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APOLLO/SATURN V SPACE VEHICLE SELECTED STRUCTURAL ELEMENT REVIEW REPORT, AS-503

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REVISIONS

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ABSTRACT

This document reports the results of a detailed review conducted on Apollo/Saturn V prime contractors manufacturing methods and quality assurance procedures for twenty-three (23) selected elements of the AS-503 Space Vehicle primary structure. Sketches are shown of appropriate fabrication and assembly operations associated with the elements. Material design allowables, stress corrosion, honeycomb structure, fracture mechanics, and hydrogen embrittlement information is also provided. Conclusions and recommendations based on an assessment of the detailed review are included.

KEY WORDS

Space Vehicle

Selected Elements

Structural Integrity

Assessment

Quality Assurance

Manufacturing Methods

On-Site Reviews

MRB Actions

Materials Design Allowables

Stress Corrosion

Honeycomb Structure

Fracture Mechanics

Hydrogen Embrittlement

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INTRODUCTION

This document contains the assessment of the manufacturing methods and quality assurance procedures used on twenty-three (23) structural elements of the AS-503 Space Vehicle selected for review by JSAT. The review was conducted in accordance with the "Technical Approach Plan for the AS-503 Structural Integrity Assessment Task" under contract NAS8-5608, Schedule IV, Exhibit "A", Part IV, Task 1.0.

The following criteria was used by JSAT in the selection of these elements:

a. Negative margins of safety
b. Analyses uncertainties
c. Lack of correlation between test and analyses
d. Complex or critical manufacturing and QC requirements
e. JSAT concern

The objective of this task was to assess the contractors manufacturing methods and quality assurance procedures used on the selected elements for assurance that the structural integrity of the fabricated elements is consistent with the AS-503 design objectives. In addition, a materials evaluation study was conducted which included stress corrosion, hydrogen embrittlement, fracture mechanics, honeycomb structures, and material design allowables.

ABBREVIATIONS

AO	Assembly Outline
AQ	As Quenched
Assy.	Assembly
Bhd.	Bulkhead
CDDT	Countdown Demonstration Test
CECO	Center Engine Cutoff
CM	Command Module
COFW	Certification of Flight Worthiness
COSMOS	Comprehensive Option, Stiffness Method Operational System
DPS	Douglas Process Standard
EO	Engineering Order
FAIR	Fabrication and Inspection Record
FARR	Failure and Rejection Report
FO	Fabrication Outline
FWD	Forward
GSE	Ground Support Equipment
HMO	Handling and Moving Orders
IBM	International Business Machines
IBMH	International Business Machines, Huntsville
Instl.	Installation
IOS	Inspection Operation Sheet
IU	Instrument Unit
ITI	Inspecting and Testing Instructions
JSAT	Joint Structural Assessment Team
KSC	Kennedy Spaceflight Center
LAD	Los Angeles Division
LM	Lunar Module
LES	Launch Escape System
LH_2	Liquid Hydrogen
LOX	Liquid Oxygen
L/V	Launch Vehicle
MDC	McDonnell-Douglas Corp.
MIG	Metal Inert Gas
MORTP	Manufacturing or Testing Procedure
MR	Material Review
MRB	Material Review Board
MRD	Material Review Disposition
MSFC	Marshall Space Flight Center
N/A	Not Available
NAA	North American Aviation
NASA	National Aeronautics and Space Administration
NASA/MICH	NASA/Michoud
NDT	Non-Destructive Test
NR	North American Rockwell Corp.
PRO	Planning Residential Order
psi	Pounds Per Square Inch
PSIG	Pounds Per Square Inch Gage

ABBREVIATIONS CONTINUED

QC	Quality Control
Q&RA	Quality and Reliability Assurance
RFC	Reason For Concern
RHR	Roughness Height Rating
RMO	Resident Manager's Office
SAMECS	Structural Analysis Method for Evaluation of Complex Structures
SLA	Spacecraft LM Adapter
SM	Service Module
SQ	Squawk
STC	Sacramento Test Center
TBC	The Boeing Company
TBC/MICH	The Boeing Company/Michoud
TIG	Tungsten Inert Gas
UER	Unplanned Event Record
VAB	Vertical Assembly Building
VSD	Vendor Shipping Document

SUMMARY

A detailed review, including on-site inspection at the contractors' plant, was conducted on twenty-three (23) selected structural elements of the AS-503 Space Vehicle in support of the Structural Integrity Assessment Task. The twenty-three elements selected by JSAT include:

1. LOX Tank Lower Bulkhead (S-IC-3)
2. Forward Skirt (S-IC-3)
3. LOX Tank Girth Weld (S-II-3)
4. LH_2 Tank Forward Bulkhead (S-II-3)
5. Forward Skirt (S-II-3)
6. Common Bulkhead - Aft Bulkhead/ Aft Bulkhead-Thrust Structure Joints (S-IVB-503)
7. Forward Skirt (S-IVB-503)
8. IU Shell (IU-503)
9. X_A 502 Interface (SLA-11)
10. SLA/LM Interface (SLA-11)
11. X_A 585 Joint (SLA-11)
12. X_A 709.9 Splice (SLA-11)
13. Shell (SLA-11)
14. SM/SLA Interface (SLA-11)
15. Aft Bulkhead (SM-103)
16. SPS Tanks (SM-103)
17. SPS Tank Skirts (SM-103)
18. SPS Fwd Tank Supports (SM-103)
19. Shell (SM-103)
20. CM/SM Interface (SM-103)
21. Longerons (CM-103)
22. Forward Bulkhead (CM-103)
23. LES/CM Interface (LES-503)

The review consisted of a detailed evaluation of each contractors manufacturing methods and quality assurance techniques and procedures used on the various selected elements.

While discrepancies occurred during fabrication and assembly of these elements, each discrepancy was dispositioned satisfactorily. Perhaps the most significant was the replacement of the S-II-3 LH_2 tank bulkhead with the bulkhead from the S-II-5 LH_2 tank. Adequacy of this disposition was verified by cryogenic proof testing.

The conclusion reached by the review team was that the contractors had demonstrated assurance that the quality and structural integrity of the selected elements was consistent with the AS-503 design objectives.

Stress analyses and structural test summaries on the AS-503 selected elements are included in the Structural Capability Document D5-15781.

SECTION 1

S-IC-3 LOX TANK LOWER BULKHEAD

SELECTED ELEMENT REPORT

1.0 SUMMARY

The purpose of this review was to evaluate the manufacturing and quality control procedures employed during fabrication and assembly of the S-IC-503 LOX Tank Lower Bulkhead to determine if the "as-built" configuration structural integrity is assured.

The conclusions of this report are founded on information obtained at TBC/MICH from:

a. The inspection of manufacturing and quality control facilities and activities.

b. The discussions with the Engineering, Manufacturing and Quality Control personnel concerning fabrication of the subject element.

c. The review of pertinent documentation including but not limited to, manufacturing plans and specifications, engineering drawings, MRB actions, and Design Certification Review, Reference 1.1.

The investigating team concludes that the methods employed and results achieved do offer assurance of the structural integrity of the lower LOX bulkhead.

1.1 DESCRIPTION

The S-IC LOX tank lower bulkhead comprises that portion of the vehicle which extends from Vehicle Station 772 to Vehicle Station 909. The bulkhead is a welded, ellipsoidal shaped dome of 2219 aluminum alloy consisting of eight (8) apex and eight (8) base gore segments, a Y-ring, and a polar cap. This element forms the aft end of the LOX tank and its Y-ring serves as the joint for the forward end of the intertank structure. See Figure 1-1.

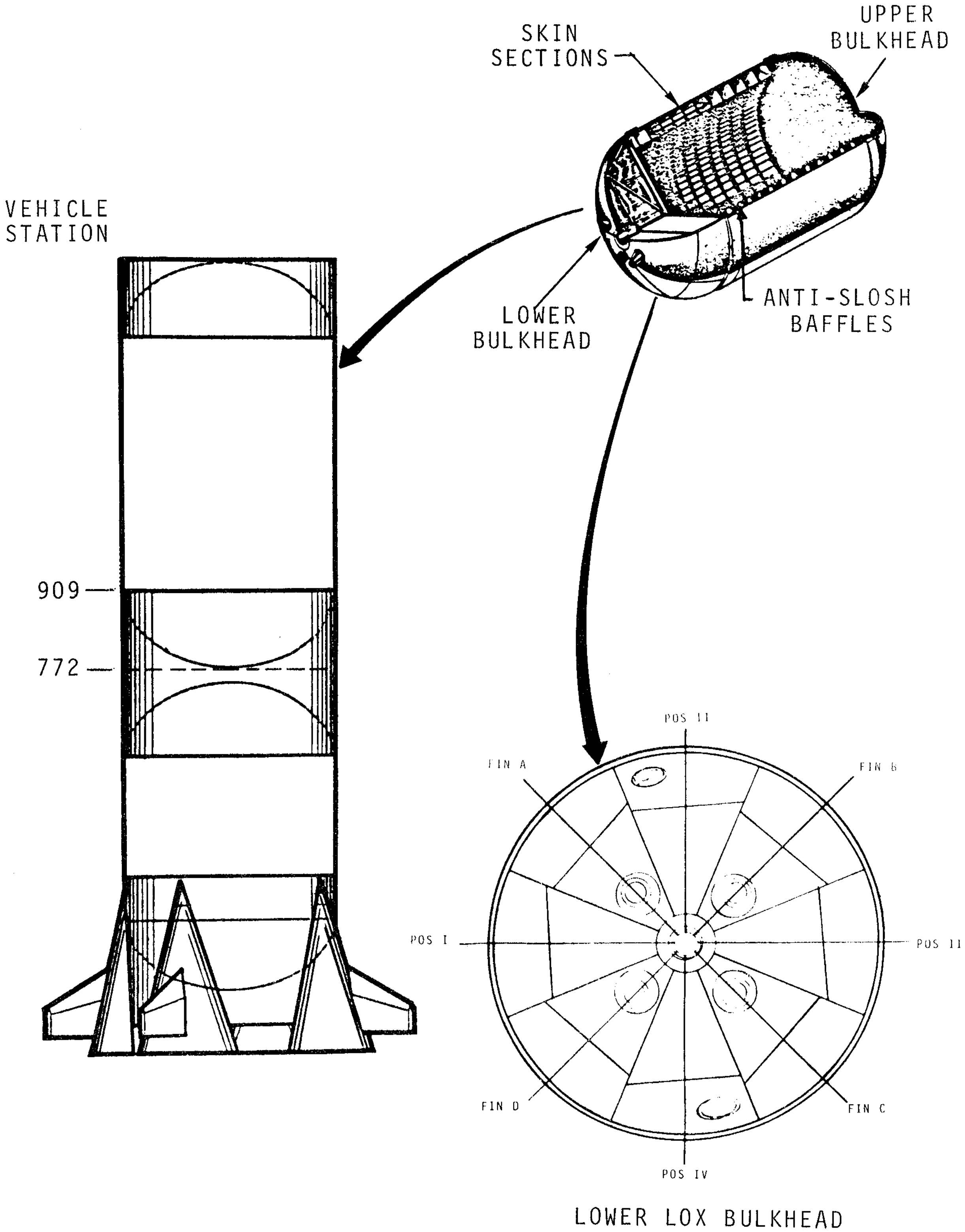


FIGURE 1-1 S-IC LOWER LOX BULKHEAD

1.2 MANUFACTURING

1.2.1 Fabrication

The apex and base gores were fabricated in Wichita from 2219-T37 aluminum sheets purchased per BMS 7-105C. The segments were sculptured and machine milled in the flat condition. The milling provided a light structure with weld lands at the edges and integral membrane and stiffener configuration in the base gore segment to carry hoop compression stresses.

Following the milling operation, the segments were rough rolled to the approximate desired contour. The segments were then hydraulically bulge formed to the finish contour, rough trimmed, cleaned, and heat treated to the T87 condition.

The polar cap was machined from 2219 aluminum.

The Y-ring was made at Michoud from 2219-T351 aluminum billets which were rolled to a radius of sixteen and a half feet and then oven aged to T851 hardness. The three billets were then butt welded to form a ring. The MIG welding was performed from both sides of the joints simultaneously (each joint required approximately 112 welding passes). The completed 19,000 pound billet ring was then placed on a boring mill and turned to the finished Y-ring configuration, having a thirty-three foot diameter which weighed approximately 3500 pounds.

1.2.2 Assembly

Following receipt of the apex and base gore segments from Wichita, the edges of the segments were prepared for joining by trimming and fitting. The appropriate apex and base gores were joined using the TIG welding process. The eight assembled gores were joined by the same process to form the gore to gore assembly. Subsequently, the Y-ring was welded to this gore assembly utilizing the TIG welding process. The final step was the TIG welding of the 54 inch polar cap into position to complete the ellipsoidal shaped bulkhead. See Figures 1-2 thru 1-5. The following MORTP's detail the operations on the foregoing steps of assembly: 60B12200-1-904 thru 907, 949, 950, 960 and 970.

In conjunction with the Y-ring to bulkhead weld, a certification weld (per MORTP WC 60B12200-1B-970) of a partial Y-ring to a partial base gore was made under the surveillance of the Boeing Welding Engineer and the NASA Certifying officer. This was for the purpose of certifying the

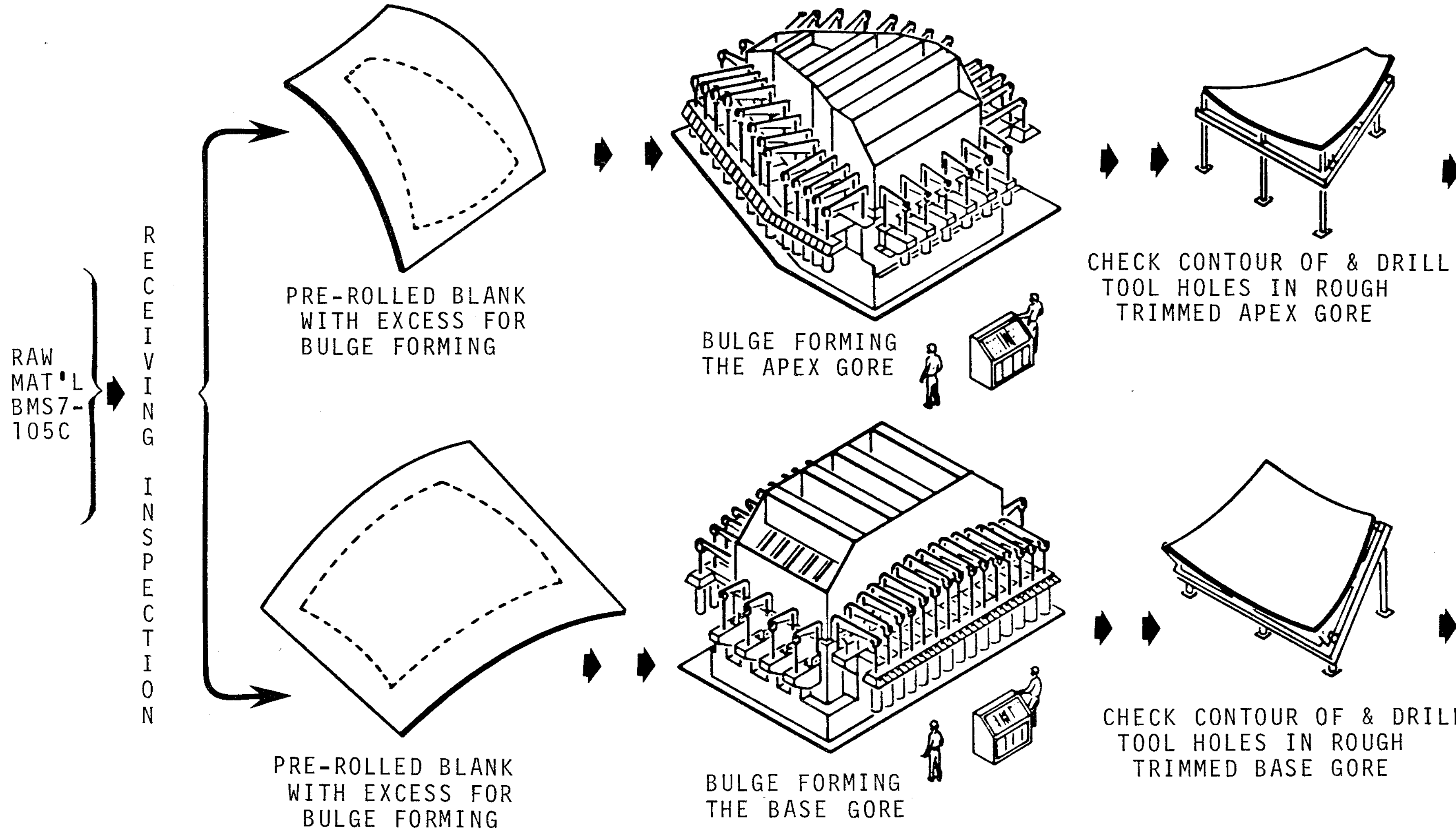


FIGURE 1-2 S-IC GORE SEGMENT FABRICATION, WICHITA

FIGURE 1-5 S-IC BULKHEAD ASSEMBLY, MICHOUD

5782

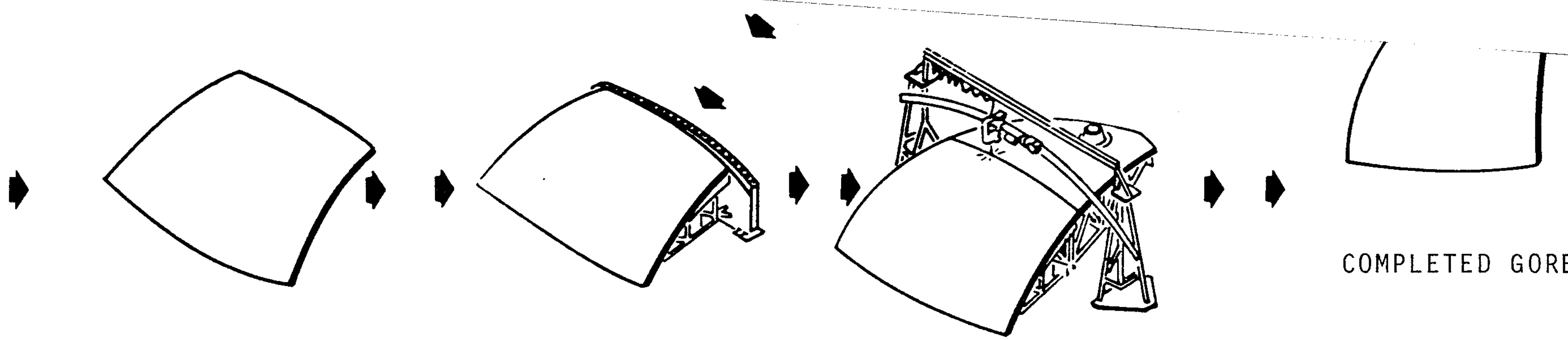
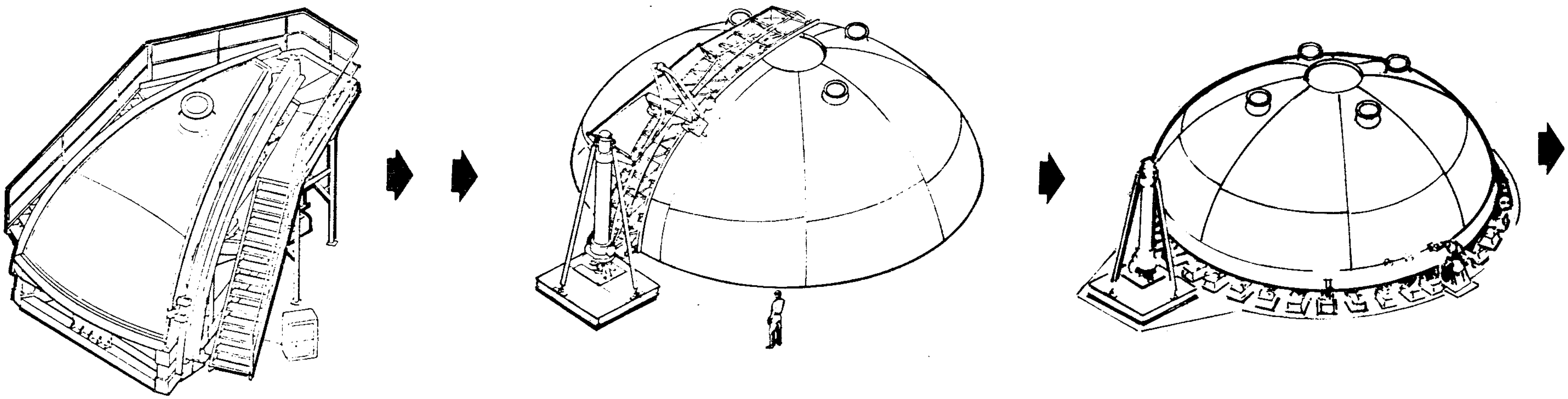


FIGURE 1-3 S-IC BULKHEAD ASSEMBLY, MICHOUD



GORE TRIM MERIDIAN WELD BULKHEAD TRIM

FIGURE 1-4 S-IC BULKHEAD ASSEMBLY, MICHOUD

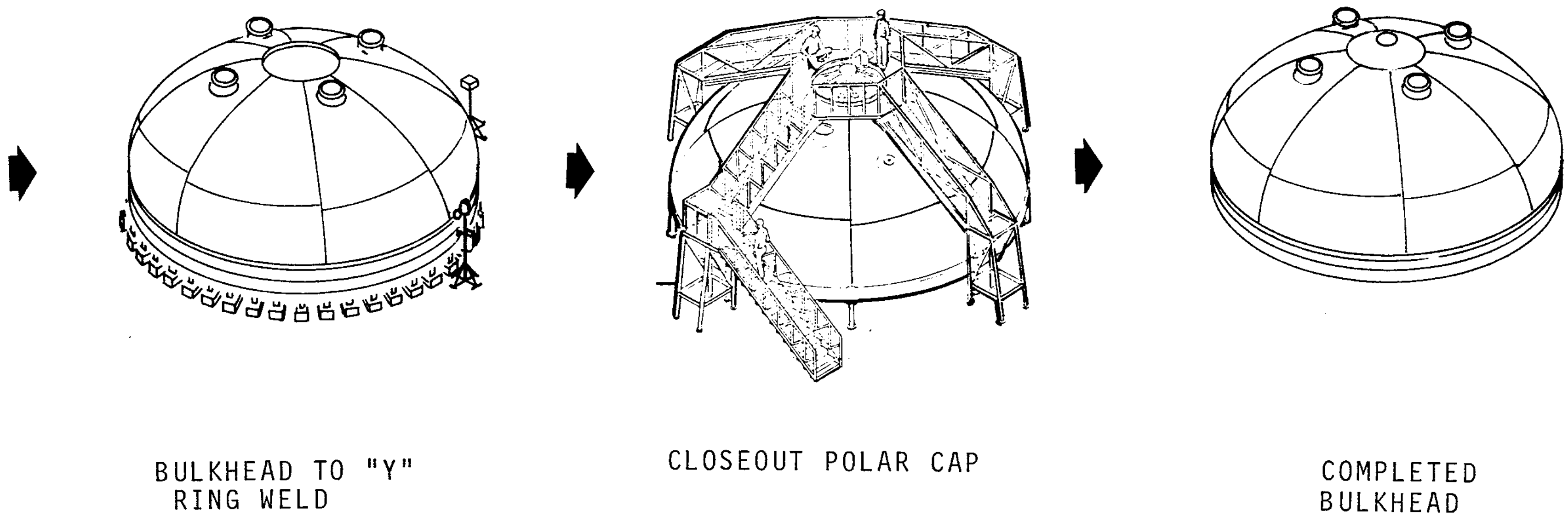


FIGURE 1-5 S-IC BULKHEAD ASSEMBLY, MICHOUD

operator and welding setup (wire, gas, voltage, torch speed, etc.). Laboratory analysis, which included radiographic and metallographic inspection plus tensile testing, proved the weld to be acceptable; therefore, the operators and settings were certified for the AS-503 bulkhead to Y-ring weld.

1.3 QUALITY AND RELIABILITY ASSURANCE

1.3.1 Receiving Inspection (Raw Material)

The incoming raw material from Wichita was thoroughly inspected for damage, and the identifying numbers were verified and recorded. The VSD's which were received with the raw material were carefully reviewed to verify compliance of the material with the mechanical, chemical, dimensional, and configuration requirements. The VSD's included: Shipping Documents, Data Transfer and Certification Record, Certified Inspection Report and Test Results (Alcoa-mechanical properties, chemical properties, and ultrasonic gird chart results), contour maps, and thickness maps. Following the visual inspection for damage, the material was cleaned, dye penetrant inspected, cleaned again, then protectively wrapped and/or stored in a controlled atmosphere area till ready for assembly.

1.3.2 In-Process Inspection

The following brief outline depicts the types of inspection performed on the various bulkhead assembly operations, and is indicative of the thoroughness of the quality control measures utilized:

Y-Ring	Assy. of Fittings	Instl. of Fittings
Non-Destructive	Non-Destructive	Non-Destructive
X-ray	X-ray	X-ray
Dye Penetrant	Dye Penetrant	Dye Penetrant
Dimensional	Dimensional	Dimensional
Optical	Mechanical	Mechanical
Mechanical		
Visual	Visual	Visual
Miscellaneous	Miscellaneous	Miscellaneous

Apex to Base Assy.	Bhd. Assy.	Y-Ring to Bhd.
Non-Destructive	Non-Destructive	Non-Destructive
X-ray	X-ray	X-ray
Dye Penetrant	Dye Penetrant	Dye Penetrant
Dimensional	Dimensional	Dimensional
Mechanical	Mechanical	Mechanical
Visual	Visual	Visual
Miscellaneous	Miscellaneous	Miscellaneous

Centerpiece Instl.	Completed Bhd. Assy.
Non-Destructive	Non-Destructive
X-ray	Dye Penetrant
Dye Penetrant	Dimensional
Dimensional	Optical
Mechanical	Visual
Visual	Miscellaneous
Miscellaneous	

Quality Control also monitors the following during manufacturing of the bulkhead: cleanliness requirements; heat treat cycles; etch and cleaning processes following dye penetrant inspection; protective wrapping; certification of welding operator and welding equipment; and welding operations.

1.3.3 Final Checkout and Inspection

1.3.3.1 Proof Pressure Test

The S-IC-503 LOX tank hydrostatic proof pressure test was performed on October 27, 1965 and adequately envelopes the AS-503 flight pressures. A maximum pressure of 66.136 psi was held for 80 seconds at the apex of the lower LOX bulkhead while the average water temperature was 74.2°F. No major problems were encountered during testing.

Maximum flight pressure at this location (Station 772) for the AS-503 C mission is projected to be 54.6 psi. Therefore, the proof factor achieved was 1.21 at the lower LOX bulkhead. This point has the lowest proof to flight pressure ratio in the entire tank.

The proof test was not performed at operational temperature (-297°F) because the tank was designed to room temperature parameters. In evaluating tank behavior at operational temperature, corrections for change in K_{IC} and initiation of deep flaw magnification are not required, Reference 1.2. However, sustained load flaw growth tests at cryogenic temperature (-320°F) for aluminum alloy 2219-T87 weldments using 2319 filler metal indicate a threshold in LOX of .80 K_{Ii}/K_{IC}, Reference 1.3. Thus to attain a guarantee for the tank life during S-IC boost, the minimum proof factor must be 1.075, Reference 1.2.

With the exception of possible damage after proof test, the 1.21 proof factor achieved more than adequately guarantees the reliability of the tank at maximum ullage pressure for the entire S-IC boost.

1.3.3.2 Optical Checkout

An optical check was performed on the completed bulkhead assembly in accordance with the provisions of D5-11982 (Special Inspection Procedures) and MORTP 60B12200-1B-988. This inspection operation was performed on the rotary turntable and encompassed the following: an inspection of the bulkhead contour; height; location and positioning of fittings; diameter of Y-ring; and target location. This operation was performed for the purpose of obtaining final assurance that the bulkhead assembly conformed to the dimensional and configuration requirements of the engineering drawings.

1.4 MRB ACTIONS

There were a total of eleven (11) UER's relating to the lower LOX bulkhead. Analysis of these UER's indicated that three (3) were structurally significant and warranted additional investigation. These three (3) are briefly described below:

UER 164252	Y-Ring	X-ray of the machined Y-ring revealed porosity and gas holes at stations 1 and 3. Disposition - Use as is. RFC-Possible reduction in margin of safety.
UER 183193	Meridian Weld	Rate of change of contour exceeds tolerance by 0.508. Disposition - Use as is. RFC-Reduction in margin of safety.
UER 181499	Polar Cap	Mismatch in polar cap to bulkhead joint in two places. Disposition - Use as is. RFC-Reduction in margin of safety.

A stress analysis of these discrepancies revealed that the dispositions taken were adequate, Reference 1.4.

See Appendix A for details of the MRB review.

1.5 HISTORY OF ELEMENT

The pressure cycles experienced by the S-IC-503 LOX tank (after hydrostatic proof and prior to launch) will not significantly reduce the flight time duration guarantee achieved by the proof test.

Following hydrostatic proof test, the LOX tank was exposed to these pressure cycles:

1. Storage pressure - 5 psig max. using dry air or nitrogen

2. One pneumatic leak check cycle - held at 11.25 psig max. for 5 min. - then vented to 8 psig and held for 10 minutes.

3. One LOX load cycle (prestatic firing) - held at 11.25 psig max. ullage for 5 mins. then vented to 8 psig and held for 11 mins.

4. One LOX loaded static firing test cycle - 18 psig ullage max.

Consequently, these pressure cycles in addition to very similar cycles which the tank will experience during CDDT and preflight pressurization do not significantly lower the guaranteed flight life of the S-IC-503 LOX tank. Their combined effect would be less than that of proof or operating pressure tolerances.

