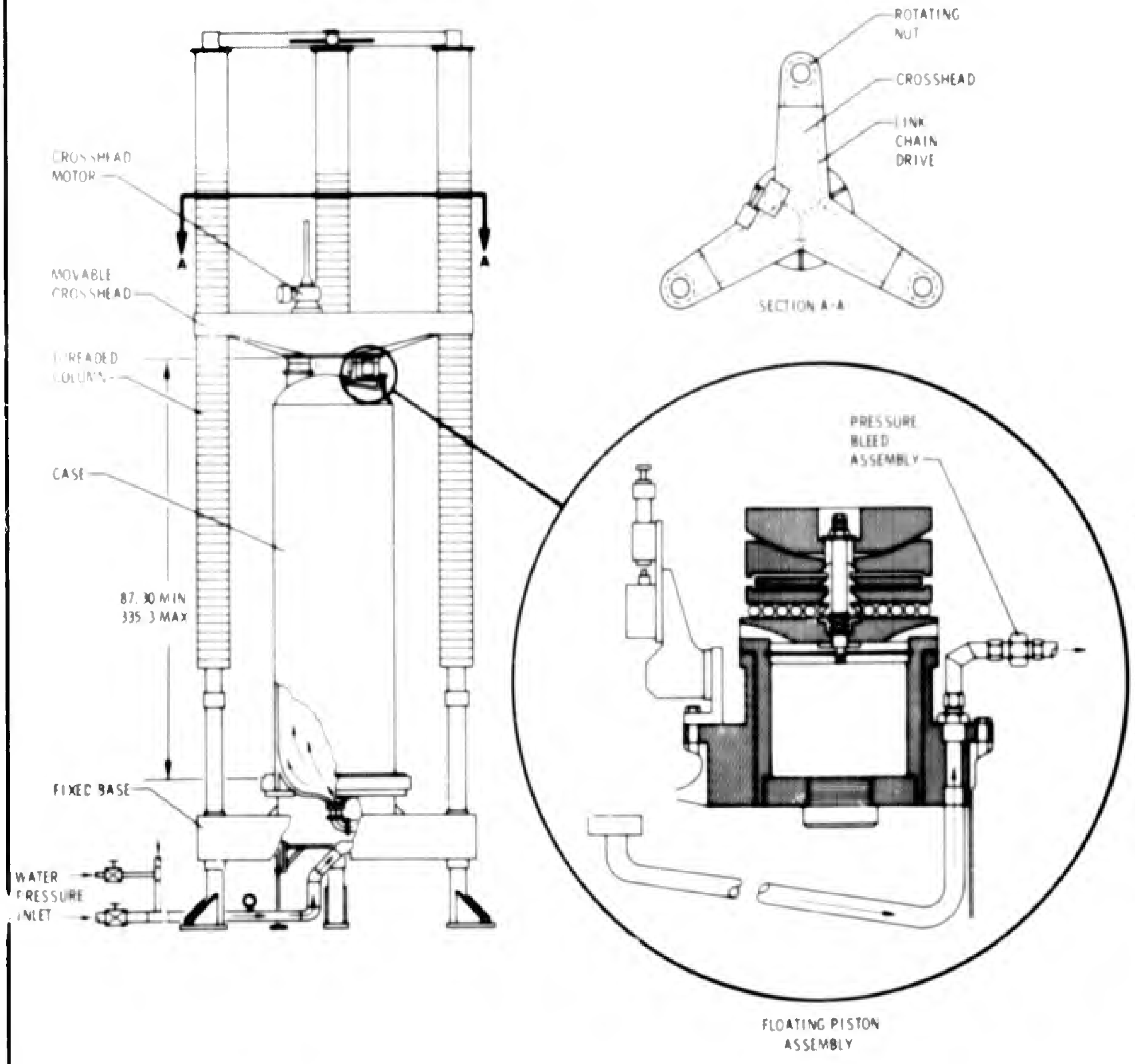

Figure 21. Thiokol Plastic Case Pressure Test Facility

b. Monolithic Case Fabrication

A detailed discussion of monolithic case fabrication and test is given in Volume II of this report. A summary of fabrication operations on these cases made in **Phase II** is presented here.

(1) TU-226A Cases--Each TU-226A case was wound in a six day interval, begun after the case mandrel had been completed (Figure 22). Reinforcements for nozzle ports were fabricated before case fabrication and stored until required. Skirts were also wound and machined before case fabrication. Longitudinal fibers were applied over the case mandrel and nozzle port reinforcements were applied between layers of helical windings. Hoop windings were applied with the skirts placed in position on the case. Nozzle ports were then cut in the aft dome. The case mandrel was broken up and removed through nozzle and polar openings. Blast tubes were mounted on the blast tube bosses, which had been previously inserted while the case was being wound. The completed case (Figure 23) was then packed for shipment.

(2) TU-226B Cases--Fabrication of TU-226B cases required four days per case. Fabrication was similar to that of TU-226A cases, with exception to the method by which nozzle openings were cut (Figure 24). Nozzle ports were cut with a router while the case, completely wound, was precisely aligned in the vertical position. Each completed case (Figure 25) was shipped within six weeks after case winding was begun.

(3) TU-227A Cases--Skirts for the TU-227A case (Figure 26) and doily and wafer reinforcements (Figure 27) were prepared before case winding. The case doilies were placed between helical layers during case winding (Figure 28). The skirts were positioned on the case with a special jig before hoop windings were applied (Figure 29).

Since the TU-227A cases were hydrotested at Allison, no packaging for shipment was necessary.

(4) TU-227B Cases--The mandrel for the TU-227B case was mounted vertically in a winding machine oriented for polar (biaxial) wrapping (Figure 30). Pins were placed on the aft dome to locate the center of each nozzle port before longitudinal windings of fiberglass were applied. After the first layer of glass had been applied to the mandrel, dome reinforcements were placed on the aft dome between helical layers. The skirts were placed on the case, and finally, hoop windings were applied. After hoop windings were completed, the case was removed from the winding machine and nozzle ports were cut in the aft dome. After blast tubes were secured in place, the completed case (Figure 31) was packed for shipment.

TU-226A CASE WINDING OPERATION

APPLICATION OF SKIRT AND HOOP WINDINGS

CUTTING NOZZLE PORTS

Figure 22. TU-226A Case Fabrication

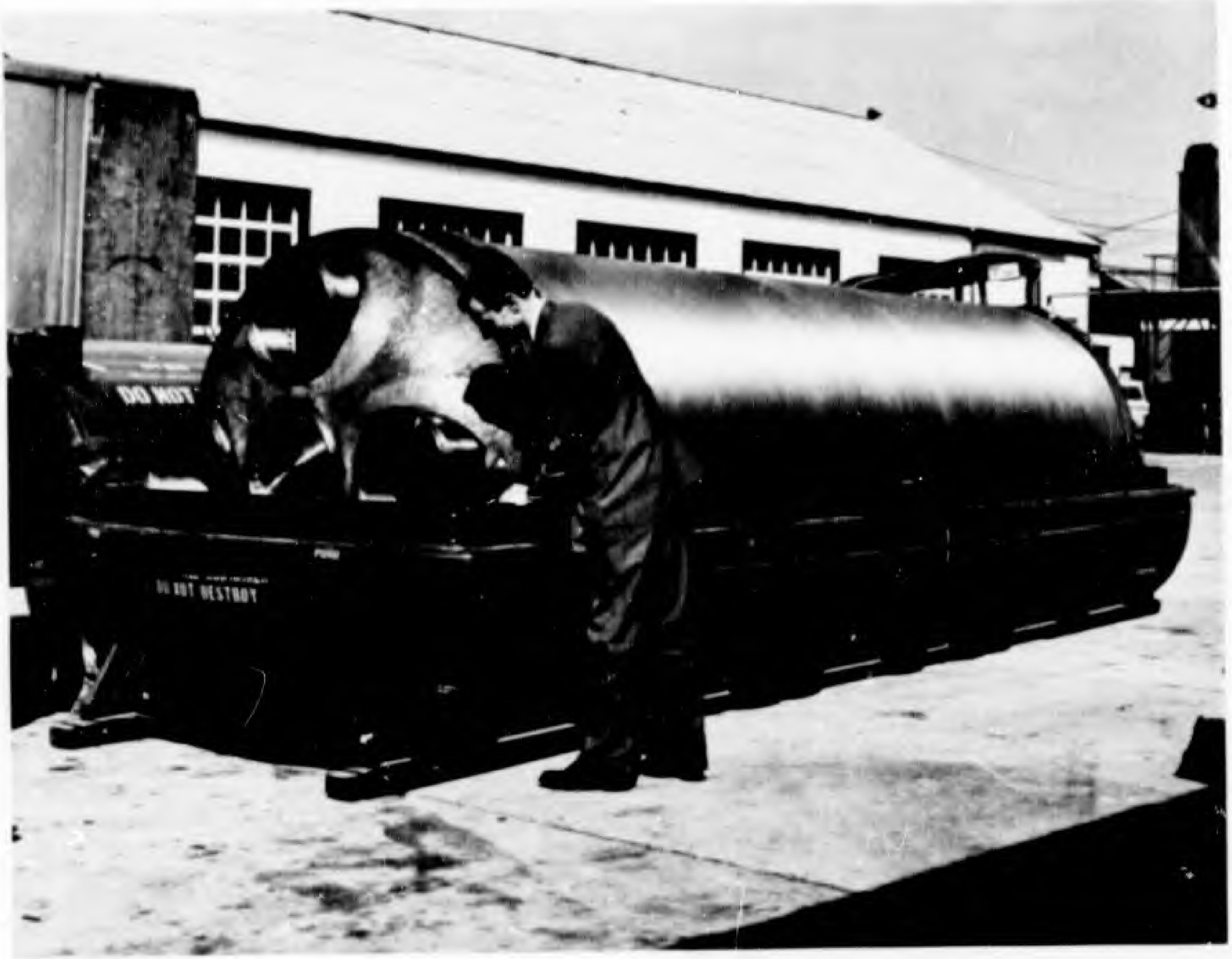

Figure 23. Completed TU-226A Case

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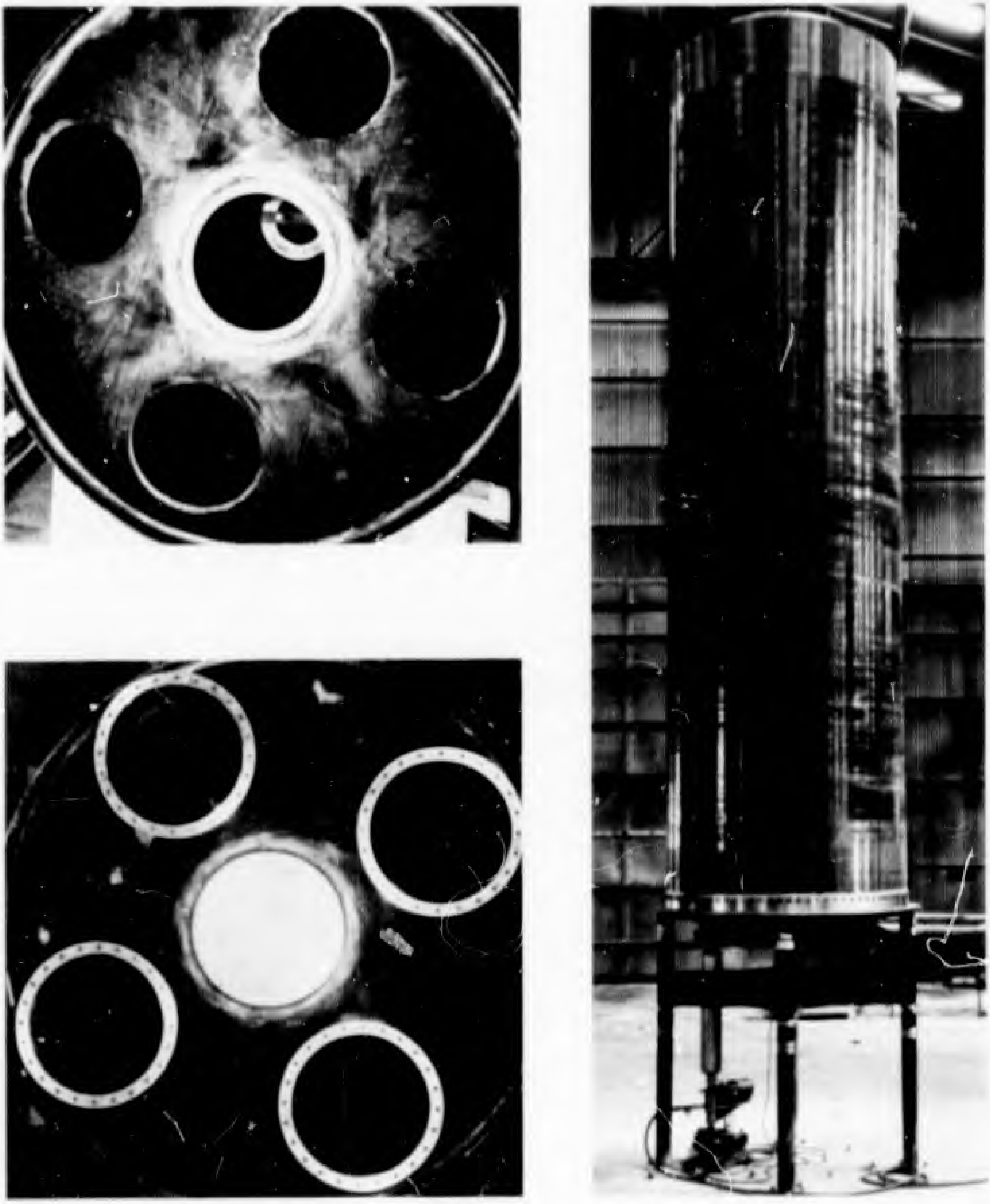

Figure 24. TU-226B Case Fabrication

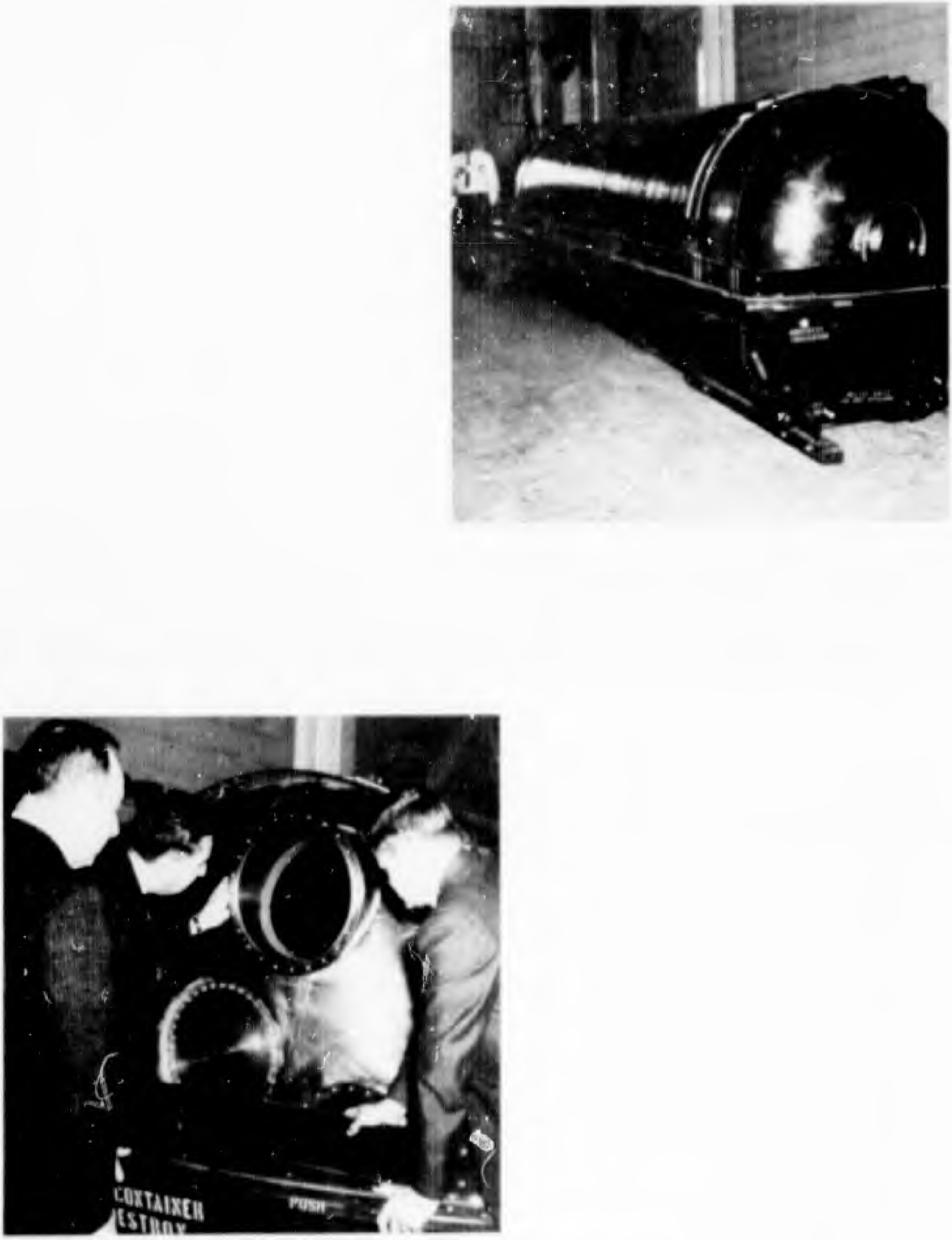

Figure 25. Completed TU-226B Case

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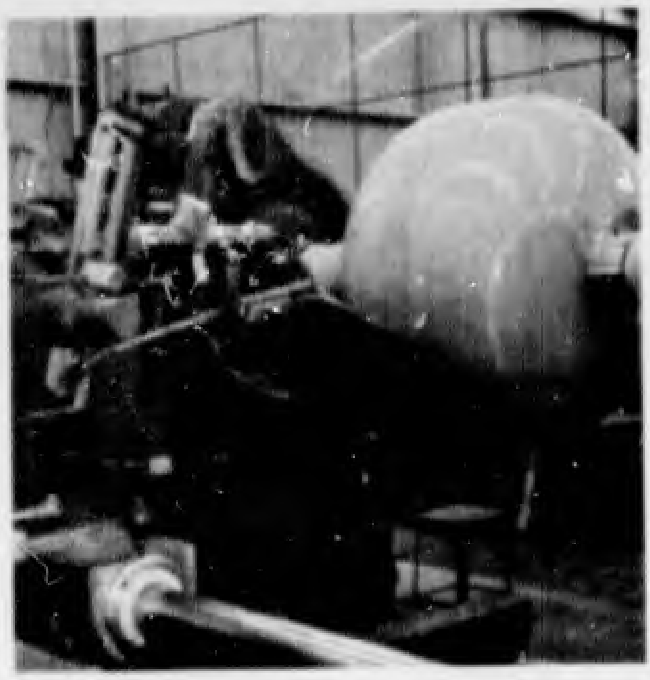
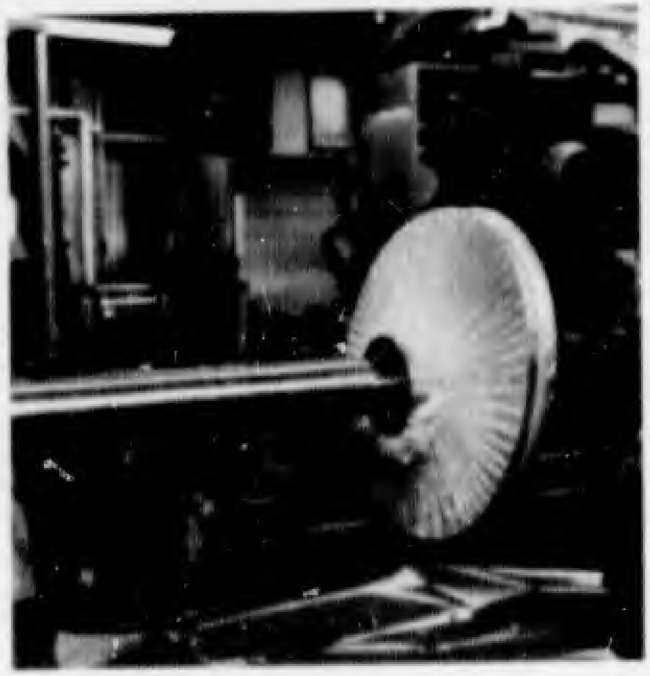
Figure 26. TU-227A Skirt Fabrication



TU-227A - DOILY FABRICATION

DOILY TRIMMING



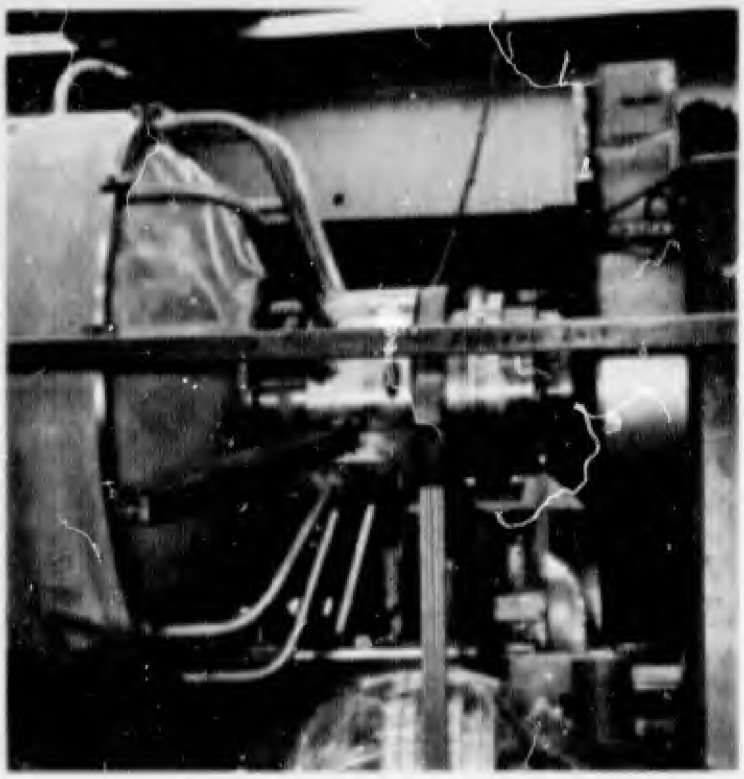
WAFER FABRICATION

Figure 27. TU-227A Wafer and Doily Fabrication

DOILY - WAFER SUBASSEMBLY

COMPLETED DOILY - WAFER INSTALLATION

Figure 28. TU-227A Case Doily Installation


Skirt positioning

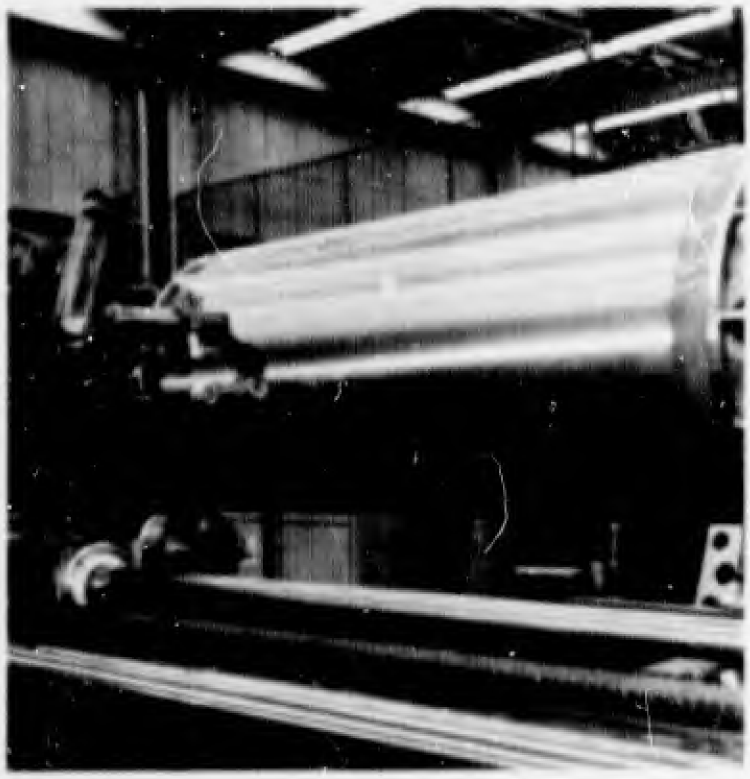
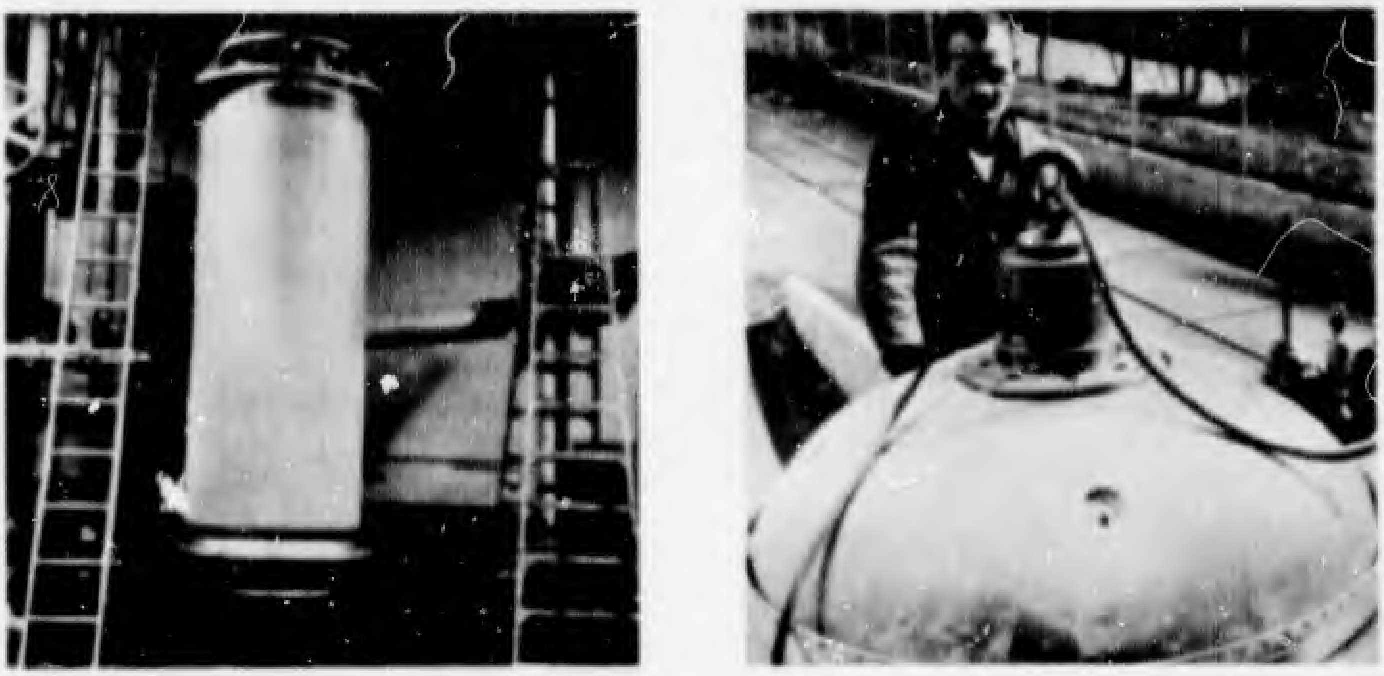

Hoop winding

Figure 29. TU-227A Case-to-Skirt Fabrication

TU-227B mandrel in winding machine

Application of polar filaments



Skirt attachment

Cutting nozzle ports

Figure 30. TU-227B Case Fabrication

Figure 31. Completed TU-227B Case

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c. Weight and Center-of-Gravity Determination

Weights and center-of-gravity determinations of TU-226A, and TU-226B, TU-227A and TU-227B cases are presented in Table II.

d. Monolithic Case Hydrostatic Pressure Tests

At least one case each of the TU-226 and TU-227 case designs was hydrotested to destruction in Phase II. A detailed discussion of case instrumentation and test procedure, and an analysis of the hydroburst failure is given in Volume II. A summary of the hydrotests follows.

(1) TU-226A Cases--Case No. 2 was tested hydrostatically so that case No. 1 could be reserved for loading of inert material simulating propellant. After checking for leaks, and after cycling at low pressure to condition gages, pressure was increased from 100 to 844 psig in 50 seconds. The planned design limit pressure (890 psig) was not attained because an insufficient volume of water was stored in the accumulators. During the hold period of 60 sec, pressure decreased to 750 psig. The pressure drop, possibly caused by leaking of the pumping system inlet-outlet valve, was substantiated by corresponding reductions in case strain and deflection indications. Following the hold period, pressure was increased to burst pressure (1164 psig) in eight seconds.

Sequence photographs (Figure 32) indicated that failure began in the helically wound fiberglass layers at the tangent point of the aft dome to the cylinder. The dome turned to one side, a typical consequence in the rupture of pressure vessels where hoop and helical windings alternate. Failure of helical fibers in tension progressed down the case cylinder. Hoop fibers failed in tension as the additional hoop load component was imposed upon them from failing helical windings which had previously carried a portion of the hoop load.

Fiberglass studies consisted of a dimensional-physical analysis of the case cylinder and domes (Table III). The average wall thickness and density were used in calculation of composite stress and the strength-to-density ratio.

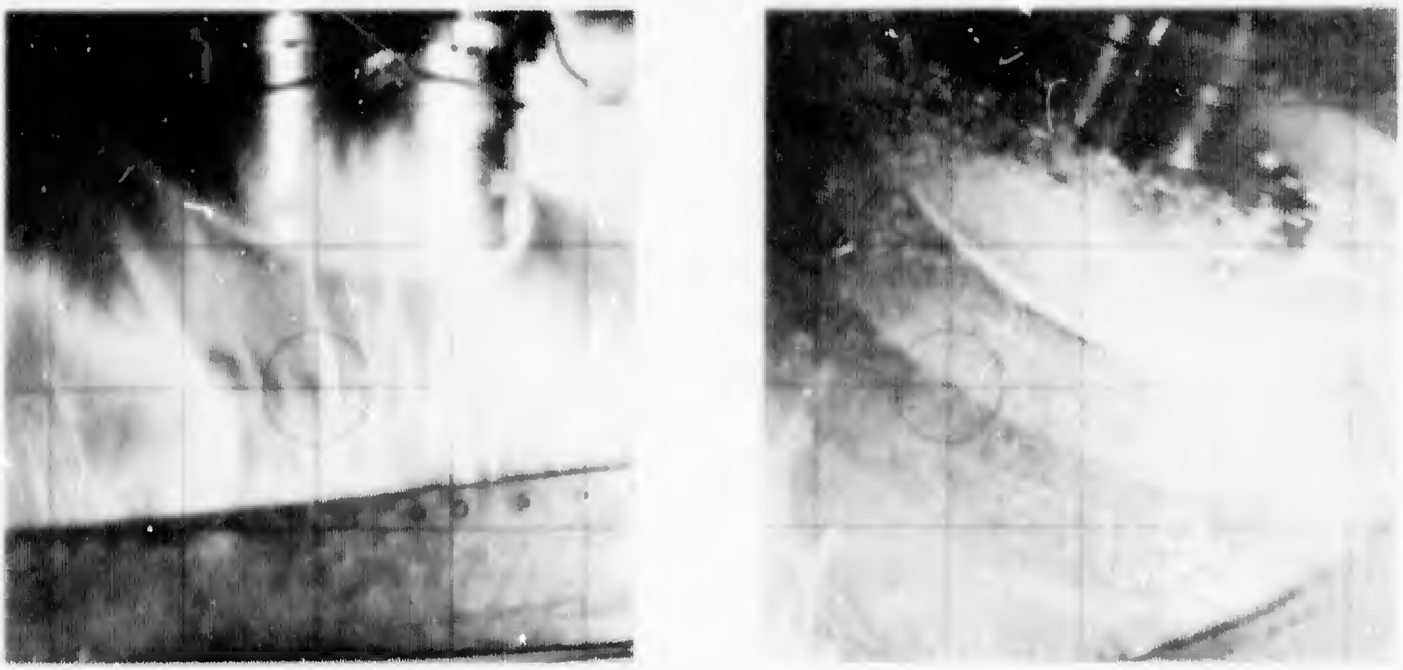
The calculated strength-to-density ratio of the case cylinder at burst pressure was 1.54×10^6 inches. The margin of safety exhibited by this case was 0.046 based upon the ultimate design pressure of 1113 psig. The TU-226 case was the first fiberglass case of this size to be hydrotested. To meet the design objectives so well, as indicated by test results, marks the venture as completely successful. The following design improvements were recommended to increase performance of the fiberglass motor case; (1) reduce the weight of the reinforced aft dome on the basis of low strain values recorded during test, and (2) refine the design of the skirt-to-case attachment.