1.6 ON-SITE REVIEW SUMMARY

1.6.1 General

The on-site, selected element review was conducted during the period September 3-6 as a part of the JSAT effort, by a group of materials and stress engineers selected to review the AS-503 aft LOX bulkhead history, in regard to manufacturing techniques and quality control procedures. This review encompassed a study of: manufacturing sequences and processes; MRB actions; handling and storage techniques; quality control procedures and results; manufacturing drawings; and engineering planning documentation.

The actual hardware being manufactured at the time, was for a much later flight effectivity. The differences between the current methods of manufacturing and quality control, and the methods employed during the construction of the AS-503 bulkhead were determined and noted. The major differences noted between the current and the 503 effectivity methods of manufacture are as follows:

The AS-503 vehicle had the solid Y-ring. At a later date tee stiffeners were machined into the Y-ring as an integral part of the base of the Y.

The TIG welding process was utilized on the bulkhead-to-Y-ring weld during assembly of AS-503. The MIG welding process is currently employed on this operation. This process utilizes a much faster torch speed, thus lessening the heat buildup and thereby reducing distortion of the bulkhead.

On the AS-503 aft LOX bulkhead assembly, the polar cap was installed by welding the polar cap to the assembled bulkhead (gores and Y-ring) with the Y-ring, supporting the weight of the assembly. At a later date this operation was accomplished by draping the gore/Y-ring assembly over a center support thereby stretching the bulkhead by its own weight. This method minimized distortion in the bulkhead following the polar cap weld. At a still later point in time the currently used method was evolved. That is - the gore/Y-ring assembly is placed over a central support and stretched in a positive manner by pulling the Y-ring towards the floor, utilizing turnbuckles, prior to installing the polar cap.

All of the fittings on the AS-503 aft LOX bulkhead were welded on the bulkhead. Beginning with the AS-504, the fittings were machined as an integral part of the bulkhead segments except for the four (4) outboard LOX suction fittings. The configuration of these fittings is such that it is impractical to make them an integral portion of the gore segments, therefore, they are still being welded to the segments.

Deviations in contour on gore segments were often corrected by aging the part within a restrained aging fixture.

During construction of the AS-503, manufacturing was still in the process of developing fabrication and assembly processes that would eliminate or minimize problems that had caused particular difficulty to that point. It was clearly evident from observation of defect charts posted at the various weld operation stations that considerable progress had been made by the time the AS-503 was built and that progress has continued to this date.

A number of X-ray films were reviewed by the group. The particular films selected were chosen so that a detailed analysis could be made of certain UER's. These films were of gore-to-gore welds, apex-to-base welds, Y-ring-to-bulkhead welds and tee stiffener welds.

1.6.2 Documentation Reviewed

The documents of prime concern to the investigating group were those involving manufacturing, inspection, and Material Review Board actions. The principal document developed for governing the former two items was the MORTP (Manufacturing or Testing Procedure) which spells out in detail the manufacturing and testing procedures used in fabricating and inspecting the individual parts. Additional documentation reviewed, which was utilized in the manufacturing and inspecting operations, was as follows: engineering drawings; welding specs (ABMA-PD-W-45A, ABMA-PD-R-27A, 60B32032, 60B32004, 60B32009, MSFC Spec 135, BAC 8401, MSFC Spec 130, MIL-T-5021C, 60B32514); cleaning specs (60B32002A, BAC 5749, BAC 5750, BAC 5765, BAC 5786, BAC 5745, BAC 5744, MSFC Spec 164); protective and wrapping specs (BAC 5034, BAC 5703, MIL-C-5541); identification specs (BAC 5307, 60B00015, 60B32059); penetrant inspection (BAC 5423); heat treat (BAC 5602); forming, straightening, and fitting (BAC 5300); and VSD's. A substantial number of UER's, UER summaries, and UER data printouts were also reviewed. The UER is the primary document of TBC/MICH dealing with MRB actions. The group also examined the S-IC AS-503 Design Certification Review and the Manufacturing Plan.

1.6.3 Conclusions

A comprehensive study and evaluation of the manufacturing and quality control procedures used during production of the S-IC-503 lower LOX bulkhead was conducted. This effort encompassed a review of events from receipt of parts to storage of completed element.

The purpose was to determine whether the procedures employed and results achieved offer adequate assurance that the finished element is structurally sound.

The investigating group concludes that sufficient assurance does exist of the structural integrity of the S-IC-503 aft LOX bulkhead. This conclusion is founded on the following observations:

> Evidence of improvement in the quality of welds from the production of the first LOX tank to the present time. This was reflected in the weld defect charts, posted at each weld station, which show marked reductions in number of weld defects from one vehicle to the next. Results of these improvements are reflected in the AS-503 Bulkhead.
>
> Adequacy of the Manufacturing or Testing Procedures plus the satisfactory documentation and implementation of same.
>
> Results obtained - based on Quality Control findings and successful proof testing of the AS-503 LOX tank.

SECTION 2

S-IC-3 FORWARD SKIRT

SELECTED ELEMENT REPORT

2.0 SUMMARY

The purpose of this review was to evaluate the manufacturing and quality control procedures used in the assembly of the S-IC-503 Forward Skirt to determine if the "as-built" configuration structural integrity is assured.

The conclusions in this report are based on information obtained at TBC/MICH from:

a. Inspection of Manufacturing and Quality Control facilities and activities.

b. Discussions with Engineering, Manufacturing and Quality Control personnel concerning fabrication of the subject element.

c. Review of applicable documentation including, but not limited to: Manufacturing Plans and specifications, engineering drawings, MRB actions and Design Certification Review.

The investigating team concludes that the methods exercised and results achieved do assure the structural integrity of this selected element.

2.1 DESCRIPTION

The S-IC Forward Skirt assembly comprises that section of the vehicle which extends from Vehicle Station 1420 to Vehicle Station 1541 as shown in Figure 2-1. It is a semi-monocoque structure joined almost entirely by mechanical fasteners. The basic structure consists of twelve skin panels, three circumferential ring frames , 216 longitudinal hat section stringers, and skin splice doublers. See Figure 2-2. One of the twelve skin panels contains an umbilical disconnect door beneath which is a small personnel access door. A small amount of welding performed in the assembly of the frame of the umbilical disconnect door is the only fastening method employed other than mechanical fasteners. The upper circumferential ring is the interface between the S-IC and S-II stages and contains the gage-controlled attach hole pattern for 216 fasteners. This pattern is obtained from a gage made by North American for use in setting up the final assembly fixture. Mechanical fasteners are used to attach the aft end of the forward skirt assembly to the forward Y-ring of the LOX tank. The upper skin panels are compound contoured (conical as well as cylindrical) and the lower panels are cylindrically contoured.

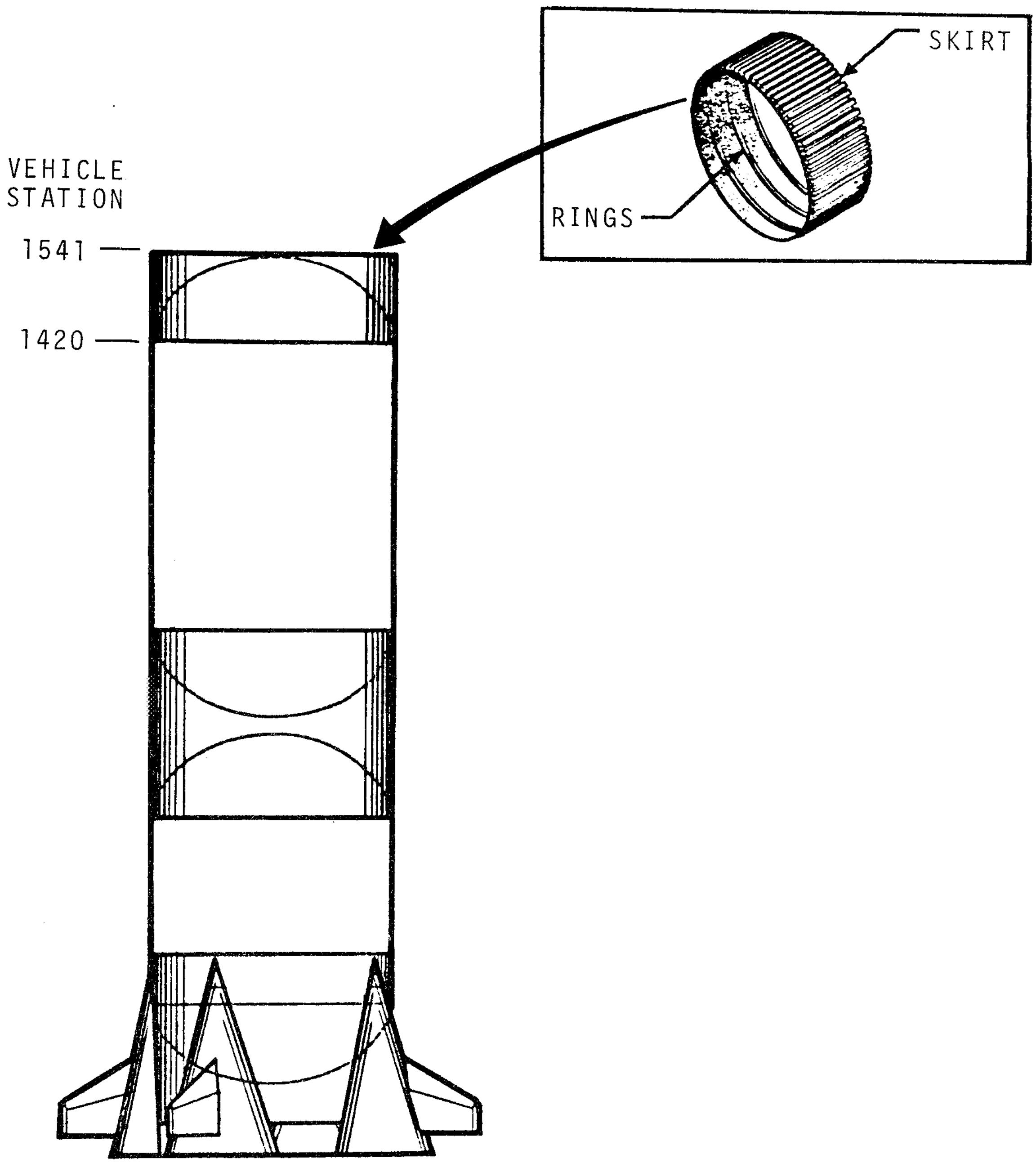


FIGURE 2-1. S-IC FORWARD SKIRT

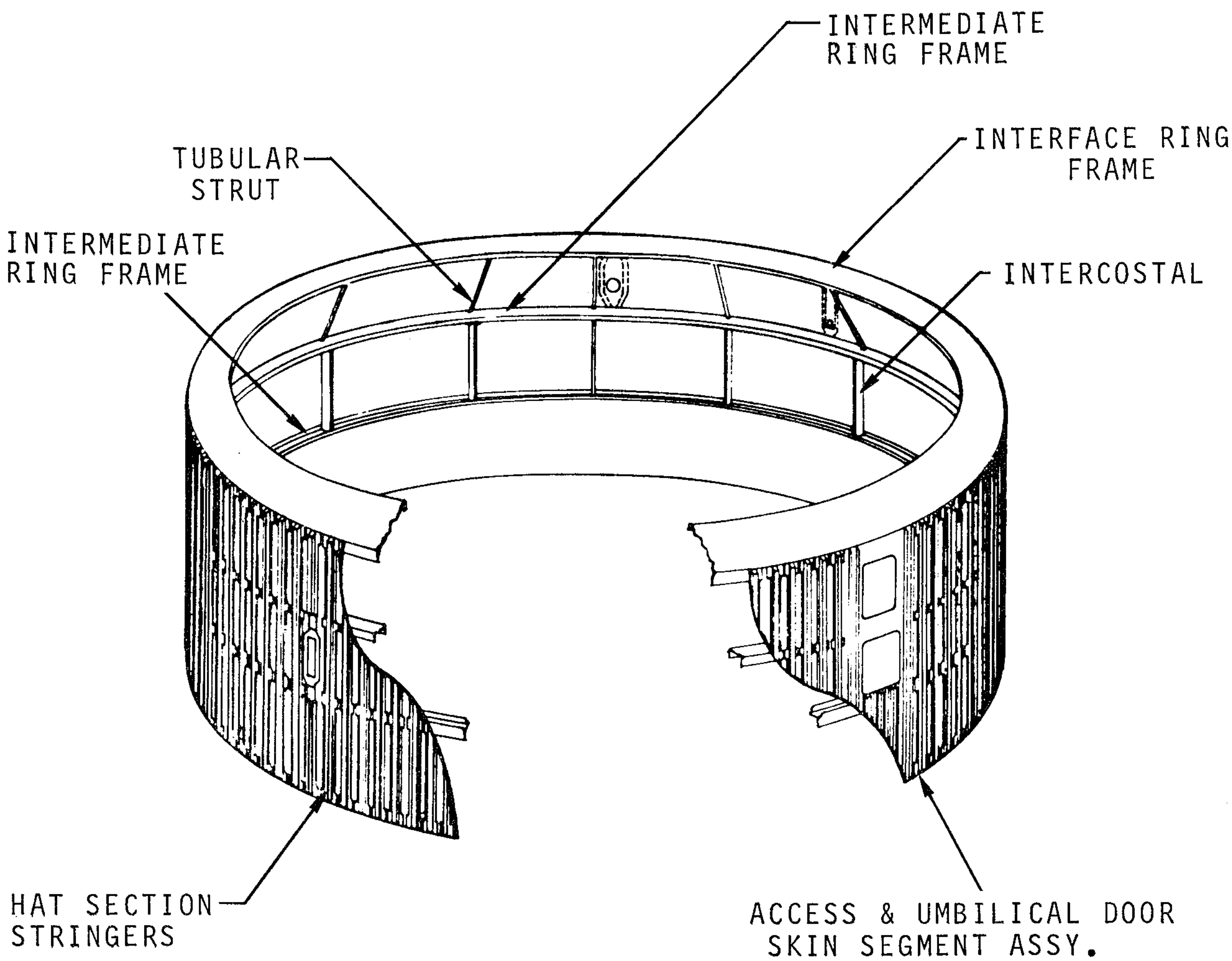


FIGURE 2-2 S-IC FORWARD SKIRT

2.2 MANUFACTURING

2.2.1 Fabrication

This component was made primarily from 7075 and 7079 aluminum alloys in the T-6 temper. The basic, and generally standard-production type parts were: constant gage thickness conical and cylindrical skins and skin doublers; hat section stringers; extruded and machined channels, angles, and J-sections; machined die forgings; rivets; and bolts.

2.2.2 Assembly

The forward skirt was assembled in an inverted position as follows:

a. The interface ring segments were set into position on the interface drill plates and spliced together.

b. The intermediate ring frames were placed in support arms and their segments spliced.

c. The skin segment assemblies were set into the assembly fixture on adjustable supports and the dummy Y-ring was attached. These skin segments were subsequently fastened to the ring frames.

d. Splicing of the skin segments was accomplished utilizing doubler plates on the inner and outer surfaces.

e. Eighteen intercostals were then installed between the intermediate ring frames for stability.

f. Nineteen diagonal tube strut assemblies which stabilize the inner chord of the interface ring were installed between the interface ring and the upper intermediate ring frame.

g. The umbilical door and access door were then placed in position and fastened.

h. The final operation was the drilling of the 216 hole pattern in the interface ring, along with the three guide pin receptacle holes, from gage-controlled bushings in the interface drill plate.

The following MORTP's detail the assembly and inspection operations performed on the foregoing steps of assembly:

60B14009-1A-910, thru 922, 924, 925, 952; 60B14200-1A-900; 60B14220-1; 60B14325-1; 60B14400-1A-900; 901; 60B14400-3A-900, 901, 902, 903; 60B14600-1A-900 thru 905; 60B14009-1A-990, 950, 951, 954, 955, 956; 60B14600-1A-950.

2.3 QUALITY AND RELIABILITY ASSURANCE

2.3.1 Receiving Inspection (Raw Material)

The only receiving inspection performed by Michoud on the forward skirt parts was to inspect for damage in transit. The inspection stamps placed on the parts by Wichita, covering dimensions, alloy, temper, etc., were honored by Michoud. VSD's and non-conformance reports were received with the incoming parts and were carefully reviewed.

2.3.2 In-Process Inspection

Inspection operations performed on the various sub-assemblies and on the final assembly were comprehensive and adequately assured compliance with the specified drawings. These inspection steps were detailed in their proper sequence of events in the MORTP's listed at the end of Par. 2.2.2. The types of inspection performed are briefly outlined as follows:

Skin Panels	Interface Ring Segments	Final Assembly
Dimensional	Dimensional	Dimensional
Mechanical	Optical	Optical
Visual	Mechanical	Mechanical
Miscellaneous	Visual	Visual
	Miscellaneous	Miscellaneous

2.3.3 Final Checkout and Inspection

As a final check the completed forward skirt was optically inspected for: radial and circumferential positioning of facility holes, skin panels, and interface control holes; location of flight position marks, forward end of skins, and electrical tunnels; diameter, roundness, circumference, concentricity, height, flatness, and parallelism. This final inspection procedure assures that the assembly complies with the dimensional and configuration requirements of the drawings.

2.4 MRB ACTIONS

There were a total of forty-one (41) UER's relating to the forward skirt. Analysis of these UER's indicated that five (5) warranted a stress analysis to verify the adequacy of the dispositions.

These five (5) are briefly outlined below:

UER 193950 — Holes elongated and short edge margin. Disposition - Plugged holes. RFC-Stress concentration.

UER 217189 — Mislocated holes. Disposition - Plugged one hole and "use as is." RFC-Possible load redistribution.

UER 206153 — Tee and clip attached to wrong channel. Intercostal doesn't pickup existing holes in angle. Disposition - "use as is" on tee and clip; install new set of fasteners on intercostal. RFC-Change in configuration.

UER 225258 — Extra hole drilled. Disposition - Plugged hole. RFC-Possible stress concentration.

UER 200568 — Hole drilled through doubler, hat stiffener and skin did not clear under GOX fitting. Disposition - Faired in discrepant area. RFC - Lowered safety margin.

A stress analysis was performed on each of the five (5) discrepancies and it was concluded that the actions taken were adequate as regards the structural integrity of the element, Reference 1.4.

See Appendix A for details of the MRB review.

2.5 ON-SITE REVIEW SUMMARY

2.5.1 General

The on-site selected element review was conducted during the period September 3-6 as a part of the JSAT effort, by a group of materials and stress engineers selected to review the AS-503 Forward Skirt history, in regard to manufacturing and quality control procedures. The review covered: manufacturing sequences and operations; MRB actions; handling and storage techniques; quality control procedures and test results; engineering drawings; and engineering planning documentation.

The actual hardware being manufactured at the time of the review, was for a later flight effectivity. The differences between the current methods of manufacturing and quality control, and the methods employed during the construction of the S-IC-503 forward skirt were determined and noted. The major differences noted were:

a. Difficulties experienced on the AS-501 and AS-502 flights, with the umbilical door, necessitated a change in the design of the closing mechanism and latch assembly. The door interfered with the umbilical lanyard cable as the umbilical disconnected, and remained open during flight. The improved design was satisfactorily tested, Reference 2.1, and a decision was made to incorporate the change in design on AS-504 rather than AS-503 since time was a factor and the problem presented an acceptable risk.

b. Titanium fasteners currently used, were installed on S-IC-AS-504 and on.

2.5.2 Documentation Reviewed

Documents of primary concern to the investigative group were those dealing with manufacturing, inspection, and Material Review Board actions. The principal document generated for controlling the first two items was the MORTP (Manufacturing or Testing Procedure) which details in step-by-step fashion the manufacturing and testing procedures utilized in fabrication and assembly of the individual components. Other documents which were reviewed and which were used in conjunction with manufacturing and inspection were: engineering drawings; identification requirement specs (BAC 5307, 60B-32059); protective covering and storage (BAC 5034);

finishing specs (MIL-C-8514A, MIL-C-15328B, MIL-C-5541, MIL-P-8585A, MIL-P-6808B); forming, straightening, fitting (BAC 5300); fastener installation (60B32040, BAC 5009, BAC 5018); heat treating (BAC 5602); and welding (ABMA-PD-W-45A). The major document at Michoud pertaining to Material Review Board actions is the UER (Unplanned Event Record). A large number of these were reviewed along with the UER data printouts and UER summaries. In addition to the foregoing documents, the group also reviewed the Manufacturing Plan and the Design Certification Review.

2.5.3 Conclusions

A comprehensive study and evaluation of the manufacturing and quality control procedures used during production of the S-IC-503 Forward Skirt was accomplished. This effort embraced a review of events from receipt of parts and material to storage of the completed element. It also included a detailed review of certain critical or complex operations.

The stated purpose was to determine whether the procedures used and results obtained offer adequate assurance that the finished item is structurally sound.

The investigating group concludes that the manufacturing and quality control methods employed and the results obtained, offer assurance of the elements' structural integrity.

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SECTION 3

S-II-3 LOX TANK GIRTH WELD

SELECTED ELEMENT REPORT

3.0 SUMMARY

The purpose of this review was to evaluate the manufacturing and quality control procedures used in the assembly of the S-II-3 LOX Tank Girth Weld, to determine if the "as-built" configuration structural integrity is assured.

The conclusions of this report are based on information obtained at NR from:

a. Inspection of manufacturing and quality control facilities and activities at Seal Beach.

b. Discussions with Engineering, Manufacturing and Quality Control personnel concerning fabrication of the subject element.

c. Review of applicable documentation including, but not limited to: manufacturing plans and specifications, engineering drawings, MRB actions, and design certification reviews.

NR's proof testing philosophy dictates that tanks be tested as subassemblies. Consequently, the LOX tank was not hydrostatically proof tested as a unit. Instead the aft LOX bulkhead and the common bulkhead were proof tested separately. This leaves the girth weld unproofed and its reliability dependent on NDT inspection and analysis. The critical crack size for this weld at flight pressures, is 0.370 inches. This size crack would be detected by NDT techniques incorporating penetrant, radiographic, or eddy current inspection methods. Inspection verified that no crack was present. Therefore, the investigating team concludes that the LOX tank girth weld can be considered adequate.

3.1 DESCRIPTION

The LOX tank girth weld is the circumferential weld that joins the common bulkhead to the aft LOX bulkhead, as shown in Figure 3-1. The gore segments of the aft LOX bulkhead and facing sheets of the common bulkhead are 2014-T6 aluminum alloy. The bulkhead shells are fabricated from 12 gore segments, and fusion welded by the TIG process using 2319 aluminum alloy filler wire. The common bulkhead is an adhesive-bonded sandwich assembly which employs a fiber-glass/phenolic honeycomb core. Figure 3-2 shows the physical relationship of the LOX tank, bolting ring, aft skirt, and lower LH_2 tank cylinder.

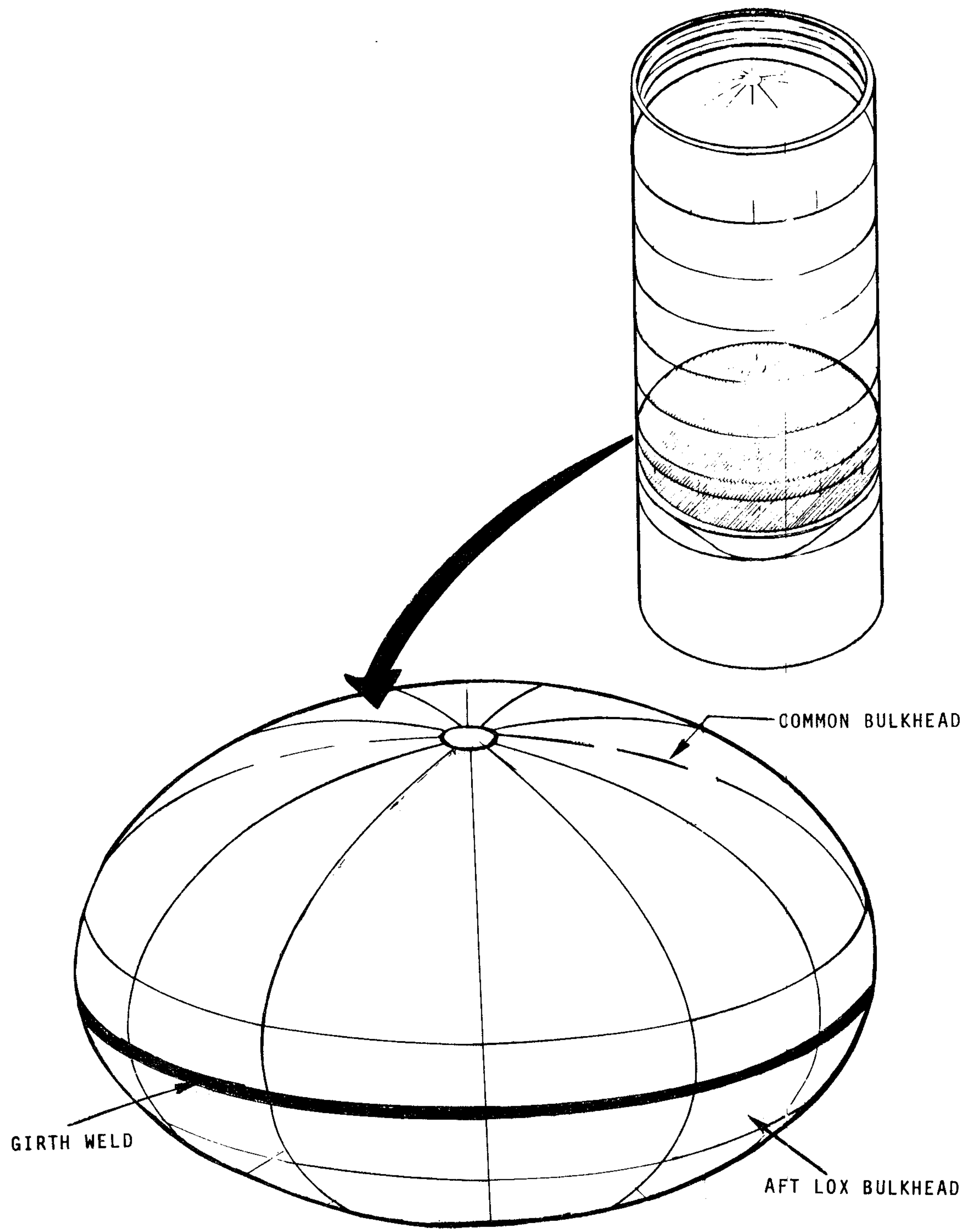

FIGURE 3-1 S-II LOX TANK GIRTH WELD

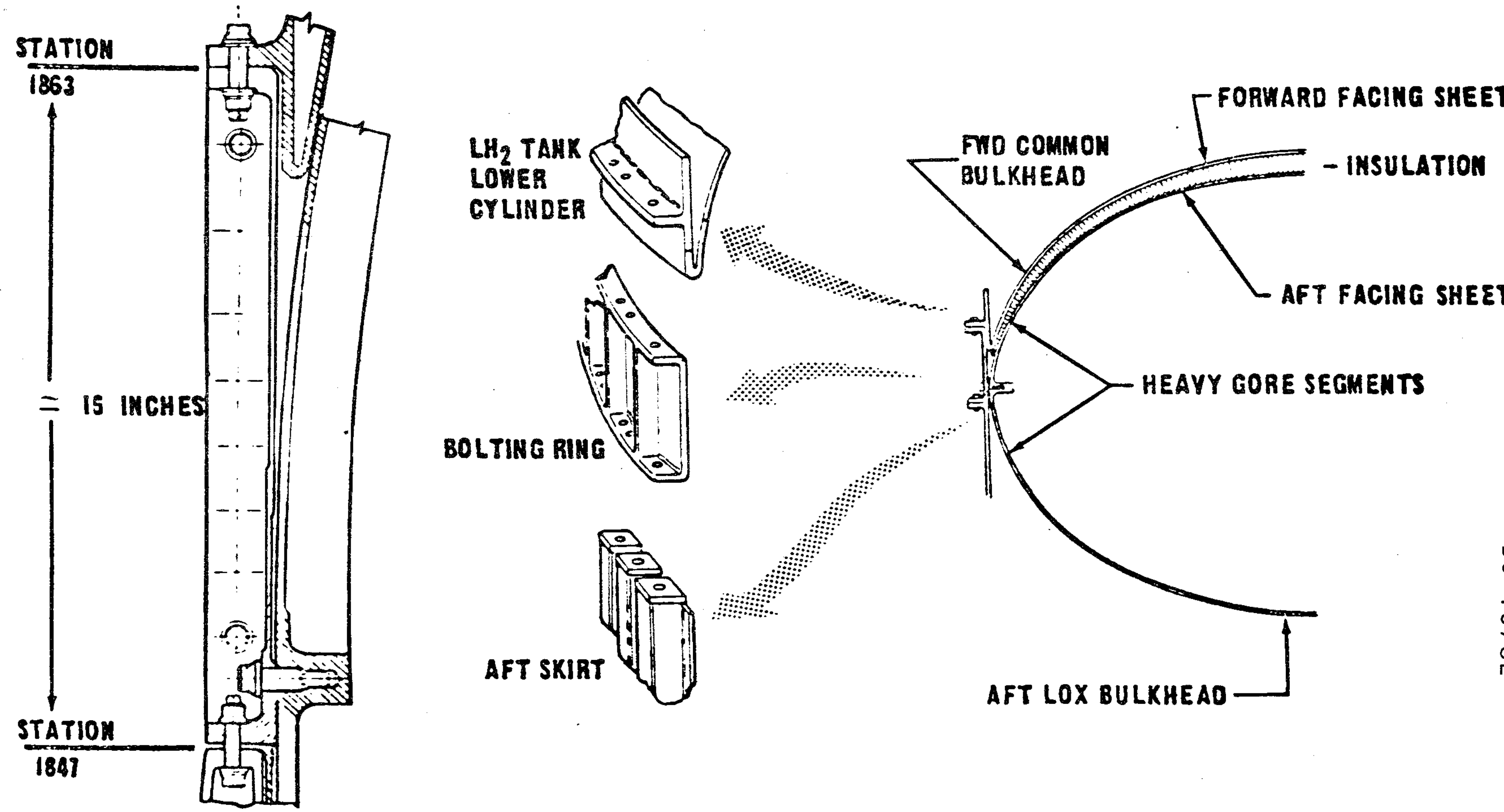

FIGURE 3-2 S-II LOX TANK, AFT SKIRT AND LH_2 TANK CONNECTION

3.2 MANUFACTURING

3.2.1 Fabrication

3.2.1.1 Common Bulkhead

The common bulkhead is an adhesive-bonded sandwich assembly employing facing sheets of 2014-T6 aluminum alloy and fiberglass/phenolic honeycomb core. An epoxy-phenolic adhesive system is employed. Bonding is accomplished in a large autoclave under pressure and elevated temperature.