TABLE II

MONOLITHIC CASE WEIGHT AND CENTER-OF-GRAVITY LOCATION

	Weight		Center-of-Gravity*
	Design	Actual	
TU-226A No. 1	2211.6	2178.5	---
TU-226A No. 2	2211.6	2204.0	140.8
TU-226B No. 1	2211.6	2442.0	141
TU-226B No. 2	2211.6	2434.0	139.3
TU-227A No. 1	538.1	568.3	---
TU-227A No. 2	538.1	564.0	---
TU-227B No. 1	523.8	555.0	69.8
TU-227B No. 2	523.8	545.0	66.4

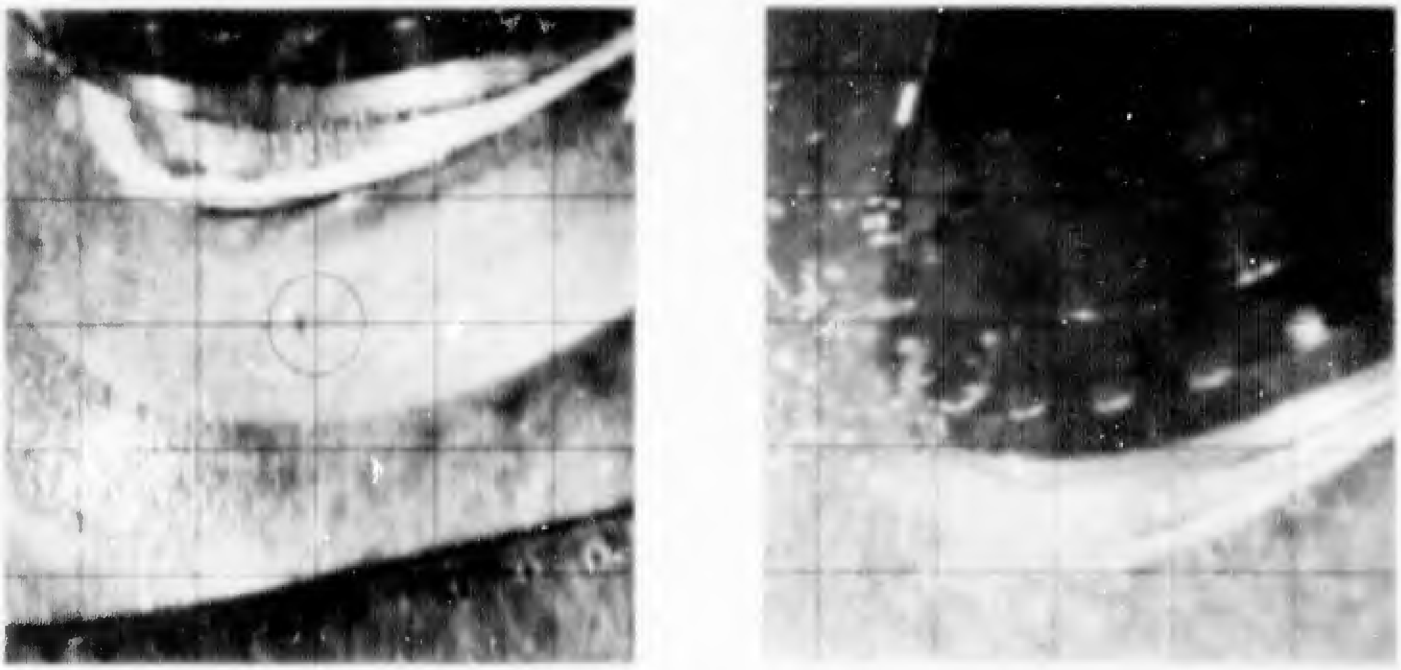
*Location is measured in inches aft of the forward edge of the forward skirt.



Failure at skirt

Dome inversion

Failure at aft dome nozzle three



Dome inversion

Dome inversion

(Upper and lower sequences are photographed 90° apart on the circumference of the aft skirt)

Figure 32. TU-226A Case No. 2 Hydroburst Failure

TABLE III

PHYSICAL PROPERTY ANALYSIS OF TU-226A CASE NO. 2

1. Cylinder Wall

Thickness (in.)	Density (lb/cu in.)	Resin Content (percent by weight)
0.352 to 0.357	0.695	23.6
(avg = 0.355)	0.695	23.2
	0.698	23.4
	0.698	24.0

2. Calculated Hoop Stress

	Stress (psi)	Pressure (psig)
Burst	106,900	1164
Ultimate Design	102,220	1113
Limit Design	81,740	890

Hoop Stress $= \dfrac{\text{(Pressure) (Radius)}}{\text{(Wall Thickness)}}$, where

the radius, R, = 32.604 in., and

the wall thickness, t, = 0.355 in.

3. Strength-to-Density Ratio $= \dfrac{\text{(Burst Pressure) (Radius)}}{\text{(Wall Thickness) (Density)}}$

$$= \frac{\text{(1164 lb/sq in.) (32.604 in.)}}{\text{(0.696 lb/cu in.) (0.355 in.)}}$$

$$= 1.54 \times 10^6 \text{ inches}$$

(2) TU-226B Cases--Case No. 2 was tested hydrostatically so that case No. 1 could be reserved for loading of inert material simulating propellant. After checking for leaks, and after cycling at low pressure to condition gages, pressure was increased from 75 to 830 psig in 34 sec, at which time the forward skirt failed. The calculated composite hoop stress at failure was 66,219 psi, but the case itself did not rupture.

After hydrotest of case No. 2, the decision to reserve case No. 1 for inert material loading was amended, and case No. 1 was hydrotested in a specific attempt to obtain case rupture data. After checking for leaks, and after cycling to condition gages, pressure was increased from 50 to 675 psig and held for 20 seconds. The planned design limit pressure (890 psig) was not attained because an insufficient volume of water had been stored in the pressurized accumulators. Additional water was introduced and the pressure was increased to 875 psig, slightly below the design limit pressure. Following a hold period, the pressure was increased to 943 psig in 47 seconds, at which time the forward skirt failed (Figure 33). The calculated composite hoop stress at failure was 75,602 psi, but the case itself did not rupture.

On each of these two cases, failure occurred in the bond between the forward skirt and the case. Failures apparently resulted from the inflexibility of the resin dam used in the skirt attachment area. The resin dam, which was designed to flex, or deform, as the case and skirt expanded at differing rates under pressure, apparently did not deform as expected. The skirt was forced to expand at a greater rate than the case, which imposed a tensile load on the bond between them.

Fiberglass studies consisted of a dimensional-physical analysis of the case cylinders and domes (Table IV). The average wall thickness and density were used to calculate composite stress and strength-to-density ratio.

The calculated strength-to-density ratio of case No. 2 at the pressure of failure (the case did not rupture) was 0.906×10^6 inches. Equivalently, this ratio for case No. 1 was 1.044×10^6 inches.

As for TU-226A cases, but with increased emphasis, Thiokol recommended a reduction in weight of aft dome reinforcement based upon low strain values recorded during test, and improvement of the skirt-to-case attachment.

(3) TU-227A Cases--Both TU-227A cases were successfully hydroburst tested with full instrumentation at Allison facilities. On case No. 1, pressure was increased from 50 to 680 psig, held at that value for 70 seconds, then increased to 1185 psig, at which time the case failed in the hoop windings near the aft skirt. On case No. 2, pressure was increased from 50 to 690 psig, held at that value for 60 seconds, then increased to 1115 psig, at which time the case failed in the hoop windings approximately three feet aft of the forward tangent line. There was no evidence of crazing of the laminate of the case. A summary of test results follows.

CASE IN TEST STAND

FORWARD SKIRT FAILURE

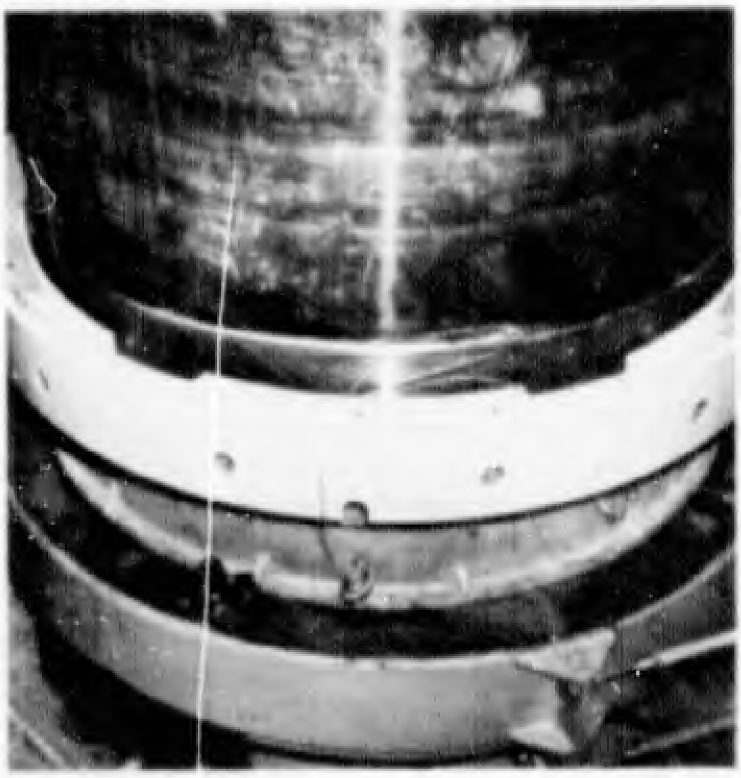


Figure 33. TU-226B Case Hydrotest

TABLE IV

PHYSICAL PROPERTY ANALYSIS OF TU-226B CASES

1. Cylinder Wall

Thickness (in.)		Density (lb/cu in.)		Resin Content (percent by weight)	
Case No. 2	Case No. 1	Case No. 2	Case No. 1	Case No. 2	Case No. 1
0.407 to 0.411	0.405 to 0.409	0.734	0.720	20.91	21.67
(avg = 0.409)	(avg = 0.407)	0.734	0.720	20.81	20.37
		0.727	0.727	21.74	20.77
		0.730	0.730	20.99	20.13
		0.730	--	21.09	--

2. Calculated Hoop Stress

	Stress (psi)		Pressure (psig)	
	Case No. 2	Case No. 1	Case No. 2	Case No. 1
Burst	66,219	75,602	830	943
Ultimate Design	102,220	102,220	1113	1113
Limit Design	81,740	81,740	890	890

$$\text{Hoop Stress} = \frac{(\text{Pressure})\ (\text{Radius})}{(\text{Wall Thickness})}\text{, where}$$

the radius, R, = 32.631 in. (Case No. 2); = 32.630 in. (Case No. 1) and

the wall thickness, t, = 0.409 in. (Case No. 2); = 0.407 in. (Case No. 1).

3. Strength-to-Density Ratio

$$= \frac{(\text{Burst Pressure})\ (\text{Radius})}{(\text{Wall Thickness})\ (\text{Density})}$$

$$= \frac{(830\ \text{lb/sq in.})\ (32.631\ \text{in.})}{(0.731\ \text{lb/cu in.})\ (0.409\ \text{in.})} = 0.906 \times 10^{6}\ \text{in. (Case No. 2)}$$

$$= \frac{(943\ \text{lb/sq in.})\ (32.630\ \text{in.})}{(0.724\ \text{lb/cu in.})\ (0.407\ \text{in.})} = 1.044 \times 10^{6}\ \text{in. (Case No. 1)}$$

Parameter	Design Value	Case No. 1	Case No. 2
Burst pressure (psig)	794	1185	1115
Composite wall stress (psi)	80,300	126,700	123,000
Wall thickness (in.)	0.219	0.207	0.200
Weight (lb)		474.7	474.8
Strength-to-density ratio (psi/lb/cu in.)	---	1.7×10^6	1.66×10^6
Strength-to-weight ratio (psi/lb)	---	2.67×10^6	2.59×10^6
Burst pressure-to-weight ratio	---	2.5	2.35

(4) TU-227B Cases--Case No. 1 was instrumented for hydrotest. After checking for leaks, and after cycling at low pressure to condition gages, pressure was increased from 100 to 763 psig in 40 seconds and held for 61 seconds. Pressure was then increased to 863 psig in 1.2 seconds, when the aft cover was blown (intact) from the case and pressure was lost.

The second case was tested for burst pressure only, in consideration of the aft cover failure. Pressure was increased from 100 to 638 psig in 13 seconds and held for 38 seconds. Pressure was increased to 860 (+) psig when, again, the aft cover was blown from the case.

The aft covers were fractured (Figure 34) upon striking the test stand crosshead. The broken pieces of the covers and bolts were examined to determine the origin of failure. Metallurgical analysis of the aluminum and a check of strength of attaching bolts indicated that both covers and bolts met appropriate specification requirements. It was concluded that the covers failed in the shear lip. After the shear lip fractured, the shear load was transferred to the bolts, causing failure under combined shear and tensile loading. When the bolts failed, the covers separated from the aft polar ring. The forward skirt of each case was permanently buckled by shifted thrust loads following cover failure.

Fiberglass studies consisted of a dimensional-physical analysis of case cylinders and domes (Table V). The average wall thickness and density were used to calculate composite stress and the strength-to-density ratios.

Design changes recommended for improvement of case design included reduction of weight in the reinforced aft dome based upon low strain values recorded during test, and improved shear lip design for aft covers.

TU-227B CASE NO. 1

TU-227B CASE NO. 2

Figure 34. TU-227B Aft Cover Failure

TABLE V

PHYSICAL PROPERTY ANALYSIS OF TU-227B CASES

1. Cylinder Wall

Thickness (in.)		Density (lb/cu in.)		Resin Content (percent by weight)	
Case No. 1	Case No. 2	Case No. 1	Case No. 2	Case No. 1	Case No. 2
0.222	0.224	0.731	0.745	19.46	18.67
0.222	0.222	0.731	0.734	20.09	20.24
0.222	0.221	0.734	0.738	19.83	19.47
		0.734	0.742	20.22	19.63
		0.734		19.64	

2. Calculated Hoop Stress

	Stress (psi)		Pressure (psig)	
	Case No. 1	Case No. 2	Case No. 1	Case No. 2
Burst	85,570	87,360	863	881
Ultimate Design	78,730	78,730	794	794
Limit Design	62,965	62,965	635	635

Hoop Stress $= \frac{\text{(Pressure) (Radius)}}{\text{Wall Thickness}}$, where

the radius, R, = 22.112 in., and

the wall thickness, t, = 0.223 inches.

3. Strength-to-Density Ratio $= \frac{\text{(Burst Pressure) (Radius)}}{\text{(Wall Thickness) (Density)}}$

$= 1.17 \times 10^6$ inches, Case No. 1

$= 1.18 \times 10^6$ inches, Case No. 2

2. Modular Construction of Fiberglass Plastic Cases

A second approach to the construction of a fiberglass plastic rocket motor case involved building shell sections (modules) which would be bonded together along longitudinal seams (joints). The case assembly so formed would then be fitted with prefabricated fiberglass hoop rings bonded together and bonded to the modules with a resin material. Design of a modular construction of a large diameter case (65 in. or larger) began in October 1961 when representatives of the H.I. Thompson Fiber Glass Company (the selected vendor) met at Thiokol to discuss the statement of work and case design (Figure 35). Effort on this portion of Phase II was divided into:

1. Evaluation and bench testing of case materials;
2. Design, fabrication, and test of a small diameter case of modular construction;
3. Design, fabrication, and test of a large diameter case of modular construction.

Following material evaluation, a small diameter (18 in.) case was designed, fabricated, and hydrotested to determine whether or not a rocket motor case could be fabricated using these materials and design. The case withstood 179 percent of the design limit pressure. The test proved the design was feasible. Also, data was obtained for certain design modifications (i.e., the use of five, instead of six, layers of glass in the modules, the use of a single thickness of stainless steel foil in place of two bonded foil strips of equivalent thickness in the aft joint, the addition of a steel strip between the aft skirt and dome to prevent glass-to-glass abrasion, etc.) for the design of a second case.

A second small diameter case was fabricated and tested incorporating modifications resulting from the first hydrotest. This case withstood 202 percent of the design limit pressure before failure in the hoop region. This highly successful test proved that a modular construction for a rocket motor case was feasible. Moreover, with the knowledge derived from both subscale tests, Thiokol could confidently design and build a large diameter (65 in. or larger) case and establish many of the tooling requirements for fabrication.

A larger diameter case was then designed with longitudinal modules, a forward dome with zero hoop loading, and a polar wrapped aft dome.

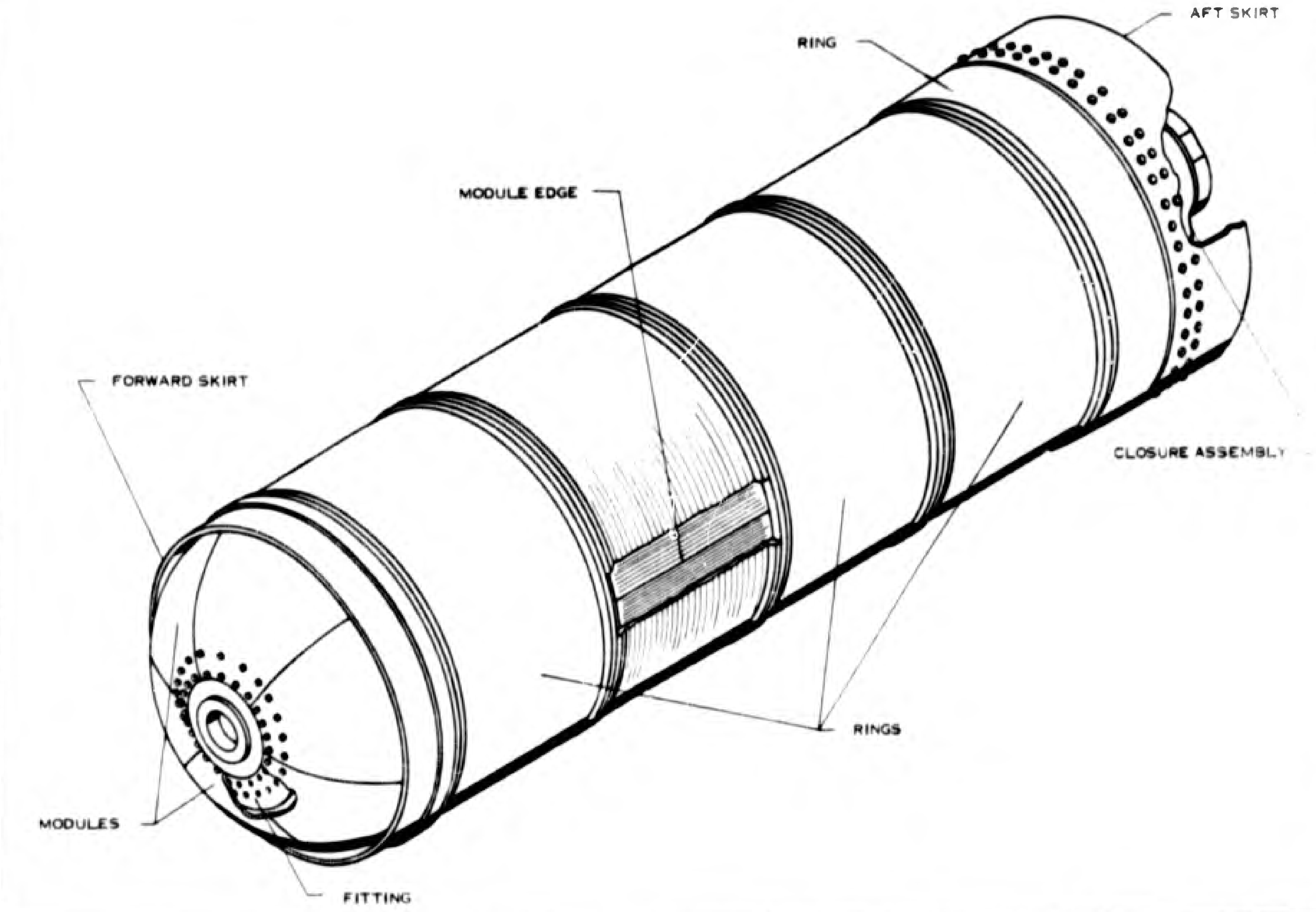


Figure 35. Tentative TU-228 Motor Case Assembly

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a. Material Evaluation and Bench Testing

To select materials for the case, joint reinforcements, and the internal liner, laboratory studies and tests were conducted on fiberglass tape, on bonding agents (resin compounds), on cleaning agents for stainless steel, and bonding agents for steel to fiberglass, and on liner materials for the case. Case materials evaluated were:

1. Coated Scotchply XP 204 glass tape (Minnesota Mining and Manufacturing Co, Minneapolis, Minn.);
2. Cordo Mobaloy ER-20, 20-end HTS roving (Cordo Chemical Corp, Norwalk, Conn.);
3. U.S. Polymeric E-787 resin on 20-end HTS roving (U.S. Polymeric Chemicals, Inc, Stamford, Conn.);
4. Epon 913 and Epon 923 resins for bonding hoop windings to fiberglass modules (Shell Chemical Corp, New York, N.Y.);
5. BR-90 resin for bonding hoop windings to fiberglass modules (Bloomingdale Rubber Co, Aberdeen, Md.);
6. BR-1009-49 compound, a primer coating for fiberglass (Bloomingdale Rubber Co);
7. FM-47 compound, a primer coating for steel to fiberglass (Bloomingdale Rubber Co);
8. AM-355XH stainless steel.

The following cleaning agents for stainless steel were tested:

1. Prebond-700 (Bloomingdale Rubber Co);
2. An acid bath (a water solution of sulphuric and hydrochloric acids) followed by an acid etch (a water solution of hydrofluoric and nitric acids).

Materials for the internal case liner were also evaluated:

1. Fairprene synthetic rubber, types 5002-D, 5009, 5023, 5039, 5751, and 5798 (E. I. du Pont de Nemours and Co Inc);
2. L. A. Standard Rubber D-400 (Los Angeles Standard Rubber Inc, Los Angeles, Calif.);

3. Firestone V-16 compound (Firestone Tire and Rubber Co, Akron, Ohio).

(1) Case Material Selection--To evaluate fiberglass and resin systems and to select the best materials for large diameter cases, Hitco fabricated, on unheated mandrels, seven fiberglass plastic cylinders (Table VI), each 6 in. ID and 18 in. long. These cylinders were later tested for tensile and shear strength of case materials. Three of these cylinders were wound using Scotchply XP-204 glass tape, two using Cordo Mobaloy ER-20 roving, and two using U.S. Polymeric E-787 resin on 20-end HTS roving. Hitco also fabricated two additional cylinders (cylinders No. 7 and 8) on heated (125 to 250°F) mandrels to study flow characteristics and physical properties of the resin. Cylinders No. 1 and 9 were damaged during fabrication; cylinders No. 10 and 11 were made to replace them. Cordo Mobaloy ER-20 was substituted for Scotchply XP-204 in cylinder No. 11.

The cylinders were cut into ring specimens (Figure 36) and tested for hoop tensile strength and interlaminar shear strength. Several ring specimens cut from damaged cylinder No. 1 were tested to evaluate the test method (Figure 37).

Test results (Tables VII and VIII) indicated Cordo Mobaloy ER-20 to be the superior material for case construction when, for example, composite wall tensile values or shear loads at failure were compared. Heating mandrels produced no appreciable improvement in physical property values of case materials. Thiokol and Hitco selected Cordo Mobaloy ER-20 for these reasons: (a) glass tensile strength, (b) glass resin shear strength, (c) a shelf life of six months, and (d) heated mandrels not required during fabrication, and (e) availability.

(2) Design Factor Determination--Using Cordo Mobaloy ER-20, Hitco fabricated eight cylinders, each 6 in. ID and either 18 or 12 in. long (Table IX) to establish factors for the design of a small and a large diameter TU-228 case. These cylinders were cut into ring specimens and tested for tensile strength values (Table X). A small (18 in. dia by 62 in. long) TU-228 case was designed to meet a burst pressure of 692 psi, using tensile values obtained from these tests. Interlaminar shear strength values were used from the first ring specimens tested.

(3) Steel Foil-to-Fiberglass Bonding Tests--Stainless steel AM-355XH was selected for strip material for laminated steel-fiberglass joints because it was sufficiently ductile in the 300,000 to 340,000 psi tensile strength range, and was available in adequate supply. But because the nature of the bond which might be developed between steel foil and fiberglass was not known at the onset of Phase II, a study was made of priming materials and test procedures for steel to glass bonding. Specimens were prepared (Figure 38) using fiberglass and steel laminations. The plies of steel foil were stacked and wrapped along one edge with Mylar tape (0.430 in. wide by 6.187 in. long) to produce specimens with a known cross section of bonded area between steel and glass. Specimens were tested according to a progressive step sequence (Figure 39) to evaluate both methods of cleaning steel foil and of bonding steel to glass.

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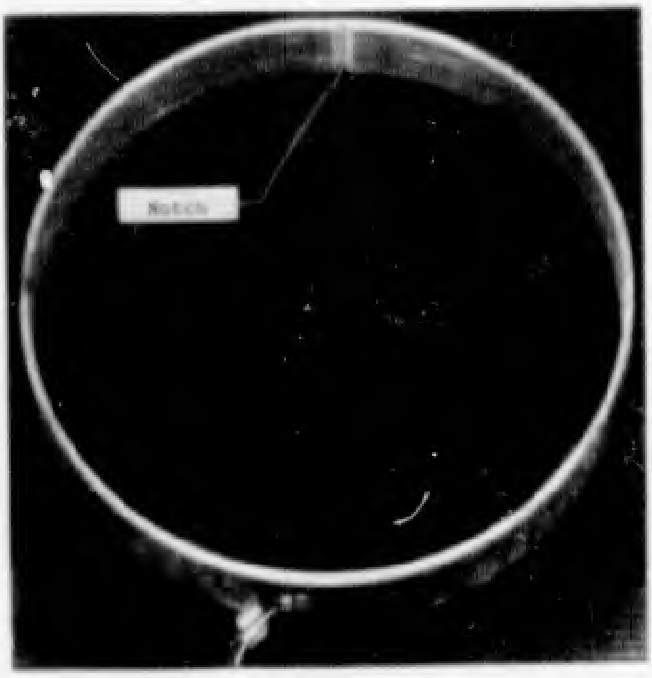
TABLE VI

TEST CYLINDER FABRICATION SUMMARY - (For Material Evaluation of Tensile and Shear Strength)

Cylinder Material	Cylinder No.	Uncured Resin Content	Cured Resin Content	Number of Rovings	Lead (in.)	Number of Ends/in.	Number of Plies	Cylinder Length (in.)	Tension (lb/end)	Curing Schedule
Scotchply XP-204	1	---	---	---	---	---	---	---	---	---
Scotchply XP-204	2	18.32	11.71	0.25 in. Tape	0.200	185	12	14.0	0.25	75 psi steam for 15 min 8 hr oven cure at 325°F
U.S. Polymeric E-787	3	21.34	20.00	3	0.234	256	12	14.0	0.25	15 psi steam 1 hr at 230°F 80 psi steam 15 min at 310°F 8 hr oven cure at 330°F
Cordo Mobaloy 20-ER	4	20.90	17.88	3	0.234	256	12	14.0	0.25	15 psi steam 1 hr at 230°F 80 psi steam 15 min at 310°F 8 hr oven cure at 330°F
Cordo Mobaloy 20-ER	5	20.90	16.46	3	0.220	272	12	14.0	0.25	15 psi steam 1 hr at 240°F 8 hr oven cure at 330°F
U.S. Polymeric E-787	6	21.34	19.00	3	0.234	256	12	14.0	0.25	15 psi steam 1 hr at 240°F 8 hr oven cure at 330°F
Cordo Mobaloy 20-ER	7	20.90	13.81	3	0.217	284	11	14.0	0.75	90 psi steam 10 min at 240°F 8 hr oven cure at 330°F
U.S. Polymeric E-787	8	21.34	16.58	3	0.234	256	12	14.0	0.75	90 psi steam 10 min at 240°F 8 hr oven cure at 330°F
Scotchply XP-204	9	---	---	---	---	---	---	---	---	---
Scotchply XP-204	10	---	---	0.25 in. Tape	0.240	250	12	14.0	0.25	90 psi steam 10 min at 240°F 8 hr oven cure at 330°F
Cordo Mobaloy 20-ER	11	18.21	---	3	0.203	297	13	14.0	0.75	90 psi steam 10 min at 240°F 8 hr oven cure at 330°F

Cylinders No. 1 and 9 damaged in fabrication; cylinders No. 10 and 11 made to replace cylinders No. 1 and 9.
Mandrel heated 125-150°F during fabrication for cylinders No. 7 and 8.
Cordo Mobaloy 20-ER substituted for Scotchply XP-204 for cylinder No. 11.

Cylinder test arrangement



Tensile test specimen

Shear test specimen

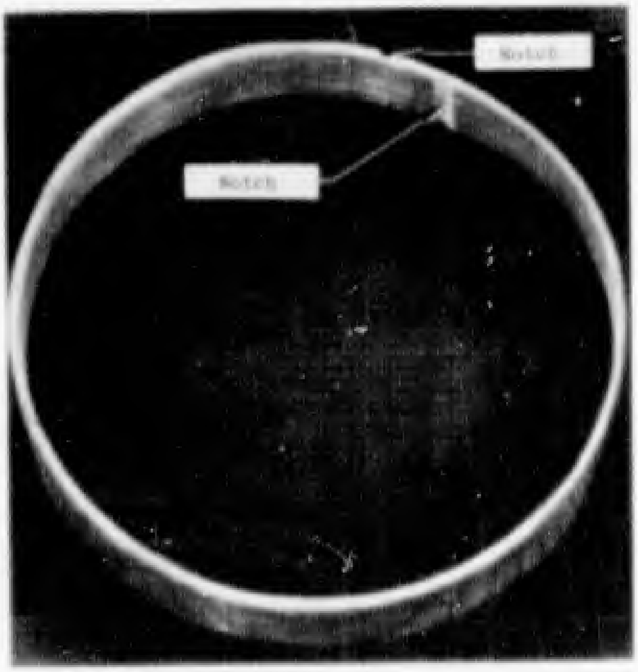


Figure 36. Cylinder Ring Physical Properties Testing

Cylinder ring specimen tensile failure

Cylinder ring specimen shear failure

Figure 37. Cylinder Ring Physical Property Specimen Failures

TABLE VII

RING SPECIMEN TENSILE TEST SUMMARY (For Case Material Selection)

Cylinder Material	Cylinder No.	Specimen No.	Notch Depth (in.)	Ring Thickness (in.)	Lead (in.)	Plies	Band Width (in.)	Band Thickness (in.)	P_t (lb)	F_{tu_C} (psi)	$F_{tu_{G_1}}$ (psi)	$F_{tu_{G_2}}$ (psi)	E_{t_C} x 10^6 psi	$E_{t_{G_1}}$ x 10^6 psi	$E_{t_{G_2}}$ x 10^6 psi
Scotchply XP-204	2	1	0.0451	0.990	0.200	8	0.200	0.0060	19,400	215,555			8.38		
		2	0.0485	1.004					19,800	200,000			8.56		
									19,600	207,778			8.47		
U.S. Polymeric E-787	3	1	0.0669	0.998	0.234	8	0.234	0.0085	30,700	210,555	350,000	343,500	7.62	11.54	11.43
		2	0.0684	1.010					30,900	224,600	340,000	340,900	7.70	11.67	11.42
		3	0.0682	0.437					13,110	220,400	334,600	334,000			
		4	0.0680	0.438					12,960	217,350	329,200	330,600			
									21,917	223,228	338,325	337,250	7.66	11.60	11.43
Cordo Mobaloy 20-ER	4	1	0.0686	0.996	0.234	8	0.234	0.0085	30,600	225,400	329,300	344,200	8.33	12.20	12.08
		2	0.0680	1.007					32,400	236,500	345,700	354,300	8.17	11.94	12.04
		3	0.0673	0.435					13,100	223,550	326,750	336,100			
		4	0.0675	0.430					12,880	222,150	321,500	334,000			
									22,245	226,975	331,613	342,200	8.25	12.07	12.06
Cordo Mobaloy 20-ER	5	1	0.0730	1.006	0.220	8	0.225	0.0091	33,700	229,410	328,000	350,500			
		2	0.0735	1.005					32,950	223,088	316,800	343,900			
		3	0.0735	1.004					33,850	230,932	328,000	352,700			
		4	0.0730	1.008					34,875	236,932	336,100	363,500	8.50	12.00	12.66
		5	0.0730	1.007					34,250	232,651	330,300	356,600	8.36	12.06	12.70
									33,925	226,561	327,540	353,440	8.43	12.03	12.68
U.S. Polymeric E-787	6	1	0.0730	1.008	0.234	8	0.234	0.0092	33,000	224,199	333,200	364,700			
		2	0.0740	1.004					31,900	213,235	316,100	354,000			
		3	0.0730	1.008					31,600	214,966	319,200	349,400			
		4	0.0710	1.007					32,000	214,766	318,900	354,000	7.74	11.50	12.22
		5	0.0710	1.004					32,725	223,208	330,300	363,500	7.69	11.42	12.34
									32,245	218,151	323,660	357,120	7.71	11.46	12.28
Cordo Mobaloy 20-ER	7	1	0.0571	1.011	0.211	7	0.211	0.0084	30,900	267,532	356,000	362,100			
		2	0.0561	1.012					29,200	257,155	334,000	331,500			
		3	0.0556	1.012					30,900	274,398	350,000	362,100			
		4	0.0561	1.010					30,000	264,784	332,400	341,000	4.86	11.40	11.10
		5	0.0558	1.012					30,325	252,246	336,000	342,500	4.77	11.70	11.27
									30,265	263,262	341,900	347,840	4.81	11.55	11.18
U.S. Polymeric E-787	8	1	0.0680	1.010	0.234	8	0.234	0.0092	29,375	230,826	325,400	324,000			
		2	0.0658	1.013					32,975	247,374	348,300	364,000			
		3	0.0659	1.008					32,300	243,168	342,700	363,500			
		4	0.0656	1.006					32,075	231,052	326,000	357,000	4.83	12.14	12.55
		5	0.0648	1.010					31,800	242,738	342,400	350,600	4.64	12.13	12.44
									31,750	239,024	336,960	350,220	4.74	12.11	12.49
Cordo Mobaloy 20-ER	11	1	0.066	1.005	0.202	8	0.202	0.0081	34,875	266,984	310,287	334,400			
		2	0.066	1.004					36,800	277,673	334,977	352,500			
		3	0.0693	1.009					37,500	264,439	341,016	377,400			
		4	0.0695	1.012					38,250	271,915	346,834	364,000			
		5	0.0699	1.009					39,325	279,792	355,391	374,800			
									37,350	273,032	340,102	358,640			

LEGEND

F_{tu_C} = Composite wall strength

$F_{tu_{G_1}}$ = Glass tensile strength by resin content

$F_{tu_{G_2}}$ = Glass strength by glass area

E_{t_C} = Composite tensile modulus

$E_{t_{G_1}}$ = Glass modulus by resin content

$E_{t_{G_2}}$ = Glass modulus by glass area

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TABLE VIII

RING SPECIMEN INTERLAMINAR SHEAR TEST SUMMARY (For Case Material Selection)

Material	Cylinder No.	Specimen No.	Cured Resin Content	Length Lap (in.)	Width (in.)	Failing Load (lb)	F_{si} (psi)
Scotchply XP 204	2	1	11.71	0.505	1.003	3750	3702
		2		0.514	1.107	2700	2609
		3		0.525	1.002	3025	2876
		4		0.502	1.002	3210	3028
		5		0.486	1.002	3110	3193
							3081 (Average)
U. S. Polymeric E-787	3	1	20.00	0.505	1.008	4550	4470
		2		0.529	1.008	3825	3605
		3		0.513	1.004	4140	4004
		4		0.545	.999	4535	4164
		5		0.524	1.003	4065	3868
							4022 (Average)
Cordo Mobaloy 20-ER	4	1	17.86	0.501	1.007	5820	5768
		2		0.472	1.009	5660	5946
		3		0.487	1.009	4450	4573
		4		0.495	.999	4320	4368
		5		0.530	1.006	4540	4259
							4983 (Average)
Cordo Mobaloy 20-ER	5	1	16.46	0.617	1.006	6020	4851
		2		0.525	1.005	3640	3450
		3		0.523	1.003	4260	4061
		4		0.520	1.000	3600	3461
		5		0.517	1.005	4880	4692
							4103 (Average)
U.S. Polymeric E-787	6	1	19.00	0.512	1.001	3110	3034
		2		0.496	1.006	2840	2840
		3		0.493	1.005	2300	2321
		4		0.517	1.006	2620	2520
		5		0.505	1.006	2600	2559
							2655 (Average)
Cordo Mobaloy 20-ER	7	1	13.81	0.513	1.012	5110	4920
		2		0.525	1.013	4720	4425
		3		0.510	1.013	5720	5530
		4		0.505	1.012	5160	5050
		5		0.509	1.002	5140	5040
							4993 (Average)
U.S. Polymeric E-787	8	1	16.58	0.511	1.008	4200	4075
		2		0.521	1.009	3860	3680
							3877 (Average)

TABLE IX

TEST CYLINDER FABRICATION SUMMARY - (For Establishment of Case Design Factors)

Cylinder Material	Cylinder No.	Uncured Resin Content	Cured Resin Content	Number of Rovings	Lead (in.)	Number of ends (in.)	Number of Plies	Cylinder Length (in.)	Tension (lb/end)	Curing Schedule
Cordo Mobaloy 20-ER	12	17.48	12.01	3	0.201	298	12	13	0.75	90 psi steam 10 min at 240°F 8 hr oven cure at 330°F
Cordo Mobaloy 20-ER	13	15.55	12.45	3	0.192	312	12	13	0.75	Same
Cordo Mobaloy 20-ER	14	15.55	11.84	3	0.202	297	12	12	0.75	Same
Cordo Mobaloy 20-ER	15	16.40	11.46	3	0.202	297	12	12	0.75	Same
Cordo Mobaloy 20-ER	16	15.55	11.39	3	0.202	297	12	12	0.75	Same
Cordo Mobaloy 20-ER	17	18.34	12.46	3	0.202	297	12	12	0.75	Same
Cordo Mobaloy 20-ER	18	15.82	12.26	3	0.202	297	12	12	0.75	Same
Cordo Mobaloy 20-ER	19	17.86	12.47	3	0.202	297	12	12	0.75	Same

TABLE X

RING SPECIMEN TENSILE TEST SUMMARY (For Establishment of Case Design Factors)

Material	Cylinder No.	Specimen No.	t (in.)	b (in.)	Lead (in.)	Plies	Band Width (in.)	Band Thickness (in.)	P_t (lb)	F_{tu_C} (psi)	$F_{tu_{G_1}}$ (psi)	$F_{tu_{G_2}}$ (psi)	E_{t_C} (x 10^6 psi)	$E_{t_{G_1}}$ (x 10^6 psi)	$E_{t_{G_2}}$ (x 10^6 psi)
								Average	37,350	233,032	384,061	356,649			
Cordo Mobaloy 20-ER	12	1	0.0653	1.008	0.201	8	0.201	0.0081	33,700	256,250	329,000	319,996	9.18	11.73	12.06
		2	0.0642	1.004					34,300	264,506	338,944	325,693	9.57	12.28	12.46
		3	0.0652	1.005					34,700	264,750	338,880	330,475	9.47	12.13	12.17
		4	0.0650	1.007					29,800	227,500	291,200	283,245	7.62	9.73	9.90
								Average	33,125	253,325	324,256	314,852	8.96	11.47	11.65
Cordo Mobaloy 20-ER	13	1	0.0790	1.012	0.192	8	0.192	0.0094	39,150	244,840	316,970	353,700	8.50	11.00	11.05
		2	0.0710	1.012					36,800	245,061	318,032	332,460	8.70	11.26	11.51
		3	0.0740	1.013					38,100	254,160	329,047	343,974	8.67	11.22	11.39
		4	0.0730	1.011					39,000	264,227	343,063	352,693	8.86	11.47	12.22
								Average	38,262	252,224	326,529	345,684	8.68	11.24	11.90
Cordo Mobaloy 20-ER	14	1	0.0698	1.004	0.202	8	0.202	0.0087	36,725	265,066	339,814	351,930	8.80	11.28	11.52
		2	0.0680	1.006					38,950	283,970	364,049	371,409	8.87	11.37	11.53
		3	0.0673	1.007					37,100	272,232	349,027	354,394	9.31	11.93	12.30
		4	0.0680	1.007					36,575	267,798	343,317	350,324	9.44	12.10	12.52
								Average	37,337	272,271	349,054	357,000	9.10	11.67	12.00
Cordo Mobaloy 20-ER	15	1	0.0664	0.991	0.202	8	0.202	0.00837	36,400	276,595	352,105	353,311	9.10	11.58	12.02
		2	0.0653	1.003					35,800	272,471	348,835	343,130	9.40	11.90	12.20
		3	0.0662	1.005					33,800	253,639	322,892	323,504	9.64	12.27	12.49
		4	0.0609	1.004					38,400	273,582	348,289	367,495	9.12	11.58	12.07
								Average	36,100	269,072	342,527	347,010	9.30	11.91	12.27
Cordo Mobaloy 20-ER	16	1	0.0678	1.008	0.202	8	0.202	0.00847	36,800	270,032	343,210	351,169	9.13	11.62	12.17
		2	0.0677	1.007					36,400	267,765	340,329	347,657	9.07	11.52	11.75
		3	0.0673	1.006					39,000	288,035	366,092	372,903	9.29	11.80	12.25
		4	0.0688	1.002					35,400	256,758	326,345	339,432	9.45	12.01	12.30
								Average	36,900	270,648	343,994	352,800	9.23	11.71	12.22
Cordo Mobaloy 20-ER	17	1	0.0660	1.001	0.202	8	0.202	0.00840	33,100	250,316	320,505	318,073	8.92	11.61	12.11
		2	0.0700	1.002					36,400	259,481	335,563	349,432	8.95	11.77	12.05
		3	0.0650	0.999					36,200	282,590	368,497	353,370	8.74	11.40	12.00
		4	0.0680	1.000					34,100	250,735	326,958	328,007	8.95	11.67	12.17
								Average	35,075	260,829	340,120	337,220	8.91	11.62	12.05
Cordo Mobaloy 20-ER	18	1	0.064	0.980	0.202	8	0.202	0.00810	35,950	283,294	369,531	351,878	9.26	11.91	11.87
		2	0.066	0.990					36,950	282,751	365,597	350,013	8.91	11.50	11.60
		3	0.066	0.990					34,800	269,016	347,817	343,172	8.95	11.61	11.50
		4	0.063	0.995					35,100	271,356	350,803	339,123	9.38	12.14	12.20
								Average	35,675	277,229	358,457	347,946	9.14	11.81	11.80
Cordo Mobaloy 20-ER	19	1	0.064	0.970	0.202	8	0.202	0.00859	32,400	249,269	325,046	321,294	8.58	11.73	11.63
		2	0.070	1.000					36,300	258,571	337,176	348,297	9.04	11.79	11.88
		3	0.068	0.980					37,000	271,806	358,347	359,196	8.83	11.53	12.40
		4	0.070	0.980					35,600	260,932	340,255	351,387	9.46	12.33	12.50
								Average	35,330	260,894	340,206	345,080	9.08	11.83	12.12
								Average of Eight Cylinders	35,978	261,561	340,642	343,352	9.06	11.96	12.02

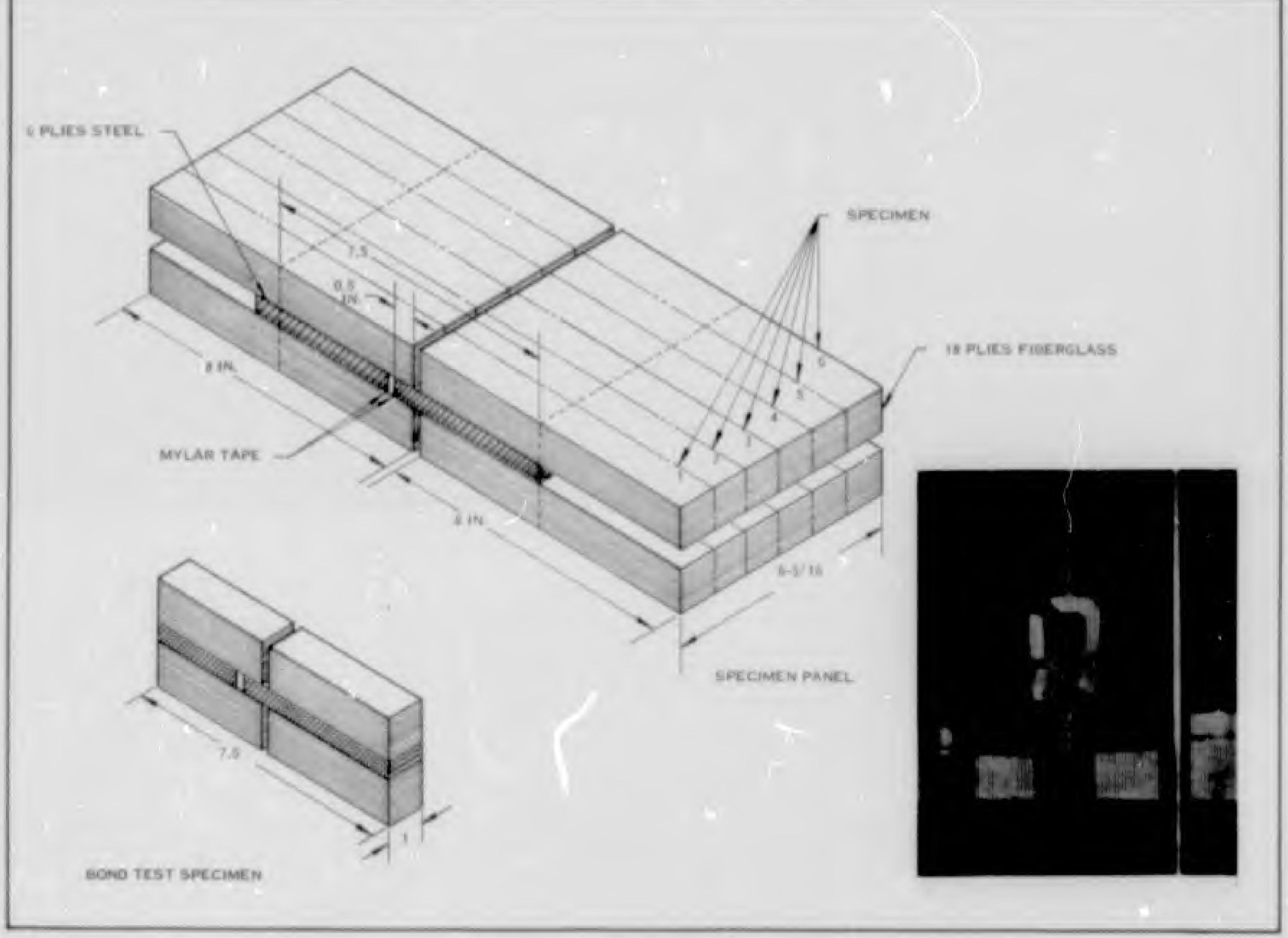

Figure 38. Steel Foil-to-Fiberglass Bond Test

- CLEAN STEEL FOIL FOR ONE PANEL BY METHOD "A"
    - Degrease with solvent, wipe dry with trichloroethylene.
    - Immerse 7 min in water solution of Bloomingdale Prebond-700 (283 gm/gal. water at 200 to 225°F).
    - Rinse with running water, dry in oven at 150 to 180°F.
- PRIME STEEL FOIL BY METHOD I
    - Spray both sides of steel foil with Bloomingdale primer material BR-1009-49.
    - Dry in air 15 to 90 minutes.
- ASSEMBLE SPECIMEN PANEL
    - Place two stacks of fiberglass (18 plies each) side by side but separated 0.012 inch.
    - Place two stacks of steel foil (6 plies each) side by side but separated by a strip of 0.430 in. wide Mylar tape. Note orientation of Mylar tape on steel, and of the steel stacks on fiberglass.
    - Place two stacks of fiberglass (18 plies each) side by side over the steel stacks. Orient the top stacks of fiberglass directly over the bottom stacks.
    - Place the assembly in a vacuum bag and cure in an oven for two hours at 325°F.
- PREPARE SPECIMENS FOR TEST
    - Cut five specimens from panel with a diamond wheel and a water coolant.
    - Trim each specimen to 1 in. wide by 7.5 in. long.

- CLEAN STEEL FOIL FOR ONE PANEL BY METHOD "B"
    - Degrease with solvent, wipe dry with trichloroethylene.
    - Immerse 20 min in acid bath (water solution containing 4 percent sulfuric 4 percent hydrochloric acid).
    - Immerse 15 min in acid etch (water solution containing 12 percent nitric 2 percent hydrofluoric acid).
    - Rinse with running water, dry in oven at 150 to 180°F.
- PRIME STEEL FOIL BY METHOD I
    - See previous instructions for priming by Method I.
- ASSEMBLE SPECIMEN PANEL
    - See previous instructions for panel assembly.
- PREPARE SPECIMENS FOR TEST
    - See previous instructions for specimen cutting.
- TEST SPECIMENS
    - Use HITCO Test Procedure TM-4.

- CLEAN STEEL FOIL FOR ONE PANEL BY METHOD "A" OR METHOD "B"
    - Using the method (Method "A" or Method "B") which yielded the greater test values, clean steel foil for one panel.
- PRIME STEEL FOIL BY METHOD II
    - Spray both sides of steel foil with Bloomingdale primer material FM-47, except for one surface on each of four plies.
    - Dry in air for a minimum of two hours.
    - Place two stacks of steel foil (6 plies each) side by side, with the unsprayed surfaces of plies forming the top and bottom surfaces of the stacks. Apply Mylar tape to one stack of steel plies. Note orientation of Mylar tape on steel.
    - Place the stacks in a heated (375°F) press with the platens closed but not under pressure for 30 minutes. Apply 200 psi pressure to the platens and cure for 70 minutes. Remove the stacks from the press.
    - Spray the top and bottom surfaces of the stacks with Bloomingdale primer material FM-47.
    - Cure in an oven at 300°F for 30 minutes.
- ASSEMBLE SPECIMEN PANEL
    - See previous instructions for panel assembly.
- PREPARE SPECIMENS FOR TEST
    - See previous instructions for specimen cutting and trimming.
- TEST SPECIMENS
    - See previous instructions for specimen testing.

Figure 39. Steel Foil-to-Fiberglass Bond Specimen Preparation and Test

The first specimens prepared (Scotchply XP-204) failed at approximately 1200 psi in the glass laminate, rather than in the bond. The tests were repeated using Cordo Mobaloy ER-20 (which failed, as desired, in the steel-to-glass bond region) for all subsequent evaluations of cleaning and bonding methods. One specimen panel was made and tested to establish a relationship between cured and uncured primer material.

The evaluation of materials, and methods of cleaning and priming steel foil (Figure 39), and test results (Table XI) permitted these conclusions to the study:

1. Cleaning method "A" (Bloomingdale Prebond-700) is superior to method "B" (acid bath and acid etch);
2. Bloomingdale priming material BR-1009-49 is superior to their FM-47 priming material;
3. Uncured priming material is superior to cured priming material.

(4) Clevis Bolt Joint Tests--Steel foil-fiberglass clevis joints were designed to join modules to the aft closure and to the forward polar ring of the TU-228 case. After case materials were selected and methods for cleaning and priming stainless steel foil were evaluated, single bolt joint specimens were prepared to establish the strength of the joint. Multiple bolt joints were to be developed following these tests.

Single bolt specimens, fabricated to fail in the steel laminate portion, (Figure 40) were cut to various widths. Holes for clevis bolts were drilled using carbide drills, but with each surface of the specimen supported to prevent delamination during drilling. Test results are summarized in Table XII.

Multibolt joint specimens (Figure 40) were similarly tested. The tests indicated that the steel foil breaks between plies of fiberglass (Figure 41) and that the load is transmitted past the first bolt into the glass. The multibolt joint was modified so that the load was not transmitted into the glass, by arrangement of the bolts on longitudinal meridians.

(5) Case Adhesive Tests--Hoop rings and longitudinal modules, each prefabricated of fiberglass and a resin system, must be bonded together for case assembly. The adhesive to be used for the bond had to meet several fabrication processing requirements, in addition to physical property requirements of high shear strength and high bonding strength. The size of the case, and the fact that Cordo Mobaloy ER-20 material is not stable at elevated temperatures, precluded the use of a curing oven. After application of the resin to hoop and module surfaces, considerable time (4 to 8 hr) might be required to assemble and position hoop rings. Thus, resin pot life should be ten hours, and the resin must be cured at ambient temperatures.

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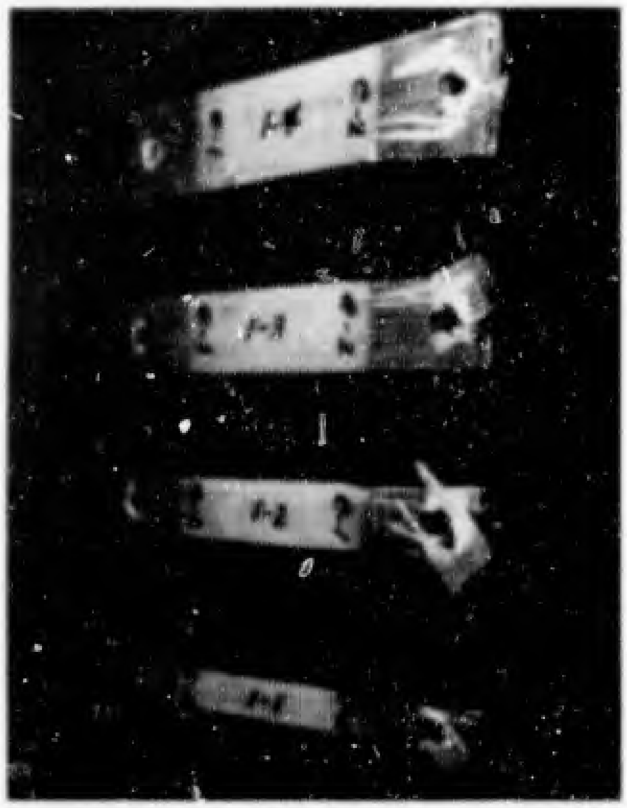
TABLE XI

STAINLESS STEEL FOIL-TO-FIBERGLASS BONDING EVALUATION

Primer	Panel	Specimen	Bonded Dimensions (in.) Length	Bonded Dimensions (in.) Width	Ultimate Shear Load (lb)	Ultimate Shear Strength (psi)
BR-1009-49	1	1	0.375	1.046	2010	2560
		2	0.472	1.041	3660	3725
		3	0.480	1.034	3885	3910
		4	0.385	1.028	2850	3610
		5	0.470	0.984	3140	3400
						3441 (Average)
BR-1009-49	2	1	0.478	1.021	3750	3840
		2	0.450	1.011	3595	3952
		3	0.470	1.025	4475	4645
		4	0.465	1.022	3785	3980
		5	0.470	1.013	3680	3767
						4037 (Average)
FM-47	3	1	0.480	1.009	2650	2730
		2	0.484	1.008	2225	2330
		3	0.475	1.008	2030	2115
		4	0.482	1.009	1925	1980
		5	0.479	0.996	1820	1905
						2212 (Average)

Ultimate Shear Load on Specimen (P_{su})
Ultimate Shear Strength of Adhesive (F_{su}) are related as follows:

$$F_{su(psi)} = \frac{P_{su}\ (lb)}{2 \times \text{Bond Dimensions (in. x in.)}}$$



SINGLE BOLT SPECIMEN FAILURE

MULTIPLE BOLT SPECIMEN FAILURE

Figure 40. Clevis Joint Specimen Failure

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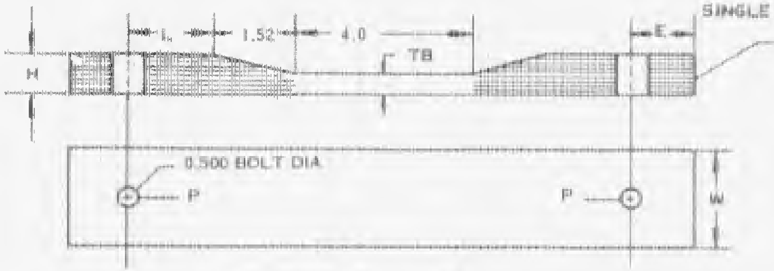
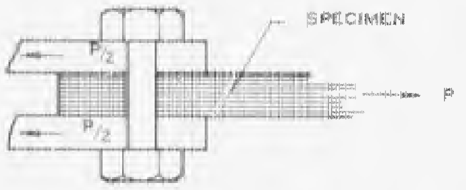
TABLE XII

SINGLE BOLT JOINT TEST SUMMARY





	LENGTH			THICKNESS					STRESS AT FAILURE							
SPECIMEN	HOLD-TO-TAPER LENGTH (L; IN.)	EDGE DISTANCE (E; IN.)	WIDTH (W; IN.)	GLASS COMPOSITE (TB; IN.)	SPECIMEN (H; IN.)	MOMENT COUPLING (B; IN.)	ULTIMATE LOAD (P; LB)	TYPE OF FAILURE (SEE NOTE)	GLASS TENSILE (FT; PSI)	STEEL TENSILE (NET) (FT; PSI)	BOLT SHEAR (FS; PSI)	BOLT BENDING (FB; PSI)	BOLT-TO-STEEL BEARING (FBR; PSI)	ALLOWABLE BEARING (FBR AT 4% D; PSI)	STEEL TENSILE FACTOR (KT)	BEARING FACTOR (KBR)
1-1	2.00	1.125	0.996	0.331	0.457	0.239	22,000	A	141,500	292,553	56,050	214,064	289,473	>289,473	0.85	---
1-2	2.00	1.100	1.525	0.333	0.455	0.239	39,200	A	164,511	251,604	99,872	381,420	515,789	>515,789	0.74	---
1-3	2.00	1.075	1.996	0.333	0.454	0.239	44,600	B & C	143,006	186,130	113,630	433,964	586,842	---	>0.57	1.72
1-4	2.00	1.120	2.530	0.333	0.450	0.238	40,750	B & C	103,083	132,047	103,821	394,845	536,184	---	>0.39	1.57
2-1	2.00	1.007	1.048	0.333	0.460	0.240	19,000	A	116,030	228,091	48,407	185,646	250,000	>250,000	0.67	---
2-2	2.00	1.003	1.550	0.333	0.453	0.238	41,300	A	170,529	258,771	105,222	408,173	543,421	>543,421	0.76	---
2-3	2.00	1.057	2.011	0.333	0.454	0.239	50,200	B & C	159,761	218,848	127,898	488,452	660,526	528,947	>0.64	1.93
2-4	2.00	1.102	2.493	0.333	0.455	0.239	49,000	B & C	125,792	161,769	124,840	476,778	644,736	482,631	>0.47	1.89
3-1	2.00	1.034	1.024	0.299	0.448	0.237	25,700	A	160,625	316,502	65,477	247,372	338,157	>338,157	0.93	---
3-4	2.00	1.025	2.525	0.299	0.455	0.239	46,900	B & C	118,875	152,371	119,490	456,343	617,105	526,315	>0.45	1.81
3-9	1.00	1.031	1.519	0.299	0.452	0.238	44,200	A	186,227	285,345	112,611	426,272	581,578	>581,578	0.83	---
3-10	0.50	1.044	1.515	0.333	0.440	0.235	43,300	A	182,917	280,622	110,318	414,264	569,736	>569,736	0.82	---
3-10A	0.50	0.996	1.508	0.299	0.446	0.237	42,700	A	276,310**	278,720	108,789	412,000	561,842	>561,842	0.82	---
4-12	0.25	1.011	1.497	0.299	0.423	0.231	43,880	A	187,596	289,636	111,796	412,667	577,368	>577,368	0.85	---

TYPE OF FAILURE — A = NET TENSILE TEAROUT FAILURE; B = BEARING FAILURE; C = SHEAR TEAROUT FAILURE.
SPECIMEN 3-10A WIDTH REDUCED TO 0.989 IN. FROM 1.515 IN. DURING GLASS TENSILE TEST.

$$FT_{(GLASS)} = \frac{(2.13)\ (P)}{(W)\ (TB)}$$

$$FT_{(SHIM)} = \frac{(P)}{(0.008)\ (W-D)}$$

$$FS = \frac{(P)}{(2\pi/4)\ (D)^2}$$

$$FB = \frac{(16)\ (P)\ (B)}{(\pi)\ (D)^3}$$

$$FBR = \frac{(P)}{(0.152)\ (D)}$$

$$KT = \frac{FT}{FTU}\ ;\ FTU = 340{,}000\ PSI$$

$$KBR = \frac{FBR}{FTU}\ ;\ FTU = 340{,}000\ PSI$$

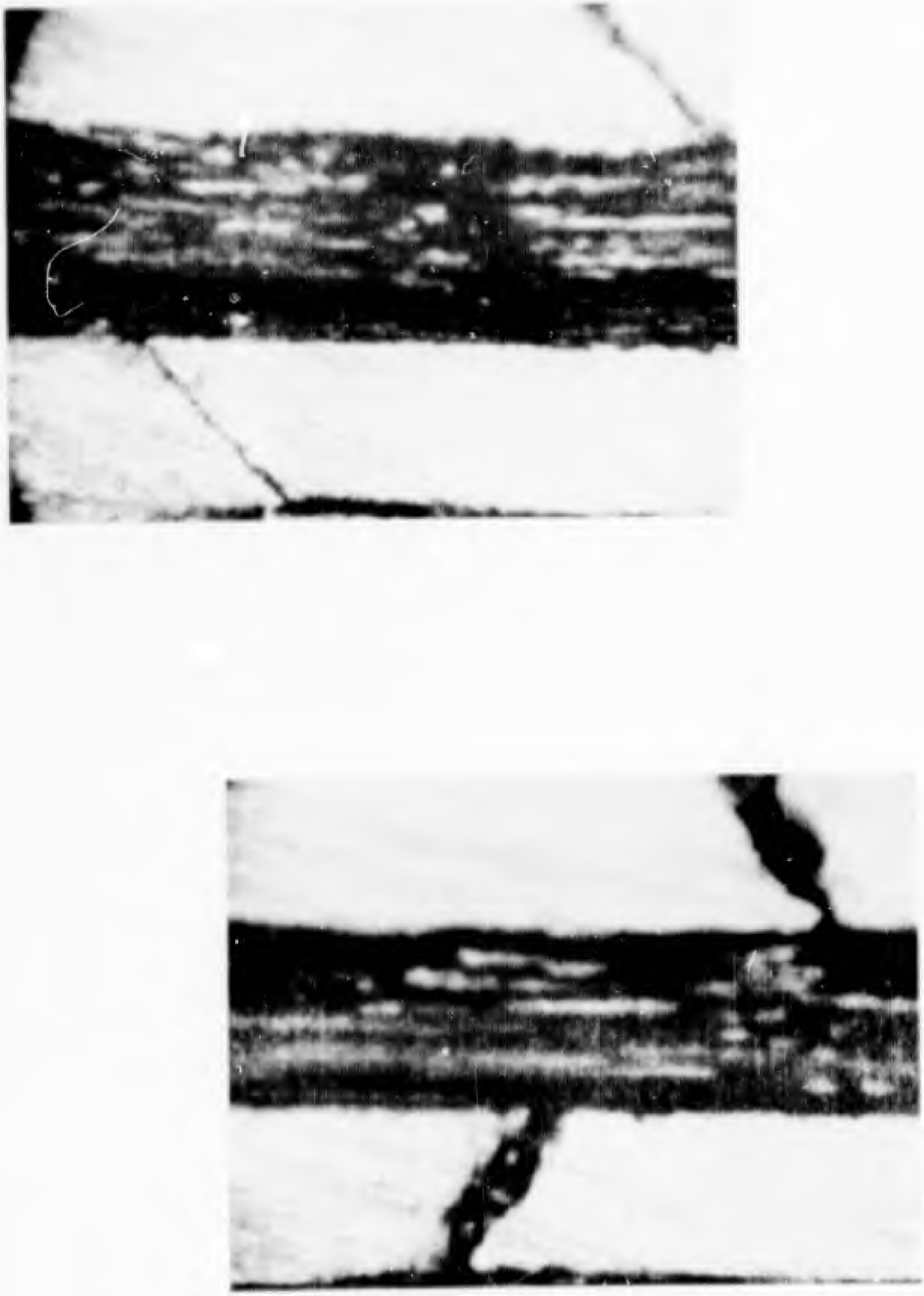


Figure 41. Steel Foil Failure Between Fiberglass Plies

Epon 913 and Epon 923 (Shell) and BR-90 (Bloomingdale) adhesives were selected for evaluation. Specimen panels were fabricated of laminated glass fabric containing a 0.500 in. lap joint. Adhesive was applied to the lap joint in varying thicknesses on different specimens, and cured. The panels were cut into specimens and tested (Table XIII).