Contouring of the 2014-T6 gore segments is accomplished by stretch forming the forward facing and explosive forming of the aft facing gores. Gores are chem-milled after forming to incorporate weld lands and tapers. The gore segments are tapered in thickness over the meridian length to maintain an approximately constant meridian stress level. The bulkhead shells are fabricated from 12 gore segments by fusion welding, employing the TIG process and 2319 aluminum alloy filler wire, as shown in Figure 3-3.

A honeycomb core depth of 4.75" is maintained over most of the surface. However, the core depth is gradually tapered towards the equator to a nominal value of 0.050 inch as shown in Figure 3-2. This is done because only the inner facing (LOX side) of the common bulkhead is carried through to provide structural continuity with the LOX tank aft bulkhead. The forward facing sheet terminates in the J-ring section welded to the LH_2 tank wall. Waffle-stiffened gore sections are employed in the aft facing gores to provide shell stability under design collapse pressures in the region where sandwich shell stability is reduced or negated because of the tapered core. The waffle-stiffened gore segments extend approximately 56 inches in the meridional direction above the equator. A heavy integral bolting bar is provided at the equator of the waffle sections to permit blind bolt attachment to the LH_2 tank wall through the external bolting ring.

3.2.1.2 Aft LOX Bulkhead

The LOX tank aft bulkhead is a modified ellipsoidal shell. The bulkhead is fabricated of 12 gores and a large (111 inch diameter) dollar section of 2014-T6 aluminum alloy as shown in Figure 3-4. The gore sections and dollar sections are contoured by explosive forming. The dollar section incorporates an integral reinforcing ring to provide for attachment of a central sump at the apex of the bulkhead. The sump is machined from 2014-T6 forging and provides attach fittings for the five LOX feed lines and the LOX fill and drain line. The circumferential weld between the dollar section and the upper portion of the

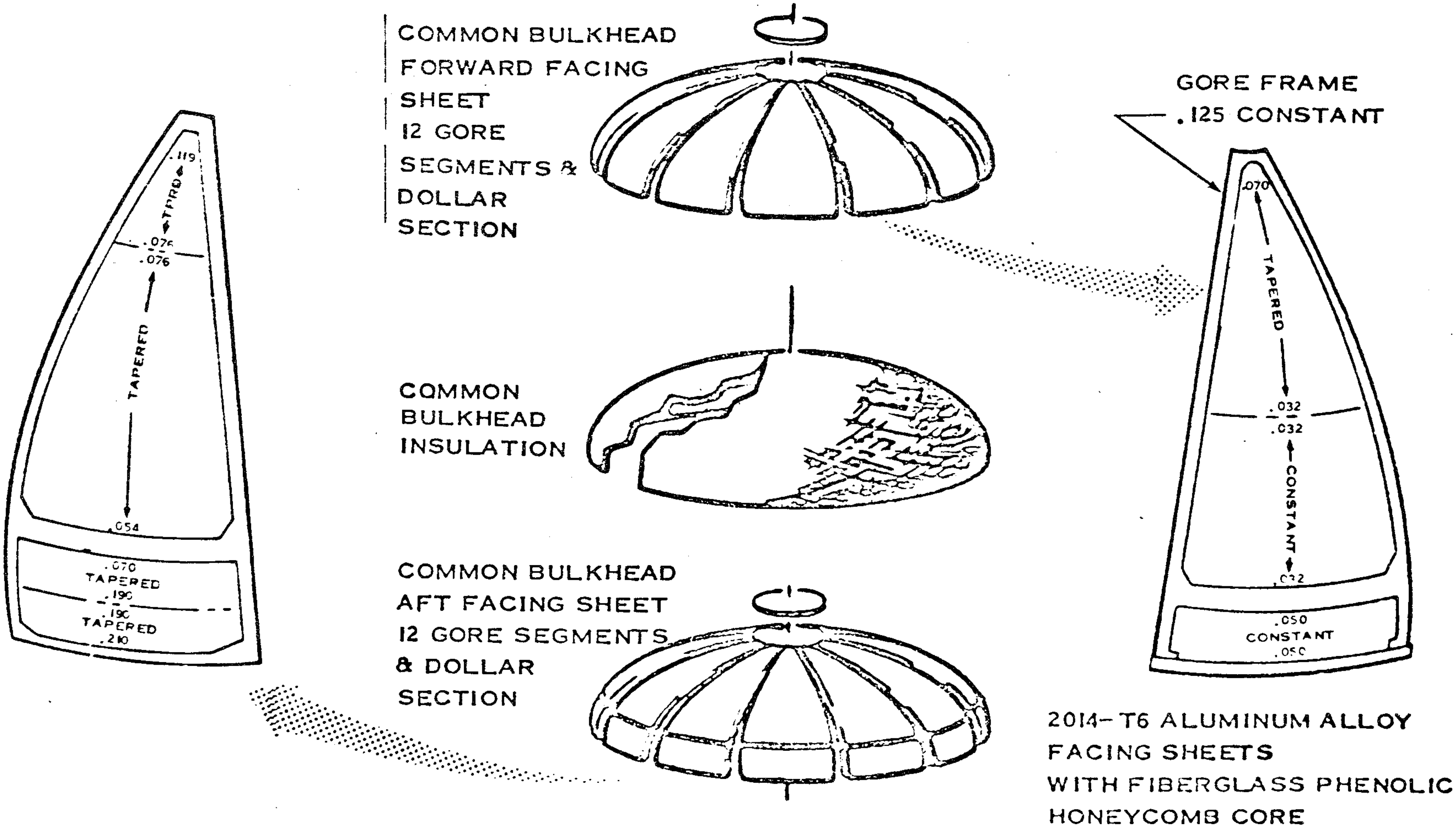

FIGURE 3-3 S-II COMMON BULKHEAD CONSTRUCTION

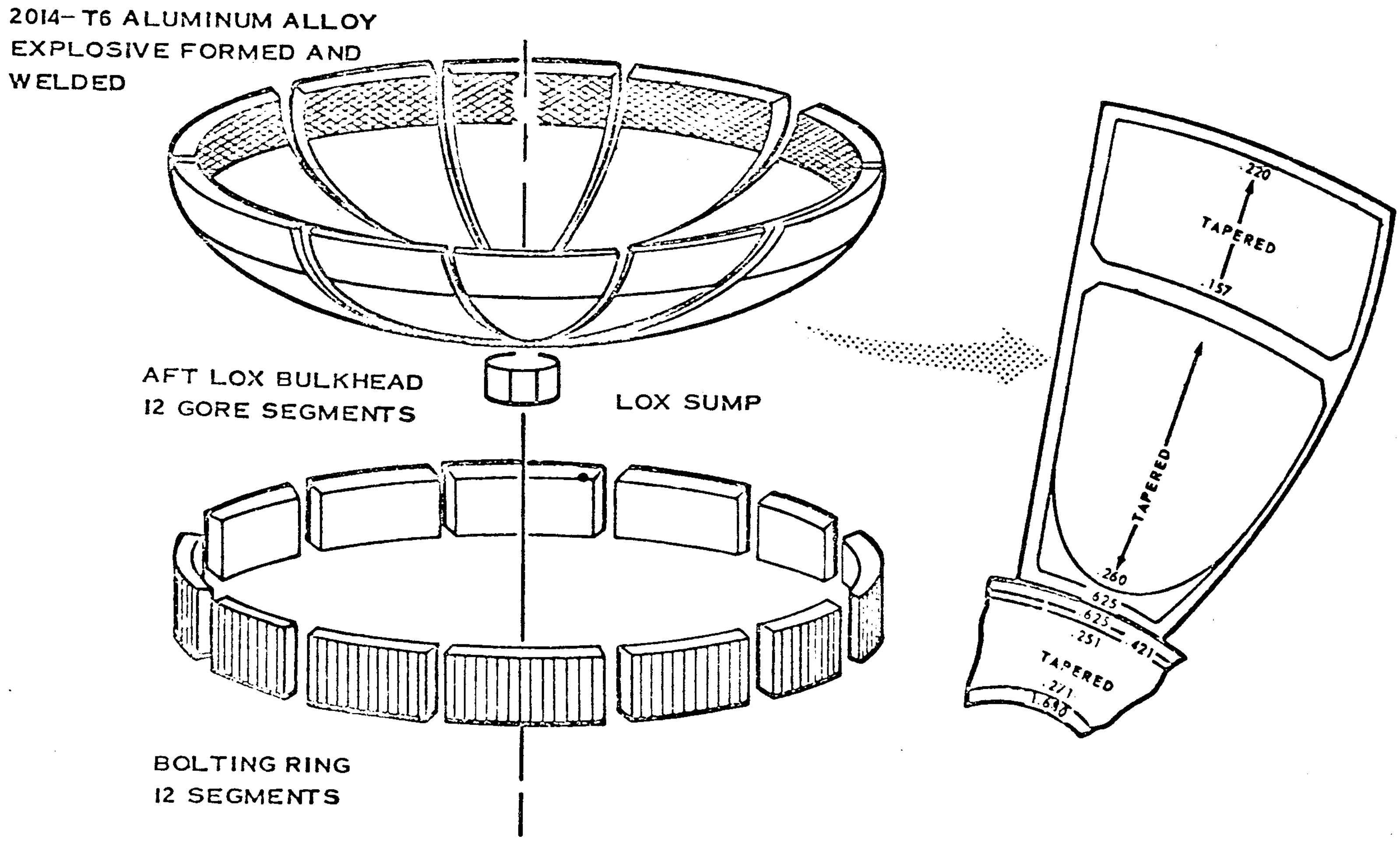

FIGURE 3-4 S-II AFT LOX BULKHEAD

bulkhead is reinforced with a doubler that is attached by two rows of bolts on each side of the weld. An access door is provided in one of the gore panels above the dollar section. The door (23 inches dia.) is attached by bolts to an integral land provided in the gore panel. Sealing of the door is accomplished by a Naflex seal.

3.2.2 Assembly

3.2.2.1 Aft LOX Bulkhead

The aft LOX bulkhead shell is positioned, leveled and clamped in a tooling fixture and the equatorial scribe line is determined. The plane of the scribe line is verified and recorded in the "FAIR" book. Using the "Skate Saw" a trim cut is made approximately 1" above the scribe mark with one pass (Figure 3-5). The level of the saw cut and the scribe line is rechecked to determine if the cut is parallel. The height of the saw is adjusted and the net trim cut is made with one pass. The dimensions of the bulkhead are determined and recorded in the "FAIR" book.

3.2.2.2 Common Bulkhead

The Common Bulkhead is placed in a tooling fixture and oriented so that Pos. I aligns with Pos. I on the aft LOX bulkhead. The bulkhead is leveled and the net trim line is marked and recorded in the "FAIR" book and cut with the "Skate Saw." The circumference is measured (Pi Tape), verified, and recorded in the "FAIR" book. The material thickness of the circumference is measured in 3 inch increments and recorded in the "FAIR" book.

3.2.2.3 Girth Weld

The common bulkhead is lowered into position over the aft LOX bulkhead and aligned. The backup bars are pressurized maintaining a 0.040 inch gap between butting surfaces. The edges are cleaned, then inspected with black light. Should any butting edges make contact, the surfaces must be re-cleaned. The offset is verified and recorded in the "FAIR" book. Figure 3-6 shows the backup bar and the offset verification tool.

The welding operation is a "white glove" operation. A welding engineer and a QC representative must be present while the welding machine is in operation. Verification of machine weld quality is made prior to each girth weld.

A machine tack weld 2-1/2" long is made intermittently around the entire periphery of the bulkheads and off-set verified. These tack welds are inspected for visible

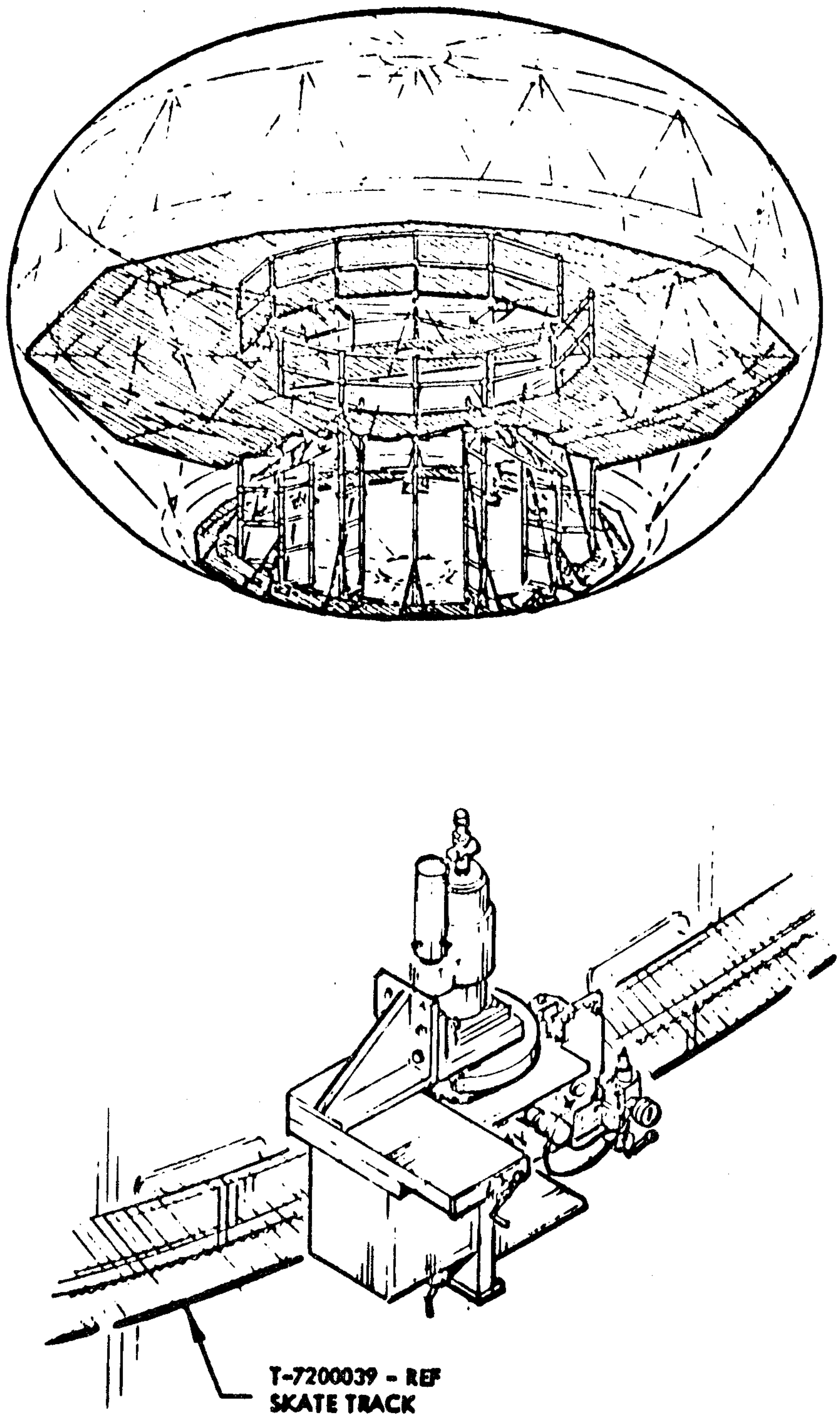

FIGURE 3-5 COLLAPSIBLE WORK PLATFORM AND SKATE SAW

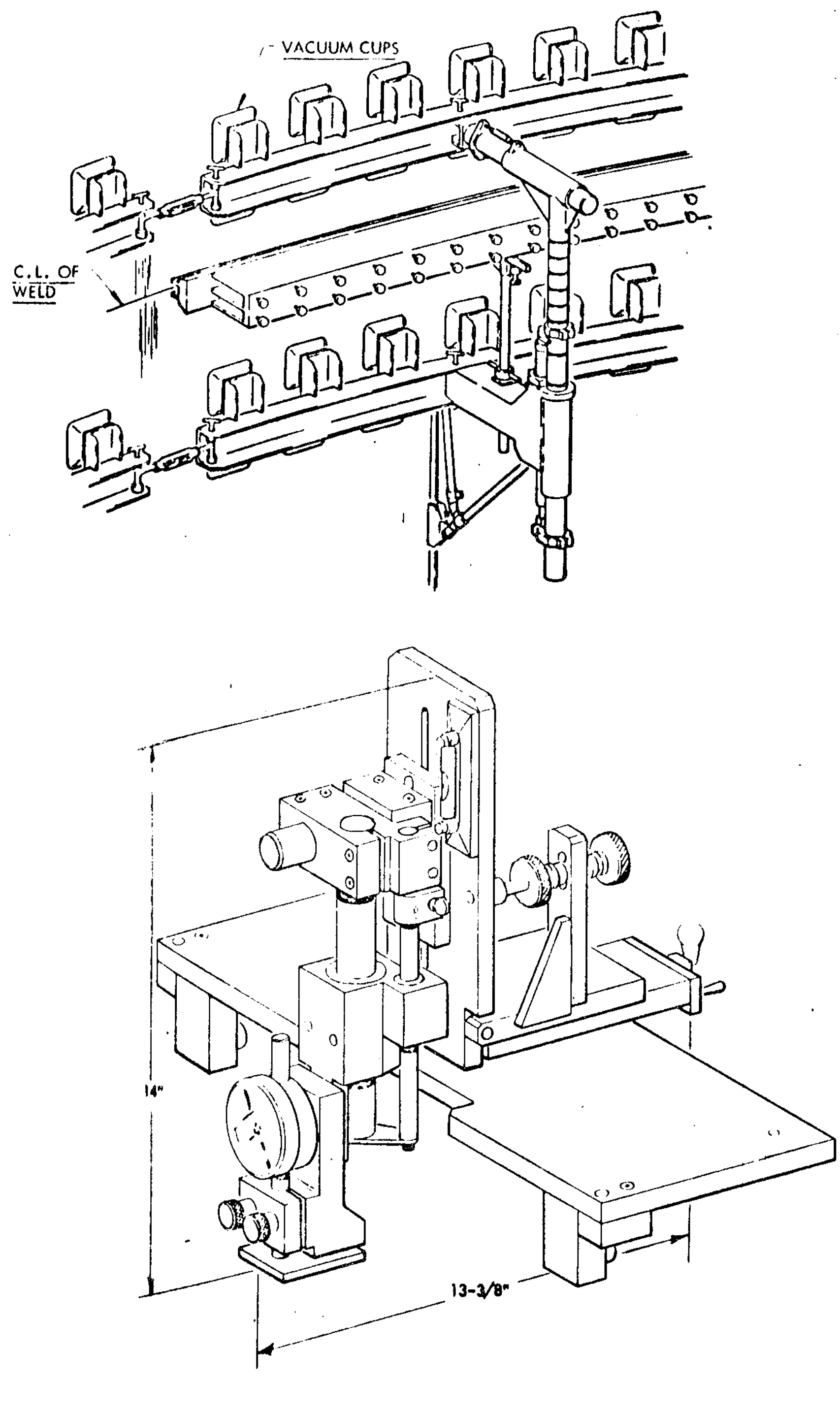

FIGURE 3-6 BACKUP BAR AND OFFSET TOOL

defects and excessively high weld nuggets are milled with the weld bead shaver.

The penetration pass is made using 2 welding heads 180° apart. The outside of the weld bead is cleaned with a stainless steel brush and then the weld is radiographically inspected and results recorded in the "FAIR" book.

The cover pass is made and examined for defects. If a second cover pass is required, it is made at the option of Manufacturing with the concurrence of the Weld Engineering Representative. The weld is then milled to a smooth surface (125 RHR or less) and radiographically inspected. Off-set readings are taken and any repairs that are needed are made at this time. The weld is then penetrant inspected to complement the radiographic inspection.

3.3 QUALITY AND RELIABILITY ASSURANCE

3.3.1 Receiving Inspection (Raw Materials)

The vendor supplies a certification of the physical, chemical, and ultrasonic inspection of the raw material. These results are verified by the Quality and Reliability Assurance Dept., Los Angeles Division.

3.3.2 In-Process Inspection

a. The protection of completed bulkheads is governed by specification MA0616-002. General Process Specification MA0609-007 establishes the corrosion control and ITI-3526 describes the inspection methods for the detection and prevention of corrosion to the bulkheads.

b. The joining of the Aft LOX tank to the common bulkhead is a "white glove" operation. All operators and attendant personnel must wear clean, lint-free white gloves and prescribed clothing to avoid possible contamination of the weld. Welding is done by certified machine fusion welders under direction of a welding engineer and the observation of a Quality Control representative. Prior to welding or a change in weld parameters, a "bead-on-plate" verification is made per PRO-MW-565-010B to determine adequacy of gas coverage, gas purity, operating condition of welding machine and repeatability of bead geometry.

The bulkheads are tack welded, the weldment is inspected for visible defects, and off-sets are verified. The penetration pass is made, cleaned, and subjected to X-ray examination. Prior to the cover pass weld the bead is contoured to a smooth surface. The cover pass is made per Weld Schedule 971-D, then milled and submitted for X-ray examination per "FAIR" book. Post-weld offset readings are made and recorded in the "FAIR" book. Any necessary weld repairs are made per direction of Welding and Testing, Seal Beach Operations Dept. The weld is then penetrant inspected and results recorded in the "FAIR" book.

3.4 MRB ACTIONS

A review of the "Circumferential Weld History Log" indicates that the girth weld of the S-II-3 LOX tank was an exceptionally good weld. One discrepancy (MR#140602) indicated ten (10) oxide or porosity defects and these were "acceptable as is." The MR#140602 was the only discrepancy against the girth weld.

Stress analysis reported in Reference 1.4 verified the adequacy of the dispositions.

See Appendix A for details of the MRB review.

3.5 HISTORY OF ELEMENT

The "Circumferential Weld History Log" indicates that no discrepancies (QC Squawks or MR Actions) were written against the tack welding or the offset measurement of the girth weld. Radiographic inspection after the cover pass disclosed ten scattered oxide or porosity defects which were "acceptable as is and which will not affect the design requirement."

Shipping and storage of gore segments, bulkheads, and the completed LOX tank is governed by MA0616-002 "Intra/Inter Plant Protection Requirements for the Saturn S-II Program." Corrosion control requirements are given in specification MA0609-007 and the detection and prevention of corrosion is described in ITI-3526.

The manufacturer's proof testing philosophy dictates that tanks be tested as subassemblies. Consequently, the S-II-3 LOX tank was hydrostatically proof tested at room temperature on special tooling as aft LOX bulkhead and common bulkhead sections before assembly into the existing LOX tank. These areas proofed well in excess of the 1.05 proof factor. The girth weld remains essentially unproofed. The adequacy of the contractual 1.05 proof test factor at room temperature for guaranteed operational life in LOX at -297°F is demonstrated in document D5-15767, Reference 3.1.

The dollar weld in the aft LOX bulkhead did not receive an adequate proof test, however, a 1.03 proof factor was achieved in this area.

Consequently, the reliability of these two unproofed weld areas must depend on NDT inspection and analysis. The critical crack sizes at flight pressures, for these areas are 0.370 and 0.290 inches respectively. This size crack can be detected by radiographic, penetrant, and even visual inspection.

3.6 ON-SITE REVIEW SUMMARY

3.6.1 General

An on-site review was carried out at the Seal Beach facility of North American Rockwell Corporation. Inspection of the manufacturing and testing facilities was made to observe in detail the manufacturing and quality control procedures employed in the assembly of the LOX tank.

3.6.2 Documentation Reviewed

Manufacturing steps and quality control inspections are documented in "FAIR" books. A new "FAIR" book is issued for each assembly phase and all open items (shortages, Squawks, MR's, etc.) that have not been rectified are carried to the new "FAIR" book on shortage sheets. A final audit is made by QC and RMO prior to delivery to assure that all items have been closed out.

Planning Resident Order (PRO MW565-011B) identifies in detail the manufacturing procedure that is followed in the assembly of the LOX tank. The "Circumferential Weld History Log, S-II-1 to Present" allows a comparison of welds and the manufacturing deviations that could influence the quality of the weldment.

Corrosion control requirements are given in process specification MA0690-007 and prevention of corrosion for S-II stage subassemblies is described in ITI 3526.

3.6.3 Conclusions

From the on-site detailed element review, it was concluded that excellent traceability exists at the Seal Beach facilities with regard to manufacturing, quality control, and MR action related to the LOX tank.

The manufacturing processes and Quality Control procedures employed provide a high degree of confidence in the structural adequacy of the selected element.

SECTION 4

S-II-3 FORWARD LH_2 BULKHEAD

SELECTED ELEMENT REPORT

4.0 SUMMARY

The purpose of this review was to evaluate the manufacturing and quality control procedures used in the assembly of the S-II-3 Forward LH_2 Bulkhead, to determine if the "as-built" configuration structural integrity is assured.

The conclusions of this report are based on information obtained at NR from:

a. Inspection of manufacturing and quality control facilities and activities at Seal Beach.

b. Discussions with Engineering, Manfuacturing and Quality Control personnel concerning fabrication of the subject element.

c. Review of applicable documentation including, but not limited to: manufacturing plans and specifications, engineering drawings, MRB actions, and design certification reviews.

As a result of the extensive damage caused to the S-II-3 forward LH_2 bulkhead, complete replacement was necessary. The replacement bulkhead was intended for use on the S-II-5 stage and is of thinner gauge aluminum. The LH_2 tank has been cryogenic proof tested to 1.05 times the maximum anticipated flight pressures at operating temperature (-423°F). This proof test validates the adequacy of MR discrepancy dispositions and establishes a high level of confidence in the reliability of the LH_2 bulkhead for the AS-503 flight mission.

4.1 DESCRIPTION

The S-II-3 forward LH_2 bulkhead has a modified ellipsoidal shape as shown in Figure 4-1. The bulkhead is composed of 12 equal gore segments of 2014-T6 aluminum sheet. It has an access door, 36 inches in diameter located in the center. The gore segments are contoured by high energy forming and are subsequently chem-milled to incorporate weld lands and skin tapers. This skin tapering permits an approximately constant meridional stress distribution. All permanent joints of the bulkhead are fusion welded employing the TIG process and 2319 aluminum alloy filler wire.

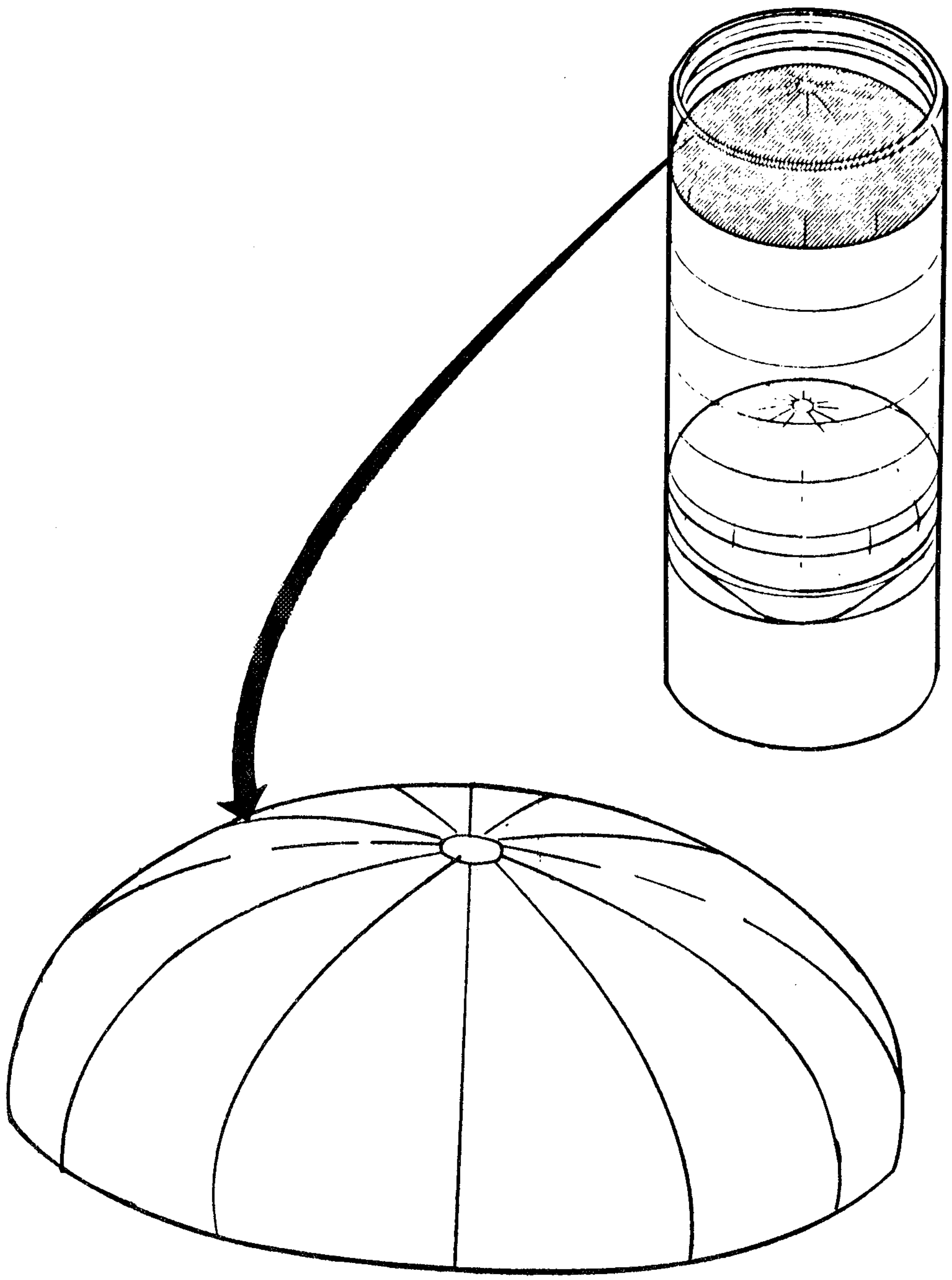

FIGURE 4-1 S-II FORWARD LH_2 BULKHEAD

4.2 MANUFACTURING

4.2.1 Fabrication

The LH_2 forward bulkhead is composed of 12 equal gore segments of 2014-T6 aluminum sheet. The gore segments are contoured by explosive forming and subsequently chem-milled to incorporate weld lands and skin tapers. All permanent joints of the bulkhead are fusion welded employing the TIG process and 2319 aluminum alloy filler wire. An access cover, 36 inches in diameter is welded in the center of the bulkhead. A layer of insulation which is an adhesive-bonded sandwich consisting of a nylon/phenolic laminate, phenolic/glass honeycomb, urethane foam filled core, and an outer skin of Tedlar film, is bonded in place after hydrostatic test.