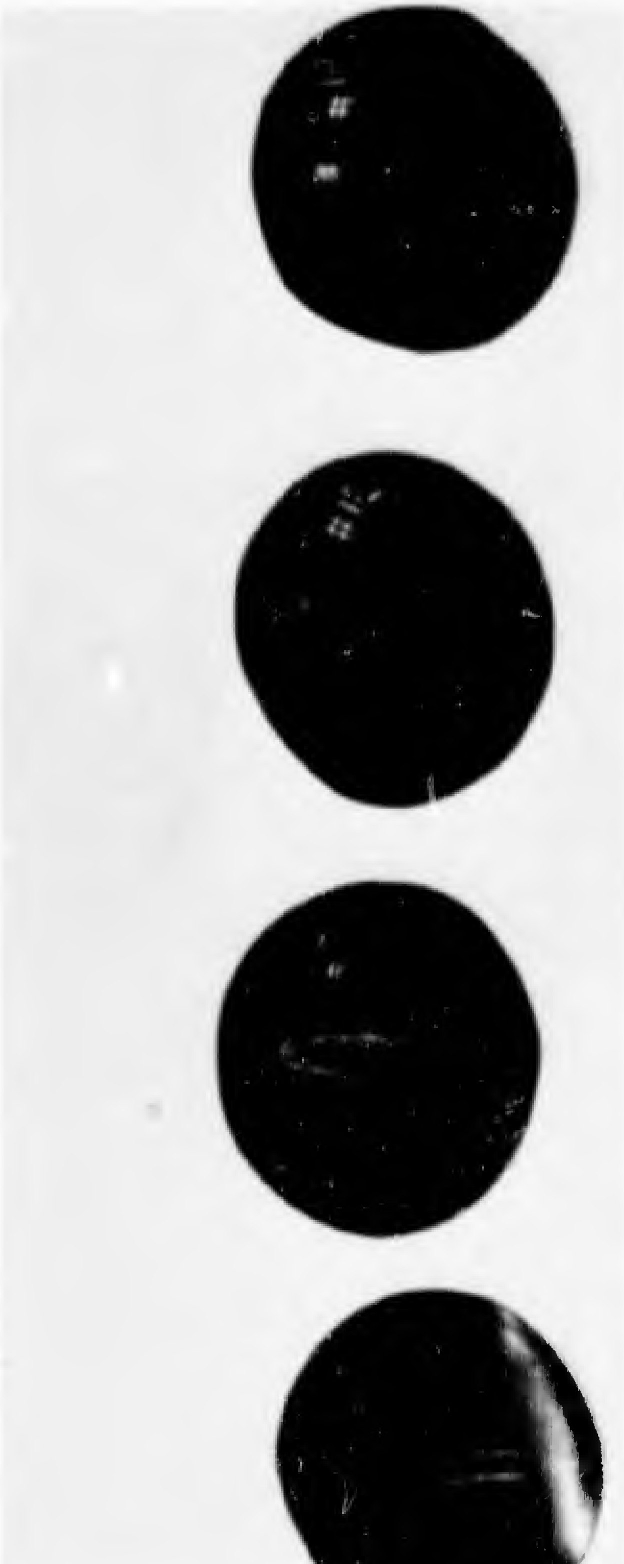
Epon 923 adhesive was selected because of high shear strength values when applied in thicknesses of 0.030 to 0.060 inch.

(6) Liner Material Evaluation Tests--To evaluate materials which could withstand rocket motor case pressures across module joints, a number of neoprene compounds were reinforced with nylon, dacron, cotton, or fiberglass, and tested with an unsupported portion exposed to pressure. A special test fixture (Figure 42) was arranged so that reinforcing material lay at either 45 or 90 deg to a slot (gap) in a backing plate simulating the case wall. Gap widths chosen for this series of tests were either 0.154 or 0.263 inch. Hydraulic pressure was applied to one side of a neoprene disc specimen against the backing plate until the specimen ruptured in the gap area. Test results are summarized in Table XIV. A number of compounds (Western Backing Co, du Pont, and Hitco type 5 reinforcement) were eliminated because of low tear resistance even though high stress values were sustained. Hitco fabricated a liner material of Firestone type 16-A uncured, uncoated fabric, bonded to a neoprene sheet and identified as Hitco one-ply Type 16-A reinforcement. Hitco also fabricated a two-ply Type 16-A reinforcement consisting of a neoprene sheet, a Type 16-A fabric layer, and a neoprene sheet for material evaluation. Hitco one-ply Type 16-A reinforcement was selected as a case liner material as a result of these tests.

DISASSEMBLED

TEST ARRANGEMENT

ASSEMBLED



SPECIMENS AFTER RUPTURE

Figure 42. Liner Material Evaluation Test Arrangement

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TABLE XIII.

CASE ADHESIVE EVALUATION

Adhesive*	Specimen	Length	Width	Thickness	Ultimate Load (lb)	Stress (psi)
Shell Epon 813	A-1	0.516	1.003	0.019	840	1622
	A-2	0.516	1.011	0.005	910	1744 (1678 Avg)
	A-3	0.516	1.005	0.009	865	1668
	B-1	0.519	1.003	0.010	920	1775
	B-2	0.508	1.009	0.007	950	1855 (1811 Avg)
	B-3	0.508	1.013	0.007	935	1804
	C-1	0.505	1.000	0.036	570	1129
	C-2	0.500	1.001	0.035	600	1199 (1187 Avg)
	C-3	0.502	1.019	0.030	625	1234
	D-1	0.520	1.000	0.070	540	1038
	D-2	0.514	1.012	0.067	605	1163 (1106 Avg)
	D-3	0.516	1.005	0.062	580	1118
Shell Epon 923	A-1	0.516	1.001	0.006	745	1442
	A-2	0.514	1.005	0.015	750	1451 (1419 Avg)
	A-3	0.522	1.010	0.009	720	1363
	B-1	0.512	1.012	0.005	710	1370
	B-2	0.500	1.004	0.005	730	1454 (1434 Avg)
	B-3	0.502	1.003	0.006	745	1479
	C-1	0.510	1.000	0.030	785	1524
	C-2	0.519	1.002	0.035	885	1705 (1676 Avg)
	C-3	0.508	1.003	0.034	890	1746
	D-1	0.520	0.995	0.015	620	1201
	D-2	0.510	0.991	0.059	605	1221 (1242 Avg)
	D-3	0.507	0.947	0.059	650	1245

*All specimens cured for 7 days at ambient temperatures.

Adhesive*	Specimen	Length	Width	Thickness	Ultimate Load (lb)	Stress (psi)
Bloomingdale BR-90	A-1	0.521	1.004	0.006	600	1147
	A-2	0.484	1.004	0.006	655	1395 (1247 Avg)
	A-3	0.525	1.002	0.006	630	1200
	B-1	0.504	1.000	0.007	750	1488
	B-2	0.513	1.002	0.007	650	1267 (1323 Avg)
	B-3	0.512	1.013	0.006	630	1214
	C-1	0.507	1.002	0.032	530	1043
	C-2	0.507	0.992	0.033	550	1094
	C-3	0.502	1.000	0.031	550	1096
	D-1	0.508	1.000	0.061	530	1043
	D-2	0.508	1.004	0.060	590	1157 (1193 Avg)
	D-3	0.512	1.004	0.060	710	1376

*All specimens cured for 7 days at ambient temperatures.

TABLE XIV
LINER MATERIAL EVALUATION

Specimen	Identification **	Reinforcement	Wrap Angle (deg)	Thickness (in.)	Gap (in.)	Ultimate Pressure (psi)	Gap to Thickness Ratio	Stress*
1	du Pont "Fairprene" 5002-D	Cotton	90	0.013	0.154	900 (porosity leak)	11.83	10,647
1a	↓	↓	90	0.020	0.154	1140	7.70	8,778
2	↓	↓	45	0.013	0.154	800 (porosity leak)	11.83	9,464
2a	↓	↓	45	0.020	0.154	1230	7.70	9,471
3	↓	↓	90	0.013	0.263	620 (porosity leak)	20.23	12,542
3a	↓	↓	90	0.020	0.263	700	13.15	9,205
4	↓	↓	45	0.013	0.263	670 (porosity leak)	20.23	13,554
4a	↓	↓	45	0.020	0.263	745	13.15	9,697
5	du Pont "Fairprene" 5023	Cotton	90	0.032	0.154	620 (porosity leak)	4.81	2,982
5a	↓	↓	90	0.039	0.154	600 (porosity leak)	3.94	2,364
6	↓	↓	45	0.032	0.154	400 (porosity leak)	4.81	1,924
6a	↓	↓	45	0.039	0.154	600 (porosity leak)	3.94	2,364
7	↓	↓	90	0.032	0.263	400 (porosity leak)	8.22	3,288
7a	↓	↓	90	0.039	0.263	600 (porosity leak)	6.74	4,044
8	↓	↓	45	0.032	0.263	400 (porosity leak)	8.22	3,288
8a	↓	↓	45	0.039	0.263	600 (porosity leak)	6.74	4,044
9	du Pont "Fairprene" 5009	Nylon	90	0.014	0.154	790	11.00	8,690
10	↓	↓	45	0.014	0.154	860	11.00	9,460
11	↓	↓	90	0.014	0.263	490	18.79	9,203
12	↓	↓	45	0.014	0.263	510	18.79	9,578
13	du Pont "Fairprene" 5798	Nylon	90	0.023	0.154	2125	6.70	14,238
14	↓	↓	45	0.023	0.154	2750	6.70	18,425
15	↓	↓	90	0.023	0.263	1450	11.43	16,534
16	↓	↓	45	0.023	0.263	1610	11.43	18,402

*Product of Gap to Thickness Ratio times Pressure.

**All specimens made of Neoprene with reinforcement as specified.

TABLE XIV (Cont)
LINER MATERIAL EVALUATION

Specimen	Identification**	Reinforcement	Wrap Angle (deg)	Thickness (in.)	Gap (in.)	Ultimate Pressure (psi)	Gap to Thickness Ratio	Stress*
17	du Pont "Fairprene" 5751	Fiberglass	90	0.015	No failure at gap--developed leak			
17a	↓	↓	90	0.022	0.154	770	7.00	5,990
18	↓	↓	45	0.015	No failure at gap--developed leak			
18a	↓	↓	45	0.022	0.154	770	7.00	5,990
19	↓	↓	90	0.015	No failure at gap--developed leak			
19a	↓	↓	90	0.022	0.263	650	11.95	7,768
20	↓	↓	45	0.015	No failure at gap--developed leak			
20a	↓	↓	45	0.022	0.263	625	11.95	7,469
21	L. A. Standard Rubber D-400	Dacron	90	0.023	0.154	1410	6.70	9,447
22	↓	↓	45	0.023	0.154	1010	6.70	6,767
23	↓	↓	90	0.023	0.263	900	11.42	10,278
24	↓	↓	45	0.023	0.263	640	11.42	7,309
25	↓	None		0.023	0.154	520	6.70	3,484
26	↓	None		0.023	0.263	270	11.42	3,083
27	du Pont "Fairprene" 5039	Nylon	90	0.025	0.154	2525	6.16	15,554
28	↓	↓	45	0.025	0.154	2475	6.16	15,246
29	↓	↓	90	0.025	0.263	2050	10.52	21,566
30	↓	↓	45	0.025	0.263	2050	10.52	21,566
31	↓	↓	90	0.050	0.154	2825	3.08	8,701
32	↓	↓	45	0.050	0.154	2875	3.08	8,855
33	↓	↓	90	0.050	0.263	2425	5.26	12,756
34	↓	↓	45	0.050	0.263	2380	5.26	12,519

*Product of Gap to Thickness Ratio times Pressure.

**All specimens made of Neoprene with reinforcement as specified.

TABLE XIV (Cont)

LINER MATERIAL EVALUATION

Specimen	Identification**	Reinforcement	Wrap Angle (deg)	Thickness (in.)	Gap (in.)	Ultimate Pressure (psi)	Gap to Thickness Ratio	Stress*
35	Western Backing Corp	Dacron	90	0.016	0.154	2500	9.62	24,050
36			45	0.016	0.154	2600	9.62	25,000
37			90	0.016	0.263	1750	16.42	28,750
38			45	0.016	0.263	1600	16.42	26,300
39			90	0.023	0.154	3200	6.70	21,450
40			45	0.023	0.154	3300	6.70	22,500
41			90	0.023	0.263	2550	11.42	29,150
42			45	0.023	0.263	2600	11.42	29,700
43	HITCO 1 ply type 5 reinf	Nylon	90	0.021	0.154	1550	7.33	11,361
44			45	0.021	0.154	1600	7.33	11,728
45			90	0.021	0.263	1620	12.52	10,282
46			45	0.021	0.263	2050	12.52	26,676
47			90	0.042	0.154	2810	3.66	10,284
48			45	0.042	0.154	2910	3.66	10,631
49			90	0.042	0.263	3100	6.26	19,406
50			45	0.042	0.263	3500	6.26	21,910
51	HITCO 1 ply type 16 A reinf		90	0.0245	0.154	1650	6.28	10,362
52			45	0.0245	0.154	1950	6.28	12,242
53			90	0.0245	0.263	----	----	----
54			45	0.0245	0.263	1650	10.73	17,704
55	HITCO 2 ply type 16 A reinf		90	0.0465	0.154	2690	3.31	8,904
56			45	0.0465	0.154	3050	3.31	10,096
57			90	0.0465	0.263	2150	5.67	12,104
58		Nylon	45	0.0465	0.263	2170	5.67	12,421

*Product of Gap to Thickness Ratio times Pressure.

**All specimens made of Neoprene with reinforcement as specified.

TABLE XIV (Cont)

LINER MATERIAL EVALUATION

Specimen	Identification**	Reinforcement	Wrap Angle (deg)	Thickness (in.)	Gap (in.)	Ultimate Pressure (psi)	Gap to Thickness Ratio	Stress*
59	Module liner after cure		0	0.050 - 0.052	0.263	2525	5.16	13,029
60			45		0.263	2410	5.16	12,436
61			90		0.263	No failure at gap--torn at edge		
62			90		0.263	2530	5.16	13,055
63			0		0.154	3800	3.02	11,476
64			45		0.154	4100	3.02	12,382
65			90		0.154	3650	3.02	11,023

*Product of Gap to Thickness Ratio times Pressure.

**All specimens made of Neoprene with reinforcement as specified.

b. Small Diameter TU-228 Cases

(1) Case No. 1 Design--A small diameter case (18.13 in.) was designed, having six, zero hoop load, longitudinal, prefabricated fiberglass modules, covered by seven prefabricated fiberglass hoop ring segments. The design was based on the use of Owens-Corning "E" glass with a high tensile strength finish and the use of a Cordo Mobaloy ER resin system for modules, hoop rings, closure, and skirts. The case was designed to withstand the following stresses and strains at ultimate pressure:

		Stress (psi)	Strain (in./in.)
1.	Radial hoop rings	182,000	0.0173
2.	Longitudinal modules	135,300	0.0129
3.	Composite wall	69,490	---
4.	Glass-to-steel shear	692	---
5.	Fiberglass closure	115,500	0.110 (helical)
6.	Aft joint steel (tension)	205,000	---

Critical case dimensions included:

1.	Overall length (in.)	62.03
2.	Tangent-to-tangent length (in.)	49.32
3.	Forward polar ring ID (in.)	2.20
4.	Aft polar ring ID (in.)	4.90

Other criteria established for the design of this case were:

1.	Wrapping angle (deg)	13.55
2.	Tangent-to-tangent deflection (in.)	0.64
3.	Dome-to-dome deflection (in.)	0.77
4.	Radial deflection (in.)	0.16

AM 355 CRES SH steel was specified for lamination with fiberglass of longitudinal modules in the aft joint region. Both polar rings (forward-4340ST-AMS-6359 steel, and aft-2024-T6 aluminum) were designed to insure failure in the fiberglass portion of the case. The design called for two concentric rings of bolts to secure the forward polar ring to the modules, and for prefabricated forward and aft skirts.

The strength-to-density ratio was calculated to be 0.98 x 10^6 inch. Other case design parameters determined were:

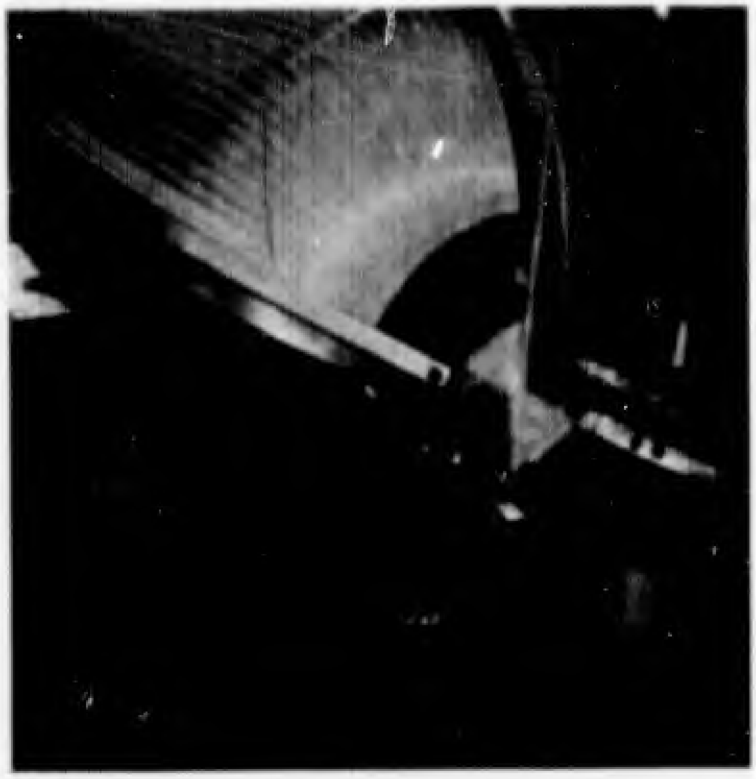
		Density (lb/cu in.)	Resin Content (percent by weight)
1.	Longitudinal modules (composite)	0.067	27
2.	Hoop rings (composite)	0.076	11
3.	Wall (composite)	0.071	--

(2) Case No. 1 Fabrication--Hoop rings for the small diameter cases were fabricated on a cylindrical mandrel, and following acceptance, were stored for use. Modules were fabricated with the one piece steel foil reinforcement at the forward joint (Figure 43). The reinforcing foil was cut into four segments per module after the module was trimmed. Steel foil was laminated into the module at the aft joint before trimming. The skirt was bonded to the aft closure (Figure 44) before assembly with the modules. All components were assembled in the drilling fixture, and holes for attachment bolts were drilled through mating parts. The components were then disassembled, burrs were removed, and the parts inspected. Final assembly was completed in the drilling fixture. The completed case weighed 55.79 pounds (Table XV).

(3) Case No. 1 Hydrotest--After instrumentation was completed, the case was successfully hydrotested on 10 Mar 1962 (Figure 45). The case burst at 1595 psi near the aft dome tangent point where the steel reinforcement stopped. The case was designed for a burst pressure of 1113 psi, a value which included a 1.6 safety factor. The case withstood 179.2 percent of the design burst pressure.

Assuming a zero hoop restraint by the skirt, the net steel stress at failure was 209,000 psi. The composite wall stress was 105,000 psi; the module glass stress was 194,000 psi; and the hoop glass stress was 262,000 psi.

Loud cracking noise developed during pressurization, which subsided nearly completely as the internal pressure approached burst pressure. The noise was apparently due to cracking of the resin in tension as glass fibers were strained beyond the capability of the resin to stretch. Hoop rings and longitudinal modules showed resin crazing approximately every half-inch parallel to the fibers, but there was no indication of separation where modules butted modules or where hoops butted hoops. During pressurization, module and hoop growth were uniform over the entire length and circumference of the case. The modules were uniformly cracked into longitudinal strips approximately a half inch wide (cf above) and the outer hoops were cracked, although not as uniformly, in planes parallel to the circumference. Other failures noted (believed to be secondary in nature) included a failure in shear in the bond between stainless steel foil and glass in the aft closure, and two failures in tension, one in the aft closure and one in the aft skirt.



INSTALLATION OF STEEL FOIL AT FORWARD JOINT

INSTALLATION OF STEEL FOIL AT AFT JOINT

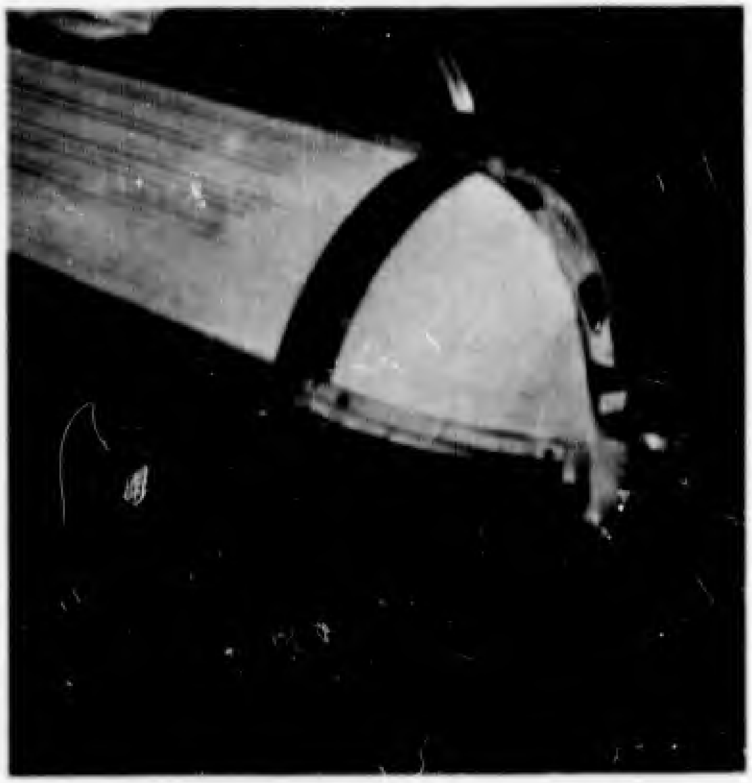


Figure 43. Small Diameter TU-228 Case Module Fabrication

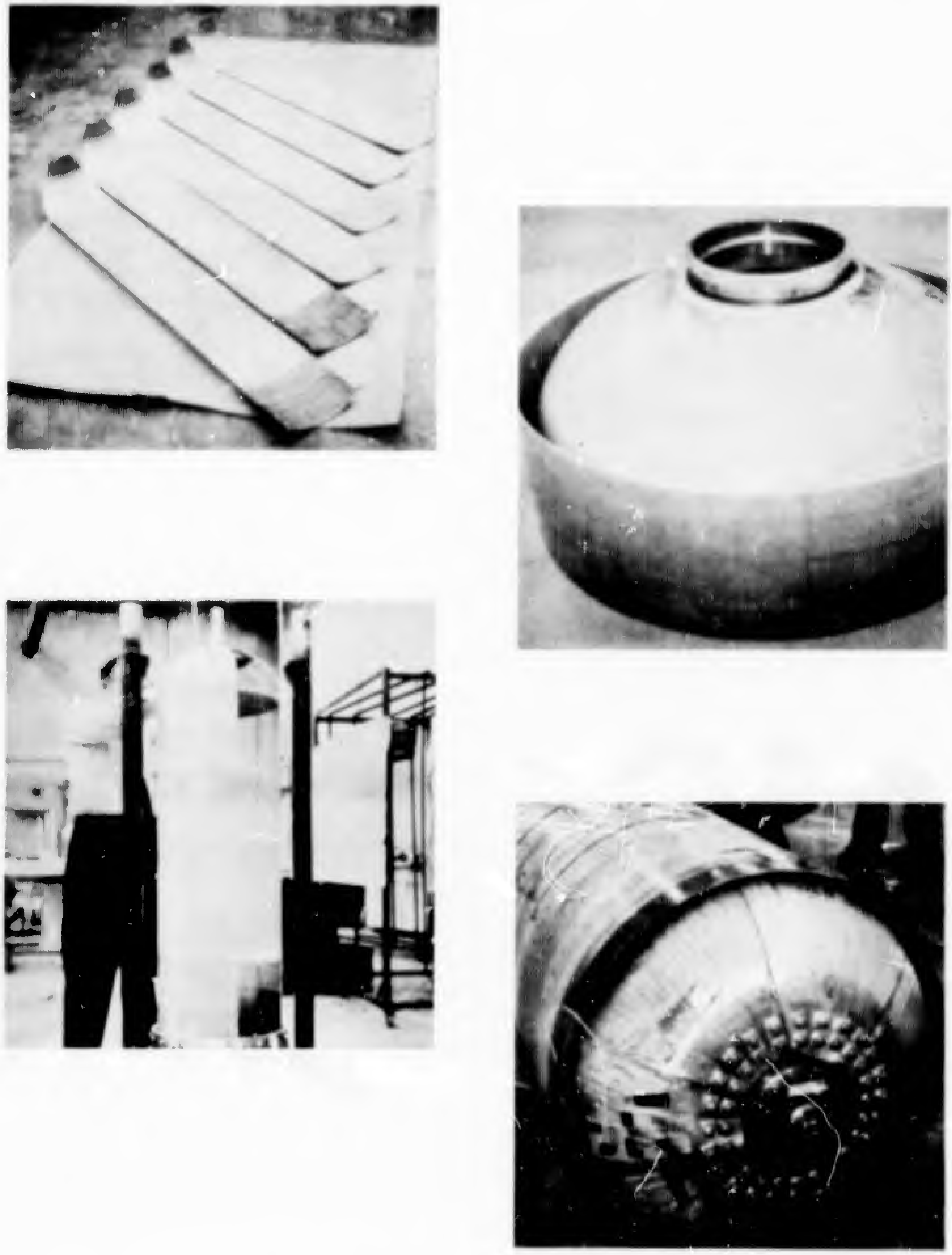


Figure 44. Small Diameter TU-228 Case Assembly

Case before test

Aft dome failure

Figure 45. Small Diameter TU-228 Case No. 1 Hydrotest

TABLE XV

SMALL DIAMETER TU-228 CASE WEIGHT SUMMARY

Component				Case No. 1		Case No. 2	
				Metal Weight (lb)	Total Weight (lb)	Metal Weight (lb)	Total Weight (lb)
Module Assembly							
Case No. 1	No. 3	Case No. 2	No. 9	0.39	2.90	0.40	2.61
	4		10	0.39	2.90	0.40	2.61
	5		11	0.39	2.87	0.40	2.63
	6		12	0.39	2.89	0.40	2.62
	7		13	0.39	2.91	0.40	2.60
	8		14	0.39	2.91	0.40	2.61
Closure Assembly							
Aft Fitting				2.07	---	2.73	---
Forward Skirt				---	8.59	---	9.25
Aft Skirt				---	1.09	---	1.10
Ring				---	2.50	---	3.14
Case No. 1	No. 5	Case No. 2	No. 9	---	3.59	---	3.59
	6		10	---	3.57	---	3.62
	7		11	---	3.59	---	3.62
	8		12	---	3.59	---	3.62
Forward Fitting				2.88	4.01	2.94	4.07
Aft Ring				---	2.52	---	2.82
Hardware				3.49	3.49	3.49	3.49
Adhesive				---	1.89	---	1.89
Total				10.78	55.81	11.56	55.87

(4) Case No. 2 Design--From the experience gained in testing case No. 1, modifications were made in the design of a second small diameter case. The aft dome contour was altered to decrease hoop restraint and consequent dome stresses. To increase the longitudinal stress load, modules were made with five plies of glass rather than six. To compensate for the reduction in glass content, and to maintain the original wall thickness at the forward and aft ends of the modules, a short piece of filler glass material was added at each end.

For ease in processing, a single strip of 0.008 in. stainless steel was used in the joint area in place of two strips (0.003 and 0.005 in.) of steel used for the first case. The change eliminated a need for bonding two thinner strips. Stainless steel strips in the aft closure, butt jointed on the first case, were lap jointed (and bonded at the lap joint) for easier fabrication on the second.

To prevent hoop failure in the aft joint region, two strips of 0.008 in. and two strips of 0.005 in. steel in the aft skirt were replaced by four strips of 0.008 in. steel. To prevent glass-to-glass abrasion between aft dome, aft skirt, and the modules, 0.008 in. strips of stainless steel were introduced between the aft skirt and the aft dome, and between the modules and the aft closure. Elimination of direct contact between glass fibers also precluded cutting fibers during fabrication of the aft closure.

(5) Case No. 2 Fabrication--Fabrication techniques, with exception to those required by design changes, were the same as for the first case.

(6) Case No. 2 Hydrotest--After instrumentation, the second case was hydrotested successfully on 20 March (Figure 46). The case burst at 1800 psi, with failure occurring in the hoop fibers in the cylindrical wall of the case. The case withstood 202 percent of design burst pressure.

Composite wall stress at failure was 129,000 psi; module glass stress was 263,000 psi; and hoop glass stress was 293,000 psi.

Cracking noises (resin crazing) were less, during pressurization, than with the first case. Failure of hoop windings in tension resulted in total destruction of the center circumferential ring and a partial destruction of adjacent rings. The aft closure-aft skirt subassembly was not damaged during the test. Longitudinal modules cracked into strips 0.375 to 0.500 in. wide, a condition noted also on the first case.

Effort on small diameter cases was terminated following the successful test on the second case, and directed to development of a large diameter (65 in. or larger) TU-228 case.

c. Large Diameter TU-228 Case Design

(1) **Case Assembly**--Thiokol prepared design drawing 9U33094 (Figure 3) based upon material evaluations and small diameter case hydrotests for the modular construction of a large diameter (65.90 in.) TU-228 case. The case was segmented longitudinally into six prefabricated fiberglass plastic modules to form the case shell. Seven prefabricated fiberglass plastic hoops were designed to be placed over the modules and bonded together and to the modules. The modules, with fibers parallel to the case centerline, would withstand all longitudinal loads. The hoops, with fibers normal to the case centerline, would withstand all hoop loads. The forward dome, formed by modules alone, was designed to carry no hoop load whatsoever. (A stress analysis of the zero hoop load forward dome is given in Volume VI.) The designs for clevis joints between the aft closure and the modules, for the zero hoop load forward dome, and for the forward polar ring and clevis joint were matters of especially thorough investigation.