4.2.2 Assembly

Gore panels are inspected and positioned in the automatic weld jig and then trimmed and cleaned. The first two panels are then fusion welded using the TIG process. Gap, offset and eccentricity are checked per ITI SB121. The weldment is then milled and radiographically and dye penetrant inspected for any discrepancy. Adjacent panels are then fitted, cleaned, welded, milled and inspected. The final gore segment is trimmed to fit the opening and welded into place. The shell is then inspected and transferred to the dollar weld fixture. The dollar weld opening is routed and attachment ring fitted to match the contour of the bulkhead. The cover is welded to the attaching ring, milled and inspected. The LH_2 forward bulkhead is then hydrostatically tested, penetrant inspected, and finally insulated.

The bulkhead is positioned on the upper LH_2, #6 cylinder as shown in Figure 4-2. The trim operation is shown in Figure 4-3 along with the skate saw and the skate track which is used to make the equatorial trim cut. The weld preparation and operation are shown in Figures 4-4, 4-5, and 4-6.

As a result of extensive damage attributed to a maintenance ladder failure, the original forward bulkhead was removed and replaced by the S-II-5 bulkhead (MR 14096). This bulkhead is of the light weight configuration and the weld land thickness of the #6 cylinder was machined to match the land thickness of the bulkhead. Figure 4-7 illustrates the sequence of operations required to remove the damaged bulkhead.

(1) POSITION LH_2 BHD IN SADDLE SPACERS

- ALIGN CYL. POSITION I TO LH_2 BHD POSITION I
- LEVEL BHD FOR TRIM-INSPECT PER 1T1
- INSTALL UPPER VACUUM DETAILS - WELD BACKUP BAR & APPLY INITIAL PRESSURE

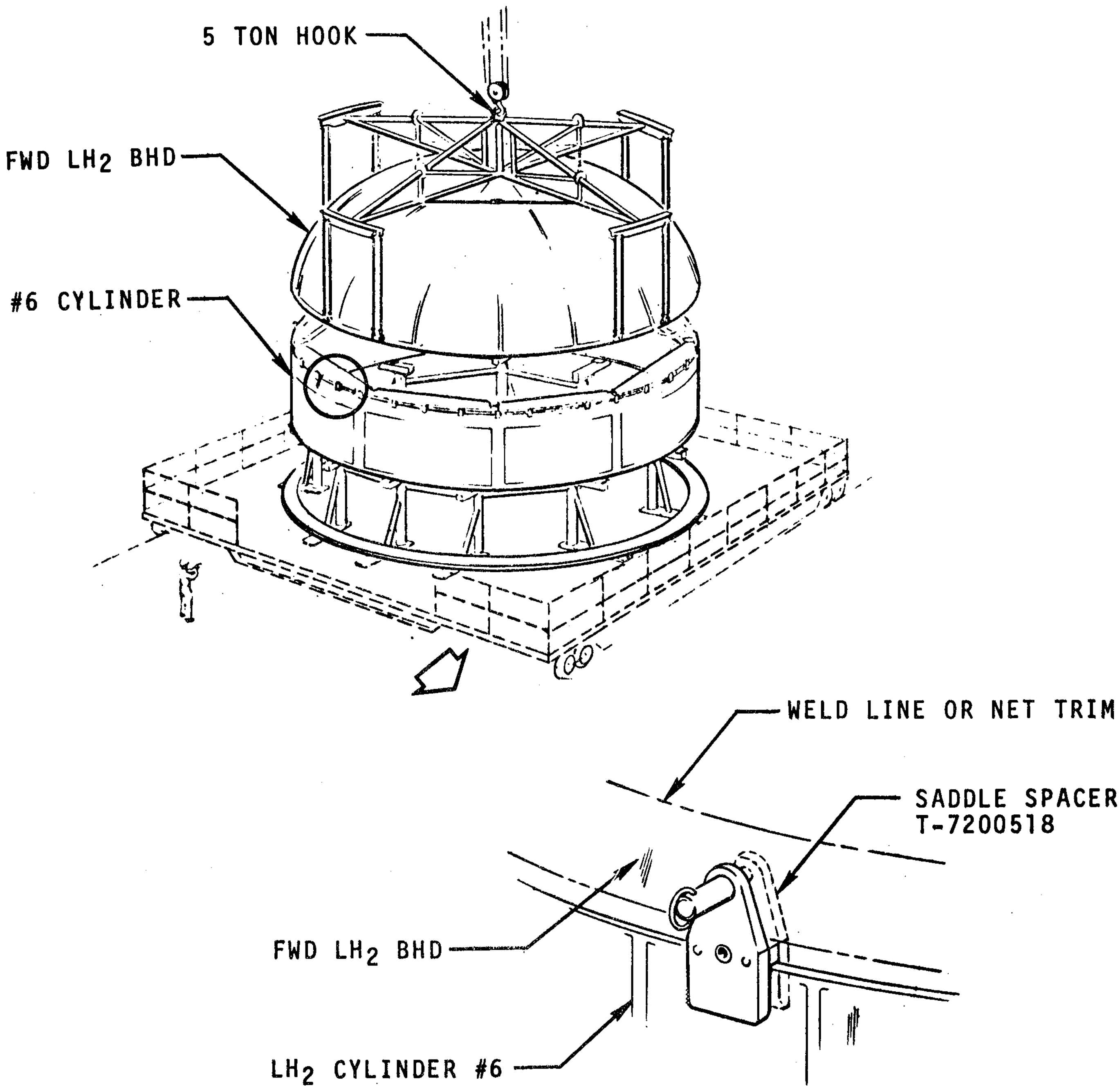

FIGURE 4-2 POSITION LH_2 BULKHEAD IN SADDLE SPACERS

(2) TRIM OPERATION LH_2 BHD.

- POSITION SKATE SAW - MAKE
- ROUGH TRIM
- VACUUM CHIPS
- CHECK FOR PLANE
- MAKE NET TRIM
- INSPECT TRIM

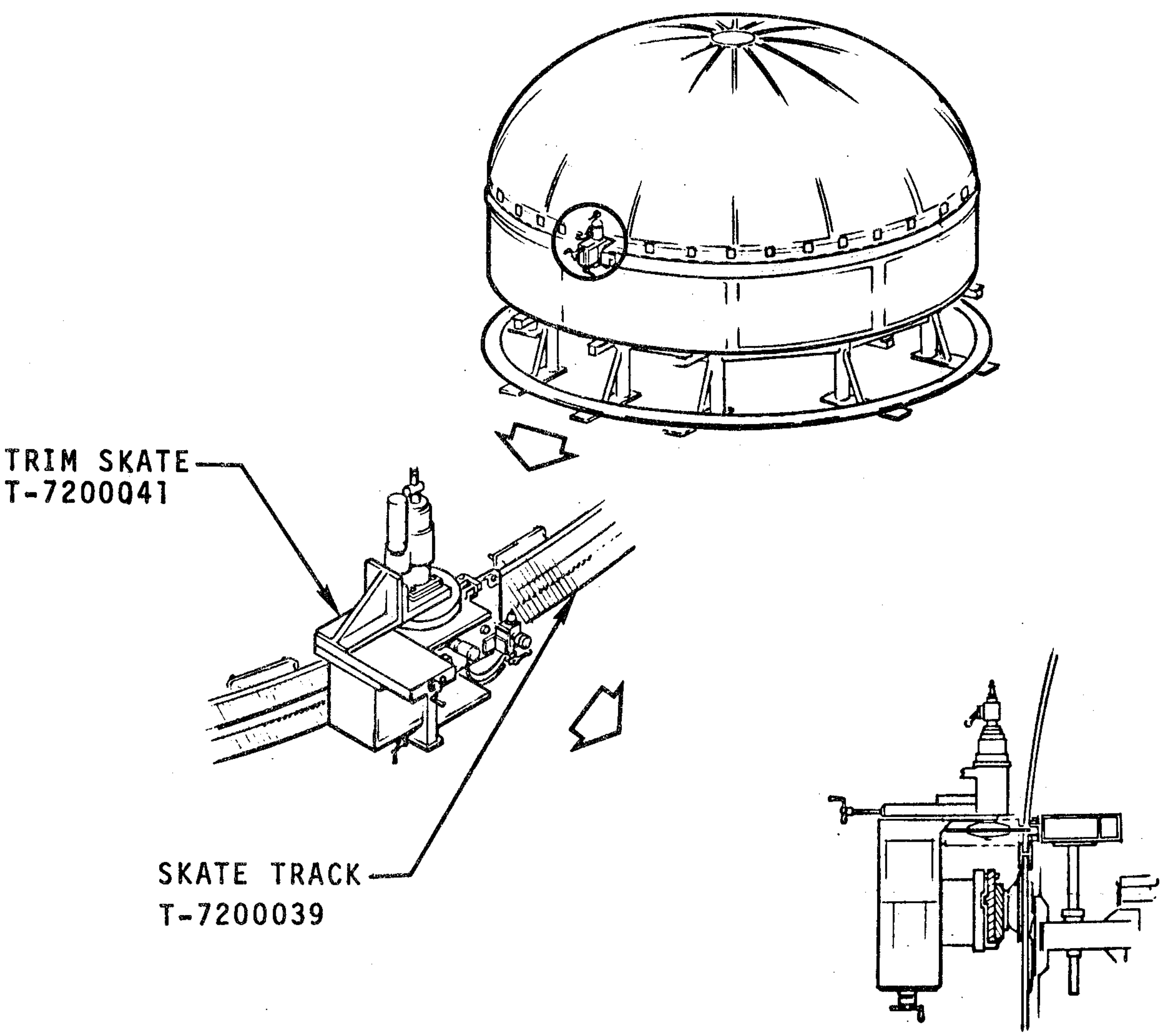

FIGURE 4-3 TRIM OPERATION LH_2 BULKHEAD

(3) WELD PREPARATION

- DROP BACKUP BAR PRESSURE
- RAISE BULKHEAD USING VACUUM DETAILS
- RETRACT BACKUP BAR
- CLEAN & INSPECT

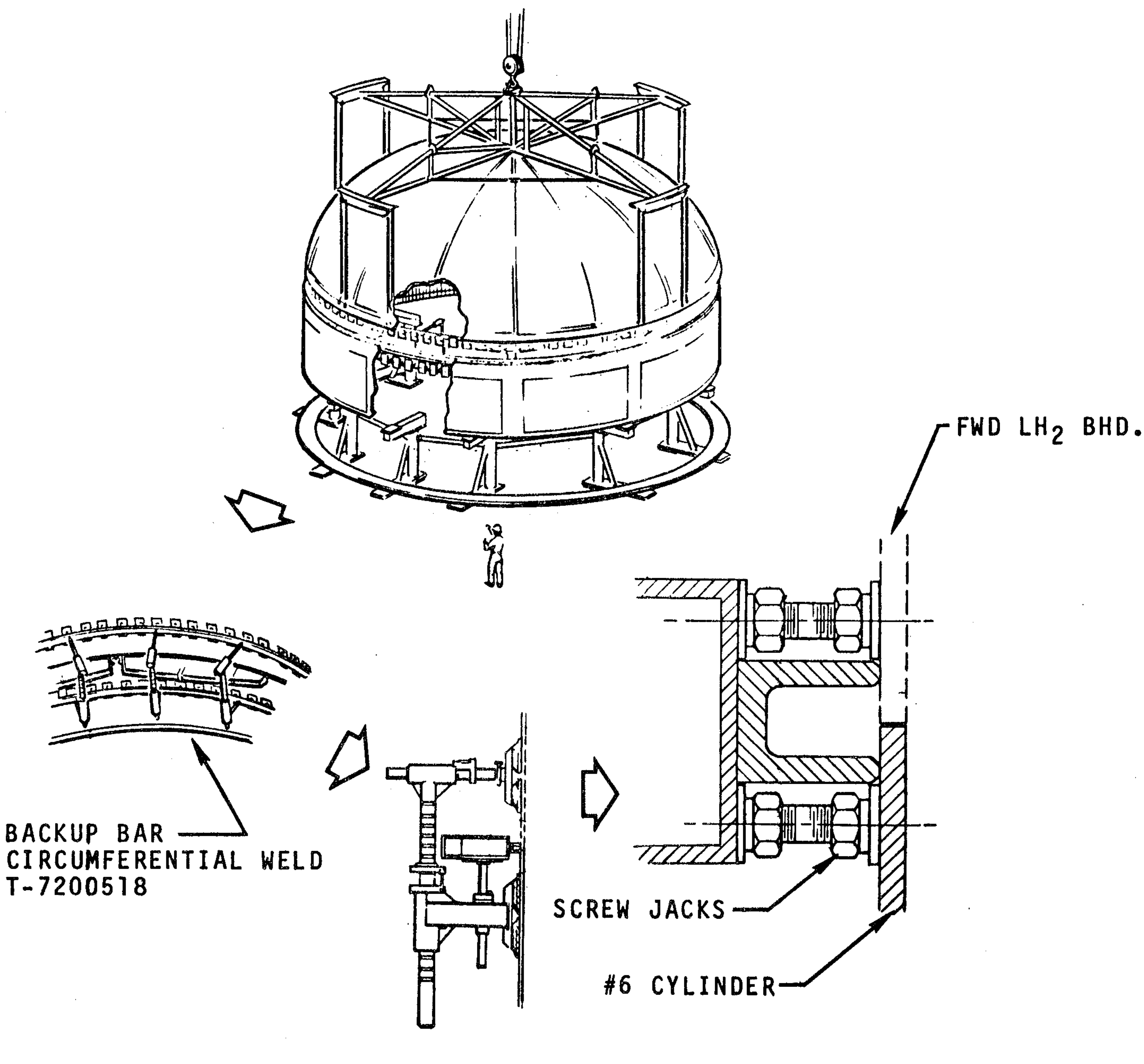

FIGURE 4-4 WELD PREPARATION

(4) WELD OPERATION

- REINSTALL BACKUP BAR
- ALIGN TO WELD
- POSITION BHD: FOR DRAW FILING
- VACUUM & INSPECT
- POSITION BHD. FOR WELDING
- ITI INSPECT, NASA INSPECT
- APPLY BACKUP BAR PRESS 6,000 LBS. HYDRAULIC PRESSURE
- SCREW JACKS IN EXCESSIVE OFF SET AREAS & START INTERMITTANT TACK WELD
- REMOVE SCREW JACKS
- PENETRATION PASS
- REMOVE BACKUP BAR
- SHAVE INTERNAL WELD BEAD
- MAKE CONTINUOUS TACK PASS

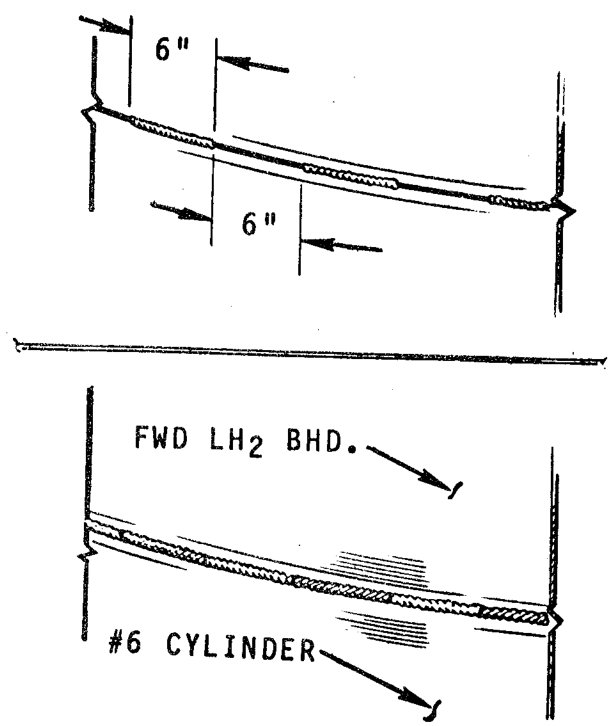

FIGURE 4-5 WELD OPERATION

(5) WELD COVER PASS OPERATION

- MAKE IN-PROCESS REPAIRS AS REQUIRED
- CLEAN-UP SHARP EDGES OF PENETRATION PASS
- X-RAY & INSPECT - REPAIR AS REQUIRED
- INSTALL BACKUP BARS,
  APPLY 5000 LBS. HYDRAULIC PRESSURE
- RUN COVER PASS
- MILL COVER PASS, BEAR-TEX & CLEAN-UP AREA
- DYE PENETRANT, INSPECT ALL ACCEPTED X-RAY
  VIEWS & CHEM FILM

INSPECT, CLOSE FAIR BOOK

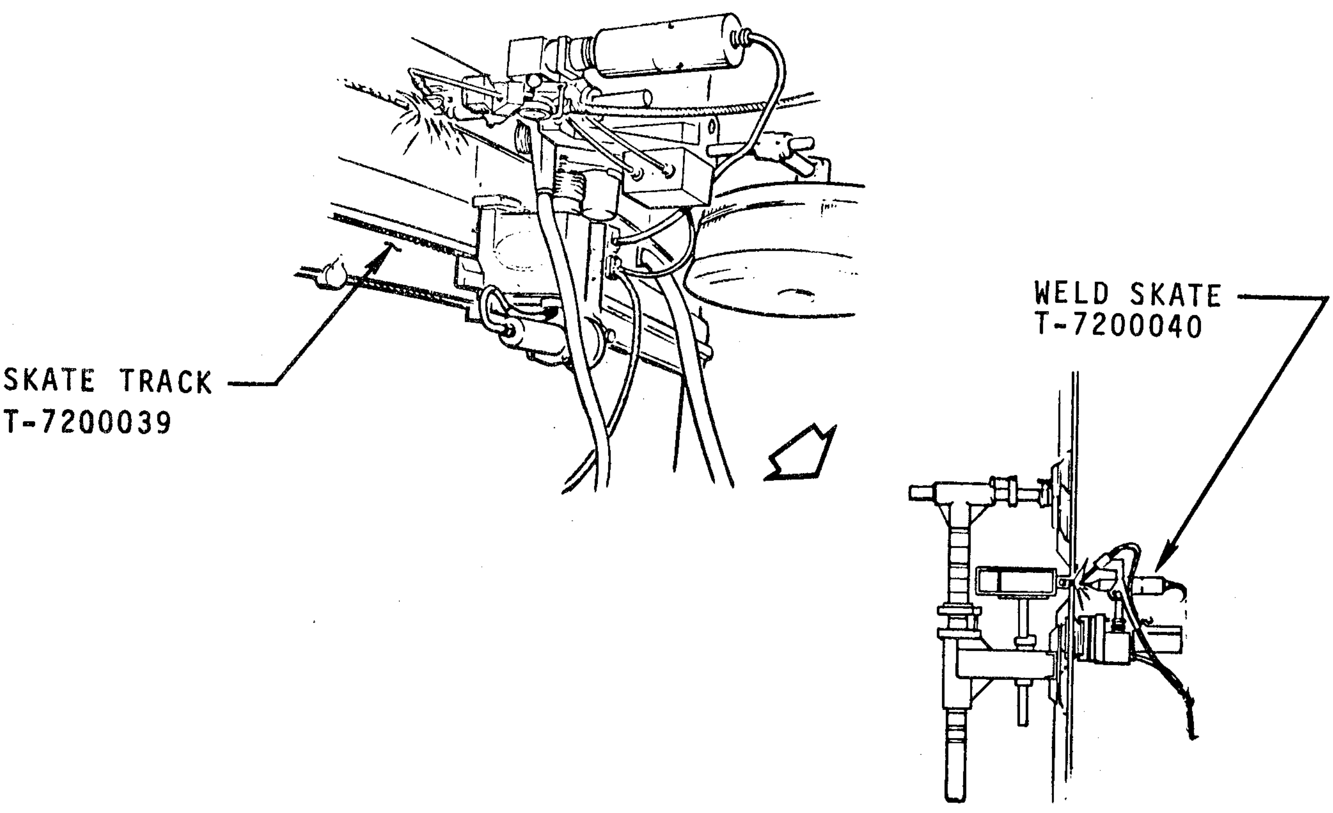

FIGURE 4-6 WELD COVER PASS OPERATION

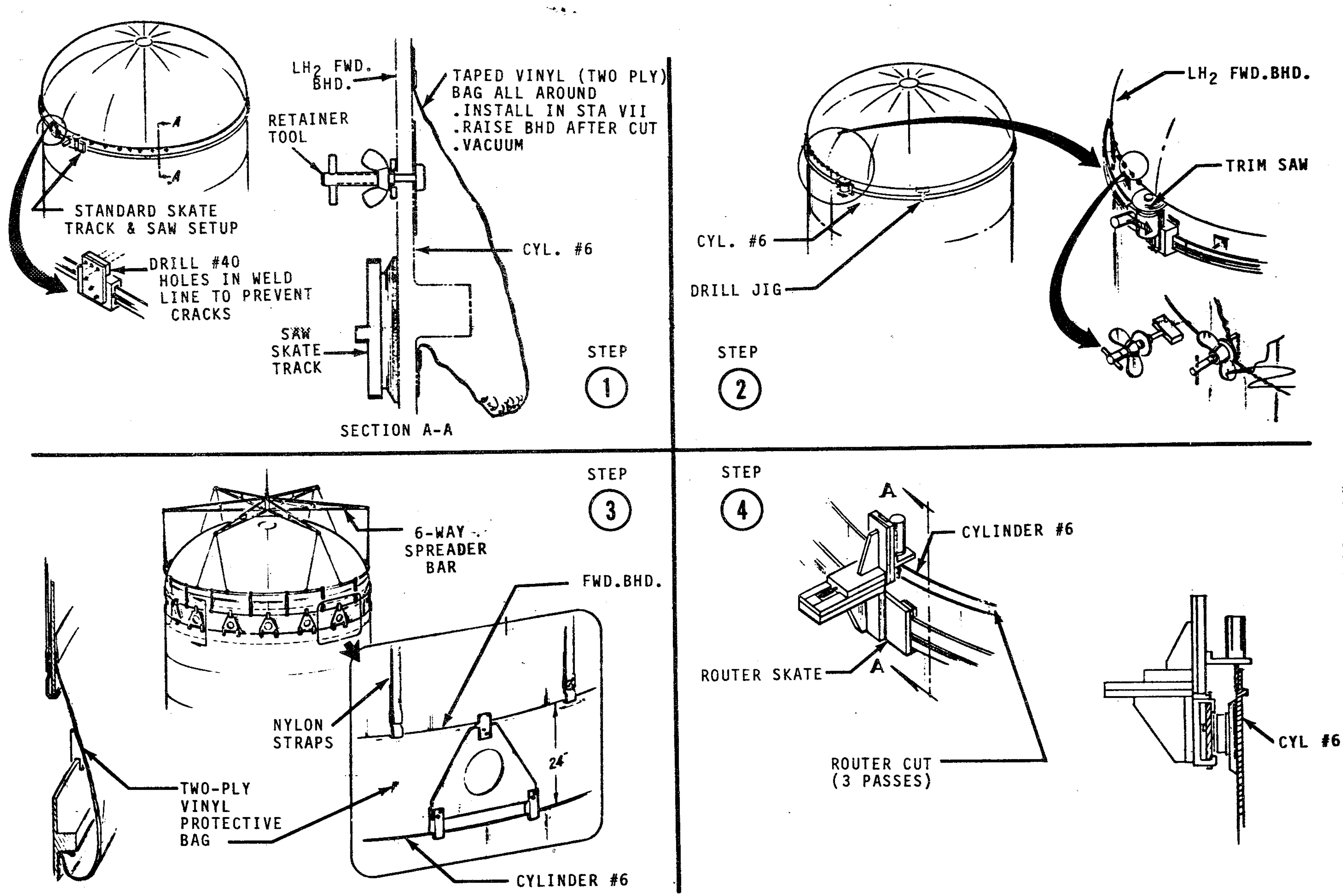

FIGURE 4-7 SEQUENCE OF OPERATIONS FOR REMOVAL OF DAMAGED BULKHEAD

4.3 QUALITY AND RELIABILITY ASSURANCE

4.3.1 Receiving Inspection (Raw Materials)

The vendor supplies a certification of physical, chemical, and ultrasonic inspection of the raw material. This data is verified by NR's Los Angeles Division, Quality Control Department.

Gore segments are visually inspected per MA0616-002 specification with the aid of high intensity lighting to detect any surface discontinuity or corrosion.

4.3.2 In-Process Inspection

A daily visual inspection per MA0609-007 specification is performed during all phases of processing and assembly for adherence to corrosion control requirements. The visual inspection is conducted with the aid of high intensity lighting and any suspected corrosion or pitting is examined using 10 X magnification per ITI 3526.

A welding engineer and a quality control representative are in attendance during all welding operations. Each gore to gore weld is radiographically and dye penetrant inspected prior to the joining of another segment (MA0107-016). The bulkhead assembly is then subjected to hydrostatic testing and again dye penetrant inspected prior to application of insulation.

The joining of the forward LH_2 bulkhead to #6 cylinder is a "white glove" welding operation performed in a controlled environment. The quality of the weld is determined by making a pre-production weld. After the weld quality is verified, the machine settings (gas purity and coverage, voltage, torch speed, etc.) are certified for production.

The penetration weld is radiographically inspected and any discrepancy found is corrected prior to the cover pass. The cover pass weldment is milled to a smooth surface and inspected radiographically. Discrepancies are recorded and corrected per Quality Control directive and re-inspected.

4.4 MRB ACTIONS

There were fifty-five (55) MR's assessed on the forward LH_2 bulkhead. The manufacturing plan and procedure for removal of the damaged S-II-3 bulkhead is dispositioned by MR 142134 and ITI 3292. The #6 cylinder weld land was machined to match the land thickness of the bulkhead as dispositioned by MR 176528. Discrepancies on the forward LH_2 bulkhead include: unrepaired weld defects, offsets between mating parts, under tolerance weld land thickness, stringer and horizontal rib ends with cracks, and skin out of tolerances. These discrepancies were dispositioned "use as is", but tend to reduce the margin of safety. However, the cryogenic proof testing of the LH_2 tank to 1.05 times the maximum anticipated flight loads at operating temperature (-423°F), validates all discrepancy dispositions. No MR actions have occurred against the LH_2 tank after this proof test.

Stress analysis reported in Reference 1.4 verified the adequacy of the dispositions.

See Appendix A for details of the MRB review.

4.5 HISTORY OF ELEMENT

As a result of extensive damage attributed to a maintenance ladder failure, the original bulkhead was removed and replaced with the thinner gauge S-II-5 bulkhead. The cryogenic proof test of this tank with the light weight bulkhead at -423°F, guarantees the LH_2 tank's reliability for the 503 flight mission.

AS-503 flight predictions indicate a maximum ullage of 33 psi during S-II burn and a Station 326 maximum pressure of 35.5 psi at S-IC CECO. The LH_2 proof test (36.1 psi ullage and 37.6 at Station 326) envelopes the maximum operational pressures by a minimum of 1.06 proof factor. Since design, flight, and proof test, temperatures are identical, the required proof test factor is dependent only upon sustained load flaw growth characteristics and total time at high flight pressures. This specific problem was investigated and reported (D5-15767, "Sustained Load Flaw Growth Investigation for 2014-T6 Aluminum Weldments Used in the Saturn S-II Stage LH_2 Tanks"). The finding of this report indicates that a 1.05 proof factor minimum is required to guarantee the mission life of the S-II-3 stage.

4.6 ON-SITE REVIEW SUMMARY

4.6.1 General

An on-site review was carried out at the Seal Beach facility of North American Rockwell. Inspection of the manufacturing and test facilities was made to observe in detail the procedures employed in the assembly of the LH_2 tank. It was found that traceability was excellent in regard to manufacturing and quality control as documented in the "FAIR" books.

4.6.2 Documentation Reviewed

Manufacturing steps and quality control inspections are documented in "FAIR" books. A new "FAIR" book is issued for each assembly phase, and all open items (shortage, squawks, MR's, etc.) that have not been rectified are carried to the new "FAIR" book on shortage sheets. A final audit is made by QC and RMO prior to delivery, to assure that all discrepancies have been corrected. SK-017140 outlines the "Manufacturing Plan and Sequence of Operations" required to remove the damaged forward LH_2 bulkhead on the S-II-3 and replace with the forward LH_2 bulkhead previously designated as the S-II-5. SK-017116 outlines the "Manufacturing Plan and Sequence of Operations" for stringer repair of the LH_2 tank. The "Circumferential Weld History Log S-II-1 to Present", allows a comparison of welds and manufacturing deviations that could influence the quality of the weldment.

4.6.3 Conclusions

From the on-site detailed element review it was concluded that excellent traceability exists at the Seal Beach facilities with regard to manufacturing, quality control and MR documentation related to the LH_2 bulkhead and LH_2 tank. The manufacturing processes and quality control procedures provide a high degree of confidence in the structural adequacy of the selected element.

The LH_2 tank has been proof tested to 1.05 times the maximum anticipated flight loads at the operating temperature of -423°F. This proof validates the adequacy of MR discrepancy dispositions and increases the confidence level of the reliability of the light weight LH_2 bulkhead for the AS-503 flight mission.

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SECTION 5

S-II-3 FORWARD SKIRT

SELECTED ELEMENT REPORT

5.0 SUMMARY

The forward skirt is manufactured in three phases. Panels and stringers are fabricated at Tulsa, Oklahoma. Bracketry is made at Los Angeles Division, California. The sub-assembly of the quarter panels and the final assembly is accomplished at Seal Beach, California. Complete documentation of each manufacturing phase, Quality Control, and MRB Action is collected in FAIR books. Review of these documentations and inspection of the manufacturing facilities at Seal Beach, California, provides assurance that the fabricated elements of the Forward Skirt represent the design to an adequate degree. Consequently, the end item does not impair the structural integrity of the design.

5.1 DESCRIPTION

The S-II forward skirt assembly extends from Vehicle Station 2382 to 2519 as shown in Figure 5-1. The skirt is a cylindrical shell consisting of a riveted, semi-monocoque, skin-stringer construction of four segments, fabricated from 7075-T6 aluminum alloy skin and extruded external stringers. The shell is stabilized by four internal ring frames. These frames are constructed of 7075-T6 sheet and extruded shapes. The skirt structure includes a bolting flange and mating face at Vehicle Station 2519 for attachment to the S-II/S-IVB interstage. Attachment of the lower end of the skirt to the LH_2 tank is a simple lap shear joint, employing a single row of 7/16-5/16 diameter, A-286 blind shoulder bolts located at the stringer flanges and on the skin at the midpoints between stiffeners. A 30 by 33 inch access door is located between Vehicle Stations 2458 and 2494. Longitudinal stiffeners are spaced uniformly around the circumference. An I-cross section intermediate stringer between the primary stringers stiffens the basic 0.040 inch skin panels at all four splicing locations.

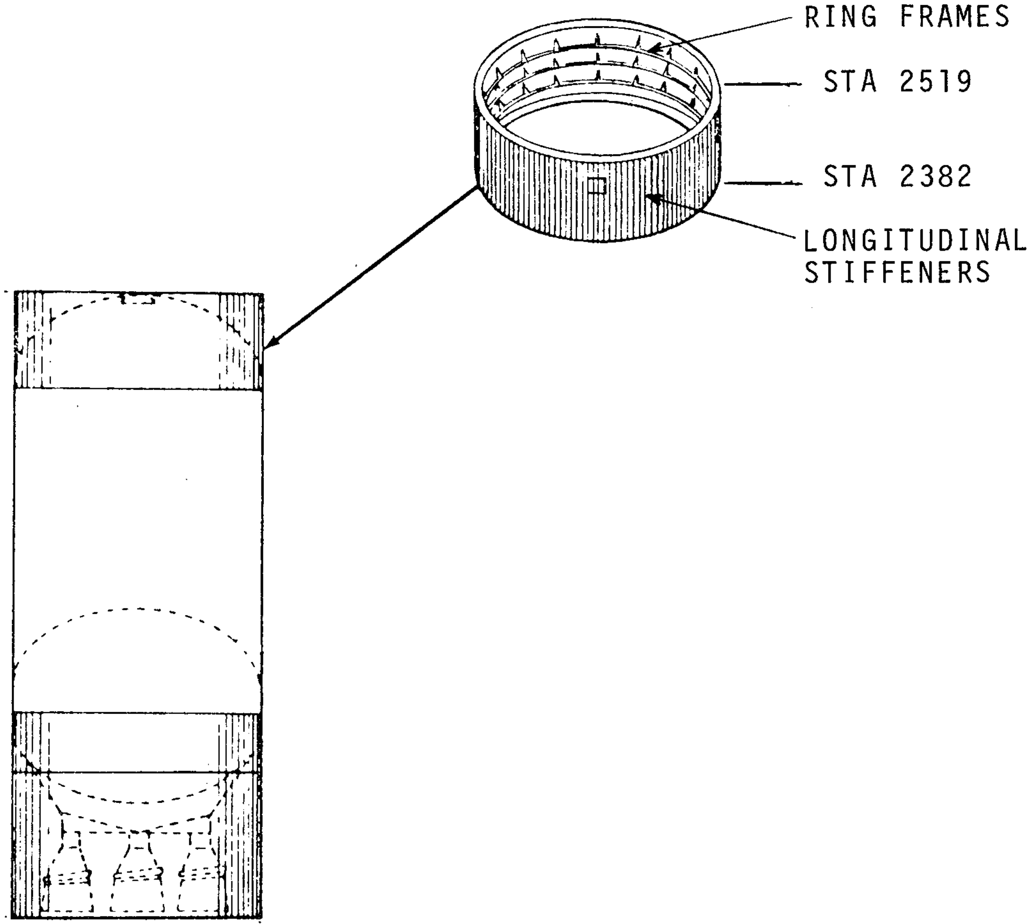


FIGURE 5-1 S-II FORWARD SKIRT

5.2 MANUFACTURING

5.2.1 Fabrication

Raw stock material is subjected to the following manufacturing procedures (see Figure 5-2):

a. Skin panels are cold rolled into cylindrical form and trimmed.

b. Frame angles are end trimmed and cold rolled into circular form.

c. Extruded stringers are end trimmed.

d. Frame webs are trimmed.

A sub-assembly jig is used for drilling and tack riveting the web and cap segments of the ring frames, the skin segments, and the external hat section.

Skin panels and subassembled frames are drilled and riveted in an assembly jig per Engineering Specification LA0101-004.

5.2.2 Assembly

Four forward skirt segments are riveted together on assembly jig T-7204443. The drilling operation is preceded by drawing a single, continuous line, using locating fixture T-7201255, for guiding the master drill jig. For alignment and drilling, fixture T-7200691 is utilized. Drilling and riveting is accomplished per Engineering Specification MA0601-001. Threaded fasteners are installed per MA0601-002. In order to meet the flatness tolerance ($\pm$.010") required by drawing V7-311002 on the mating surface with the S-IVB, the entire skirt is assembled in an inverted position on the assembly jig T-7204443. See Figure 5-3.

The aft end of the forward skirt is bolted to the forward end of the LH_2 tank. To assure perfect matching of the skirt with the LH_2 tank forward sub-assembly, #6 cylinder splicing is not completed during assembly of the segments. Approximately forty (40) inches of splicing is left open at the aft end. After lowering the forward skirt to the LH_2 tank, laminated, peel-type shimming (0.002 thick) is used on the open section for establishing the exact thickness. The peel type shim is then replaced with a fabricated shim of the same thickness.

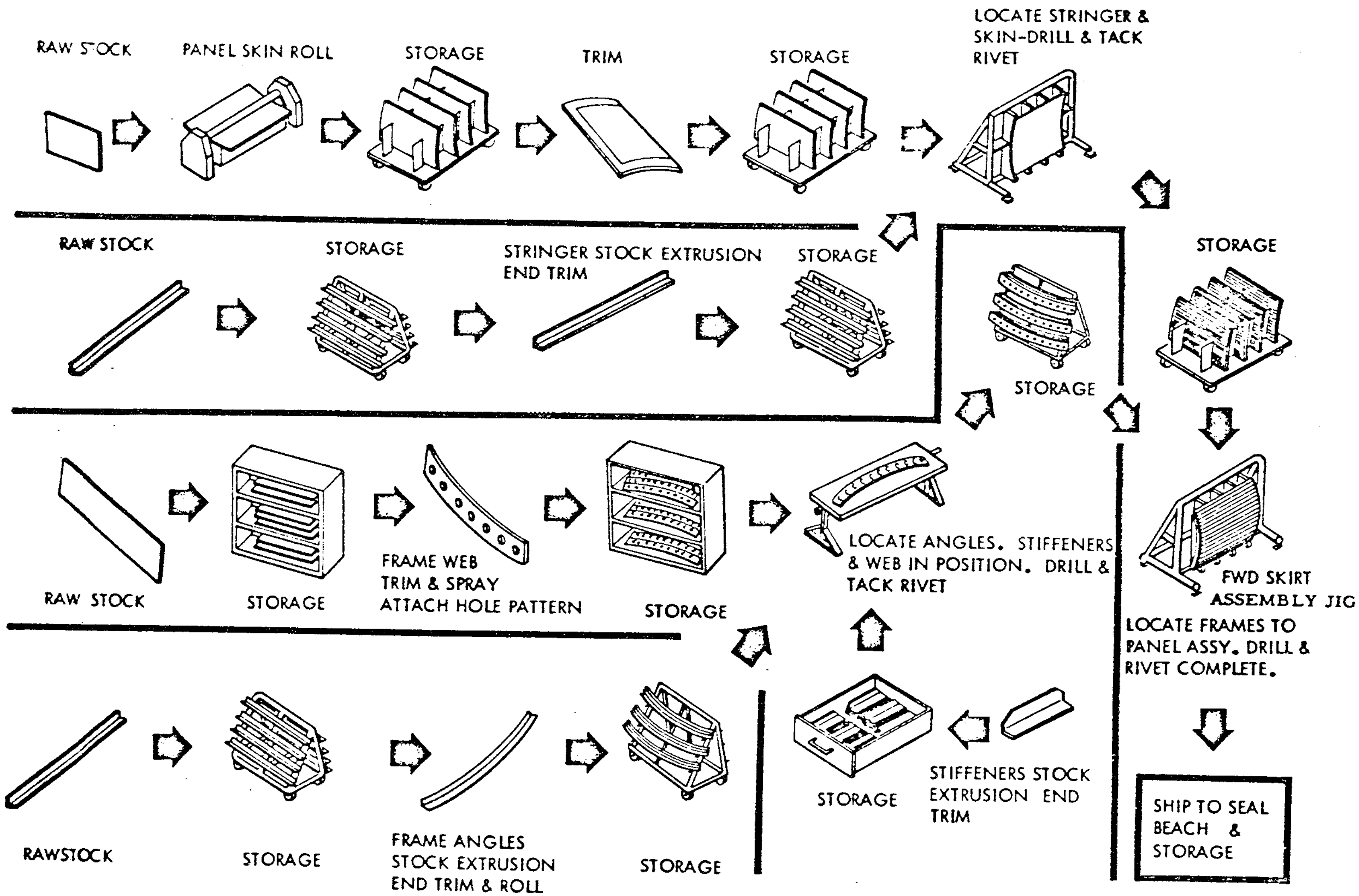
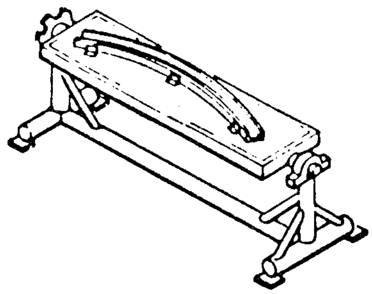
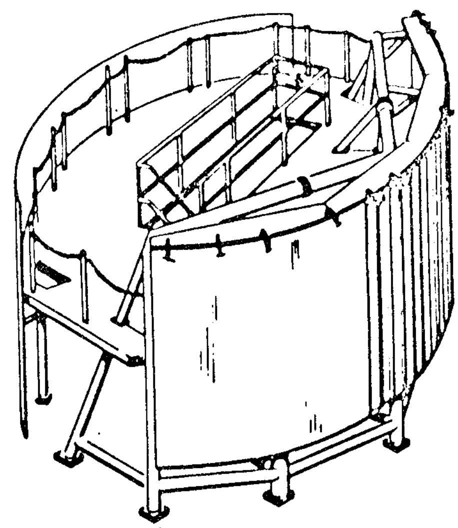


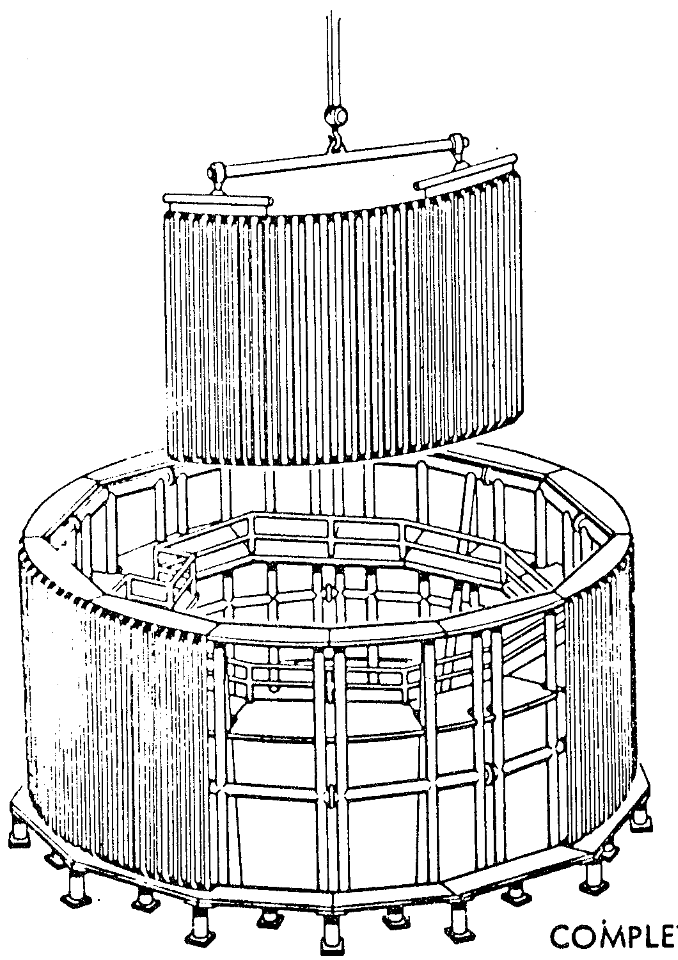
FIGURE 5-2 S-II FORWARD SKIRT FABRICATION SEQUENCE



FRAME SUBASSEMBLY



SKIN SUBASSEMBLY AND FRAME ASSEMBLY



COMPLETE FORWARD SKIRT ASSEMBLY

FIGURE 5-3 S-II FORWARD SKIRT ASSEMBLY

5.3 QUALITY AND RELIABILITY ASSURANCE

5.3.1 Receiving Inspection (Raw Materials)

Raw material for the forward skirt assembly is accompanied by the vendor's letter of certification for every shipment. The certification contains data on specific physical and chemical properties, and ultrasonic records to prove that the shipped raw material has no detectible discrepancy. Verification is accomplished by the Q C department by generating another set of ultrasonic records which are compared with the set submitted by the vendor.

Prefabricated quarter panel assemblies from Tulsa are subjected to the following inspection on receipt at Seal Beach:

a. Visual examination for surface damage.

b. Verification of proper serial number and traceability of any corrective action taken during manufacturing.

c. Corrosion inspection per MA0609-007 (ITI 3526).

5.3.2 In-Process Inspection

The frame subassembly is inspected and location identified after drilling and tack riveting the web and cap segments. Skin segment and stringers are inspected and the location identified after drilling and tack riveting skin segments to external hat sections. Skin panels and frames are inspected and the location identified after drilling and riveting.

5.4 MRB ACTIONS

There were a total of forty-six (46) MR's related to the forward skirt. Analysis of these MRB actions indicated that three (3) were candidates for additional investigation by Stress. A re-evaluation of these three MRB actions showed that the discrepancies were adequately analyzed and the dispositions were found to be structurally acceptable, Reference 1.4.

See Appendix A for details of the MRB review.

5.5 HISTORY OF ELEMENT

5.5.1 Shipping

Prefabricated parts are shipped in plywood crates. Loading and unloading is done by fork lift. Skin segments have double protection against handling and shipping damage, i.e. blue vinyl mask and protective foam cover.

5.5.2 Storage

Storage practice is outlined in Specification MA0616-002, Rev. E. Required protection for the Forward Skirt Panels which have been delivered to Seal Beach and their subsequent assembly is as follows:

a. Initial Storage (Outside)

All panels have to be coated with MB0125-006 and M602 Primer prior to placement in the container (Drawing No. MK392-78004). The top of the container shall be covered with a waterproof material which does not block the ventilation opening.

b. Indoor Storage

Panels - All surfaces shall be coated with the primer designated. Any areas where the primer has been removed must be recoated.

Assembly-After the foam insulation has been applied and trimmed, protective covers (Dwg. #MK395-78006) are applied.

NOTE: Outdoor storage of the Forward Skirt Assembly, with insulation applied, is not permitted.

5.6 ON-SITE REVIEW SUMMARY

5.6.1 General

Original documentation related to manufacturing processes and Quality Control inspection is compiled in FAIR books. NR's policy prohibits copying these documents. Copies of MRD's received for the review, were made from a master file which is not updated. Therefore, the main objective of the on-site inspection was to verify that every manufacturing process was performed to satisfy design specifications and the rework was completed and accepted as outlined on significant MRD's.

5.6.2 Documentation Reviewed

Manufacturing steps and quality control inspections are documented in "FAIR" books. Each assembly phase starts with a new "FAIR" book. All open items (shortages, squawks, MR's, etc.) that have not been rectified are carried to the new "FAIR" book on shortage sheets. The following is a list of the "FAIR" books reviewed.

FAIR Book No.	Serial No.	Contents
V7-311102-401	TAC 5340	Quarter Panel #1
V7-311202-301	TAB 9161	Quarter Panel #2
V7-311302-401	TAC 5327	Quarter Panel #3
V7-311402-301	TAC 5341	Quarter Panel #4
V7-311002-909	TAC 7836	Mate & demate quarter panels at Tulsa, Okla.
V7-311002-976	TAC 0566	Instl. of bracketry on Qtr. Panel #1
V7-311002-978	TAC 0557	" " " #2
V7-311002-980	TAC 0560	" " " #3
V7-311002-982	TAC 7896	" " " #4
V7-311002-925	SAA 3737	Instl. of quarter panels and bracketry
V7-311002-933	SAA 3730	Fwd Skirt Complete
V7-000002-905	--	Fwd Skirt system instl. complete

Corrosion control requirements are given in process specification MA0690-007. Prevention of corrosion for S-II stage subassemblies is described in ITI-3526.

5.6.3 Conclusions

The detailed element review is summarized in the following conclusions:

5.6.3 Conclusions - continued

a. It was found that traceability is excellent in regard to Manufacturing, Quality Control and MR action related to the S-II-3 Forward Skirt.

b. Assurance is provided that the fabricated elements represent their design to an adequate degree, and the quality of the end item does not impair the structural integrity of that design.

SECTION 6

S-IVB-503 COMMON BULKHEAD/AFT BULKHEAD-
AFT BULKHEAD/THRUST STRUCTURE JOINTS
SELECTED ELEMENT REPORT

6.0 SUMMARY

The purpose of this review was to evaluate the manufacturing and quality control procedures used in the assembly of the S-IVB-503 Common Bulkhead/Aft Bulkhead-Aft Bulkhead/Thrust Structure Joints, to determine if the "as-built" configuration structural integrity is assured.

The conclusions of this report are based on information obtained at MDC from:

a. Inspection of manufacturing and quality control facilities and activities at Huntington Beach and Santa Monica.

b. Discussions with engineering, manufacturing and quality control personnel concerning fabrication of the subject element.

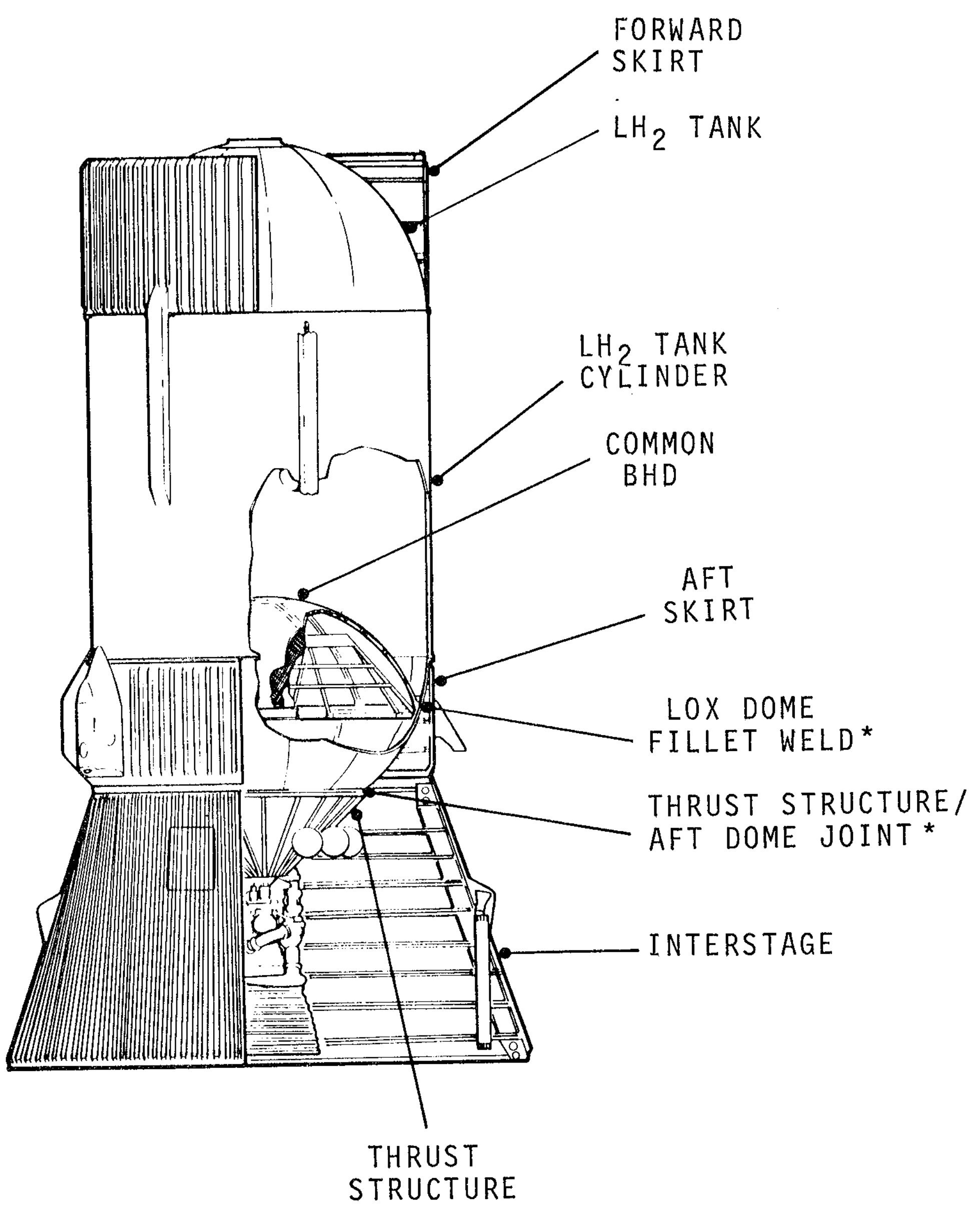
c. Review of applicable documentation including, but not limited to: manufacturing plans and specifications, engineering drawings, MRB actions and design certification reviews.

The investigating team concludes that the methods exercised and results achieved do assure the structural integrity of this selected element.

6.1 DESCRIPTION

The element selected for this review is the complex pair of joints in close proximity to each other which join the common bulkhead and the thrust structure to the aft bulkhead* of the S-IVB LOX tank. This area is considered an area of concern because of the variety of complex structural members involved. The common bulkhead is a metal-phenolic honeycomb sandwich, the thrust structure is of skin-and-stringer construction, while the aft bulkhead is formed by welding thin aluminum gore-shaped segments. The two joints in question also differ from one another. The common bulkhead is joined to the aft bulkhead by both welding and bolting techniques, while the thrust structure is joined to the aft bulkhead by bolting only. Figure 6-1 illustrates the physical relationships of the two joints.

*NOTE: MDC refers to the aft bulkhead as the aft dome. For purposes of this report the terms are considered interchangeable.



* STRUCTURAL JOINTS REVIEWED

FIGURE 6-1 S-IVB

6.2 MANUFACTURING

In order to appreciate the complexities of the two joints in question, a description of the manufacture of the three components involved is outlined.

6.2.1 Fabrication

6.2.1.1 Common Bulkhead

The common bulkhead assembly is a two inch thick sandwich honeycomb structure, Reference 6.1. It consists of a fiber-glass reinforced phenolic honeycomb core adhesively bonded between two hemispherically shaped domes per DPS 31150-1. The forward and aft dome assemblies are produced from 2014 aluminum material. Each assembly is fusion welded (MIG process, DPS 14052) and consists of a contoured center plate, nine gore segments, and a circumferential ring assembly. Figure 6-2 shows the common bulkhead and a close-up of the common bulkhead/aft dome joint.

The ring assembly is composed of three identical ring segments fabricated from an extruded angle, formed on a stretch die, and heat treated by aging to T6 condition. The three segments are joined by fusion welding in a weld fixture, then machined in a large boring mill.

The forward dome segments and center plate are fabricated from 0.125 inch thick sheet aluminum, and the aft dome segments and center plate from 0.133 inch thick sheet aluminum. Figure 6-3 shows the manufacturing sequence for the common bulkhead.

The adhesive bonding sequence subjects the entire assembly of aft dome, honeycomb and bonding tool to a vacuum of 25" Hg. and the bond is cured with heat (330°F) and pressure (10 psi) in a large autoclave. When cure is complete, the forward surface of the honeycomb is carefully fitted to the contour of the aft face of the forward dome. The bonding sequence is repeated, with vacuum, heat and pressure to achieve final cure. The seal weld completes closure of the common bulkhead, and the final finish steps are taken as shown in Figure 6-3.