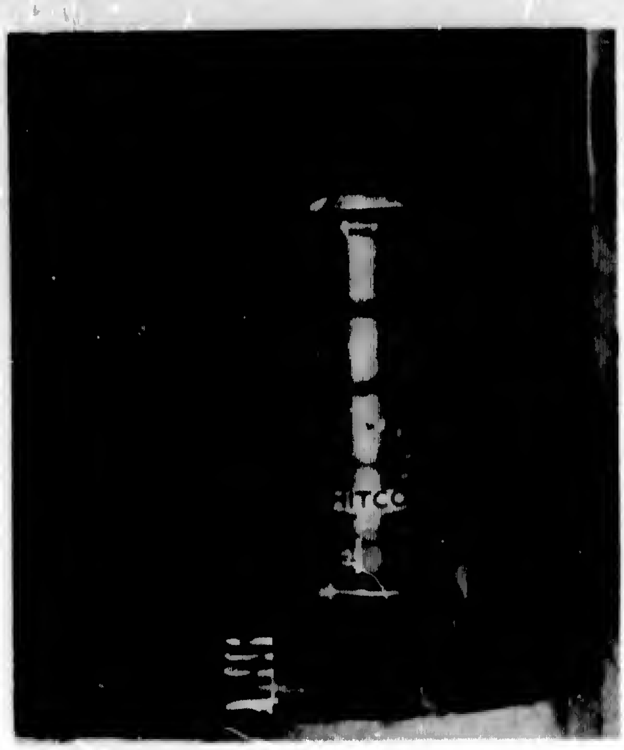
High tensile strength finish "E" glass (Owens-Corning Fiberglas Corp, Toledo, Ohio) to be used with a Cordo Mobaloy "ER" resin system was specified for all fiberglass plastic case components (modules, hoops, skirts, and aft dome). Critical composition parameters were determined as follows:

	Density (lb/cu in.)	Resin Content (percent by weight)
1. Longitudinal composite density	0.071	20
2. Hoop composite density	0.073	18
3. Wall composite density	0.072	--

The strength-to-density ratio was calculated to be 1.6×10^6 inches.

Case dimensions which were established included:

1. Overall length (aft cover plate to forward polar ring; in.)	258.39
2. Tangent-to-tangent length (in.)	215.88
3. Forward polar ring ID (in.)	8.00
4. Aft polar ring ID (in.)	14.00



CASE NO. 2 IN TEST STAND

CASE NO. 2 AFTER TEST

Figure 46. Small Diameter TU-228 Case No. 2 Hydrotest

The case was designed to withstand the following stresses and strains at ultimate pressures:

		Stress (psi)	Strain (in./in.)
1.	Radial hoops	204,600	0.0195
2.	Longitudinal modules	184,200	0.0175
3.	Wall (composite)	83,700	---

The stresses imposed at ultimate pressure would cause deflections of the case as follows:

1.	Radial increase (in.)	0.64
2.	Tangent-to-tangent length (in.)	3.78
3.	Overall length (in.)	4.42

(2) Modules--Longitudinal modules (Thiokol drawing 9U33098; Figure 47) were designed to form an integral case cylinder and forward dome (six modules/case). The design was based on these factors:

1. The meridional load increases as the radius on a plane normal to the centerline decreases;
2. The hoop load is zero at all points on the dome.

Clevis joints were designed (Figure 48), tested, and modified from a single bolt to a multibolt arrangement for the attachment of the forward polar ring to the modules. Attachment bolts were arranged radially in two concentric circles. Tensile stress magnitude and distribution in glass fibers in the region of attachment was a critical design consideration. Clevis joints were constructed of AM 355-XH stainless steel laminated with plies of fiberglass. The computed stress in the glass around the attachment bolts was 204,000 psi.

(3) Aft Dome--The aft dome (Thiokol drawing 9U33094; Figure 3) was designed for a modified polar wrap using helical windings only (15.09 deg wrapping angle). The design approximated a constant fiber stress design. The band path was assumed to be a straight line from the polar ring to the tangent point of the case to the dome. This deviation (from a geodesic or isotensoid contour) has negligible effect on stress distribution (Volume VI). Clevis joints (Figure 49) were designed for stainless steel foil laminated with fiberglass plies, in which the glass fibers would carry all tensile loads and steel would transfer the bearing load only into the bolts. Loads in the joints would be transferred from glass to steel by interlaminar shear stress. The hoop load would be carried by the steel in the aft closure.

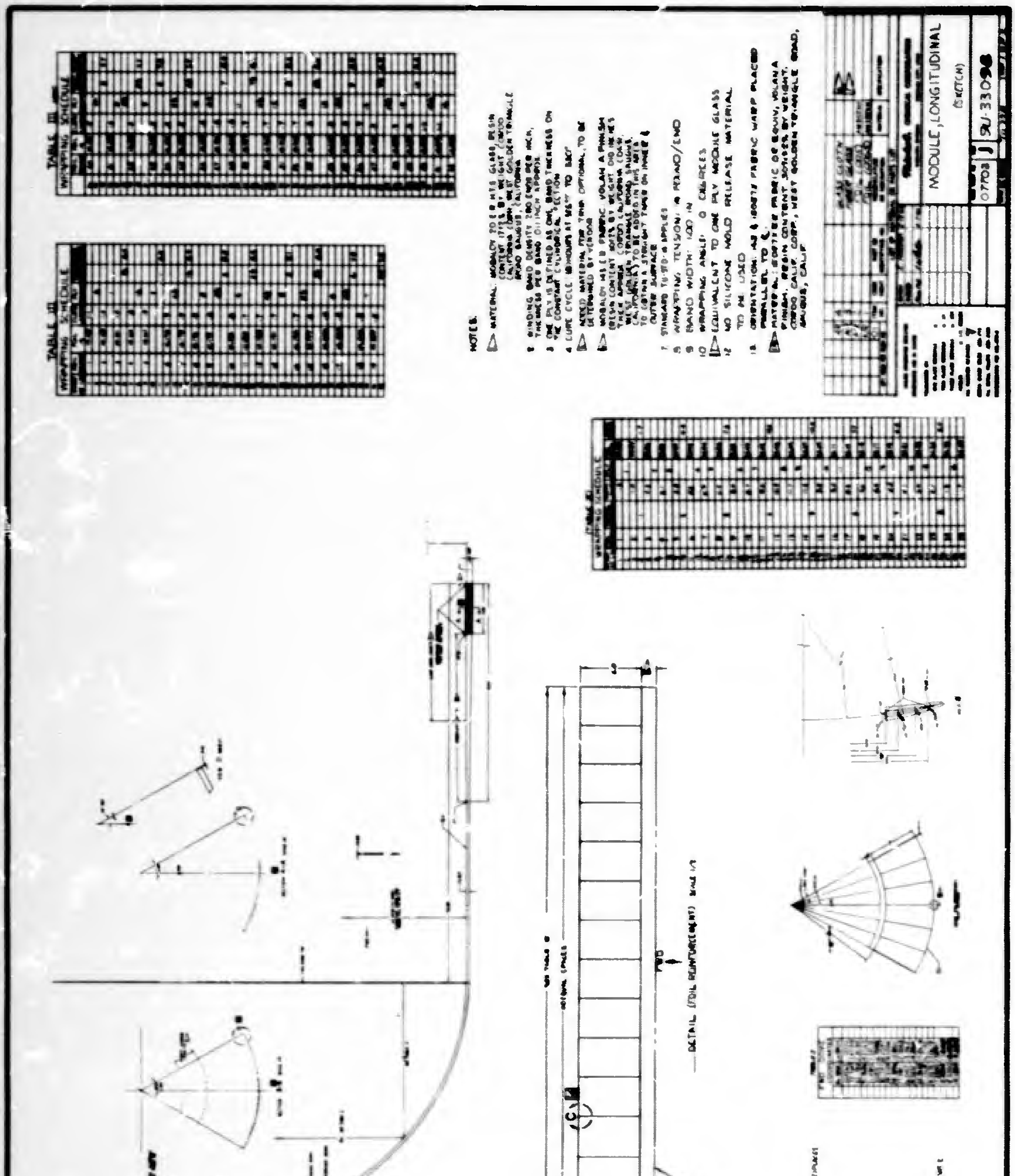


Figure 47. TU-228 Case Module Drawing 9U33098

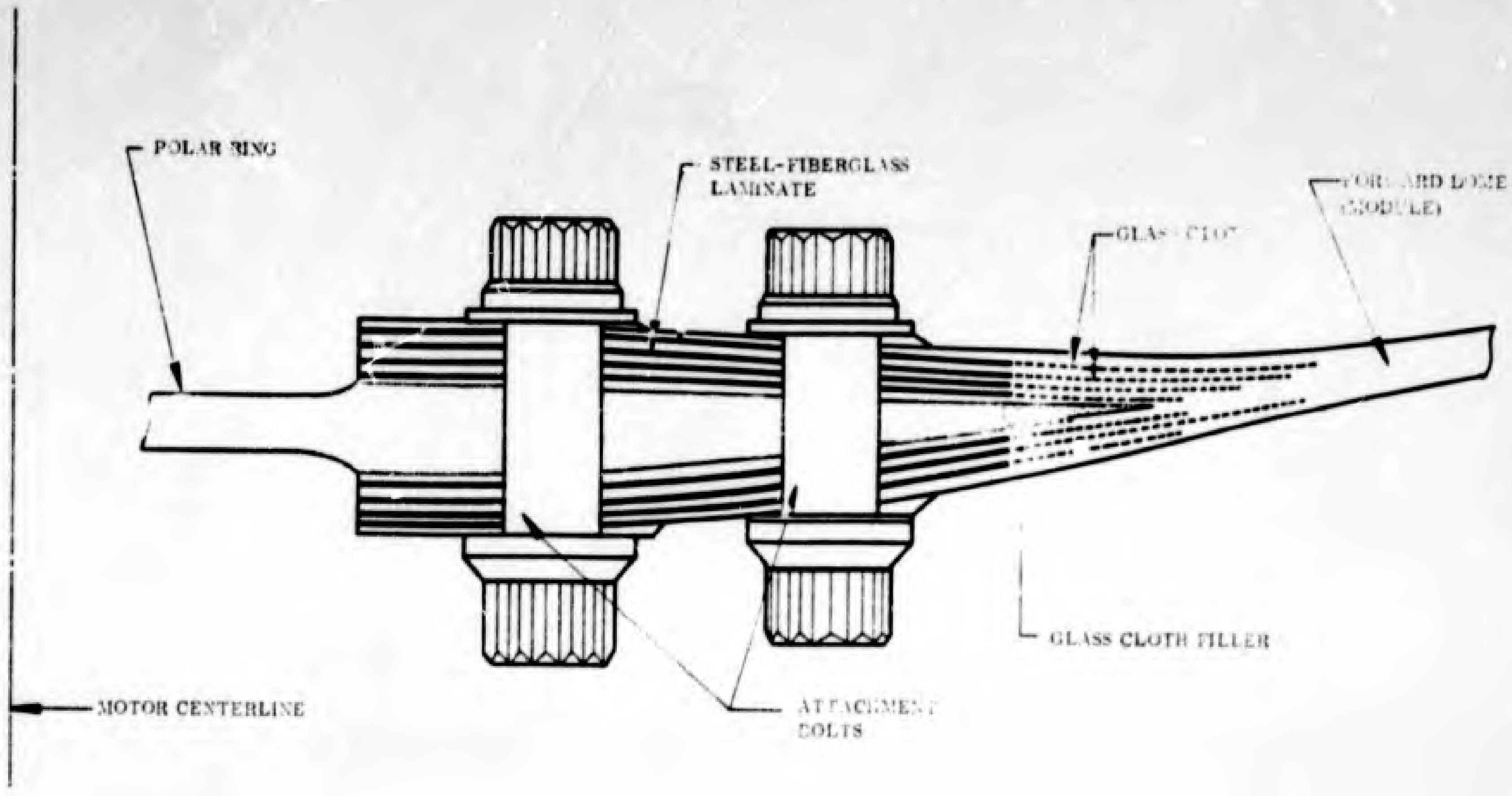


Figure 48. TU-228 Forward Closure Clevis Joint

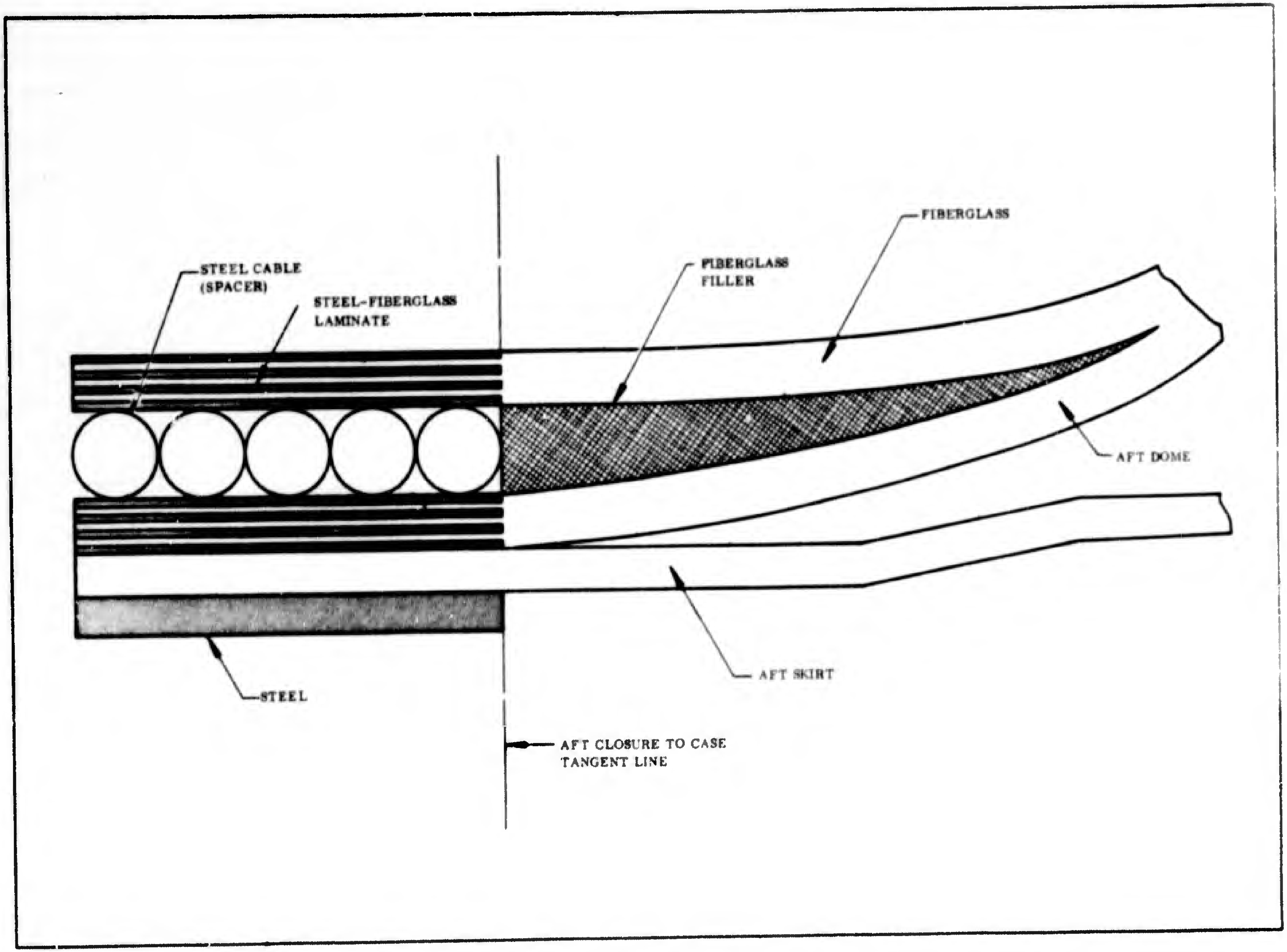


Figure 49 TU-228 Aft Closure Clevis Joint

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The critical factor in the aft dome design was the hoop tensile stress in the laminated aft clevis joint. This was established at 192,000 psi. Helical glass stress was calculated to be 157,000 psi and the glass strain to be 0.0151 in./in. at ultimate pressure.

The aft dome and aft skirt were to be made independently but fabricated into an integral aft closure in the final stages of aft dome fabrication.

(4) Forward Skirt--The forward skirt design (Thiokol drawing 9U33099; Figure 50) called for glass fabric laminations with hoop windings. Early program investigations indicated that a skirt made entirely of fiberglass (with exception to protective metal bushings inserted into bolt holes) would meet all loading requirements. A skirt having an all-fiberglass design would cost less than one of alternate design having strips of steel between layers of fiberglass. The all-fiberglass design was selected for the TU-228 forward skirt because the skirt could be prefabricated, slipped over the modules, and secured in place with adhesive. The metal bushings would distribute bearing loads and reduce bearing stresses. Glass cloth reinforcement, Type 341 and 181 Volan finish (Owens-Corning) was specified for use with a Cordo Mobaloy "ER" resin system.

The critical factor in the design was the thrust (buckling) load. This was computed to be 1540 lb/in. (1600 lb/in. allowable). Maximum loads established were:

1. Axial compressive (lb)	336,000
2. Axial tensile (lb)	37,500
3. Vertical shear (lb)	112,000

(5) Aft Skirt--The basic arrangement of laminated glass cloth with hoop windings was used in both forward and aft skirt designs (Thiokol drawing 9U33100; Figure 50), but the aft skirt incorporated steel foil in the skirt-to-dome joint region to transfer bearing loads to the attachment bolts. Metal bushings in skirt attachment bolt holes at the skirt edge reduce bearing stresses in the fiberglass.

The critical factor in design was thrust load. This was computed to be 1092 lb/in. (1600 lb/in. allowable). Maximum loads established were:

1. Axial compressive (lb)	225,000
2. Axial tensile (lb)	37,500
3. Vertical shear (lb)	112,000

(6) Forward Collar--The forward collar (Thiokol forward polar boss drawing 9U33097; Figure 51) was designed as a ring integral with, and in the center of, a perforated plate. The material specified for the collar was 4340 ST-AMS 6359 steel.

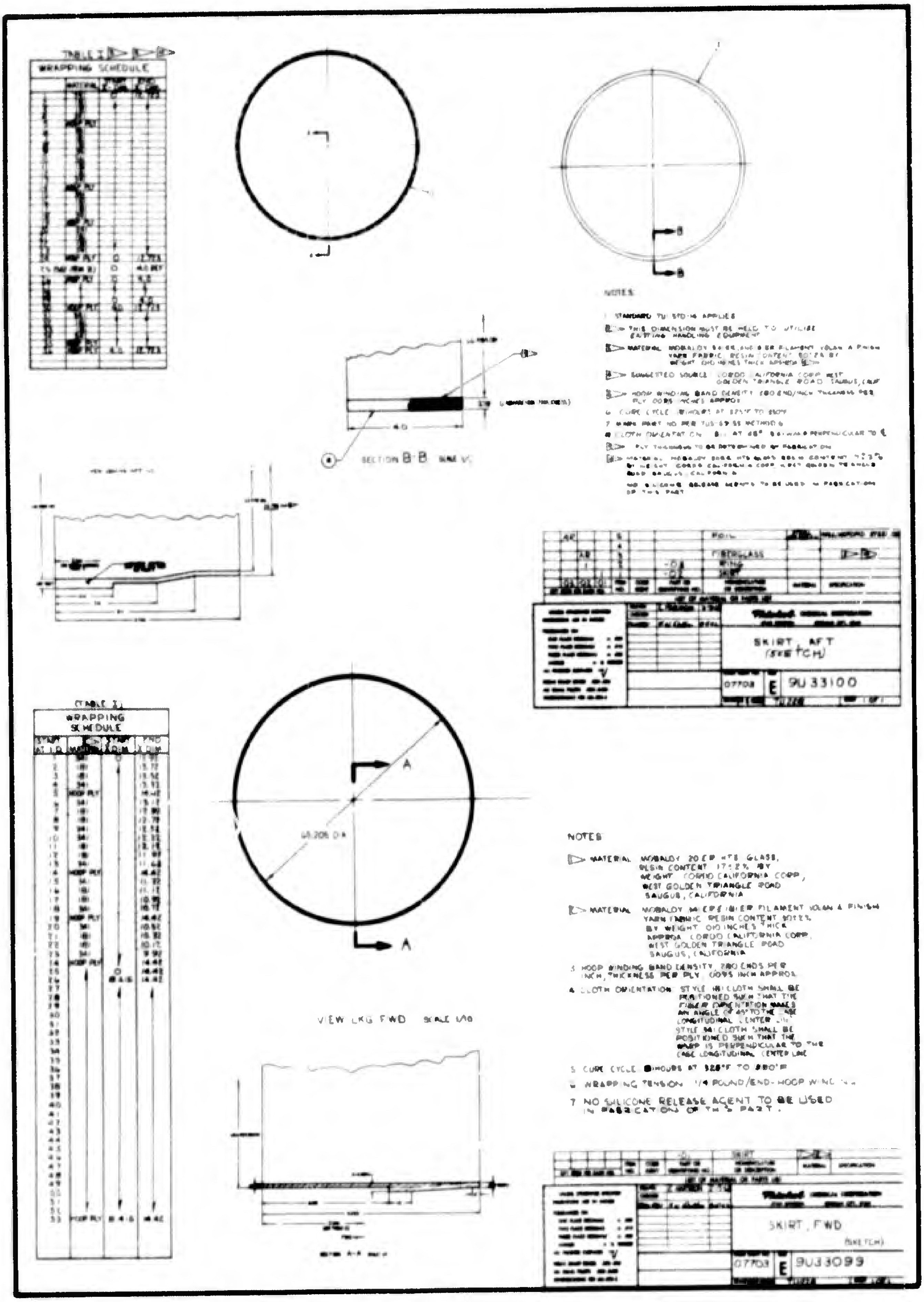

Figure 50. TU-228 Forward Skirt Drawing 9U33099 and Aft Skirt Drawing 9U33100

The ring would permit attachment of a PYROGEN type igniter. The perforated plate was a surface of revolution from the ring to the end of the fiberglass module, to which the modules could be attached by two concentric, radially arranged, rows of bolts. The critical factor in design was the hoop stress in the ring portion. The hoop stress was calculated to be 154,000 psi.

(7) Aft Collar--The aft collar (Thiokol aft polar boss drawing 9U33095; Figure 51) was designed as a ring on which the angle of interface between the collar and fiberglass dome restrains the collar while the case is under pressure. The basic dimensions (the inner and outer diameters and the angle of interface) were determined in a computer program (Volume VI) by equating the force required to expel the collar from the dome and the restraining force imposed by the fiberglass against the collar interface. The forces acting while the components were in a strained position (at ultimate case pressure) were considered. The collar material specified was 4340 ST (MIL-S-18729) steel.

(8) Hoop Rings--Hoop rings (Thiokol drawing 9U33426; Figure 52) were designed to restrain the modules in the cylindrical section of the case. Seven prefabricated fiberglass sections would be used. The maximum strain was calculated to be 0.0195 in./in. at 204,000 psi (i.e., at ultimate case pressure).

d. Large Diameter TU-228 Case Fabrication

(1) Aft Closures--Aft domes were fabricated of glass fibers wrapped on a rotating mandrel, two domes being wrapped simultaneously (Figure 53). Spools (mounted on platforms which travelled a circular track around the mandrel) fed glass onto the mandrel surface at a fixed plane. Two reels were fixed in location to feed parallel strips of steel foil flat against the mandrel surface between layers of glass.

Wrinkling of foil and fiberglass (Figure 53) developed during the initial curing cycle for the domes. As a result, one dome segment was rejected at this stage of manufacture. The segment was left intact to permit subsequent fabrication, and the curing method was investigated. Wrinkling was attributed to a differential in thermal expansion between glass and steel during cure.

The dome segments were cured in an oven without being removed from the mandrel. The outside surface of the fiberglass absorbed and conducted oven heat inward to the mandrel more slowly than the steel foil. Due to higher temperature, the foil expanded more than the fiberglass, permitting fiberglass to wrinkle because of a loss of tension.

The expansion of the mandrel and the steel foil should be relatively equivalent during the cure to maintain constant stress on fiberglass and resin. Increased tension on the steel foil during the winding operation, and internal heating of the mandrel (in addition to the heated environment of the oven) overcame this problem.

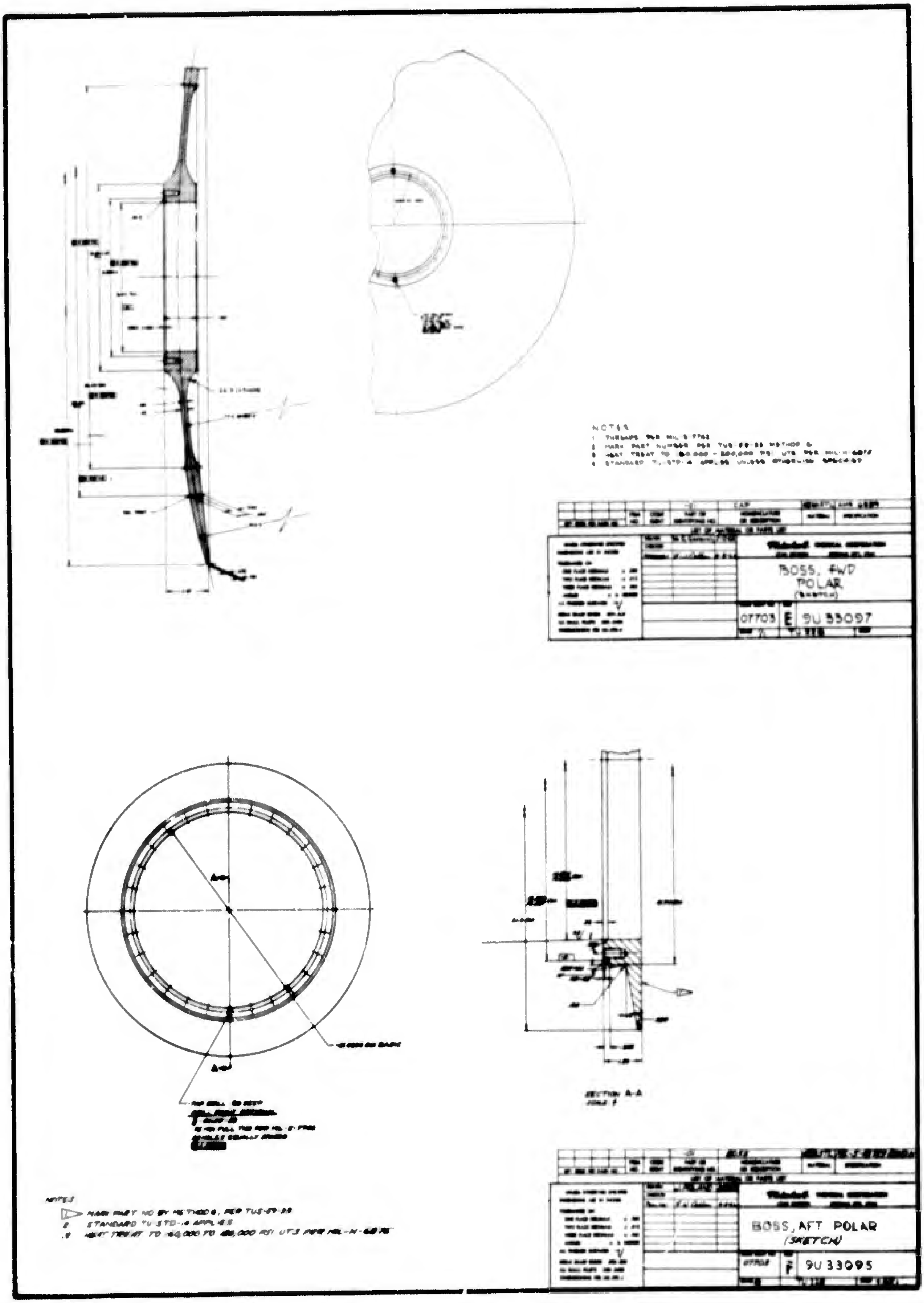

Figure 51. TU-228 Forward Polar Boss Drawing 9U33097 and Aft Polar Boss Drawing 9U33095

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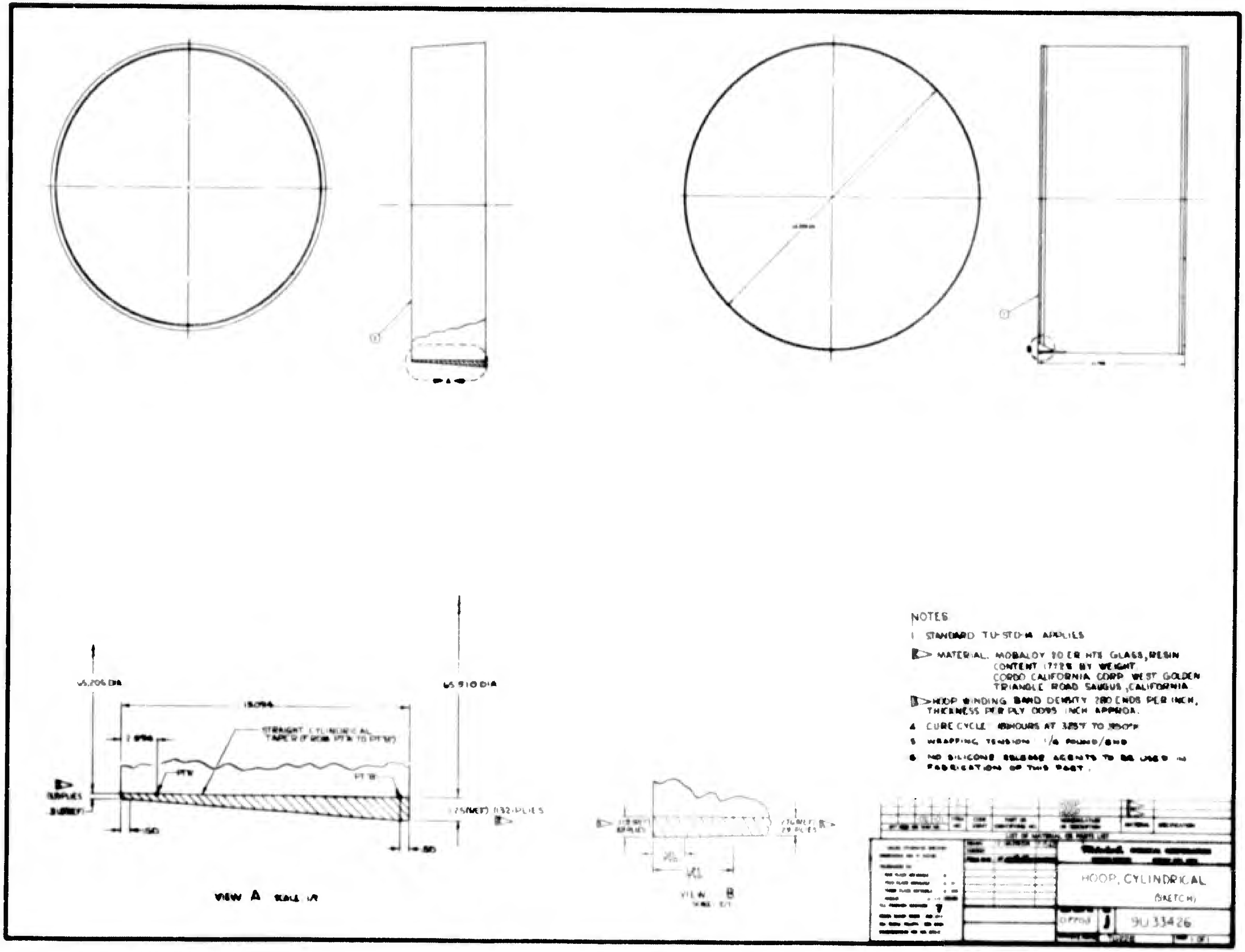
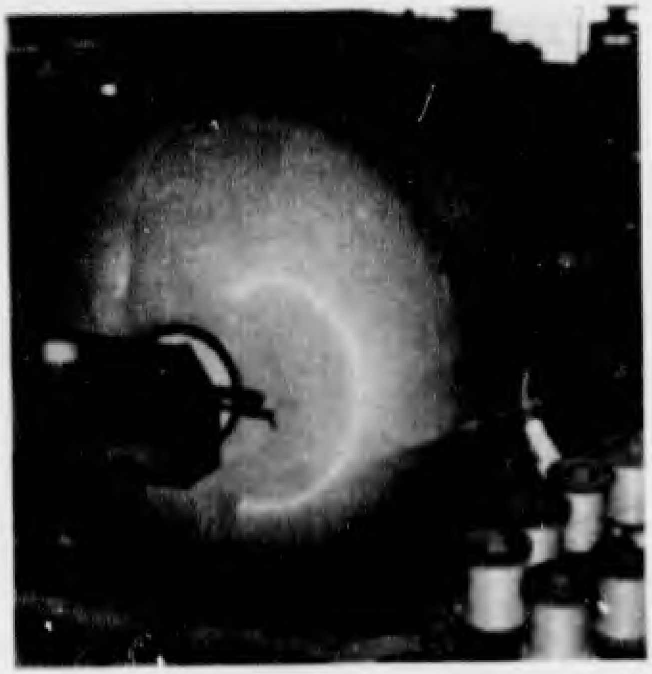


Figure 52. TU-228 Cylindrical Hoop Drawing 9U33426

FIRST FIBERGLASS LAYER GENERATION

SUCCESSIVE FIBERGLASS LAYER GENERATION (NOTE STEEL FOIL APPLICATION FOR EACH DOME)



AFT DOMES BEFORE FORMATION OF CLEVIS JOINT (NOTE WRINKLES IN STEEL FOIL)

Figure 53. TU-228 Aft Dome Fabrication

Aft dome filler pieces were installed on the existing dome contour. Steel cable (0.375 in.) as a spacer material was used to form the cavity of a clevis (Figure 49). A second set of layers of glass and steel foil was wound on the mandrel, and cured. Each dome was cut from the center section near the edge of the steel foil. Each dome was trimmed and the steel spacer material was removed. One aft dome (of two) was accepted at this stage of manufacture and removed from the mandrel.