6.2.1.2 Aft Bulkhead

The aft bulkhead of the LOX tank is a hemispherically shaped aluminum structure consisting of nine gore segments, and various flanges, fittings and elbow assemblies. The nine gore segments are fabricated from 0.280 inch thick 2014 sheet aluminum. Forming of individual segments

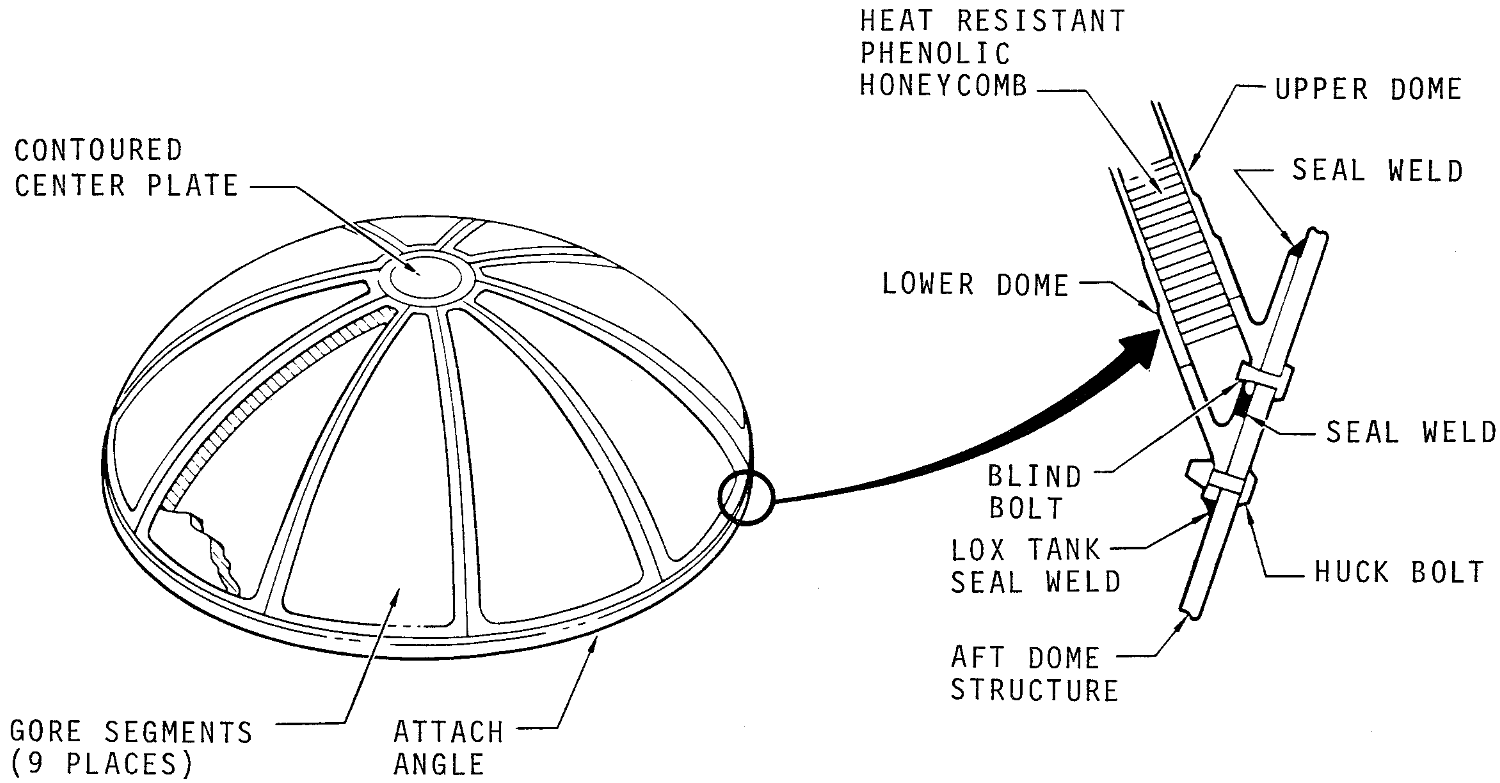


FIGURE 6-2 S-IVB COMMON BULKHEAD AND COMMON BULKHEAD/AFT BULKHEAD JOINT

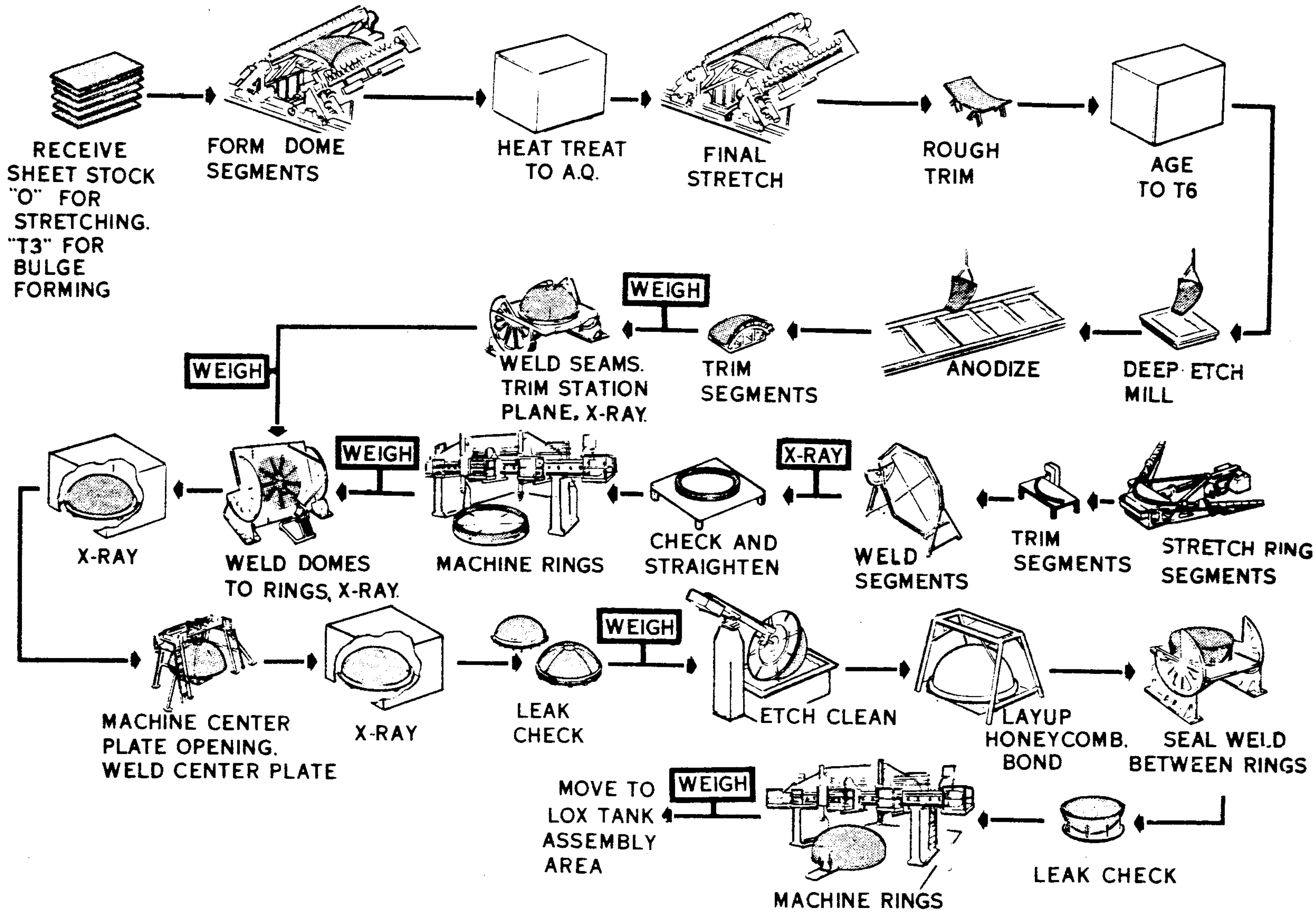


FIGURE 6-3 S-IVB COMMON BULKHEAD MANUFACTURING SEQUENCE

and fabrication sequence of the bulkhead is detailed in Figure 6-4. All parts are joined by MIG process fusion welding using the welding jig as shown in Figure 6-5.

6.2.1.3 Thrust Structure

The thrust structure assembly is composed of skins, stringers, frames, attach angles, doors, splices, doublers and an engine mount fitting. All parts but the engine mount fitting are fabricated from 7075-T6 aluminum sheet or extrusion. The engine mount fitting is fabricated from a high purity, 356-T6 aluminum casting, machined in a numerically controlled vertical turret lathe. Figure 6-6 shows details of the assembly of the thrust structure, as well as final configuration.

6.2.2 Assembly

The LOX tank assembly is composed of the LOX tank baffle assembly, the common bulkhead assembly, the aft bulkhead assembly, and the segmented attach angle. The attach angle is used to secure the thrust structure to the vehicle during final assembly. Figures 6-7, 6-8 and 6-9 show details of assembly of the LOX tank. Figure 6-10 depicts the transportation techniques used to move the LOX tank assembly from Santa Monica to Huntington Beach.

The thrust structure is attached to the aft bulkhead during final assembly. This is shown in Figure 6-12.

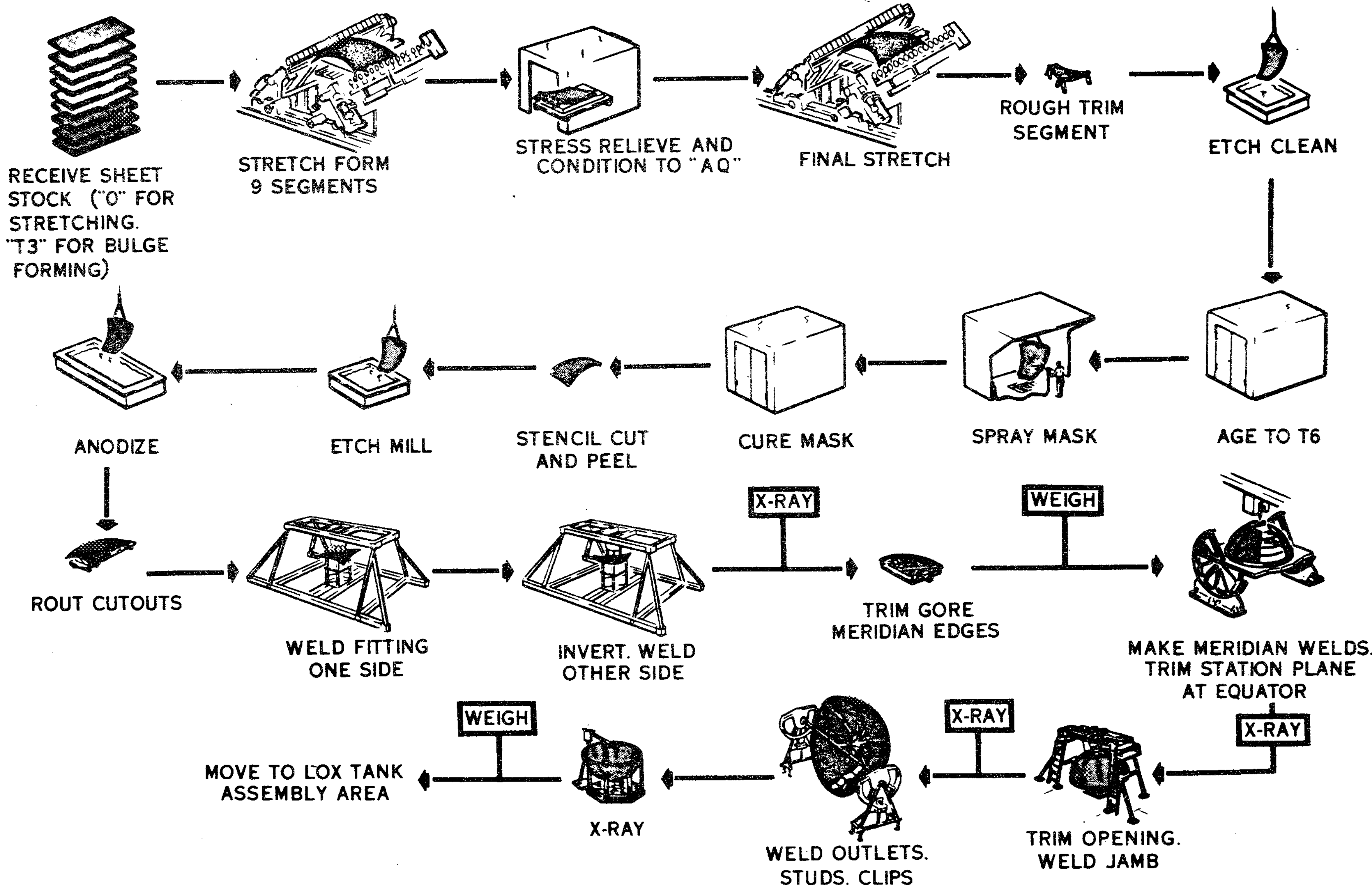
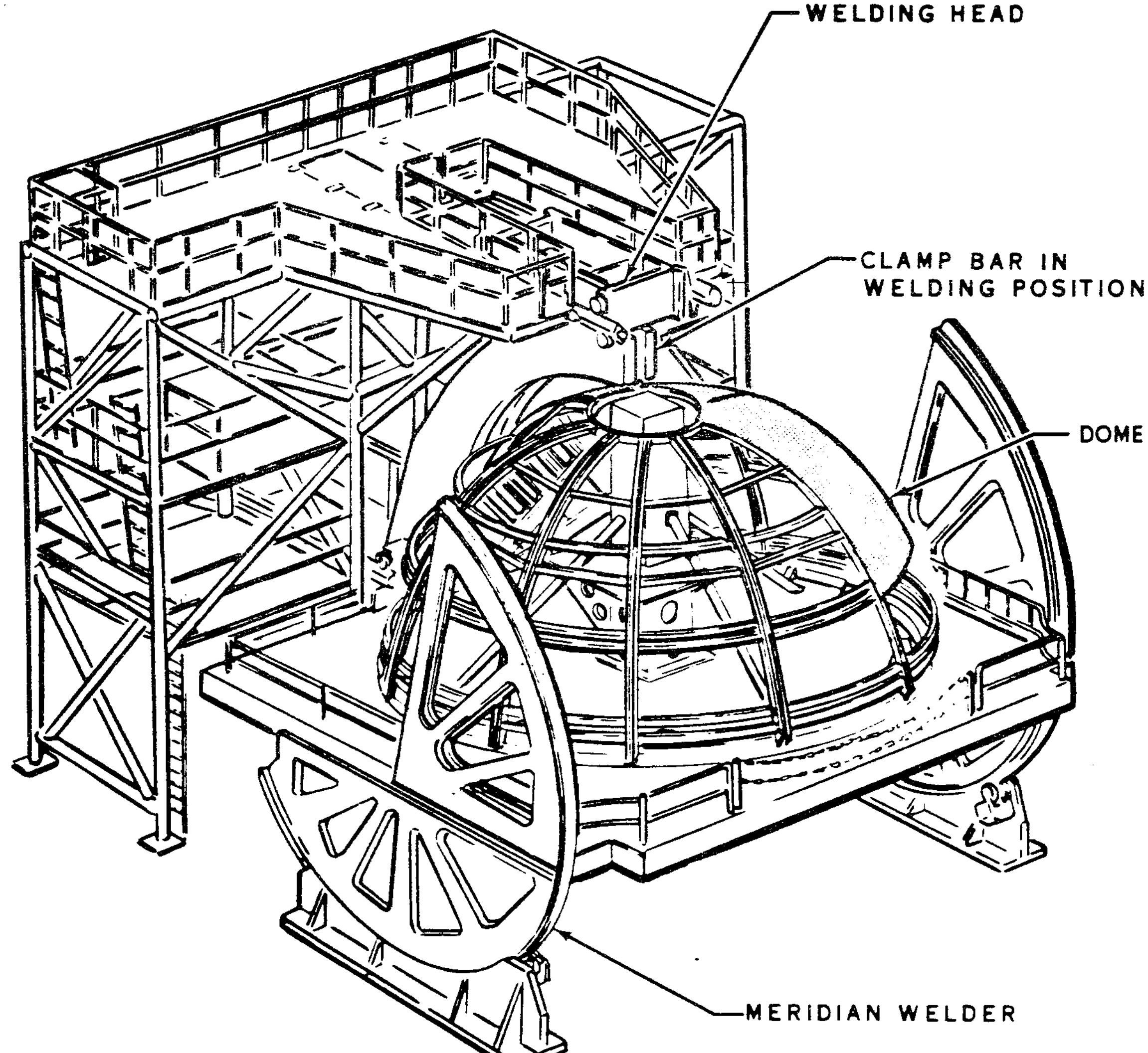
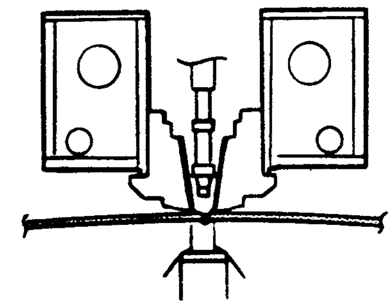


FIGURE 6-4 S-IVB LOX TANK AFT BULKHEAD MANUFACTURING SEQUENCE





CROSS SECTION SHOWING WELDING OPERATION

FIGURE 6-5 S-IVB WELDING GORE SEGMENTS AFT AND COMMON BULKHEADS

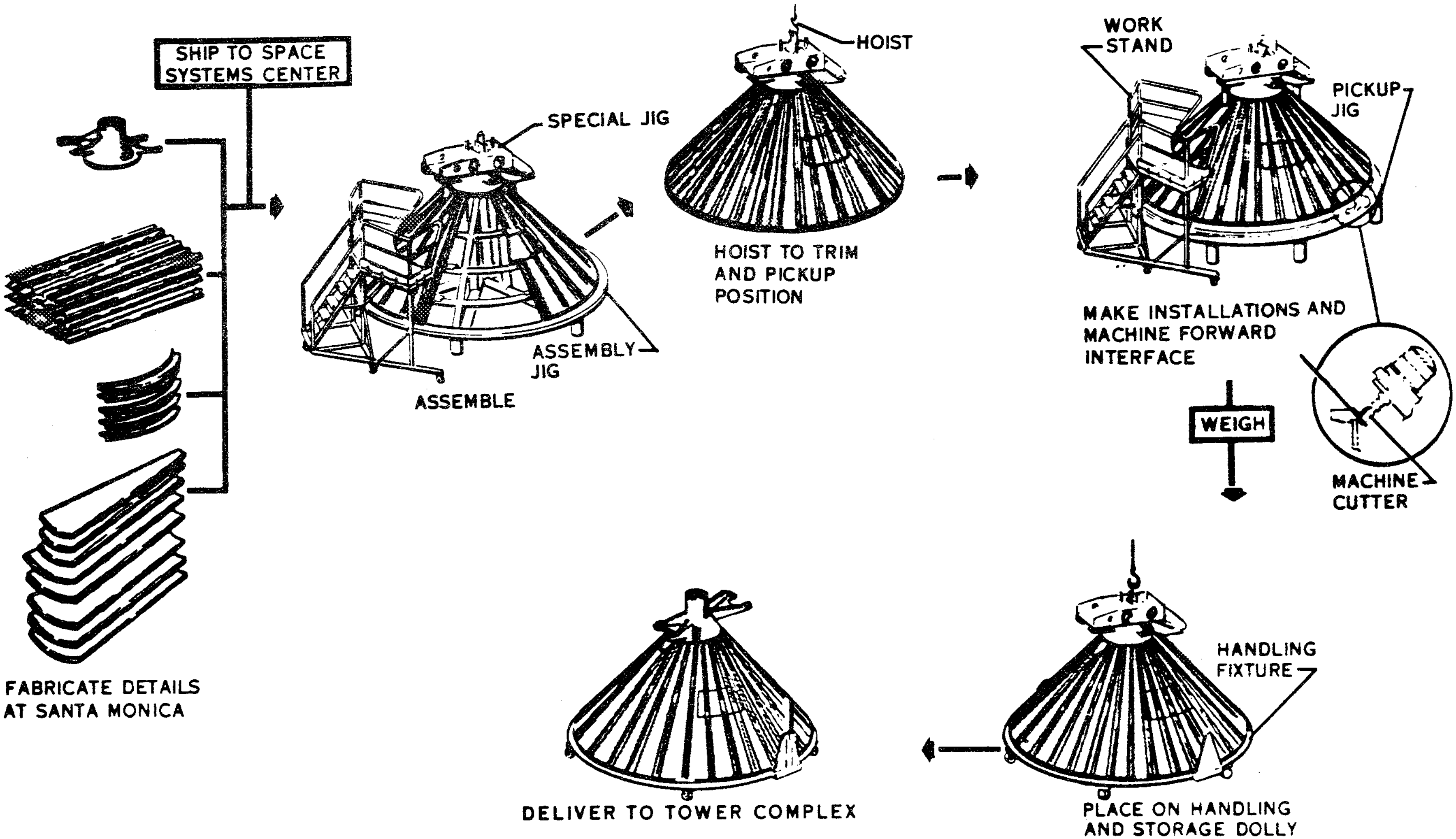


FIGURE 6-6 S-IVB THRUST STRUCTURE MANUFACTURING SEQUENCE

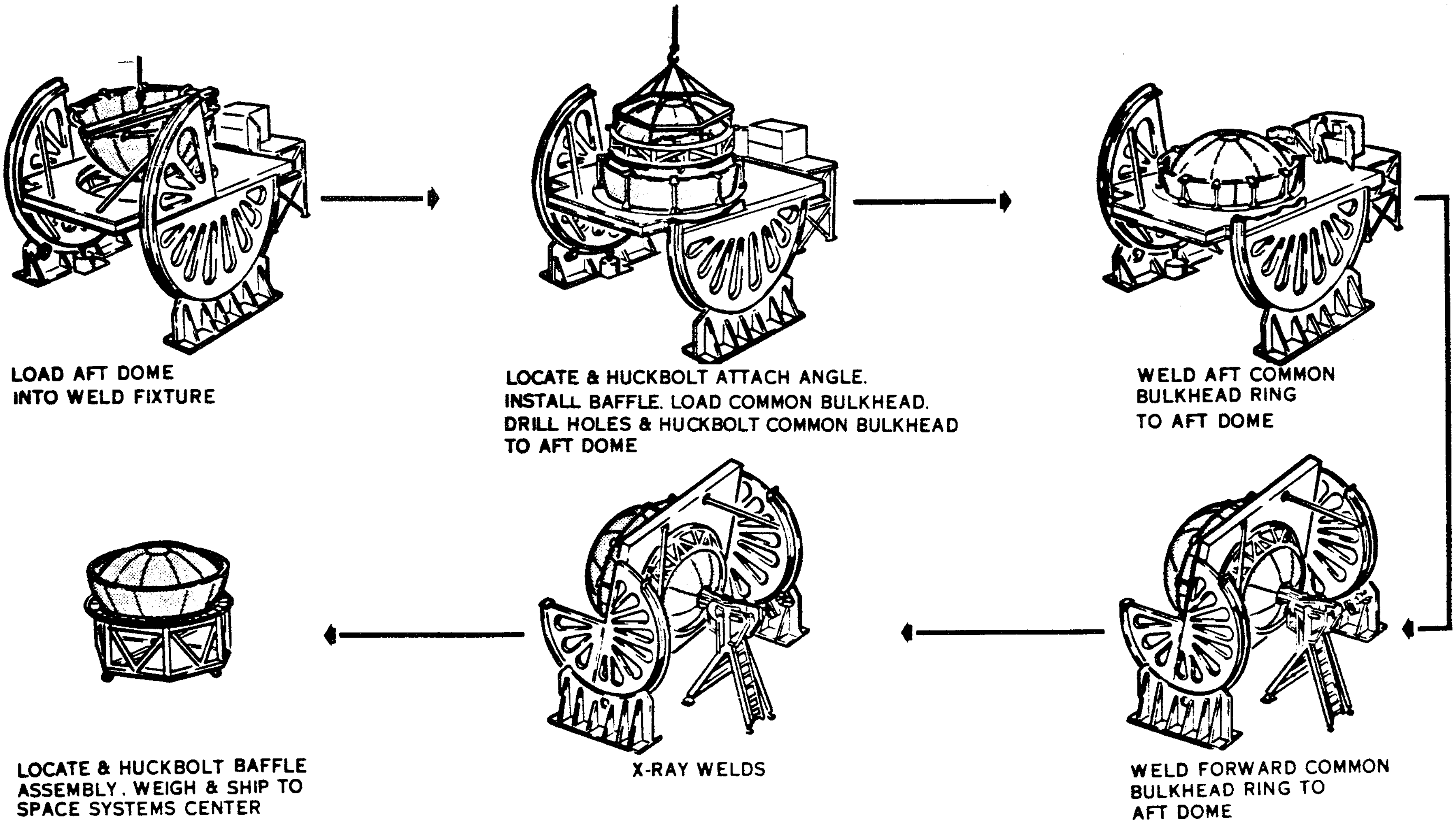


FIGURE 6-7 S-IVB LOX TANK
ASSEMBLY SEQUENCE

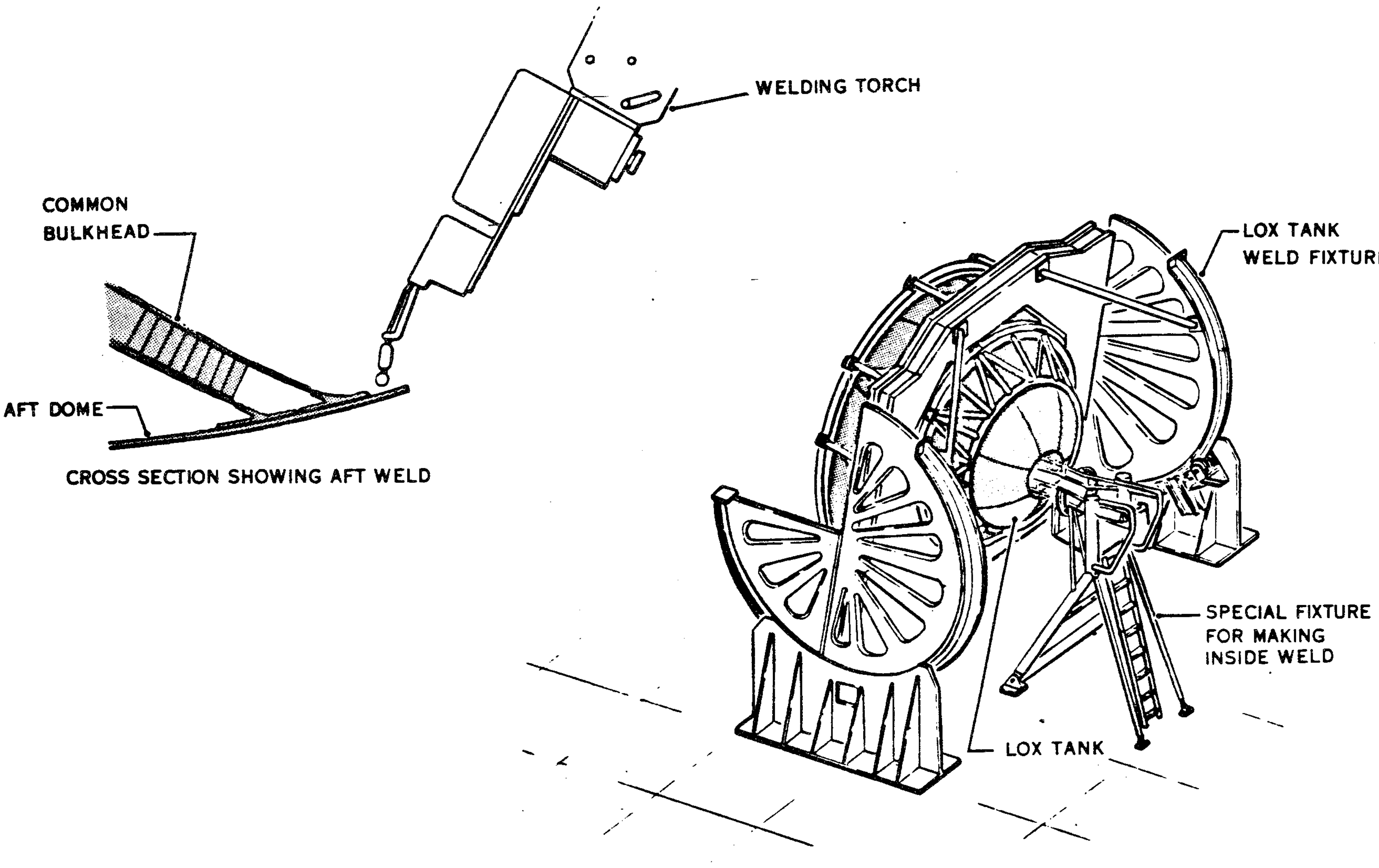


FIGURE 6-8 S-IVB LOX TANK-JOINING COMMON BULKHEAD AND AFT BULKHEAD

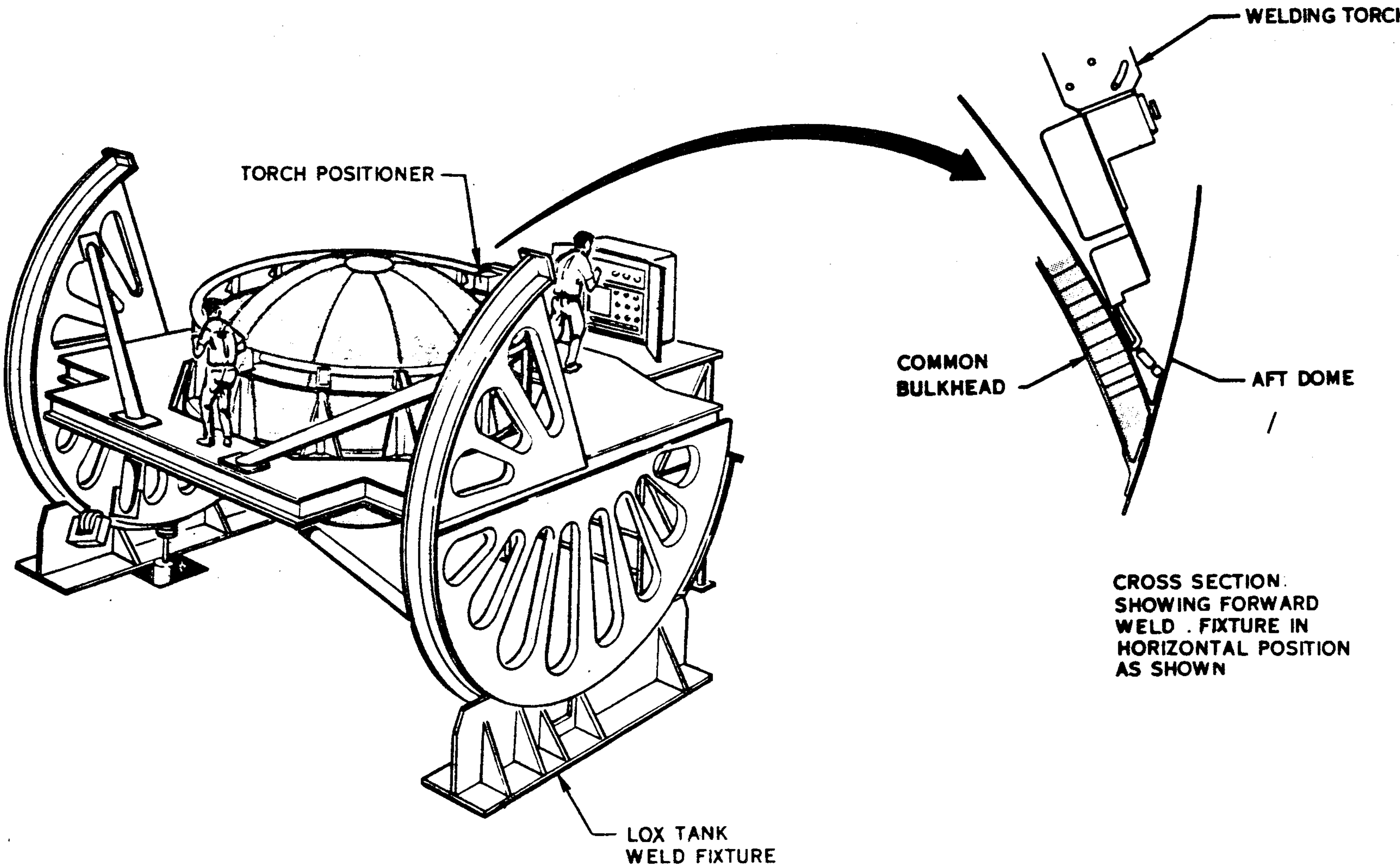


FIGURE 6-9 S-IVB JOINING LOX TANK ASSEMBLY COMMON BULKHEAD AND AFT BULKHEAD

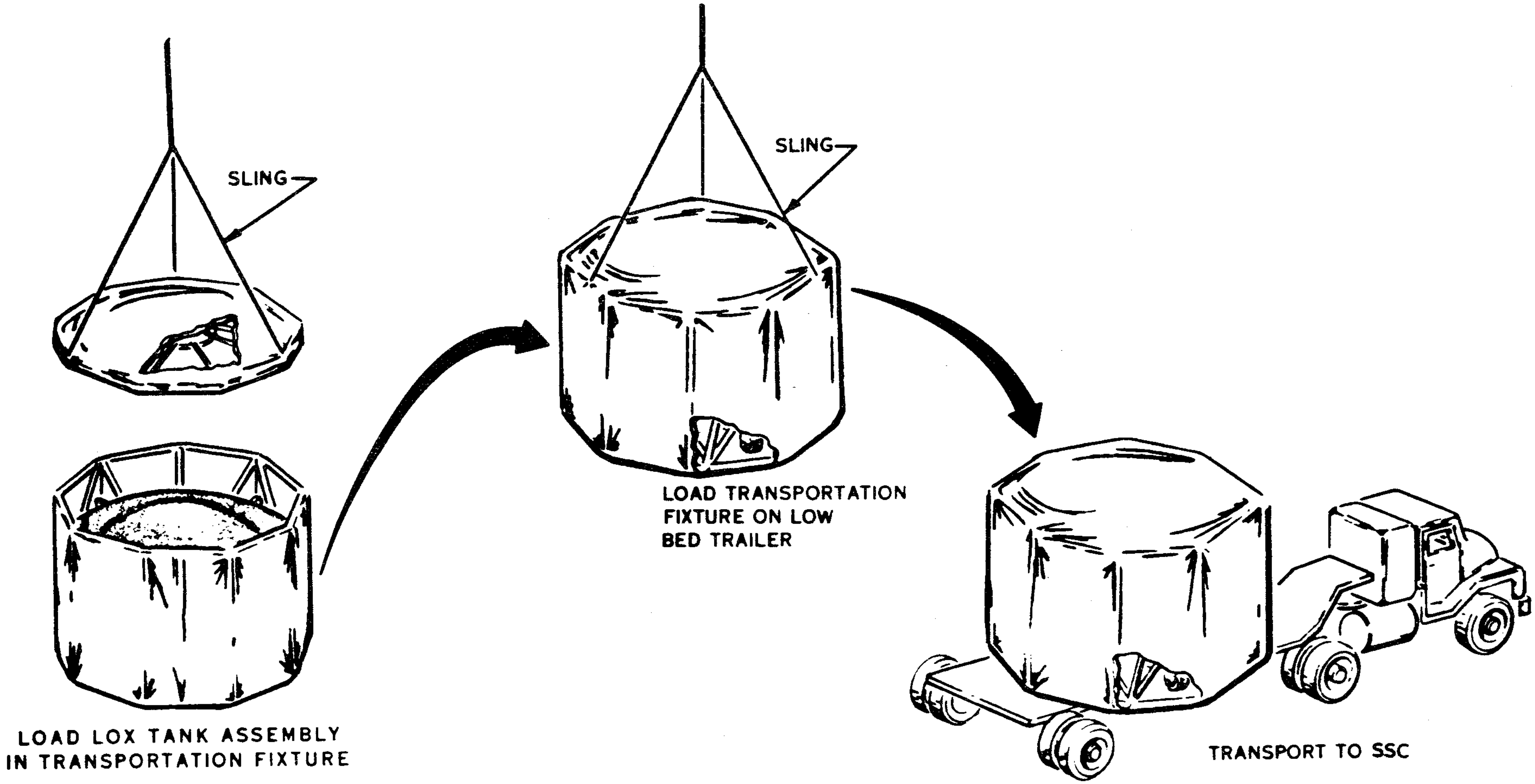


FIGURE 6-10 S-IVB SHIPPING LOX TANK
TO SPACE SYSTEMS CENTER

6.3 QUALITY AND RELIABILITY ASSURANCE

"Quality Control shall be in accordance with NASA NPC 200-3 and applicable portions of NASA NPC 200-2 as defined in the Douglas Reliability Control Specification," Reference 6.2.

6.3.1 Receiving Inspection (Raw Materials)

Raw materials are inspected for identification, damage, dimensional characteristics and evidence of non-destructive tests. All receiving paper is reviewed for the suppliers chemical and/or physical test reports, test certification, material certification, etc., to the applicable specifications noted on the purchase order. In the absence of acceptable suppliers test data, MDC tests as required by the applicable specifications. In addition to the foregoing testing, periodic testing is performed by Q&RA personnel on a prescribed random basis to assure accuracy of suppliers' test results.

All raw materials requiring test are withheld pending completion of these tests. Reliability assurance verifies that the requirements of the specifications are met.

6.3.2 In-Process Inspection

Inspection procedures for fabrication, assembly and test operations are an integral part of the detail manufacturing documents (A.O.'s). Both standard and special inspection procedures are issued and controlled by the Reliability Assurance Department.

All tooling is optically inspected at regular intervals, and realigned as required.

Etch baths, chem-mill solutions and anodizing solutions have their composition and concentration verified before use.

Welding personnel are certified and must be recertified at regular intervals. All welding is done under rigid clean room conditions, under personal supervision of a welding engineer, per DPS 41006. Every step of the welding procedure must be signed off by Q&RA inspectors.

Bonding technicians undergo intensive training before being allowed to work on the common bulkhead. Refresher training courses are also required. Adhesive bonding is carried out under rigid clean room procedures. Adhesive batches are checked before use to verify age and bond strength, per DPS 31150-1. All temperatures, pressures and vacuums are recorded and monitored.

As indicated in Figure 6-3, 6-5, and 6-7, 100% x-ray inspection is carried out on all welds as standard procedure (DPS 15200, QCM 0008). In addition, all welds are examined visually under white light, black light and by penetrant techniques (DPS 15101, DPS 15105). Weld settings are determined in advance of production welding by running preproduction sample welds on production weight metal. Preproduction weld samples are subjected to full inspection and tensile testing before production welding may proceed (DPS 14052).

After welding, but before final bolting of the common bulkhead/aft bulkhead joint, the assembly is leak tested by pressurizing the area between the two welds.

6.3.3 Final Checkout and Inspection

Final assembly of the tanks of the S-IVB is accomplished in the Tooling Tower complex at the Huntington Beach facility. The assembled tank is proof-pressure tested hydrostatically in this building (Figure 6-11) then all welds are again checked by dye penetrant techniques, per References 6-3 and 6-4.

Following insulation of the LH_2 tank interior, the tank assembly is returned to the Tooling Tower complex for attachment of skirts, thrust structure, J-2 engine, electrical and hydraulic systems. The procedures followed, with checkout points noted, are shown in Figure 6-12.

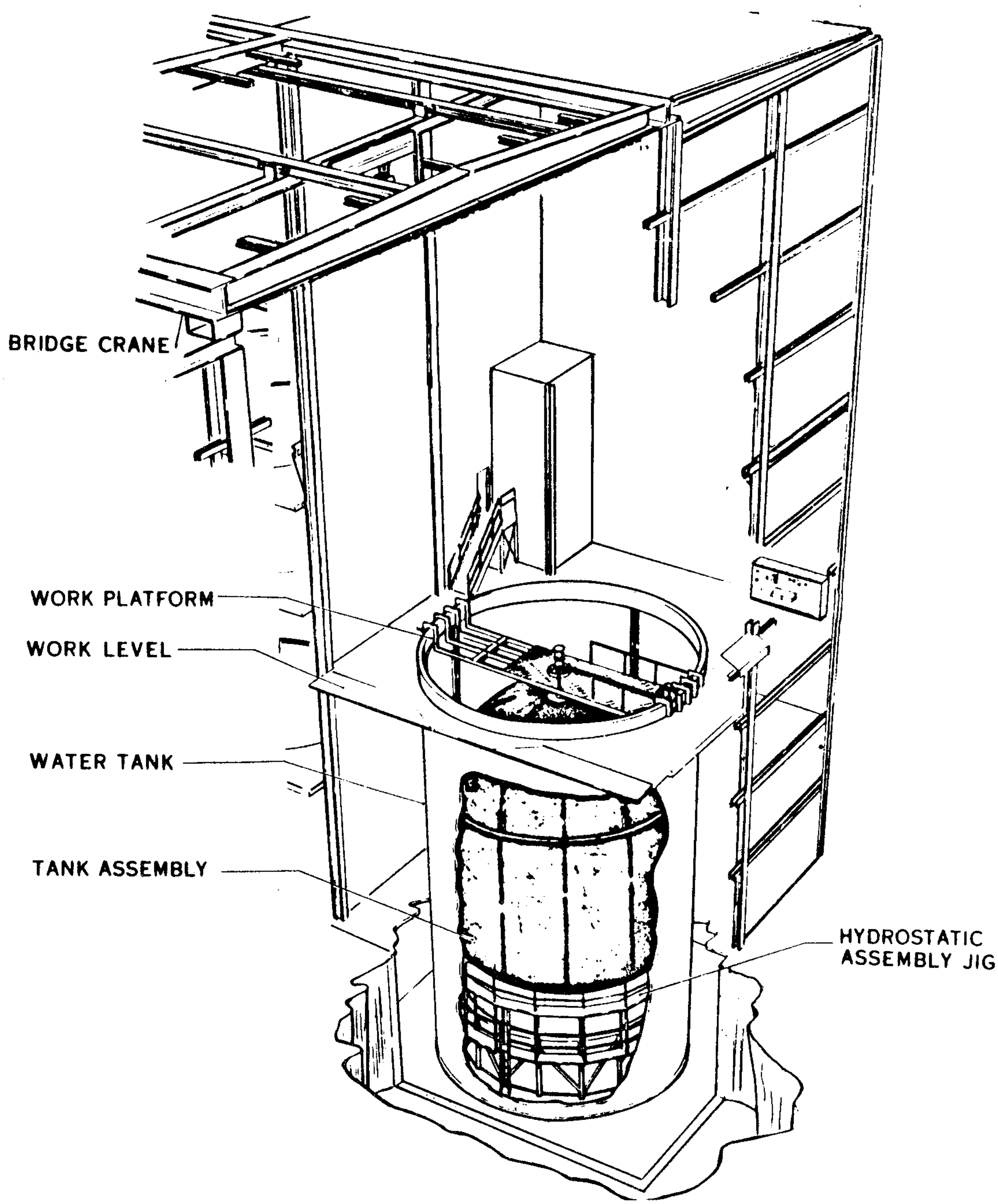


FIGURE 6-11 S-IVB HYDROSTATIC TESTING

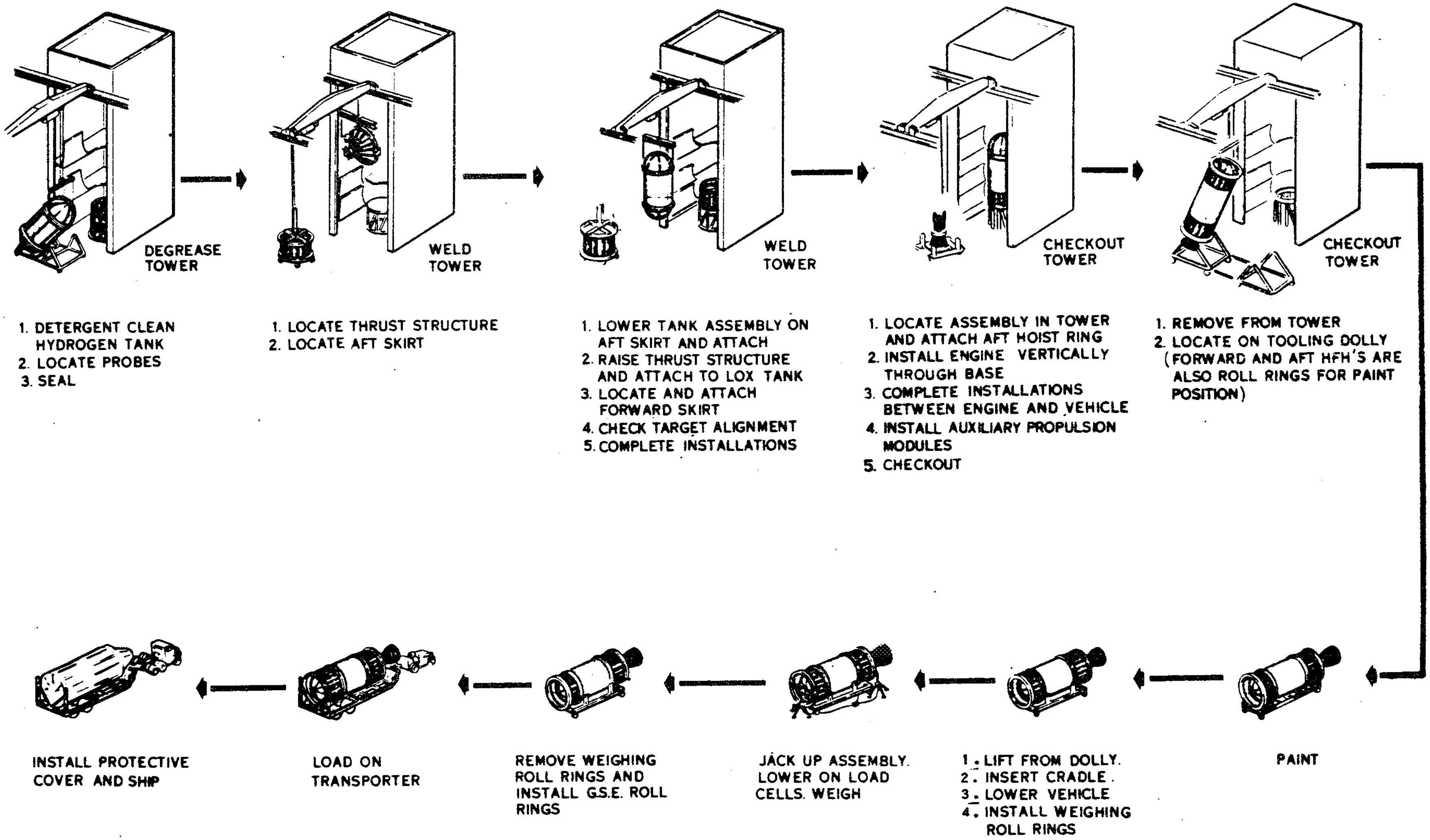


FIGURE 6-12 S-IVB FINAL ASSEMBLY

6.4 MRB ACTIONS

A total of forty-six (46) Failure and Rejection Reports (FARR) were reviewed relating to the three components under discussion. Only two of these FARR's were considered of sufficient structural significance to warrant further study and stress analysis. They are summarized as follows:

A-193505	LH_2-LOX Tank Assy. Common Bhd.	Seal weld, common bhd/aft bulkhead joint. A third weld pass was made covering center of -9 spacers. Disposition - Acceptable as is. RFC-Deviation from welding procedures. (DPS 14052 calls out two weld passes only.)
A-193576	LOX Tank Assy. Aft Bhd.	Aft bulkhead, center flange weld. Results of pre-production test: #1 - 36, 461 psi #2 - 36, 162 psi #3 - 36, 348 psi Canned areas also evident. Disposition - Acceptable to Eng. for use. RFC-Possible decrease in margin of safety. (DPS 14052 pre-production tensile test min. acceptable is 38,500 psi.)

A stress check indicates that the dispositions made on the above discrepancies are adequate (Reference 1.4).

See Appendix A for details of the MRB review.

6.5 HISTORY OF ELEMENT

Actual manufacture of the common bulkhead and aft bulkhead of AS-503/S-IVB was performed at the Santa Monica facility of McDonnell Douglas Astronautics Company during the period from October, 1965 to May, 1966. The assembly of the two components was delivered at the Huntington Beach facility, May 11, 1966. Tank assembly was completed and the tank was hydrostatic proof tested on June 25, 1966, Reference 6.5. Skirts, thrust structure, insulation, electrical components and the J-2 engine were added and checked out by December, 1966, and the stage was shipped to Sacramento Test Center on January 25, 1967, via the Super Guppy airplane. Acceptance firing was accomplished May 3, 1967. The stage was then placed in the Vehicle Checkout Lab at Sacramento for final check and refurbishing. The stage was turned over to NASA and made ready for shipping to Cape Kennedy Spaceflight Center on July 29, 1967, again via Super Guppy. It has been stored since that time in the VAB at KSC.

6.6 ON-SITE REVIEW SUMMARY

6.6.1 General

An on-site review was carried out at the Huntington Beach facility of McDonnell Douglas Astronautics Company. Inspection of the manufacturing and test facilities was made at both Santa Monica and Huntington Beach plants. A special effort was made to observe in detail the manufacturing and quality control procedures employed in the fabrication and assembly of the common bulkhead, aft bulkhead, and thrust structure.

6.6.2 Documentation Reviewed

Of primary concern was the documentation dealing with Material Review Board action taken during the various phases of manufacture, inspection, assembly and test.

The particular paper developed by MDC to record this activity is the Failure and Rejection Report (FARR) which identifies the defective part or process, with details of the problem found. Engineering issues specific instructions in repair procedures to be followed, including final acceptance inspections required. All steps must be followed before final closing of the FARR and sign-off by MDC and NASA quality.

Other documentation examined included the Assembly Outline (A.O.). This document is the end product of the work done by Design Engineering and Manufacturing Planning, and gives step-wise instructions on every phase of manufacture, assembly and inspection. Rework resulting from FARR's also may be described in an appropriate A.O..

Also examined was a group of Douglas Process Standards, to which reference was made in appropriate places in this report. They dealt with welding preparation of aluminum alloys (DPS 41006), mechanized welding of aluminum (DPS 14052), dye penetrant inspection (DPS 15101, DPS 15105), radiographic inspection (DPS 15200, QCM0008), and bonding of the common bulkhead (DPS 31150-1).

6.6.3 Conclusions

1. Documentation examined gives excellent visibility to manufacturing processes, quality control and repair procedures. Traceability is good.

2. There are no open items of a structural nature related to the common bulkhead/aft bulkhead-aft

bulkhead/thrust structure joints, Reference 6-6.

3. The foregoing facts together with the on-site inspection of manufacturing processes and quality control provided a high degree of confidence in the structural integrity of this complex joint.

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SECTION 7

S-IVB-503 FORWARD SKIRT

SELECTED ELEMENT REPORT

7.0 SUMMARY

The purpose of this review was to evaluate the manufacturing and quality control procedures used in the assembly of the S-IVB-503 Forward Skirt, to determine if the "as-built" configuration structural integrity is assured.

The conclusions of this report are based on information obtained at MDC from:

a. Inspection of manufacturing and quality control facilities and activities at Huntington Beach and Santa Monica.

b. Discussions with Engineering, Manufacturing and Quality Control personnel concerning fabrication of the subject element.

c. Review of applicable documentation including, but not limited to: manufacturing plans and specifications, engineering drawings, MRB actions and design certification reviews.

The investigating team concludes that the methods exercised and results achieved do assure the structural integrity of this selected element.

7.1 DESCRIPTION

The forward skirt, a cylindrical section 260" in diameter and 122" high, is located on the vehicle between Vehicle Stations 3222 and 3100. See Figure 7-1. It is constructed of 7075-T6 aluminum skin with external stringers and internal frames also of 7075-T6 aluminum.

The forward skirt contains sophisticated electronic controls for the thermal conditioning system and for the GN_2 purge system. However, only the structural components of this unit will be discussed in detail.

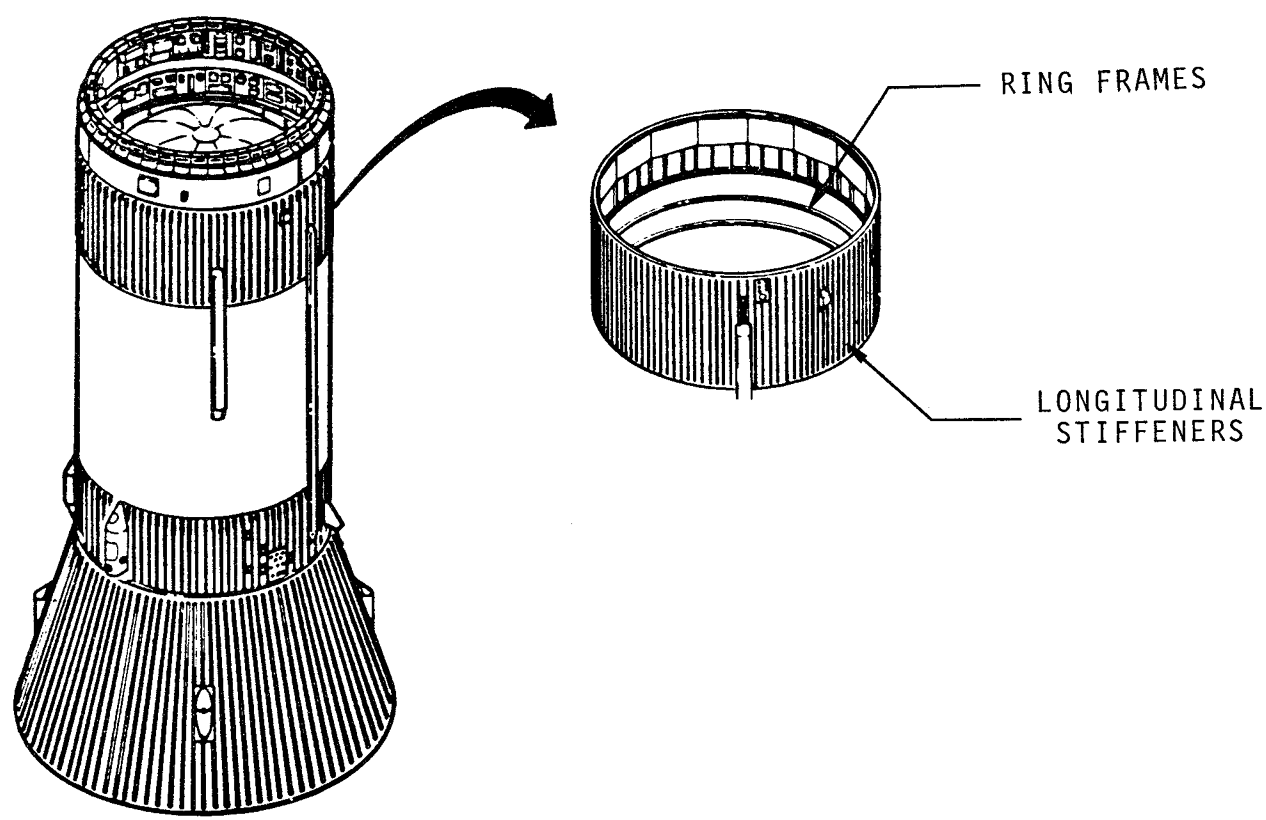

FIGURE 7-1 S-IVB FORWARD SKIRT

7.2 MANUFACTURING

7.2.1 Fabrication

All skirt structure components, including skins, hat section stringers, intercostals, frames, and forward and aft attach angles, are fabricated at the Santa Monica location then shipped to the Space Systems Center (Huntington Beach) for assembly per Reference 7.1. The fabrication and assembly sequence is depicted in Figure 7-2.

Skin sections are fabricated from 7075-T6 aluminum sheet. They are sheared to size, cutouts routed, and edges deburred. External hat stringers are fabricated from 7075-T6 aluminum extrusions. Extruded stock is cut to length on a table saw. Tack rivet holes for subsequent automatic riveting are drilled using hand drill motors and a drill template.

One interior ring frame (hat section) is fabricated from 7075-0 extruded aluminum. It is stretch formed to contour, then heat treated to the T6 condition.

Other ring frame sections are fabricated from 0.063" thick 7075-0 aluminum sheet. The sheet is sheared, then routed to size. Segments are formed to contour on a form block. Lightening holes are cut and the segments are heat treated to the T4 condition.

Following inspection, the segments are heat treat aged to T6 condition.

The forward and aft attach angles are made from 7075-0 aluminum extrusions. After cutting to length, tooling holes are drilled with the aid of a layout template. The tooling holes are used to index parts during assembly. The angles are formed to contour on a stretch press, heat treated to "AQ" condition, stretched further to remove warpage, then aged to the T6 condition.

Intercostals are fabricated from 7075-0 aluminum sheet. After routing the periphery and lightening holes, finish forming is by hydropress. Heat treatment to the T6 condition, and inspection complete fabrication.

7.2.2 Assembly

At the Space Systems Center, Huntington Beach facility, panel subassemblies, a skin and five stringers, are produced in an assembly jig. Parts are located in the jig by butt stops and joined by tack rivets. After removal

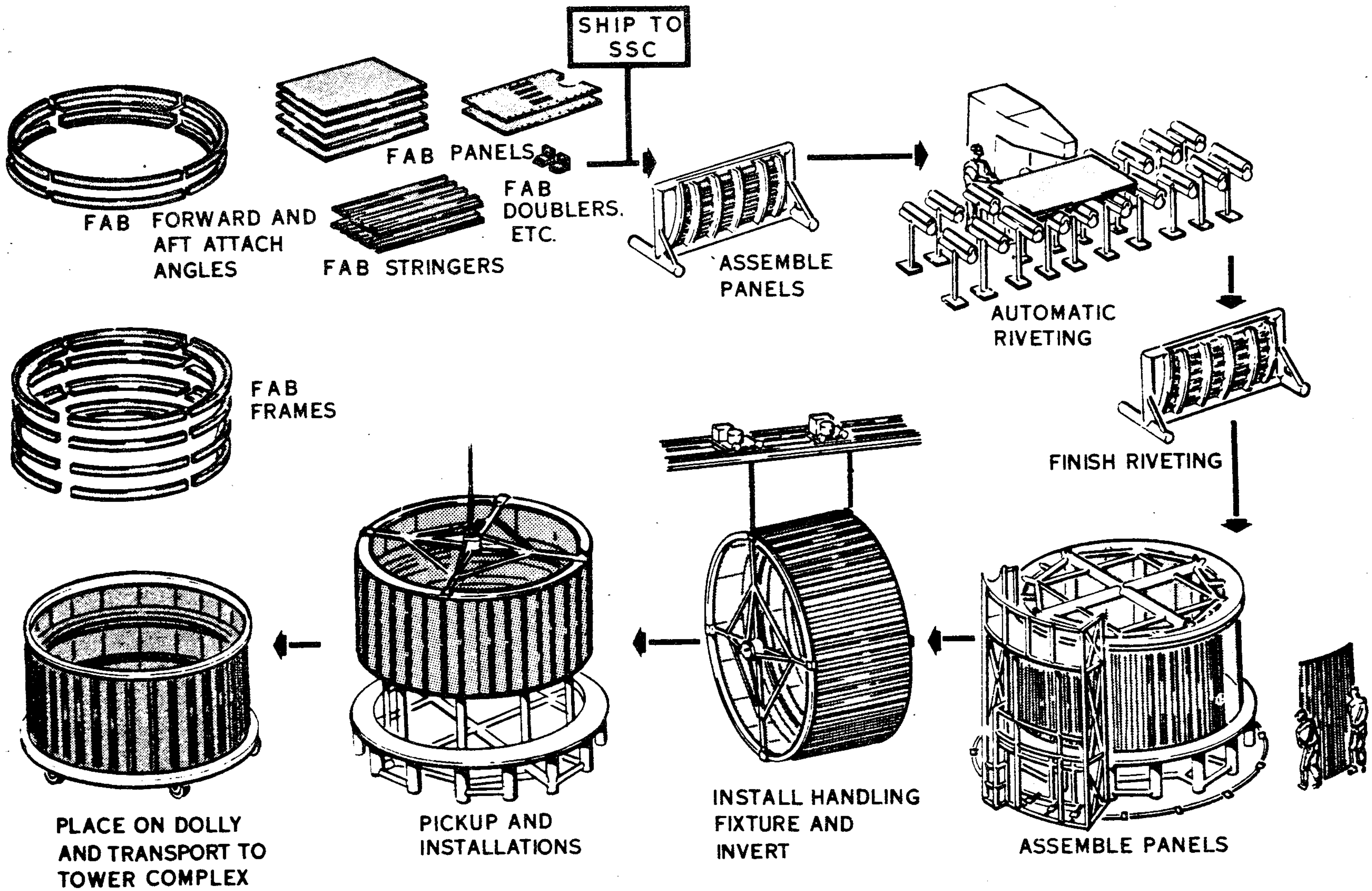

FIGURE 7-2 S-IVB FORWARD SKIRT FABRICATION AND ASSEMBLY SEQUENCE

of the jig, the assembly is automatically riveted. The tack rivets serve as indexing points for the automatic riveting. The completed panel subassembly is then inspected, weighed, and transported to the final assembly area.

During final assembly, as shown in Figure 7-2, the panel assemblies, sheet metal sections, intercostals, splices, doublers, and other details are jig located, then joined with rivets and huck bolts. Attach holes in the forward and aft angles are also drilled to size in this assembly jig.

Installation and checkout of the remainder of the electronic and mechanical components is made after inverting the assembly and placing it in a pickup fixture. When this is complete, the forward skirt assembly is placed on a dolly and transported to the tooling tower complex for joining to the vehicle.

7.3 QUALITY AND RELIABILITY ASSURANCE

Quality control is in accordance with NASA document NPC 200-3 and the applicable portion of NASA 200-2 as defined by the Douglas Reliability Control Specification, Reference 6.2 by the Douglas Reliability Control Specification.

7.3.1 Receiving Inspection (Raw Materials)

Incoming material is checked by Quality Control for damage in shipping, dimensional compliance, and material certification papers for chemical and physical tests performed by the vendor. In the absence of acceptable supplier test data, MDC will perform physical, electrical, or chemical analyses in accordance with applicable specifications which define those materials requiring test, the characteristics to be tested, the frequency of testing, acceptance, and rejection criteria. All raw material requiring chemical and/or physical tests is held pending completion of these tests. Reliability Assurance verifies that the requirements are met.