An aft skirt was bonded successfully to the dome, and this aft closure was trimmed and cleaned. Holes were then drilled in the aft skirt.

(2) Modules--Modules were fabricated two at a time on an aluminum mandrel. With allowance for difference in size and contour, the principal operations in fabrication of domes and modules remained the same. Construction of these components of the TU-228 case does not require destruction of the mandrel for removal of components. A case liner, necessary to isolate fiberglass from hydrotest fluid, was applied to the module mandrel before the fiberglass was applied (Figure 54).

The module mandrel, made of aluminum plate, was machined to the case configuration and mounted on an arbor. The mandrel was placed on a cradle inside a track on which the spools of glass were carried. The mandrel, coated with S-122 release agent, was fitted with two layers of a nylon reinforced rubber liner before application of glass and steel foil.

After module winding operations (Figure 55) were completed the unit comprising the two modules, liner, and mandrel was permitted to cure.

The first two modules were rough trimmed and removed from the mandrel, but the modules were rejected because of defects. The stainless steel foil was mislocated at the aft joint, permitting waves to develop in the foil. The steel foil had been properly positioned during the winding operation, but locator tabs, on the foil held between locators on the mandrel, shifted position as the mandrel expanded during the curing cycle. The force of expansion sheared the tabs from the foil, buckling the foil and changing its position between the layers of fiberglass. The mandrel was modified to permit removal of the locators during curing. Also, a small bracket was designed to fit over the tabs and move them as an integral unit as the mandrel expands.

The liner, installed in two layers over the mandrel, remained separated, after curing, between layers in the cylindrical section. In similar operations a vacuum bag placed over the assembly exerts an effect by which the atmospheric pressure forces fiberglass and liner against the mandrel, and the two layers of the liner are bonded together during the curing cycle. The vacuum bag failed during the curing cycle for the first two modules and contact between layers of the liner was insufficient to permit bonding. A rubber adhesive was used between layers on subsequent modules, and a longer interval for drying was allowed before application

H. I. Thompson module mandrel nylon reinforced rubber liner application

Liner fitting

Liner trimming

Figure 54. TU-228 Case Liner Fabrication

of the second layer. An improved material for the vacuum bag, Tedlar Film, was used for curing operations on subsequent modules.

Fibers were unsupported aft of the steel foil at the aft joint, and the material (fiberglass and foil) developed a wavy surface. Additional layers of 15057X Cordo ER glass fabric were added to this area on subsequent modules to support the fiberglass.

The rejected modules were used to validate trim and assembly procedures and to check trim and assembly fixtures.

A second set of modules was fabricated after modification of the mandrel, and the steel foil was correctly positioned throughout the curing cycle. However, the mold release agent failed to permit separation between mandrel and liner. The modules were deformed during removal.

Other mold release agents were applied to portions of plate, and liner material was next applied over each section. The first (control) section was coated with S-122, another with Mold Wiz-249, another with Ram-225, another (found to be the most satisfactory) with a combination of S-122 and Ram ZN15. A procedure was established in which the mold was lightly coated first with S-122, and then sprayed with ZN15 (0.005 in. thick) and allowed to dry.

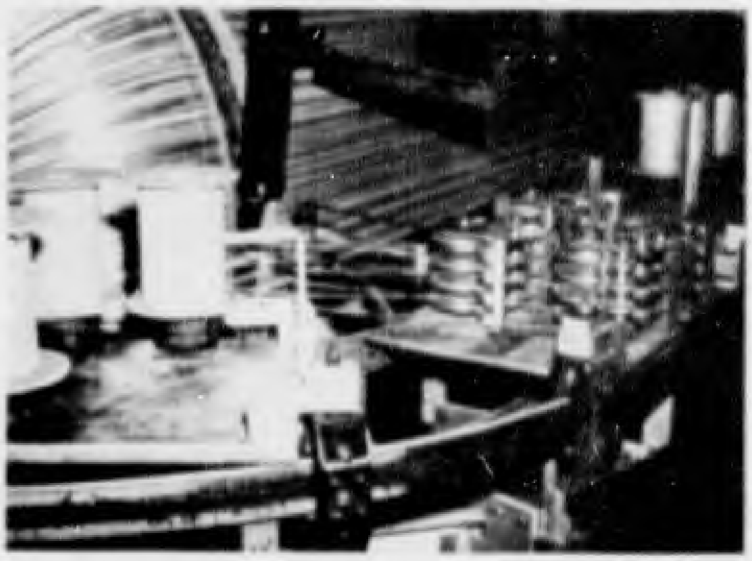
The problems encountered in removal of these modules from the mandrel were not experienced in fabrication of smaller modules, because the small modules were more flexible. The smaller modules tended to peel away from the mandrel, while these larger modules must be lifted straight away from the mandrel.

A third set of modules was easily removed from the mandrel after fabrication. Fibers wrinkled in the outer layers of the fiberglass, apparently due to a loss of vacuum during the curing cycle. Since such wrinkles could reduce case strength approximately 20 percent, the modules were rejected.

Three sets of modules were then successfully fabricated, (Figure 56) easily removed from the mandrel, trimmed, and installed into an aft closure assembly.

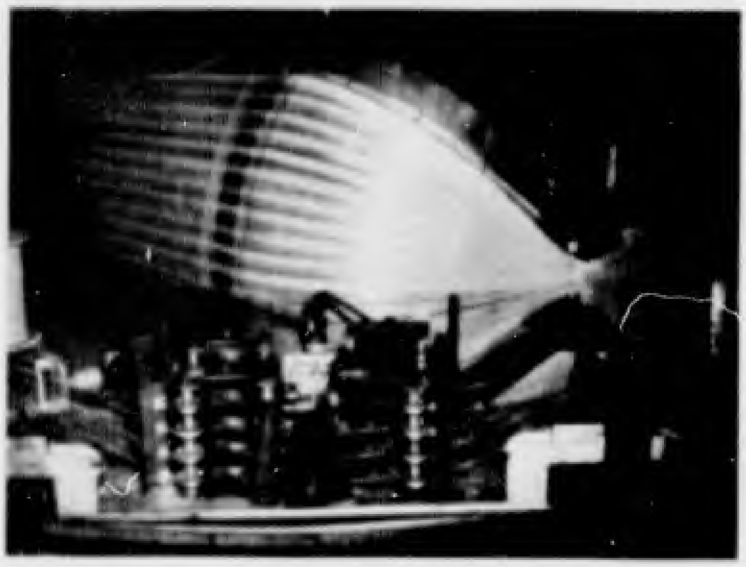
(3) Hoop Rings--Two sample hoop rings (each 57 in. dia by 4 in. wide) were fabricated to establish the winding tension per end of glass fiber. One ring was wound at 0.25 lb/end; the other was wound at 0.75 lb/end. The ring wound at 0.75 lb/end tension could not be removed from the mandrel. All hoop rings were wound at 0.25 lb/end tension.

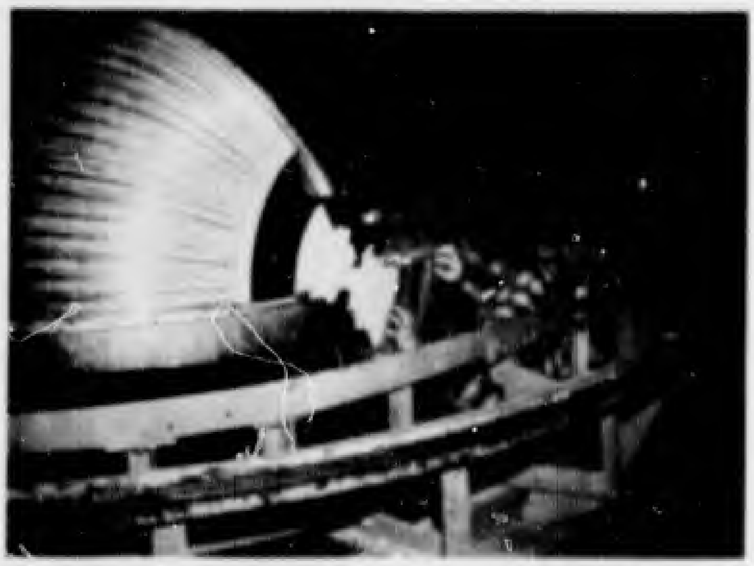
(4) Skirts--Fabrication of both forward and aft skirts proceeded without difficulty. An aft skirt was bonded to an aft dome to form an integral aft closure for the case. The drilling of holes (0.500 and 0.750 in. dia) (for special high strength bolts which attach the modules to the closure) proceeded very slowly, even after the angle of the drill point was increased to cut more effectively through the glass and foil laminate.



Application of preimpregnated glass fibers over TU-228 mandrel (note steel foil applied between layers of glass)

TU-228 module aft end





TU-228 module head end

Figure 55. TU-228 Module Fabrication

(5) Hardware--Special high tensile strength bolts were required to attach the modules to the forward pole piece and to the aft closure. Control of the initial heat treatment of blanks for the bolts proved difficult, requiring a stress relieving operation by heat treatment to permit threads to be rolled on the bolts.

(6) Case Assembly--The modules were erected in a fixture (Figure 57) and installed into the aft closure. Bolt holes were drilled in the modules to match bolt holes in the aft closure. The modules were bolted to the closure and to the forward polar fitting. The case liner was completed by covering the interior of the forward dome (seen at the top of Figure 57) with molded rubber sections taken from the unused aft portions of the modules. These sections were offset 30 deg from module joints to bridge the longitudinal butt joints between modules. In addition, strips of nylon reinforced rubber (0.025 by 6 in.) were placed over adjoining butt joints between modules in the cylindrical portion of the case assembly.

One module shifted position during the drilling operation, producing a gap of approximately 0.375 in. between it and the adjoining module. To assist in bridging this gap between modules, four layers of 0.008 in. stainless steel, 4 in. wide and 48 in. long, were interspersed into the liner over the opening.

After bolts were installed at each end of the case, an application of PR-1422B insulation (Products Research Co, Glendale, Calif.) was necessary to seal the bolt holes against pressure.

Hoop rings and the forward skirt were coated with Epon 923 (Shell) adhesive and placed over the modular assembly. The inside surface of the case was covered with one layer of 0.015 in. SMR-1 uncured rubber. The case was pressurized (10 psi) to expand the modules against the hoop rings during cure of the adhesive.

The completed case (Figure 58) weighed 2595 lb (Table XVI).

e. Large Diameter TU-228 Case Hydrotest

(1) Initial Test--The completed case was fitted with instruments and placed in the Thiokol hydrotest facility (Figure 59). Pressure was applied according to a programed schedule, but the case failed prematurely at 732 psig when the rubber liner was extruded through one of the joints in the head end and was ruptured (Figure 60). Failure of the case to expand uniformly (Table XVII) was noted.

The case was removed from the hydrotest facility and inspected for case damage. Only minor physical damage to the glass-resin matrix at one module joint was revealed but one other joint also appeared to be weakened. Both damaged joints were reinforced, therefore, to complete the hydrotest. In particular, performance data on the laminated glass-foil clevis joint during hydrotest was desired.

TU-228 MODULE HEAD END

TU-228 MODULE AFT END

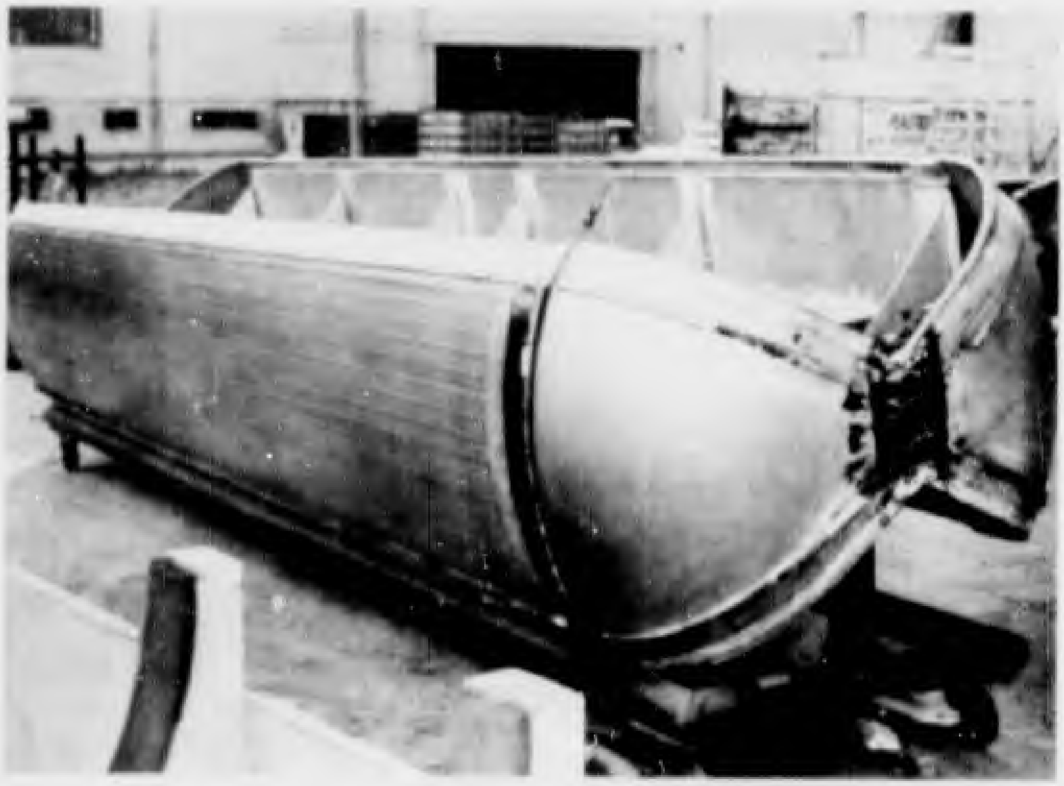


Figure 56. Completed TU-228 Module

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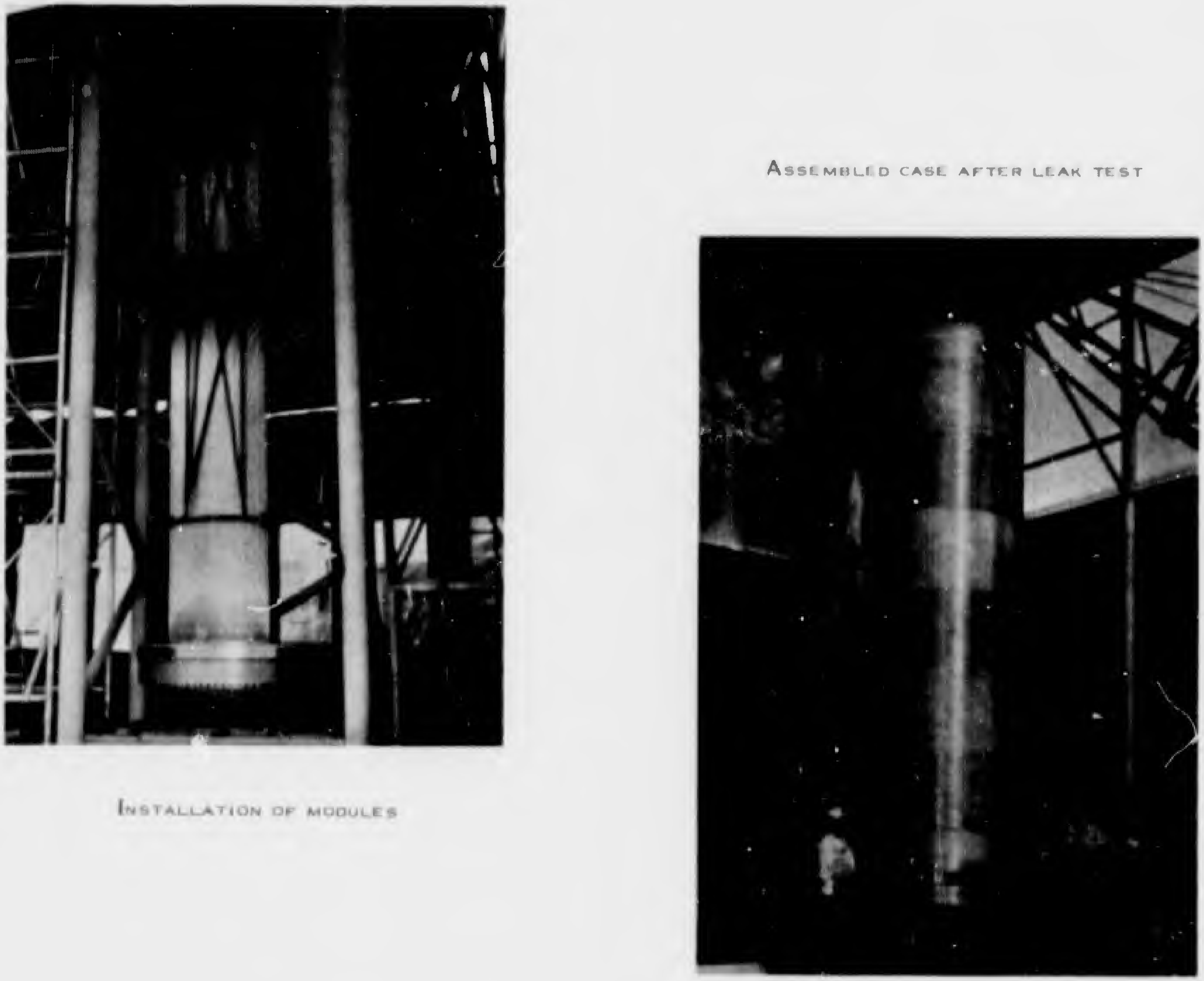


Installation of modules

Assembled case after leak test

Figure 57. TU-228 Case Assembly

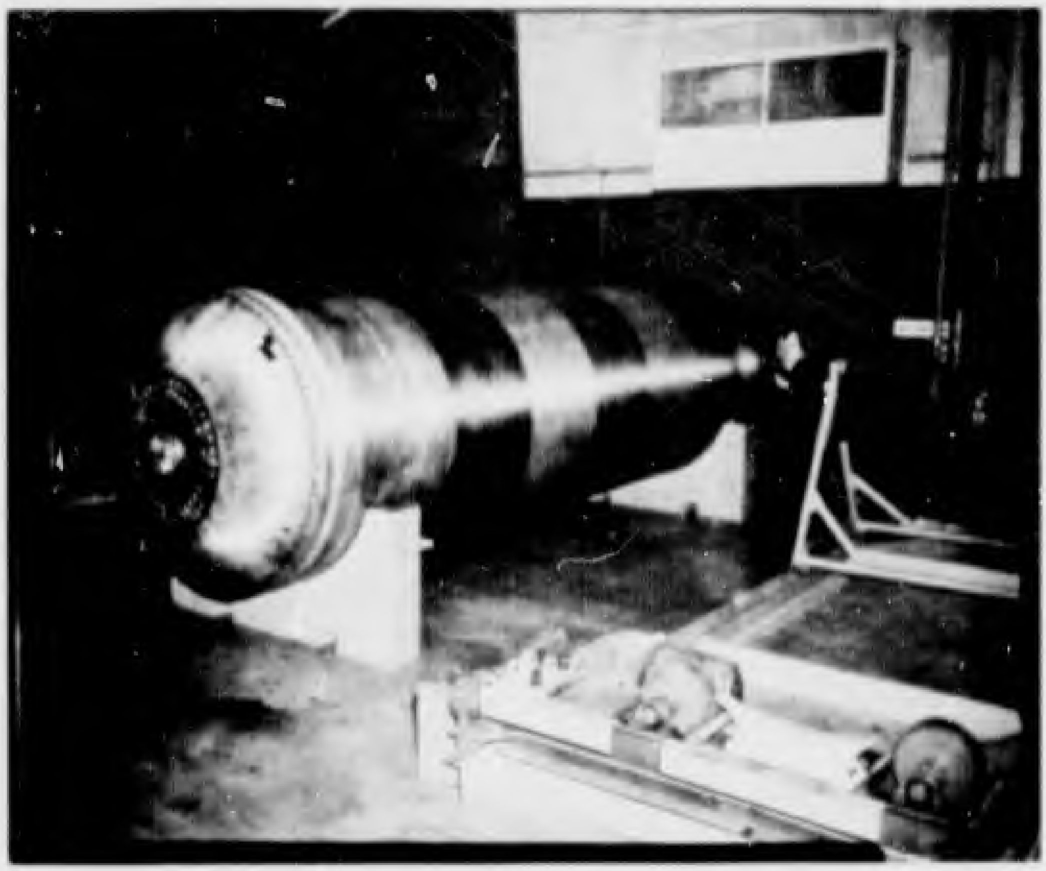


Figure 58. Completed TU-228 Case Assembly

TABLE XVI

TU-228 CASE ASSEMBLY WEIGHT SUMMARY

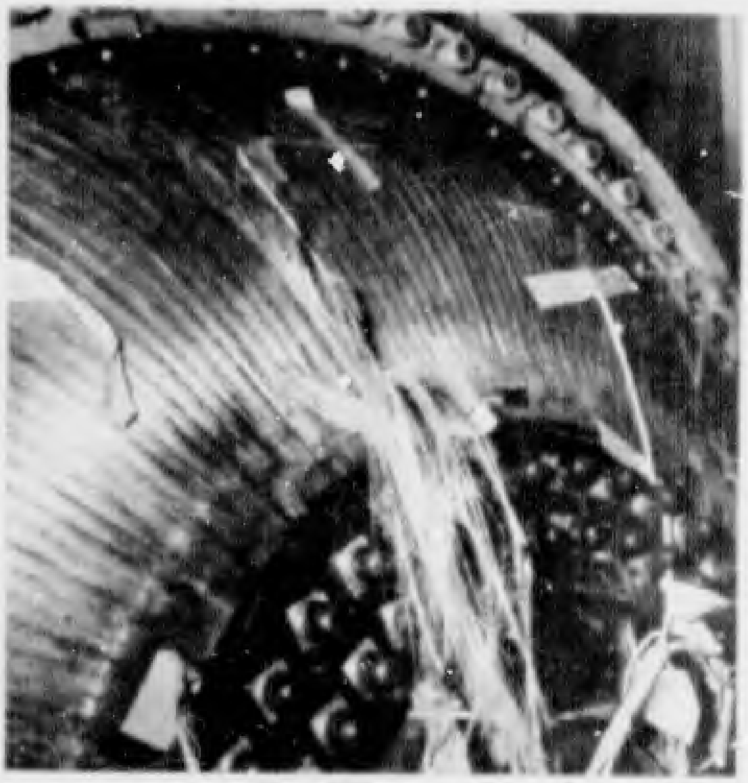
Item	Design Weight (lb)		Actual Weight
	Steel Foil	Total	
Modules (6)	67.4	812.1	785.5
Aft closure with boss	39.2	295.8	287.0
Hoop rings		1,013.6	927.0
Forward skirt		72.5	62.0
Aft skirt		82.1	118.0
Subtotal	106.6	2,276.1	2,179.5
Forward pole boss		107.4	112.0
Aft pole cover		87.4	87.5
Insulation		51.4	134.0
Liner		246.5	
Bolts, nuts and miscellaneous		92.0	82.0
Adhesive		38.2	--
Total		2,898.7	2,595.0

Figure 59. TU-228 Case in Hydrotest Facility

TABLE XVII

TU-228 CASE EXPANSION MEASUREMENTS

Initial test (failure at 732 psig)	
Longitudinal extension across one hoop ring	
At 0 deg (in.)	0.45
At 180 deg (in.)	0.35
Tangent-to-tangent extension	
At 0 deg (in.)	3.00
At 180 deg (in.)	2.00
Circumferential growth	
In cylindrical section (in.)	2.25
At joint (in.)	0
Retest (Failure at 840 psig)	
Maximum growth	
Between modules No. 11 and 12 (in.) at 704 psig	0.21
Between modules No. 8 and 9 (in.) at 840 psig	0.07
Between modules No. 9 and 10 (in.) at 840 psig	0.07



RUPTURE BETWEEN MODULES 12 AND 7

RUPTURE BETWEEN MODULES [illegible] AND [illegible]

Figure 60. TU-228 Case Hydrotest Rupture - Forward Dome Region

To complete repair of damage at the module joints, the pressure load at a joint must be reacted into undamaged portions of the modules by a bridging arrangement (Figure 61). The damaged liner material was removed, and a strip (0.125 by 6 in.) of Buna-N rubber was installed in the region of the module joint. A row of steel bars (0.250 by 1 by 4 in. or 0.250 by 1 by 6 in.) were placed with the long dimension perpendicular to the module joint. A 0.005 in. layer of nylon reinforced rubber was bonded to the surface of the dome over the steel bars. The case was pressurized (5 psig air pressure) for 48 hr to obtain an effective bond between the rubber and steel laminate while the adhesive (PR-1422) was cured. The case was coated internally with Thiokol sealant UF-3119. Extensometers were installed across three of the module joints in the forward dome region to measure increase of the opening under pressure.

(2) Retest--The case was installed again in the hydrotest facility and pressure applied. Again the case failed in the joints between modules in the forward dome region (Figure 62) at 840 psig.

Local damage at edges of modules indicated that large modules do not develop longitudinal crazing as readily as smaller modules because the cross sections are thicker. Modular cases (65 in. dia or larger) will probably require fiberglass reinforcement at the edges of the modules to effectively carry imposed loads. Test results clearly indicated that module stresses, developed in the forward dome region under pressure, did not correspond to predicted reactions. Uniform module expansion and stress relief due to resin crazing were not as pronounced in the larger module. The case failure was attributed primarily to misalignment of modules (Figure 63) during assembly. The resulting gaps were too large to be bridged effectively by the liner at design limit pressure values. The liner was extruded through the opening and subsequently ruptured.

f. Conclusions

(1) Modular Construction Concept--The basic design concept was proven in subscale hydroburst tests. Design feasibility was established by the first test, in which the case burst at 179 percent of its designed limit pressure. Fabrication techniques, as well as design feasibility, were proven by the second test, in which the case withstood 202 percent of the design limit pressure.

The larger TU-228 case burst below the design limit (1113 psig), but sufficient data for a complete evaluation of the modular design was obtained from records of case behavior under pressure and an analysis of the mode of failure.

Structural integrity in fiberglass fabrication of cases involves more than proportional scaling of small case dimensions. The stiffness of a larger module, due to thicker walls and greater widths, introduces deviations which affect case strength and performance under test. Fabrication discrepancies had not affected structural integrity of the smaller cases.

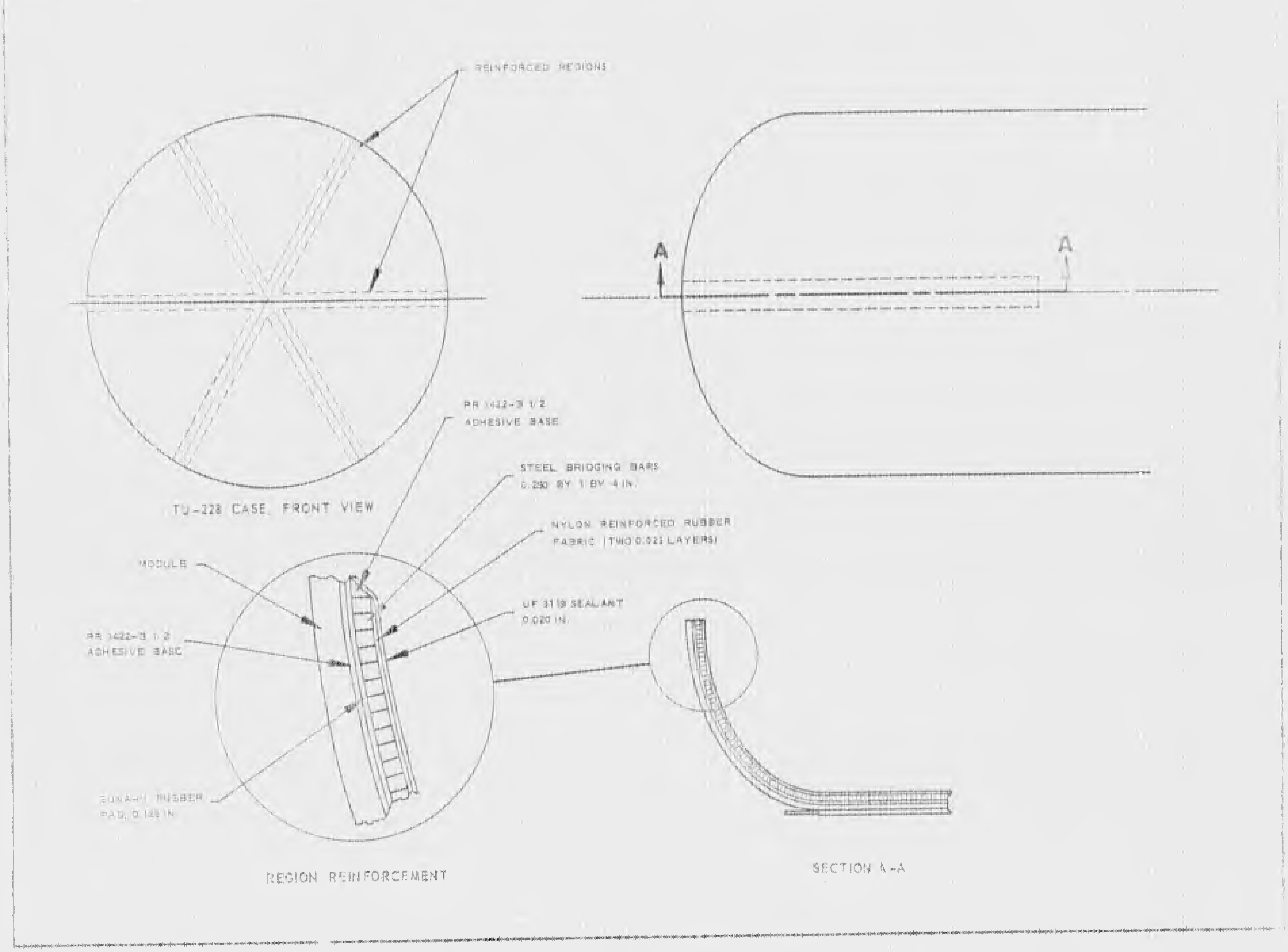


Figure 61. TU-228 Case Region Reinforcement

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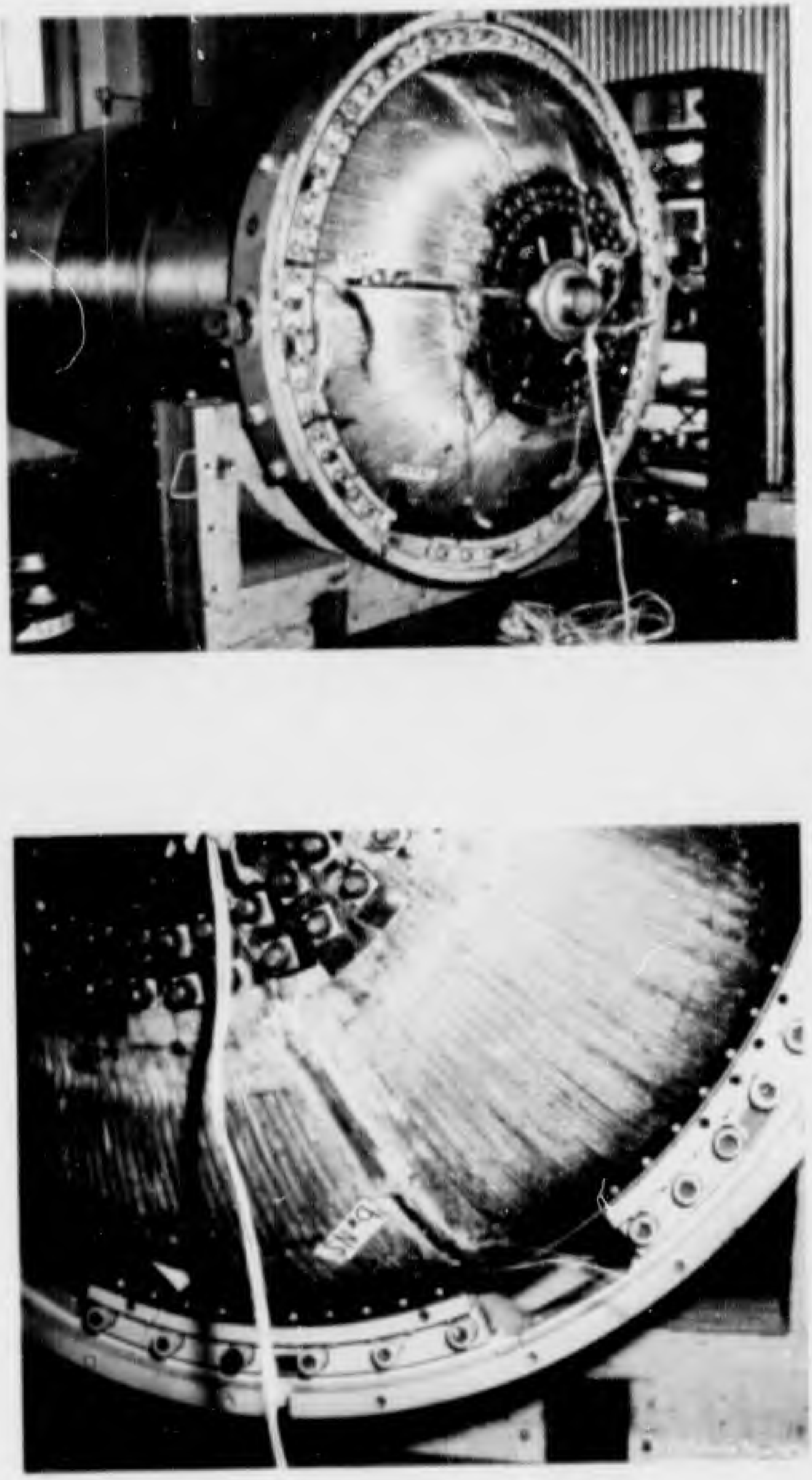

Figure 62. TU-228 Case Hydrotest Rupture after Retest

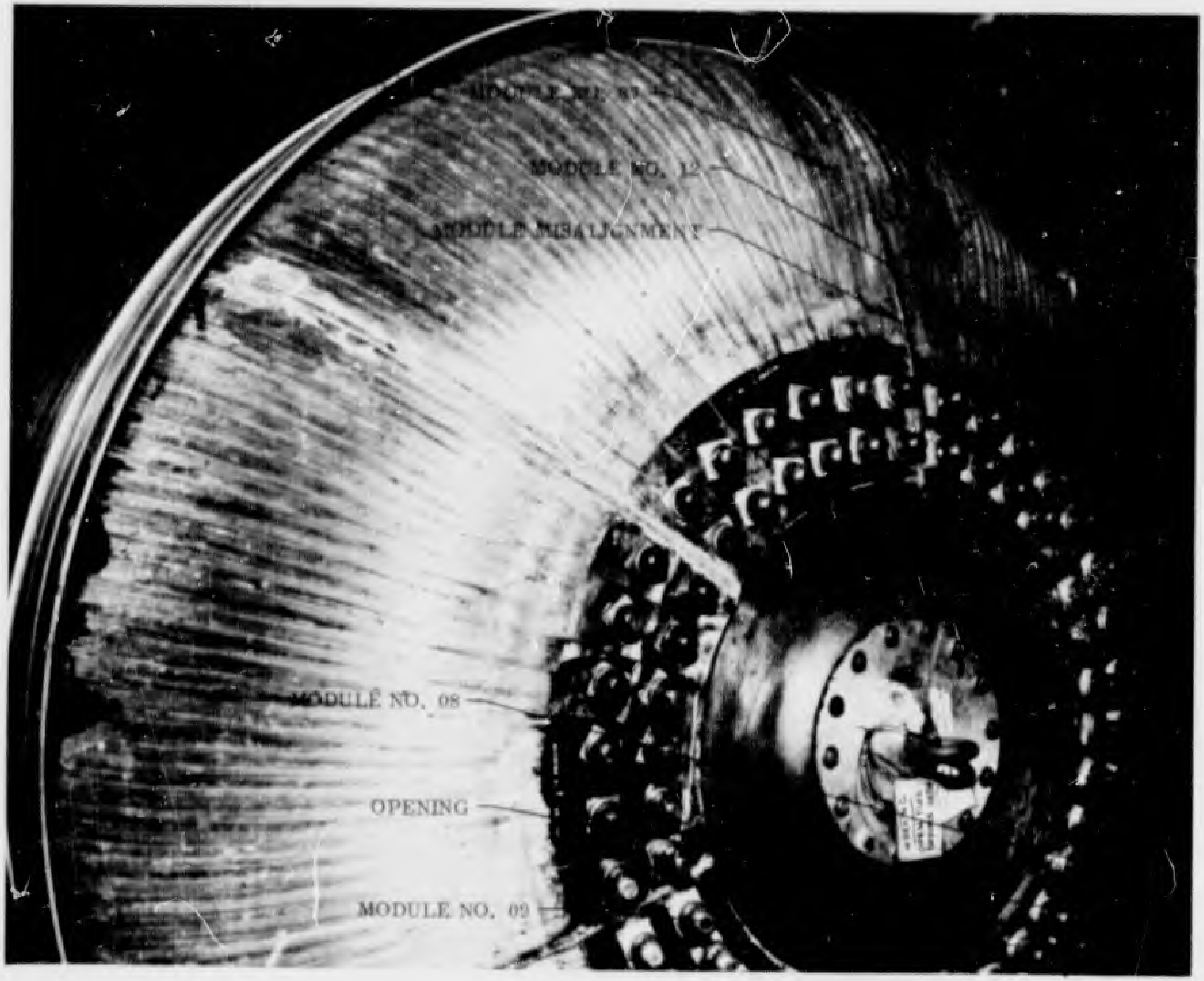

Figure 63. TU-228 Case - Module Misalignment

(2) Tests--To obtain a more complete understanding of the effects of workmanship in fabrication, and unknown factors of proportional scaling on structural integrity, additional bench tests on tensile specimens could have been conducted. The effect of varying the resin content and band width on tensile specimens loaded perpendicular to fiber orientation could have been established with greater certainty. The effect of varying steel strength, of the depth and length of steel-glass lamination, of the attachment hole diameter and of the distance of the hole from the edge of the foil could have been known also with greater precision. Compatibility of dissimilar materials having different coefficients of expansion could have been established with greater precision.

Findings of such tests might have required modifications, but modifications of a minor nature, to the existing design.

The use of double ended modules (without cylindrical joints) for modular case construction, in which modules of varying widths and thicknesses and having varied gaps between modules, could have been determined by subscale tests. The value of slotted modules for uniform case expansion could have been also explored by small case tests. The steel shim joint could have been evaluated by tests on a cylindrical case section.

(3) Tooling--Fabrication of an experimental design invariably suggests tooling changes. For fabrication of large TU-228 cases, a rigid member establishing the contour of the forward dome to inner surface of the module should be added to the case assembly fixture to hold modules in true position during drilling and assembly. A restraining member should be added on the outside surface also. These modifications would stiffen the forward dome region during the assembly and drilling operations. If the aft joint design were changed, the aft dome mandrel and the aft dome drill fixture would have to be changed.

Resin crazing produced regular longitudinal separations on modules of small cases during pressurization, which promoted regulated case expansion. To produce the same effect on larger, stiffer modules, a slot cutting tool and jig may be necessary to make slots on the module surface which will initiate separations.

Analysis of module structural integrity indicated the value of a change of glass fiber band width. The hole pattern in the mandrel indexing template (therefore, the template) would be changed by a change in band width. Similarly, a potentially desirable change of the zero hoop stress dome contour would require a change of the module mandrel.

(4) Quality Control--Quality control during the assembly of small cases appeared excellent, judged by the performance of the cases under test. To obtain similar results on larger cases, quality control standards and procedures would require re-evaluation.

C. PHASE III: TU-290 CASE FABRICATION AND HYDROSTATIC TESTING

1. Program Requirements

The objective of Phase III of this program was to design and build 44 in. dia monolithic, single nozzle, fiberglass plastic cases, designated TU-290 cases. Allison was selected to build the cases because of demonstrated capability: previous experience with fiberglass fabrications including development of the highly successful TU-227A case (300,000 psig hoop glass stress), and tooling and facilities requiring minimum adaptation for TU-290 case construction. Using a sequence of design, fabrication, burst test, analysis, and design modification, three cases were to be built. Two additional cases, designed to withstand 400,000 psi hoop stress at 792 psig, were to be hydroproof tested and delivered to the Air Force for subsequent test. Two nozzles, appropriately designed for the cases, were to be delivered with the cases.

This program portion was conducted as follows.

1. TU-290 case No. 1 configuration was to be fabricated of E-HTS glass without internal insulation. The case would be hydroburst tested to establish the basic design for case No. 2.
2. TU-290 case No. 2 was to be constructed identically to case No. 1 except that S-HTS, in place of E-HTS glass would be used. The case would be hydroburst tested and results compared with those of case No. 1.
3. TU-290 case No. 3 was to be the resultant of design experience with the first two cases. S-HTS glass would be used as case material. The case would be hydroburst tested, and design modifications, if any, would be incorporated into fabrication of cases No. 4 and 5.
4. TU-290 cases No. 4 and 5 were to be of S-HTS glass fabricated to case No. 1 design as modified by design experience gained with cases No. 2 and 3. These cases would include insulation and would be hydroproof tested only before delivery to the Air Force.

a. Case Design Considerations

Thiokol prepared the preliminary design for the TU-290 case (Figure 64 and Table XVIII). This design was the foundation for developing the first two cases. Allison modified details of the drawing for compatibility with available equipment, tooling, facilities and techniques.

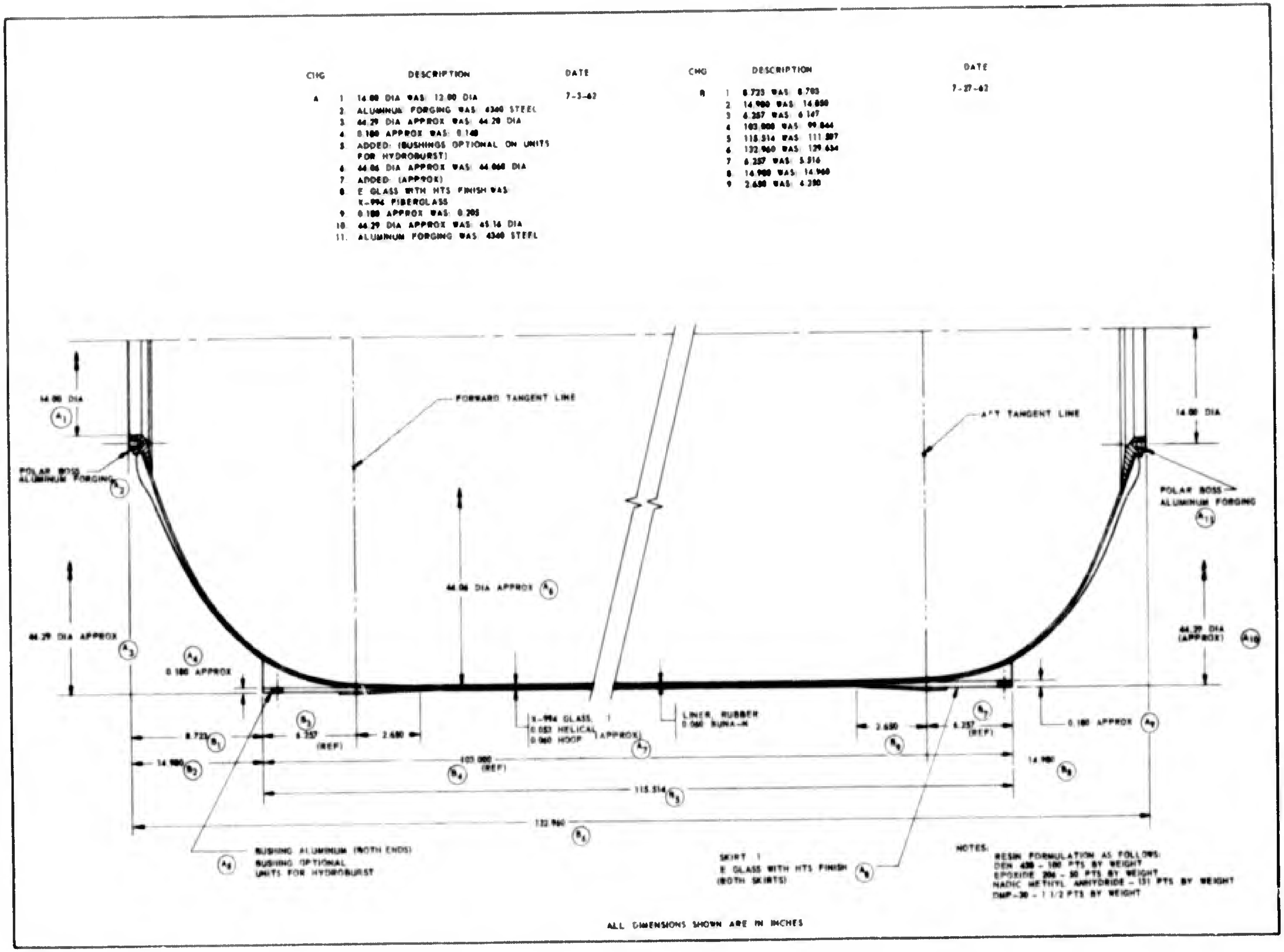

Figure 64. TU-290 Motor Case Specification Control Drawing

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TABLE XVIII

TU-290 MOTOR CASE CONFIGURATION

Nomenclature		
Geometry		
Length, tangent-to-tangent (in.)	102.844	
Diameter of glass wall, internal (in.)	44.160	
Helix angle (deg)	21.5	
Thickness, composite helical (in.)	0.040	
Thickness, composite hoop (in.)	0.058	
Thickness, case liner (in.)	0.060	
Skirts, forward and aft end		
Helix angle (deg)	21.5	
Thickness, maximum (in.)	0.125	
Pole pieces, forward and aft end		
ID (in.)	14.00	
Bolt circle (in.)	15.024	
Calculated Weight Summary (lb)		
Fiberglass laminate (helical)	64.9	
Fiberglass laminate (hoops)	63.6	
Liner	50.0	
Forward and aft skirts	20.0	
Forward and aft polar fittings	19.2	
Self-locking screw thread crescent insert	0.3	
Subtotal, filament wound case assembly after cure		218.0
PYROGEN cap	8.8	
Bolts	1.9	
Flat washers	0.1	
O-ring seal	0.1	
Self-locking screw thread crescent insert	0.1	
Total, filament wound case assembly, less nozzle and insulation		229.0

Pertinent case dimensions were an overall length of 132.04 in., a tangent-to-tangent length of 102.84 in., and an inside case diameter of 44.10 inches.

Forward and aft pole pieces (7075-T6 aluminum) were of the same basic design because of similar dome contours. Polar ring geometry was determined by dome contours, imposed loads, and the bonds between ring and fiberglass at ultimate case pressure.

A single, fixed, conical, partially recessed nozzle was designed to attain a motor mass fraction of 0.965. Use of the single nozzle design, which required only one aft opening in the case, simplified the case design and reduced case fabrication time.

Detailed theoretical stress analyses for the TU-290 case and nozzle designs are given in Volume VI.

b. Winding Pattern Considerations

(1) Case--The case cylinder was designed for a helical winding pattern. A helical angle of 21.5 deg provided constant stress at fore and aft ports of the case and prevented glass fibers from slipping after they were positioned on the mandrel. The helical filaments were covered by hoop filaments in the cylindrical section of the case. Winding equipment was electronically controlled using computer equipment to develop single or double loop patterns with 12 spools of 12 end fiberglass roving.

(2) Domes--Forward and aft domes were wrapped with a polar pattern. Since the single polar opening corresponded to the 21.5 deg helical angle of the cylindrical section, dome contours closely approximated the geodesic, or isotensoid dome configuration. The contour was evaluated using data coded for computer solution to determine inner and outer contours, weight, enclosed volume, and principal stresses.

Equations derived for the aft dome contour were basically the same as for the forward dome contour. The thin dome wall permitted realignment of filaments under load to compensate for the slightly different loading on the aft dome.

(3) Skirts--The fiberglass skirt design of the TU-227A case was selected for the TU-290 case. The cylindrical design (80 percent helical, 20 percent hoop windings) permitted the skirt to be prefabricated, slipped on the case during the wrapping process, and secured by hoop windings. Attachment bolt holes, to be drilled in the skirt after assembly of the case, were designed with metal bushing inserts to reduce bearing stress on fiberglass.

The forward and aft skirts were designed identically according to a single loop wrapping pattern at a helical angle of 21.5 degrees. Skirts for all five cases were fabricated of E-HTS glass.

c. Material Considerations

The case material was E-HTS reinforced fiberglass for case No. 1 and S-HTS glass for cases No. 2, 3, 4, and 5. The first case was a control unit used to identify design differences between TU-227A and TU-290 cases. The use of E-HTS glass provided an indication of the capability of S-HTS glass to meet case hoop glass stress (400,000 psi) and case helical glass stress (360,000 psi) requirements. (Laboratory tests showed an approximate 15 percent increase in strength of S-HTS, over E-HTS, glass.) Physical characteristics of the two glass materials (based on an ultimate case pressure of 792 psig) are listed below.

	E-HTS	S-HTS
Ultimate tensile strength, case (σ_{ug}; psi)	350,000	400,000
Helical stress (1.14 σ_{ug} - E; 0.90 σ_{ug} - S; psi)	400,000	400,000
Hoop stress (1.03 σ_{ug} - E; 1.00 σ_{ug} - S; psi)	360,000	360,000
Ultimate tensile stress, strand (psi)	550,000	600,000
Filaments per end (number)	204	204
Filament diameter (in.)	0.00037	0.00037
Glass content nominal (yd/lb)	14,000	15,000

2. TU-290 Case No. 1

a. Design

For TU-290 case No. 1 (Figure 4), the design resin content in helical windings was 19.0 percent (by weight) with a density of 0.075 lb/cu in.; the design resin content in hoop windings was 17.0 percent (by weight) with a density of 0.076 lb/cu inch. The composite wall density of 0.075 lb/cu in. is related to a strength-to-density ratio of $(1.62)(10)^6 : 1$.

At the ultimate pressure of 792 psig, maximum design allowable stress, strain, and case expansion values for S-HTS glass were:

	Stress (psi)	Strain (in./in.)	Case Expansion (in.)
Hoop glass	400,000	0.03358	---
Helical glass	360,000	0.03013	---
Composite	180,000	---	---
Dome-to-dome	---	---	3.868
Tangent-to-tangent	---	---	3.037
Radial increase	---	---	0.743

b. Fabrication

The mandrel for the TU-290 cases was identical to that for the TU-227A cases (Figures 16 and 17). A complete description of the mandrel is given in Volume V. The mandrel is basically a segmented plywood structure with machined plaster layer over domes and cylinder. The plaster is coated with Gen-Gard V-57 sealant (General Tire and Rubber Co) and covered with Gen-Gard V-45 case liner compound.

Skirts were wound for the TU-290 cases on special mandrels while the case mandrel was being prepared. The magnesium skirt mandrel was cleaned with methyl ethyl ketone, coated with four layers of carnauba wax, and buffed by machine between wax layer applications. The skirt mandrel was positioned in the wrapping machine (Figure 26). Two forward or two aft skirts were wound simultaneously and cut apart after fabrication and curing. Strip heaters within the skirt mandrel stabilized the temperature at 150°F throughout the winding operation. The mandrel was rotated at five rpm. After curing, the skirts and mandrel were placed in a lathe and machined to design dimensions.

For case fabrication, the case mandrel, with the case liner in place, was positioned in the winding machine, and eight layers of helical windings were applied. The skirts were positioned on the case with a special jig (Figure 29) and secured with hoop windings. Eleven layers of hoop windings were applied between tangent points on the case. Before the case was placed in the curing oven, the resin compound was partially cured (175°F) to set the filaments in place using heat lamps. The case and mandrel were removed from the winding machine and placed in the curing oven. Curing was accomplished by rotating the case at one to two rpm while the temperature was increased progressively from 200 to 350°F over a 20 hr interval.

Following controlled cooling to 100°F after curing, the case was removed from the oven, and the mandrel was removed from the case. The parting agent failed to release all the plaster from the case liner. Approximately two to six lb of plaster remained in the case.

Design and actual weights are compared in Table XIX for the completed case (Figure 65).

c. Test

(1) Preparation--The hydroburst test of TU-290 case No. 1 was conducted at Allison to demonstrate the structural integrity of the case, to verify designs and fabrication techniques, to obtain stress-strain data for evaluation of S-HTS glass potential strength, and to determine case elongation and radial growth. Longitudinal and radial deflection was measured by extensometer indicators, while strain on domes and cylinders was measured by strain gages cemented to the case (Figure 66). Case noise was monitored by three contact microphones. Changes of dimension were measured continuously as a function of time on strip chart recorders.

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TABLE XIX

TU-290 CASE WEIGHT SUMMARY

Item	Design Weight (lb)	Actual Weight (lb)		Weight, Case No. 3 (lb)	
	Cases No. 1 and 2	Case No. 1	Case No. 2	Design	Actual
Fiberglass	128.5	139.0	125.6	132.2	133.5
Skirts	20.0	22.2	23.1	21.3	23.4
Case liner	50.0	55.6	48.8	50.0	49.0
Elastomer	---	---	---	2.3	---
Polar fittings	19.2	17.2	17.0	16.7	17.1
Threaded inserts	0.3	---	---	0.2	---
Subtotal, case assembly	218.0	234.0	214.5	222.7	223.0
O-ring seal	0.1	0.1	0.1	0.1	0.1
PYROGEN cap	8.8	8.7	8.7	9.7	10.0
Flat washers (spacer sleeve)	0.1	0.2	0.2	0.3	0.3
Bolts	1.9	1.2	1.2	1.4	1.3
Threaded inserts	0.1	---	---	0.1	---
Total, case assembly	229.0	244.2	224.7	234.3	234.7

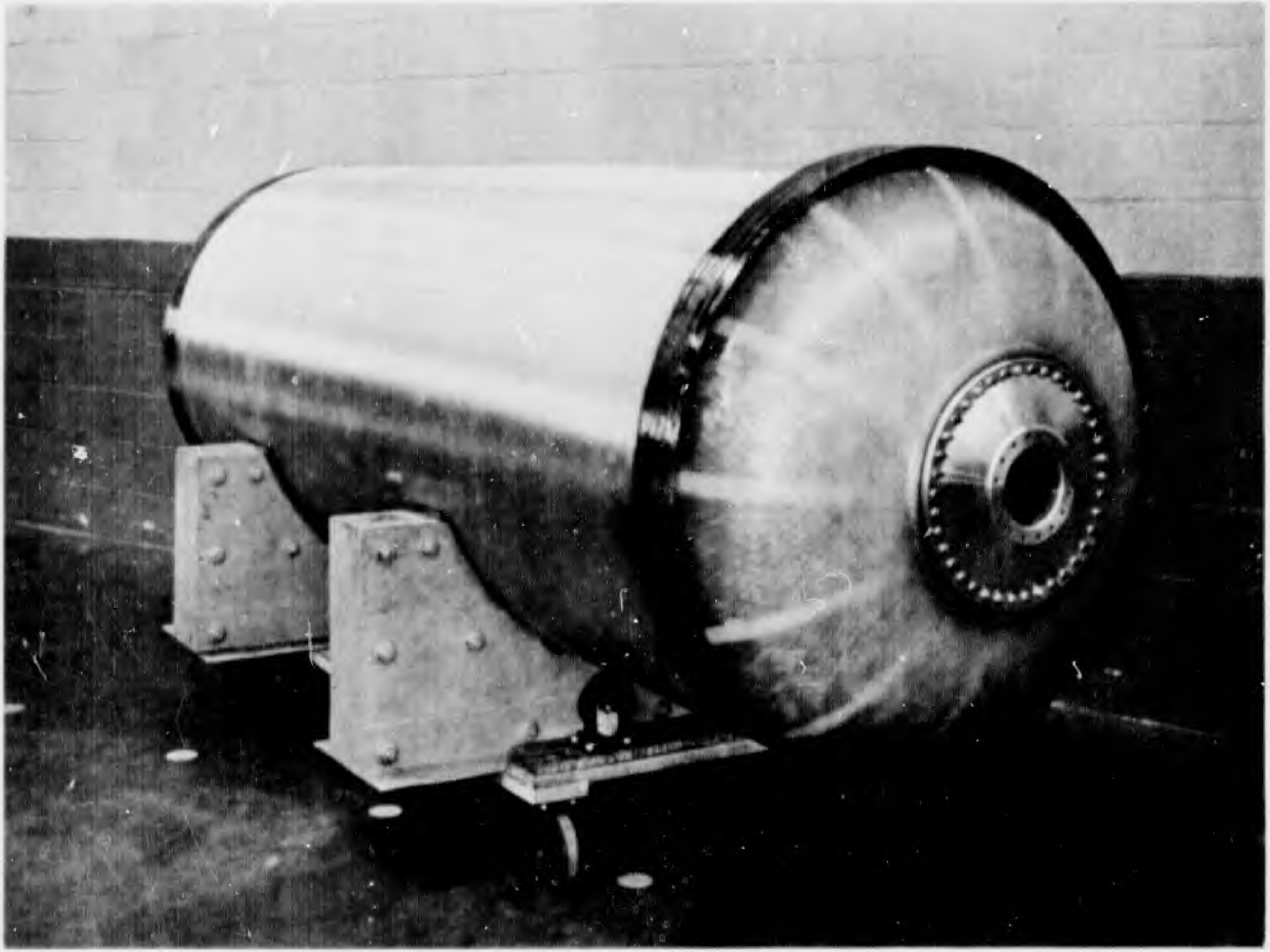

Figure 65. Completed TU-290 Case No. 1

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The case was mounted in the test stand in a vertical position and supported on the forward skirt. A sleeve and piston mounted in the nozzle port transmitted pressure from within the case as a load to the forward skirt through the test frame.

A hoop fiber stress of 350,000 psi at 700 psig burst pressure was predicted for case No. 1.

(2) Pressure Application--When the case internal pressure (Figure 67) was raised to 50 psig, sharp noises (due to resin cracking) were heard immediately, whose intensity increased to 40 db, approximately, over pump noise. Noises ceased while the pressure was maintained constant at 50 psig, but began again when more pressure was applied, increasing to a peak at 30 percent of burst pressure, then decreasing. At 50 percent of burst pressure, all noises had subsided except for sporadic cracking. Since all microphones indicated approximately similar noise levels, microphone location was not considered critical.

The case failed in the hoop fibers of the cylindrical section at 575 psig, while pressure was being increased to the proof pressure level at 660 psig (Figure 68). Pressure application was 53 sec behind the programed value, at the time of bursting. All instrumentation was working properly and all strain data appeared to be valid (Figures 69 and 70).

(3) Evaluation and Analysis--The premature case failure at 575 psig was attributed to the 53 sec lag of pressure application (relative to programed application). The failure to apply pressure at the programed rate permitted glass fibers to abrade adjacent fibers during case expansion, which reduced the strength of E-HTS glass. The manner of adding pumps to sustain pressure and water volume during case expansion was imperfect.

The water volume output of the pumps during the hydroburst test was inadequate.

Although the burst pressure and the hoop fiber stress test objectives (Table XX) for the first case were not fully met, the test results indicated that S-HTS glass, used with the basic designs and fabrication techniques would be satisfactory for the remaining TU-290 cases.

3. TU-290 Case No. 2

a. Design

The main objectives for the fabrication and test of case No. 1 were to establish the basic design of the TU-290 case and evaluate E-HTS glass. For case No. 2, the objective was to evaluate the case design using S-HTS glass. The design, wrapping pattern, hardware attachments, and winding equipment remained the same as for case No. 1.

DEFLECTION MEASUREMENT

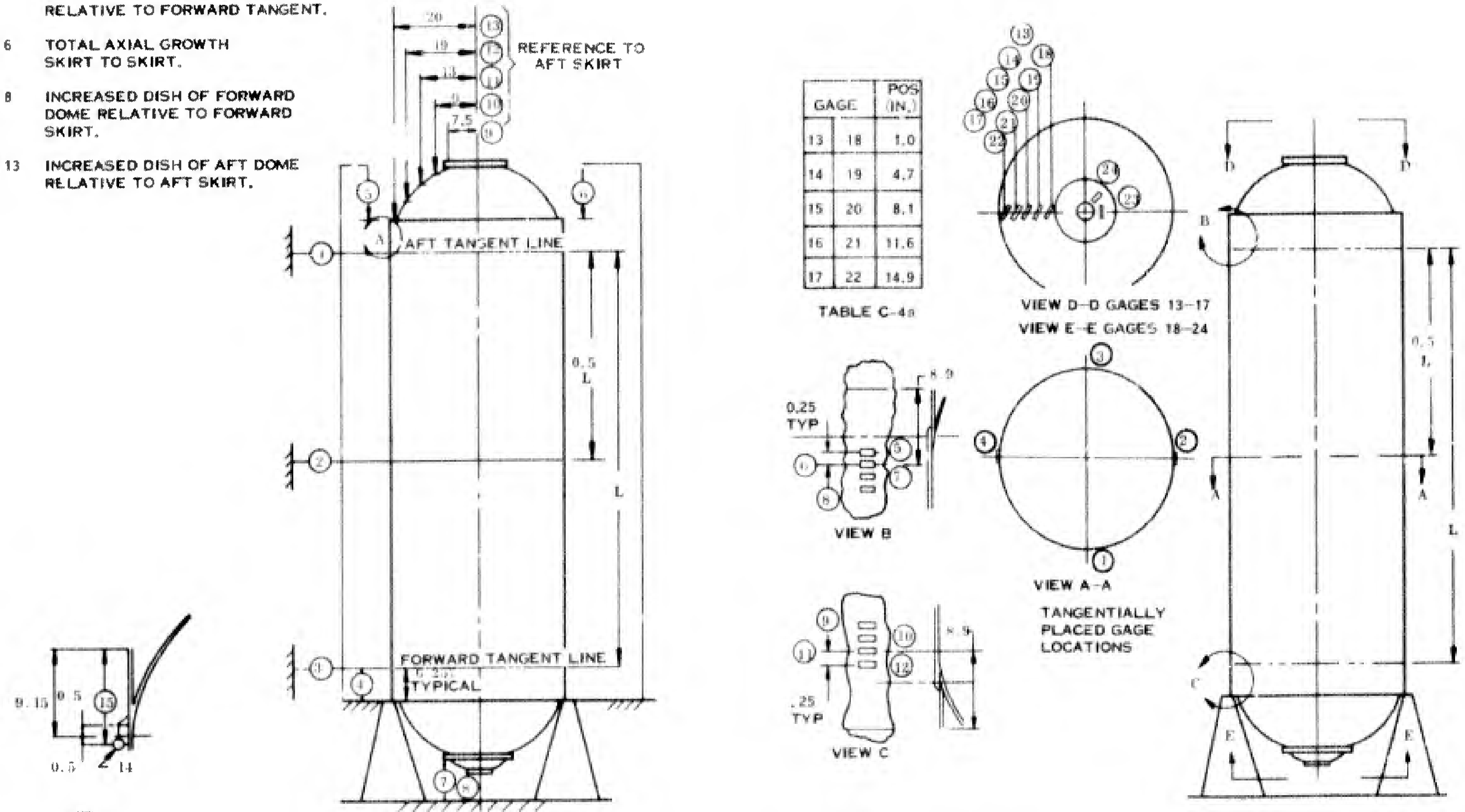
1 2 3 CIRCUMFERENTIAL GROWTH.

4 DEFLECTION FORWARD SKIRT RELATIVE TO FORWARD TANGENT.

5 6 TOTAL AXIAL GROWTH SKIRT TO SKIRT.

7 8 INCREASED DISH OF FORWARD DOME RELATIVE TO FORWARD SKIRT.

9 13 INCREASED DISH OF AFT DOME RELATIVE TO AFT SKIRT.



GAGE		POS (IN.)
13	18	1.0
14	19	4.7
15	20	8.1
16	21	11.6
17	22	14.9

TABLE C-4a

NOTES:

1. CONTACT MICROPHONES WERE LOCATED NEAR GAGES 3, 17, AND 18.
2. GAGE NO. 13 THRU 22 ARE LOCATED PARALLEL TO OUTER FILAMENT AT CONTOUR DISTANCES FROM THE OD OF THE PORT BOSS AS SHOWN IN TABLE C-4a. GAGE NO. 23 AND 24 ARE LOCATED 4.5 IN. FROM THE CENTER OF THE BOSS.

Figure 66. TU-290 Case No. 1 Hydroburst Test Instrumentation Arrangement

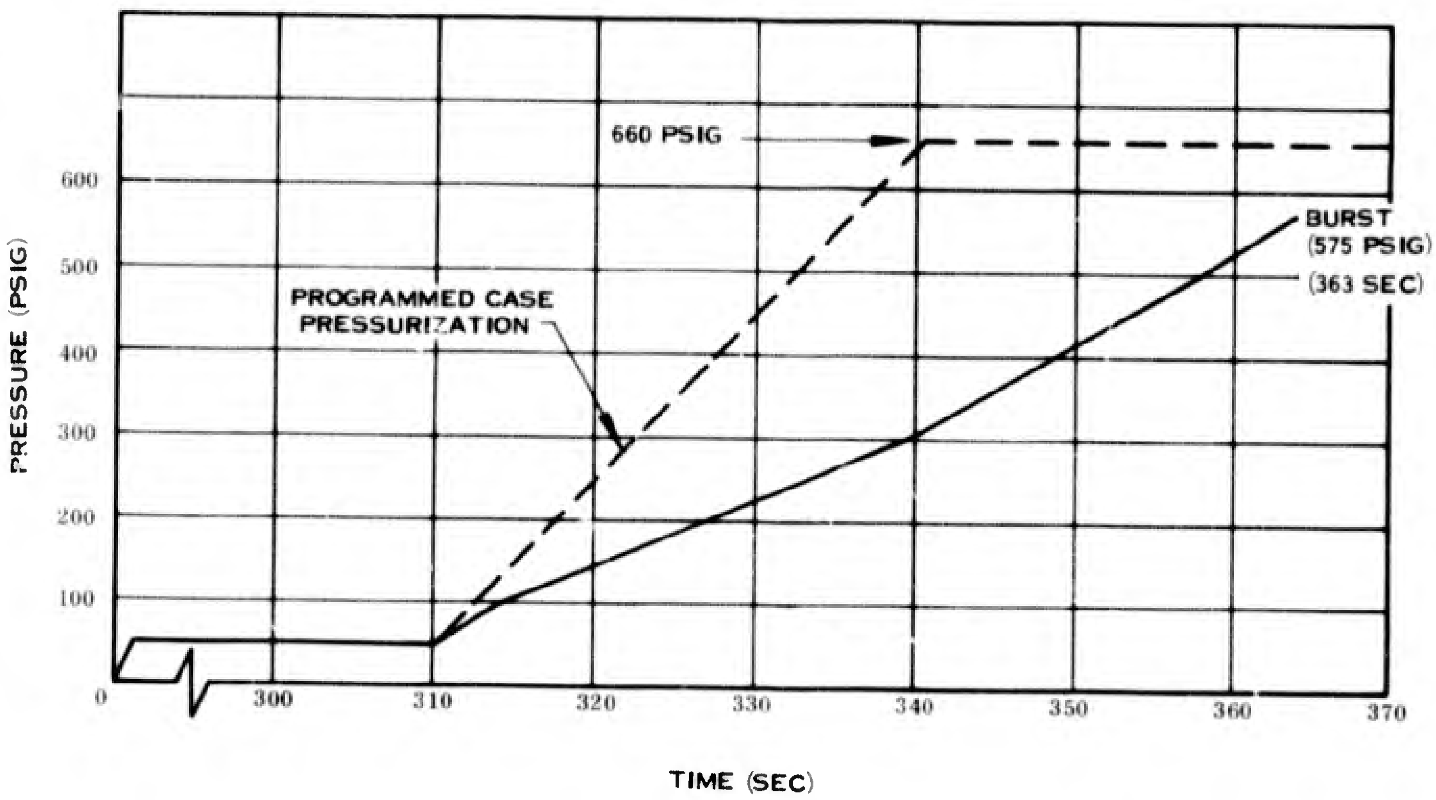


Figure 67. TU-290 Case No. 1 Hydroburst Test Pressure Record

Figure 68. TU-200 Case No. 1 After Hydroburst Testing

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TABLE XX

TU-290 CASE HYDROSTATIC TEST DATA SUMMARY

	Case No. 1	Case No. 2	Case No. 3
Burst Pressure (psig)			
Predicted	700	792	792
Actual	575	660	750
Hoop Fiber Stress (psi)			
Predicted	350,000	400,000	400,000
Actual	290,000	350,500	379,000
Ultimate Tensile Strength (psi)			
Actual	121,000	150,250	161,000
Case Wall Thickness (in.)			
Design	0.098	0.098	0.105
Actual	0.105	0.097	0.103

Note: TU-290 cases No. 4 and 5 withstood successfully 550 psig hydroproof test.

○ Indicator No.

All deflections indicate an elongation (for outward movement) of the case except No. 4 which represents a shortening of the skirt.

Indicators Nos. 9 thru 13 returned to zero at 500 psig.
Indicators Nos. 7 and 8 limited by indicator travel.

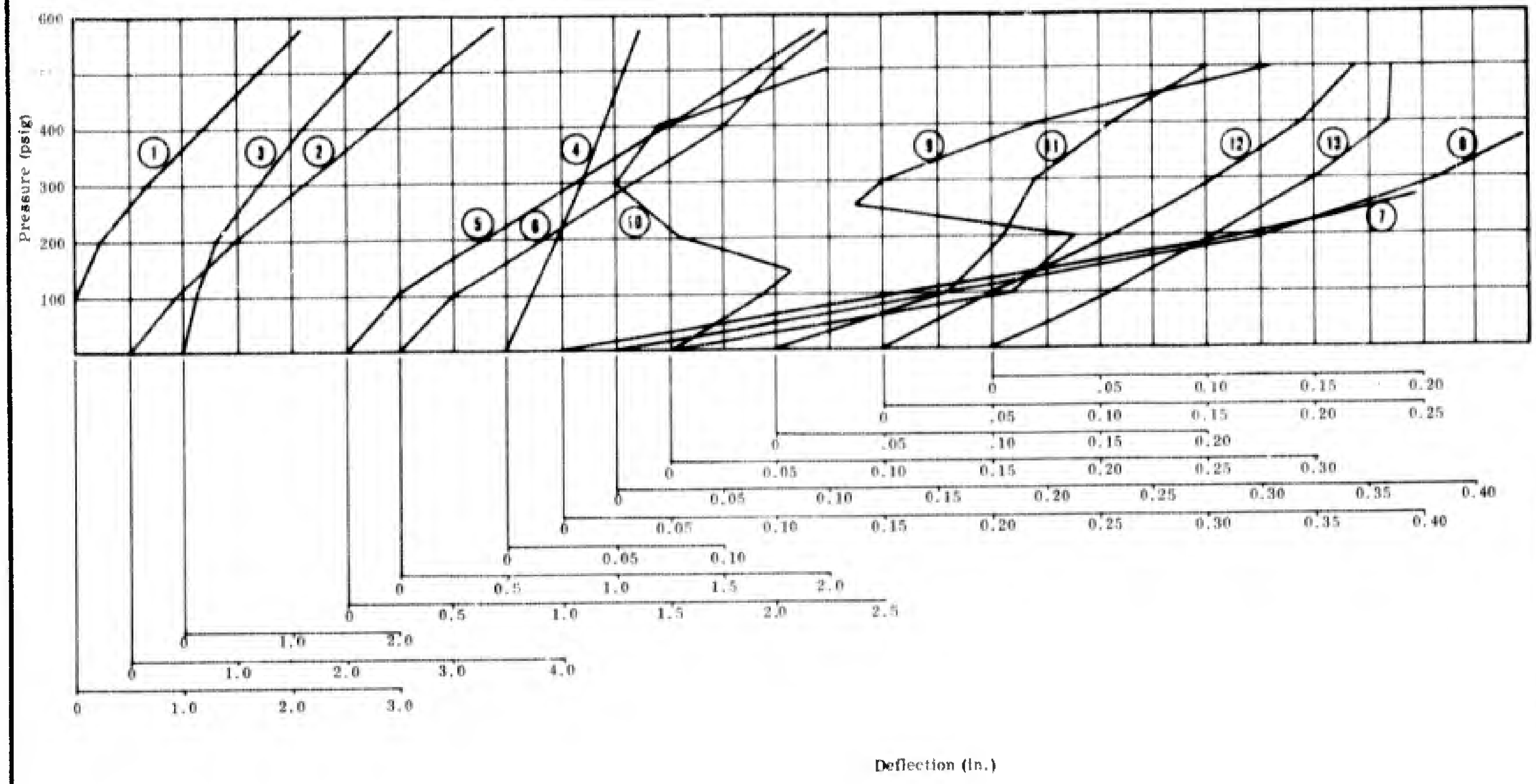

Figure 69. TU-290 Case No. 1 Hydroburst Test Deflection Indications

b. Fabrication

(1) Case--Computation of design strength of case No. 2 was based on the use of S-HTS glass having a filament diameter of 0.00037 inch. The dimension was quoted by the fiberglass supplier, Owens-Corning. During testing of materials for case No. 2, however, Allison calculated the filament diameter of S-HTS glass to be 0.00036 in., based upon the yield from the glass spools.

During fabrication of case No. 2, considerable fraying and breaking of S-HTS glass fibers was observed as the glass was fed onto the case mandrel. Thiokol and Allison conducted investigations.

Allison discovered that the direction of winding S-HTS glass on the spools (the direction in which glass strands are wound onto, or unwound from, the spools, known as "waywind"; i.e., the "lead" or "lag" of the winding pattern) differed from that of E-HTS glass. E-HTS glass had lead waywind, but S-HTS glass used for case No. 2 had lag waywind. The difference was not noticeable unless the spools were closely observed while being unwound. This difference in waywind caused unwinding S-HTS glass strands to scuff across adjacent strands and to damage the glass. The scuffing and fraying was particularly noticeable at the ends of the spools.

Allison showed that, with a lead waywind, strand being unwound left the spool without damaging strand remaining on the spool. Transfer characteristics of spools of S-HTS glass with lead waywind and with lag waywind, and a spool of E-HTS glass having lead waywind were compared. The spool of S-HTS glass having lag waywind showed the greatest damage to the glass. Ends of glass were frayed and fibers were found on the roller below the spool.

Because of fraying and reduced filament diameter, predicted strength data for case No. 2 were invalid. To determine whether or not the case was strong enough to yield significant data during hydroburst testing, Allison conducted tensile strength tests on the frayed S-HTS glass. The tests showed that damaged S-HTS was still stronger than E-HTS glass used for case No. 1.

The Allison material specification for S-HTS glass (and specifically that for use on cases No. 3, 4, and 5) was amended to include the following.

1. That S-HTS glass shall have a minimum average tensile strength of 600,000 psi, as determined by 100 percent sampling of the spools.
2. That glass shall be wound on spools with a lead waywind.
3. That the weight of glass per spool shall be between 12.5 and 15 pounds.

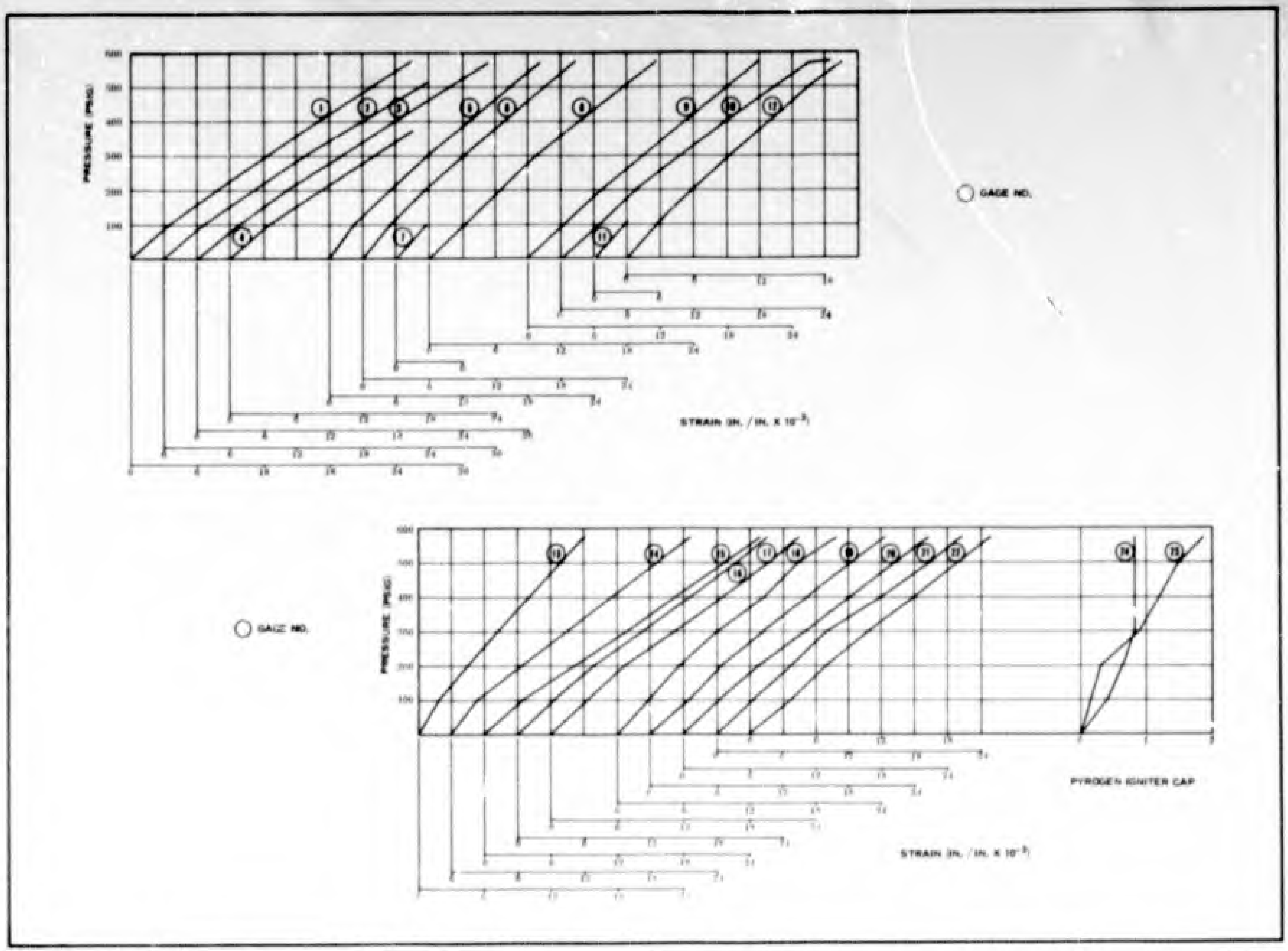

Figure 70. TU-290 Case No. 1 Hydroburst Test Strain Indications

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4. **That test data on the individual breaking loads and yield strength (gm/yd/end) for each test shall be furnished by the supplier.**

During the interval between fabrication of cases No. 2 and 3, Allison purchased and installed 12 glass transfer tensioning (replacement) systems for winding equipment from the Compensating Tension and Control Co, Irvington, N.J. (CTC) to stabilize strand tension at lower values than were possible with the existing tensioning systems.

Design and actual weights are compared in Table XIX.

c. Test

(1) Instrumentation and Pressure Application--The instrumentation arrangement for hydroburst testing of TU-290 case No. 2 was basically the same as for case No. 1. A hoop stress of 400,000 psi at a burst pressure of 792 psi was predicted for the case. The program for testing was the same as for case No. 1.

Cracking noises were heard, as when testing case No. 1. The case failed five sec after the internal case pressure leveled off at 660 psig. At the time of the failure, the pressure buildup was only 10 sec behind the programed pressure buildup. The failure started in a circumferential crack produced by the separation of hoop windings near the forward tangent line. The forward dome pole cover shear lip failed either during or immediately after the hydroburst test. The lip was found to be separated (for approximately 75 percent of the circumference) from the cover plate flange. All instrumentation operated properly and test data appeared valid.

(2) Evaluation and Analysis--The case failure (at 660 psig) was approximately 17 percent below the design burst pressure (Table XX). During the post test analysis, Allison confirmed the observation that the fiberglass diameter was only 0.00036 in., instead of 0.00037 inch. The smaller dimension was used to recalculate design parameters. The smaller diameter reduced the value for glass content in the case by 6.25 percent.

The case design was re-evaluated, using the lower value for the glass diameter, and a new pressure value was computed (725 psig). Using 725 psig as the burst pressure, the actual burst pressure of 660 psig was only 9 percent low. This difference was attributed to the glass fiber fraying and breaking which occurred during the fabrication. The fraying and breaking problem was eliminated for future cases by changing the waywind direction from lag to lead on spools of S-HTS glass.

While failure of the shear lip did not cause ultimate strength failure of the cover plate (nor of the case itself) the forward polar fitting was permanently deformed due to imposed stresses above the yield strength, after shear lip failure.

The designs, fabrication techniques, materials, and hydroburst data for cases No. 1 and 2 were thoroughly evaluated and analyzed at the end of case No. 2 effort. This evaluation and analysis showed that the basic designs, techniques, and materials for the TU-290 case were sound and that a case could be fabricated that would meet the program requirements.

The evaluation and analysis also showed that a number of minor design and fabrication changes were necessary before case No. 3 could be fabricated.

1. The case design parameters must be modified to account for the reduced glass filament diameter of 0.00036 inch.
2. The band width, band advance, and number of layers must be changed to correspond with the smaller glass filament diameter.
3. The PYROGEN igniter cap must be redesigned to prevent the shear lip from cracking.
4. Methods of adjusting case growth and skirt restraint, to prevent premature failure in the case-dome-skirt region must be studied and included in the design of case No. 3.
5. Materials acceptance specifications must be amended to prevent S-HTS glass fraying difficulties.
6. The release agent between the case liner and plaster of the mandrel must be improved to facilitate mandrel removal.
7. New tensioning systems should be installed to stabilize fiberglass tensioning values at lower levels.

4. TU-290 Case No. 3

a. Design

(1) S-HTS Glass--The TU-290 case design was modified to accommodate a glass filament diameter of 0.00036 inch. The band width, band advance, and number of glass layers were also changed to correspond with the smaller glass diameter. The wrapping path was changed to eliminate some filament contact points.

(2) Case Hardware--The PYROGEN igniter cap adapter and forward polar fitting were redesigned, to increase the thickness of the shear lip, to increase the flange thickness, and to provide a larger fillet radius between the shear lip and the body. The redesign increased strength and reduced stress concentrations in the igniter cap without altering margins of safety. (See Volume VI, "Stress Analysis.")

(3) Skirt Attachment--To improve the reliability of the case, methods of adjusting case growth and skirt restraint at the skirt-case cylinder-dome juncture were analyzed.

The skirt-case-dome juncture must withstand flight loads under all conditions from zero to ultimate design burst limit pressure. The skirt and case, under pressurization, do not expand at a common, constant rate, even though they are bonded together in a monolithic construction at the juncture. The greater rate and amount of case radial growth imposes increasing compressive stress on the juncture under increasing hoop restraint of the skirt. When the stress becomes sufficiently severe, for any case design, the juncture must inevitably rupture. The design problem was restudied, i.e., how to maintain the skirt diameter large enough to avoid severe stress while the case was under pressure, and also maintain an integral bond while the case was not pressurized.

To overcome the design problem, a shear ply (a thin sheet of Buna-N rubber) was added between the inside skirt diameter and the helical windings of the case. A stress discontinuity analysis (Volume VI) showed no appreciable change in margin of safety.

(4) Winding Mandrel--The parting mechanism used to separate the case liner from plaster on the mandrel was changed to simplify case mandrel removal. A layer of RTV rubber, 0.005 in. thick, and a layer of General Tire and Rubber Co C-41 non-curing adhesive, 0.005 to 0.10 in. thick, were applied to the mandrel. The V-45 case liner was wrapped over this layer of rubber. Seams were sprayed with V-57 sealant.

b. Fabrication

The redesigned skirts, incorporating the Buna-N shear ply to absorb case growth stress, were fabricated without incident. Removal of the skirt from the mandrel was difficult, however, due to Buna-N rubber on the skirt. The case was wound of S-HTS fiberglass without difficulty. Design and actual weights of the case are compared in Table XIX.

c. Test

(1) Instrumentation and Pressure Application--To provide an adequate volume of water, a preselected volume and flow rate, based upon case expansion under pressure, was established. The instrumentation arrangement for hydroburst test of case No. 3 was the same, basically, as for previous TU-290 cases, except that a number of strain gages (16) were placed on the forward polar fitting to gain data for stress analysis on the redesigned fitting. (The polar fitting on case No. 2 was deformed when the shear lip failed.)

The test was successfully completed through and including the proof pressure check at 660 psig for 60 seconds. Case failure occurred at 750 psig, starting in a circumferential crack in the aft tangent area. Film coverage (64 and 500 fps) of the burst showed that the failure started at the edge of the aft skirt. Strain gages located in the region of failure indicated that the hoop laminate separated at the forward edge of the aft skirt at approximately 400 psig.

The hydrostatic piston load force, which was reacted by the forward skirt to the test frame, offset the tendency of the forward skirt to move with the dome growth. As a result, separation did not occur in the hoop laminate at the trailing edge of the forward skirt.

Nonlinear deflections were recorded at extensometer stations on the aft dome of each case (e.g., extensometer indications 9 and 10, Figure 69). The erratic pattern of these indicators suggests a peculiar deflection characteristic of the aft dome design. All instrumentation operated properly and all test data appeared valid.

(2) Evaluation and Analysis--Changing the waywind direction from lag to lead on the spools of S HTS glass completely eliminated strand fraying and breaking. Hoop fiber strength was eight percent higher than for case No. 2, primarily because S-HTS glass was fed onto the case mandrel without damage.

Buna-N rubber as a shear ply between the skirt and case helical windings successfully prevented bond failure in the skirt-dome attachment regions. Fiberglass from the helical windings adhering to the inside of the rubber membrane after the hydroburst test attested to the effectiveness of the elastomeric ply.

After case No. 3 was tested, corrective action to eliminate hoop laminate separation during case pressurization was investigated. Incorporating a helically wound fiberglass mat at the forward edge of the aft skirt was considered an effective way of preventing the hoop laminates from separating. This design consideration was proposed to the Air Force for inclusion in cases No. 4 and 5.

Although a burst pressure of 792 psig and a hoop fiber stress of 400,000 psi were not attained, the values obtained (750 psig and 379,000 psi; Table XX) were deemed acceptable to satisfy program objectives (Supplemental Agreement No. 5 to Contract AF 33(600)-42511, dated 6 Jun 1963). For cases No. 4 and 5, the proof pressure was established at 550 psig.

5. TU-290 Cases No. 4 and 5

a. Design

During the analysis of case No. 3, Thiokol recommended to the Air Force that a helically wound fiberglass mat be placed over the forward edge of the aft skirt to eliminate possible hoop laminate separation. The Air Force permitted fabrication of two cases identical to case No. 3, with a modified ballistic design. The Buna-N rubber shear ply between the helical case windings and the skirts was tapered, on cases 4 and 5, to provide a flat surface in the skirt joint area for the hoop windings.

b. Fabrication and Test

With the exception of adding case insulation to the winding mandrel, cases No. 4 and 5 were fabricated identically to case No. 3. Actual weights and dimensions for the two delivery cases are shown in Table XXI. TU-290 cases No. 4 and 5 were successfully hydroproof tested at 550 psig. Following tests, the cases were packaged for shipment and forwarded to Thiokol for bonded storage.

6. TU-290 Rocket Motor Design

a. Ballistic Design

The preliminary ballistic design for the TU-290 motor was started and completed during the fabrication and hydrotest of case No. 2. The design at that time specified a six pointed star configuration using PBAA type propellant.

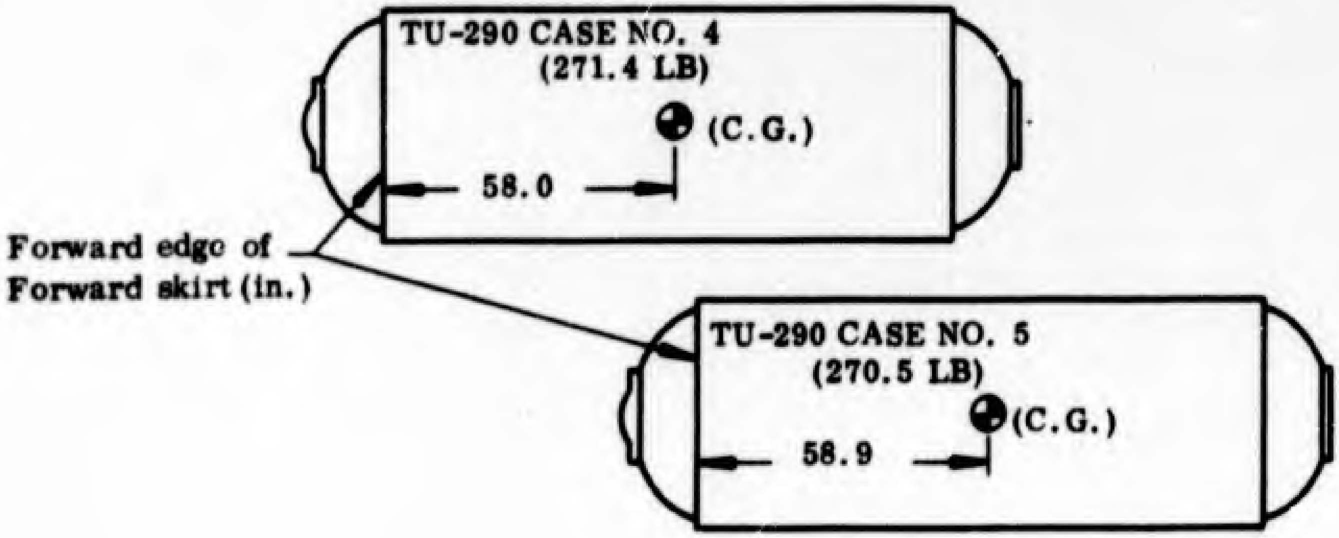
This preliminary ballistic design was later changed to a slotted, cylindrical perforation (CP) grain to reduce propellant strain during motor operation, to gain a neutral thrust characteristic curve over the entire action time, and to increase the motor mass fraction.

Changing to a slotted CP grain required slight modifications to the insulation design for cases No. 4 and 5. The thickness of V-44 rubber to insulate dome areas was increased, and the split flap was removed. Moreover, the dome insulators were changed to a homogeneous, solid part. Two additional small sections of V-44 rubber were added in aft and forward ends of the cylindrical section of the case to accommodate end burning in the slotted areas.

TABLE XXI

TU-290 CASES NO. 4 AND 5 WEIGHT SUMMARY

Item	Design Weight (lb)	Actual Weight No. 4 Case (lb)	Actual Weight No. 5 Case (lb)
Fiberglass	132.2	144.7	142.8
Skirts	23.3	25.3	23.4
Case liner	30.7	27.2	28.0
Insulation	48.6	45.5	47.8
Polar fittings	16.7	17.2	17.4
Subtotal, case assembly	251.5	259.9	259.4
O-ring seal	0.1	0.1	0.1
PYROGEN cap	9.8	9.9	9.5
Bolts	1.6	1.5	1.5
Total, case assembly	263.0	271.4	270.5



The head end of the motor was designed to accommodate a TU-222 **PYROGEN** igniter.

b. Nozzle Design

The preliminary nozzle design for the TU-290 motor was completed and analyzed (see Volume VI for analysis). The nozzle was a partially recessed, fixed, conical nozzle with HLM-85 graphite in the throat. The design was later modified to replace the monolithic graphite throat with three graphite rings to accommodate thermal expansion and prevent the HLM-85 graphite from fracturing. The revised design, submitted to Air Force Materials Laboratory and Rocket Propulsion Laboratory was further modified, all changes being incorporated into Thiokol Drawing 9U34907. The H. I. Thompson Fiber Glass Co was awarded a subcontract to build two nozzles to Drawing 9U34907. (See Volume IV.) A test of a similar nozzle at Thiokol in August 1963 indicated greater erosion in the recessed portion of the nozzle than was anticipated. Using erosion data from this test and plotting a new erosion profile at T + 55 sec, the nozzle design was found to be inadequate. The amount of insulating material remaining in the recessed region was marginal for thermal insulation and strength. The nozzle design was modified to place the metal part deeper into the surrounding insulation and a revision was made to Drawing 9U34907. (See Volume IV.) The external contour of the recessed section was not changed; only internal mating surfaces were affected. The insulating material remaining at T + 55 sec was assessed to be sufficient to protect metal parts from excessive heat and thus retain strength values.

Two nozzles for the TU-290 motor, fabricated to the revised Drawing 9U34907A were finished, and shipped to Thiokol after case No. 5 was fabricated and proof tested.

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