7.3.2 In-Process Inspection

The in-process inspection is an integral part of the detail manufacturing documents, Assembly Outlines (A O 's) and Fabrication Outlines (F O 's). Reliability Assurance reviews manufacturing documents prior to implementation and controls changes to these inspection procedures by a review of new or changed drawings, EO's, AO's, and FO's.

Special inspection procedures, Inspection Operation Sheets (IOS's) are issued and controlled by Reliability Assurance.

Test procedures are written by Manufacturing Engineering and Development Engineering, Reference 6.3. Manufacturing Engineering is responsible for issuing FO's and AO's as applicable, for the performance of a required acceptance test in accordance with applicable test procedures. Reliability Assurance is responsible for assuring conformance of product acceptance tests with all requirements.

The primary inspection procedures for the forward skirt concern dimensional tolerances of the components, proper fastener installation, and coating application (DPS 42000, A 9708926).

7.3.3 Final Checkout and Inspection

Final inspection of the forward skirt structure is made after the forward and aft attach angles are installed per applicable AO's and DPS's. The skirt is then transferred to the instrumentation installation area.

7.4 MRB ACTIONS

A total of nine (9) FARR's were written on the S-IVB-503 forward skirt, none of which is considered to be structurally significant. These FARR's and resulting MRB's involved repairing misplaced fastener holes, minor skin surface damage, improper coating application, and replacing defective rivets. The repairs were made in accordance with applicable DPS documentation.

Stress analysis reported in Reference 1.4 verified the adequacy of the dispositions.

See Appendix A for details of the MRB review.

7.5 HISTORY OF ELEMENT

After the arrival of the S-IVB—503N stage at KSC two modifications were made to the forward skirt. They were the attachment of the anti-flutter kit, Reference 7.1; and the installation of the water deluge system. The attachment of the anti-flutter kit was made at the request of NASA and work was started in August, 1967 and completed in January, 1968. The work was done without MR action. The installation of the water deluge system was made in September, 1968. The purpose of this system is to flood the IU-SIVB skirt area with water in the event of a hypergolic spill. The maximum water load is considered to be relatively small in relation to the qualified loads of the skirt.

7.5.1 Shipping

The S-IVB-503N was transported without incident to STC on January 25, 1967 for test firing, by the Super Guppy, Reference 6.5. The stage was again transported by the Super Guppy from STC to KSC in August, 1967, without incident. The S-IVB is transported with circumferential handling rings on the forward and aft skirts.

7.5.2 Storage

After completion of hydrostatic testing and final assembly, the S-IVB is wrapped in plastic, dessicant is placed in the package, and it is stored on its side in a low bay area in the final assembly section until shipment to STC. It is stored in the same manner at KSC until stacking is begun.

7.6 ON-SITE REVIEW SUMMARY

7.6.1 General

The on-site visit to the McDonnell-Douglas facilities at Huntington Beach and Santa Monica gave a very good overall picture of manufacturing processes and quality control measures employed in the production of all elements of the S-IVB-503. Documentation utilized was explained by McDonnell-Douglas personnel. This, along with the plant visits, illustrated the easy traceability of all items through assembly to the end product.

7.6.2 Documentation Reviewed

All documents relating to the selected element were reviewed. These included AO's and FO's, as well as FARR's calling for MRB action. FARR's and the MRB dispositions are easily traceable. An MRB map of the forward skirt area was provided by the contractor. Specifications relating to the organic insulation applied to the exterior of the forward skirt (DPS 42000, A9708926) were also reviewed.

7.6.3 Conclusions

a. Documentation examined gives excellent visibility into manufacturing processes, quality control techniques, and repair procedures. Traceability is good.

b. There are no open items of a structural nature related to the forward skirt, Reference 6.6.

c. The review of this element revealed that the manufacturing and quality control methods employed adequately assure the integrity of this element.

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SECTION 8

IU-503 SHELL

SELECTED ELEMENT REPORT

8.0 SUMMARY

The purpose of this review was to evaluate the manufacturing and quality control procedures employed during fabrication and assembly of the IU-503 and thus determine the structural integrity of the "as-built" configuration. The data and information upon which this report is founded included:

a. The inspection of manufacturing, and quality control facilities and activities.

b. Detailed discussions with the Engineering, Manufacturing, and Quality Control personnel concerning fabrication of the subject element.

c. The review of pertinent documentation including, but not limited to: manufacturing plans and specifications, engineering drawings, MRB actions, and Design Certification Review.

It is concluded that the methods employed and results achieved offer assurance that this selected element conforms with the design objectives.

8.1 DESCRIPTION

The Instrument Unit is located on the L/V between Vehicle Stations 3322.55 and 3358.55. It is 260" in diameter, 36" high and 0.95" thick. The unit is composed of three 120° structural honeycomb panels, mechanically spliced to form a short cylinder. Figure 8-1 shows the location of the IU on the Space Vehicle plus a larger view of the unit.

The honeycomb panels are fabricated by bonding 5052-H39 aluminum honeycomb core to 0.020" and 0.030", 7075-T6 aluminum face sheets with NARMCO Metlbond 329, high temperature resistant adhesive.

The three panels comprising the IU are identified as 101, 102, and 103; and although the basic construction and materials are identical, there are differences as noted below:

The 101 panel mounts cold plates 1 through 8 and has the access door, the umbilical plate, the ECS panel and the water accumulator.

Panel 102 mounts cold plates 9 through 16 and has the flight control computer (FCC).

Panel 103 has cold plates 17 through 24, the ST-124M Viewport, and mounts the LVDC/LVDA, ST-124 M Inertial Platform and the Gas Bearing Supply Panel.

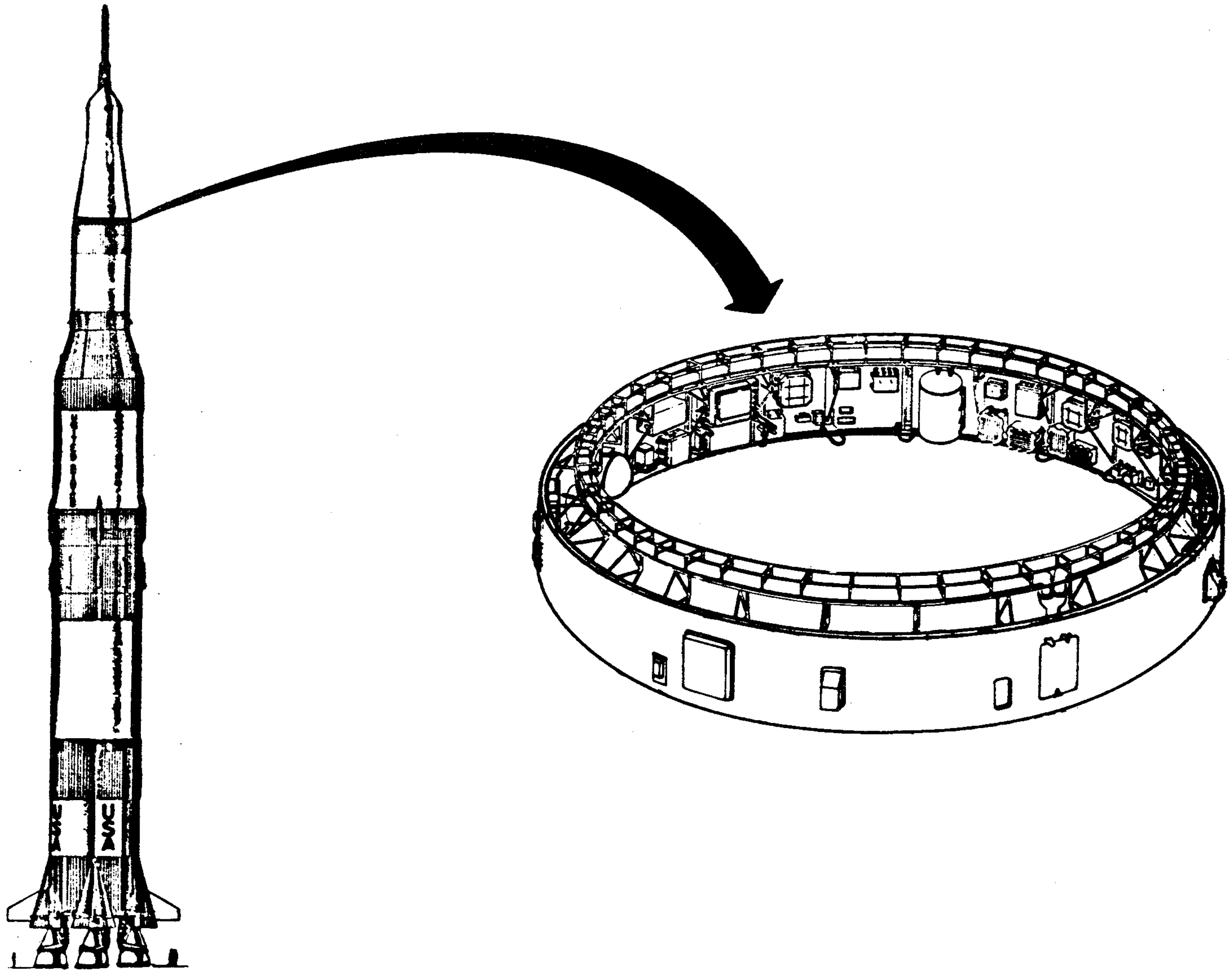

FIGURE 8-1 INSTRUMENT UNIT

8.2 MANUFACTURING

8.2.1 Fabrication

The IU structure is assembled at IBM, Huntsville from three, mated, 120° honeycomb sandwich panels manufactured at NR, Tulsa, Reference 8.1. Figure 8-2 shows typical honeycomb construction.

Design requirements include specifications which demand stringent manufacturing processes and assembly controls. Quality assurance is verified by thorough qualification, in-process, and final acceptance testing.

Cleaning of the component parts of the panels (face sheets, core, doublers and mounting rings), is governed by IBM Specification 6009029. This document specifies solutions, controls, and procedures prepatory to adhesive bonding.

The tooling employed in the fabrication of the IU segments is equipped with thermocouples to monitor temperature distribution during the bonding cycle. The autoclave used for bond curing meets the adhesive polymerization cycle requirements and has the necessary monitoring instrumentation.

8.2.2 Assembly

Assembly and bonding of the panels is controlled by SID-65T-217, Sat IB and V, Instrument Unit Bonding Manual and Manufacturing Instructions.

Assembly of a panel commences with the positioning of an outer face sheet on the bonding tool. The pre-cut core and closure rings are positioned, by template, on the face sheet to establish proper fit. The inner face sheet is positioned on the assembly and clamped. A template is then placed on the assembly to locate the position of brackets and inserts. After locating these positions on the inner face sheet, and assuring proper fit of all components, the panel is disassembled. Figure 8-3 shows details of panel construction. A layer of NARMCO 329 adhesive film is then positioned on the outer face sheet, followed by the mounting rings and the pre-cut core. Core splice adhesive (Epocast H-1310) is extruded between the core segments. Thermocouples and leads are installed, and a layer of adhesive film (NARMCO 329) is placed over the honeycomb, followed by the inner face sheet. Brackets and film adhesive (NARMCO 329) are next positioned on the inner face sheet and the whole assembly is vacuum bagged and tested for leakage. The panel and tool are then placed in the autoclave for adhesive bond curing.

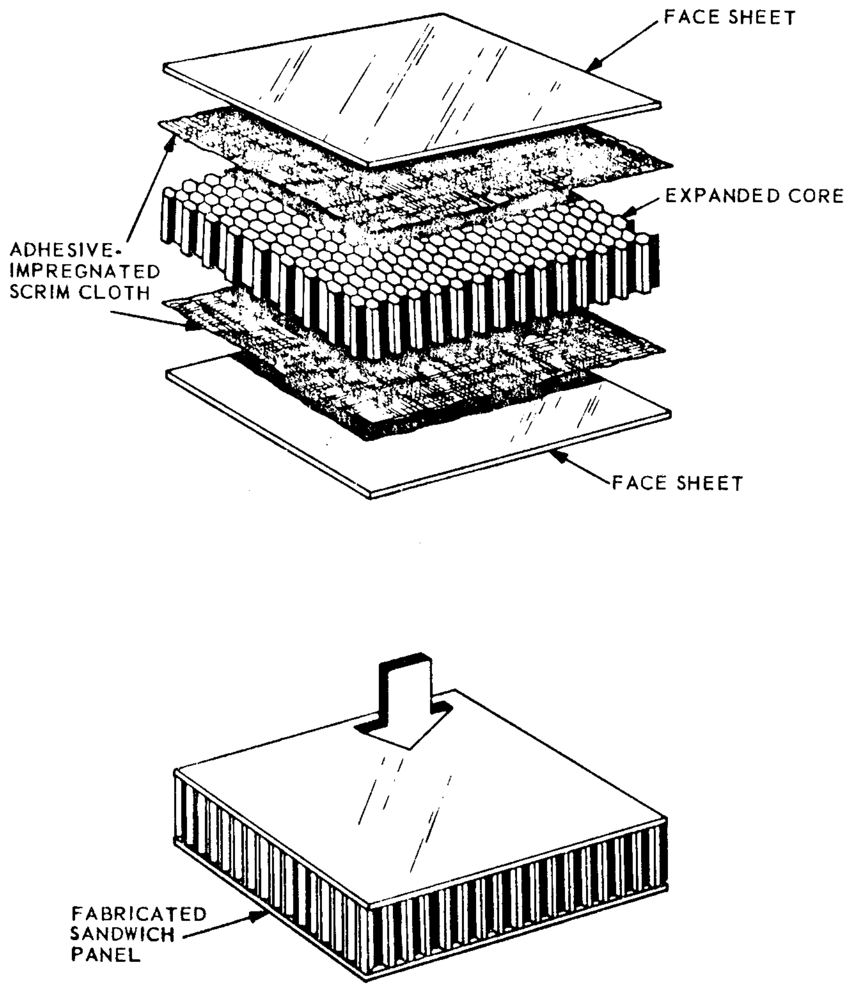

FIGURE 8-2 TYPICAL HONEYCOMB SANDWICH CONSTRUCTION

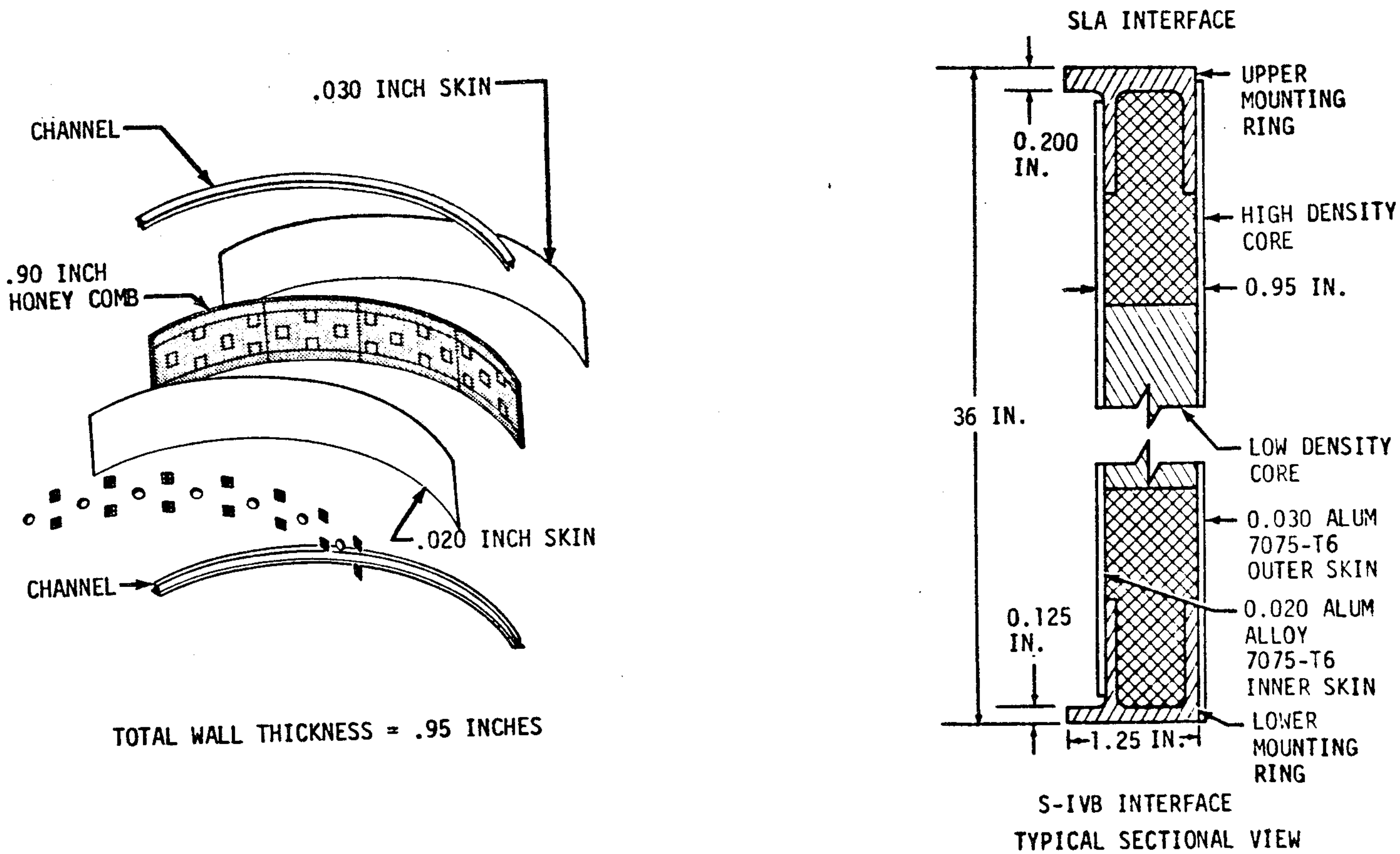

FIGURE 8-3 IU PANEL CONSTRUCTION DETAILS

8.2.2 Continued

Cleaning, layup, and curing is controlled by NR specification SID-65T-217 and IBM spec 6009029. Inspection sign off is mandatory for each step.

When the curing cycle is complete and the panel has cooled, it is removed from the tool and the ends are sealed with epoxy potting compound (Shell 934). The panels are then completely inspected by ultrasonics.

Plastic inserts are installed according to need, and potted in place (Shell 934). These inserts are of two types, "blind", which are accessible only from one end, and "pass-through," which allow bolts to pass completely through the shell (see Figure 8-4). Both types are used to mount brackets and other hardware which is required to be carried by the Instrument Unit. Following potting, 100% radiographic inspection is carried out to verify integrity of potting and core splices. All discrepancies located by X-ray or ultrasonic techniques are dispositioned as required, and reinspected after repair.

The completed panels are then wrapped, crated, and shipped to IBM Huntsville.

Following inspection of the panels received from Tulsa, the panels are fitted together on a structural assembly stand. Panel splicing is depicted in Figure 8-4. The panels are optically aligned and spliced per MEI No. 5140080 to complete the IU shell, Reference 8.2 and 8.3.

After the interface (S-IVB and SLA) assembly bolt holes through the upper and lower mounting rings have been drilled and sealed, the IU shell is bolted to the forward and aft protective rings. These rings remain on the unit until the unit is stacked at KSC.

Assembly of equipment mounting plates, damping channels, harness brackets, etc., subsequently mounted to the shell, is carefully controlled to prevent pre-stressing of the shell.

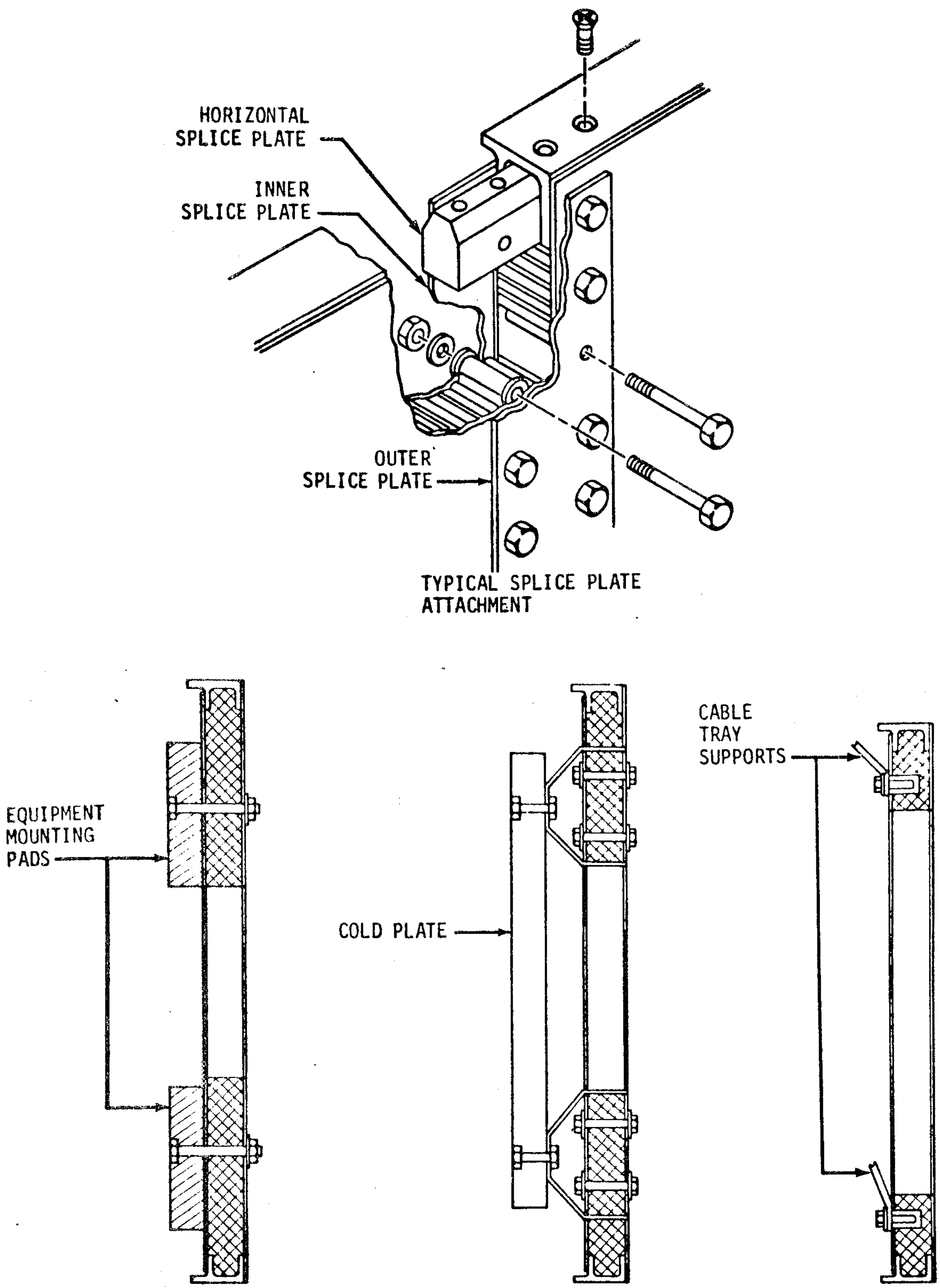

FIGURE 8-4 IU PANEL SPLICING AND BRACKET MOUNTING

8.3 QUALITY AND RELIABILITY ASSURANCE

An on-site assessment of the manufacturing and inspection methods, procedures, and relevant engineering documents disclosed that manufacturing procedures are well covered by specifications and that the quality procedures provide adequate control.

8.3.1 Receiving Inspection (Raw Materials)

Specifications controlling procurement of raw materials are industry standards. Compliance with these requirements is verified by test.

8.3.2 In-Process Inspection

The quality control procedures governing the fabrication of the IU are comprehensive and follow sound practices. IBM Resident Engineers at NR Tulsa monitored fabrication of the panels. A review and sign-off, by IBM Quality, of all discrepancies and repair activities prior to acceptance and shipping of the panels is standard procedure.

NR, Tulsa is required by contract to produce a test tab of similar construction with each panel manufactured (same materials, same cure cycle), plus an extra complete panel with each group of 15 panels manufactured, Reference 8-4. Test tabs are subjected to destructive testing (lap shear, flatwise tensile, and Porta-shear) to verify the adhesive bonding process. Test panels are subjected to these tests, plus bracket insert proof loading, sandwich beam shear, composite edge compression and tension, and sandwich peel testing. These tests verify the quality of the adhesive bond and also the load-bearing capacity of the structure.

Assembly of the panels, at IBM, Huntsville, is closely controlled by a detailed manufacturing plan and inspection of each significant operation.

During assembly of the panels, all precautions (including the use of protective devices) are exercised to prevent damage. All discrepancies are subject to MRB action.

8.3.3 Final Checkout and Inspection

Final inspection and checkout is performed at KSC in the VAB. Instrumentation records describing in-transit environmental conditions (shock, vibration, temperature, etc.) are reviewed to assess any adverse condition which could affect the function or reliability of the IU. Disposition of discrepancies is controlled by MRB action.

8.4 MRB ACTIONS

A total of 31 MR actions are recorded against the IU-503. None of these actions were classified as "Major." Thirteen (13) actions occurred at NR, Tulsa, twelve (12) at IBMH, and six (6) at KSC, Reference 8.5.

Four (4) MR's were identified as minor structural defects. Of these, one was given a stress analysis since the repair had not been qualified by test. A stress analysis was performed on this MR and it was concluded that the action taken was adequate regarding the structural integrity of the element, Reference 1.4.

See Appendix A for details of the MRB review.

8.5 HISTORY OF ELEMENT

The IU-503 panels were manufactured at NR, Tulsa. The 101, 102 and 103 panels (comprising the shell) were completed on 3-31-66, 4-14-66 and 4-23-66 respectively. They were assembled, bonded, inspected and tested without any major or significant discrepancies. Confirmation Test 2 (SID-65T-83-2, Jan., 1966) and test specimens accompanying the panels, validated the structural integrity.

Assembly of the IU-503 shell commenced at IBMH on 6-22-66 and was completed 8-8-66. Instrumentation assembly and final check out was completed 7-7-67. The unit was delivered to KSC 1-4-68, staged on 2-1-68, and de-staged on 4-27-68, with final staging on 8-14-68.

8.6 ON-SITE REVIEW SUMMARY

8.6.1 General

An on-site assessment of the IU-503 was conducted at IBMH. Since the panels are assembled and bonded at NR, Tulsa, this review was limited to the assembly of the IU, and to inspection procedures and controls governing the overall manufacture, testing, shipping and storage of the units. Specific assessments included:

a. Inspection and MRB, procedures and techniques.

b. Repair procedures.

c. Manufacturing plans.

d. Assembly and bonding, specifications and procedures.

e. Testing procedures and methods.

f. Handling, protection, transportation, and storage methods and procedures.

8.6.2 Documentation Reviewed

The documents reviewed during the assessment included drawings, MR's, manufacturing plans and instructions, testing methods and procedures, and materials and process specifications.

8.6.3 Conclusions

Documentation examined gives excellent visibility into manufacturing processes, quality control, and repair procedures. Traceability is good.

There are no open items of a structural nature related to the IU shell, Reference 8.6.

A high degree of confidence in the structural integrity of this element is provided by the foregoing facts, and the on-site inspection of the manufacturing processes and quality control procedures employed in the production of the IU-503.

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SECTION 9

MATERIALS ENGINEERING

9.0 GENERAL

This section summarizes the Materials Engineering Assessment of the following:

a. Stress Corrosion
b. Hydrogen Embrittlement
c. Fracture Mechanics
d. Honeycomb Structures
e. Materials Allowables

These assessments and their conclusions are described below.

9.1 STRESS CORROSION

9.1.1 Summary

A stress corrosion assessment for the AS-503 was conducted by first establishing stress corrosion criteria to provide ground rules by which susceptible materials could be identified.

In addition, available data from the contractors stress corrosion surveys were compiled and assessed. MR's were reviewed for assessment of potential stress corrosion problems. All questionable items were properly dispositioned or their adequacy verified. A summary of this assessment is described in Appendix B.

9.1.2 Conclusion

The primary structure of AS-503 is subjected mostly to compressive stresses (sustained tensile stress is required for stress corrosion). Known discrepancies have been properly corrected or their risk considered acceptable.

The result of the stress corrosion surveys performed by the contractors indicates that all known susceptible materials for each stage were reviewed and that primary structure has the minimum amount of susceptible materials. There is no open item remaining from this survey.

Pressure vessels and propellant tanks were assessed for structural integrity, including stress corrosion and fracture mechanics and are considered adequate. The fracture mechanics assessment is discussed in paragraph 9.3.

9.2 HYDROGEN EMBRITTLEMENT

9.2.1 Summary

Hydrogen embrittlement is a delayed brittle failure at reduced tensile stress resulting from the absorption of hydrogen in metal.

In AS-503 applications, the only susceptible metal is high strength steel which has previously absorbed hydrogen and is under applied or residual stress. The sources of atomic hydrogen for this embrittlement are processes such as plating and pickling.

To check for possible hydrogen embrittlement failure in the primary structure, selected high strength steel part drawings were reviewed. The review was to determine if process specifications assure that parts are protected against excessive hydrogen absorption during processing. MR's were reviewed for possible failures which could be attributed to hydrogen absorption. Appendix C contains a presentation on hydrogen embrittlement which was prepared during the course of the assessment.

9.2.2 Conclusions

No evidence of failure due to hydrogen embrittlement was found. Related failures were of stress corrosion origin and have been treated accordingly. A survey by the space craft contractor identified certain parts where possible hydrogen embrittlement existed. These parts were replaced where feasible. All contractor plating and finishing specifications have adequate protection specs against hydrogen embrittlement failures.

9.3 FRACTURE MECHANICS

9.3.1 Summary

The propellant tanks and all auxiliary pressure vessels of the AS-503 Launch Vehicle were reassessed for the C prime mission. Primary areas of investigation were:

a. Proof pressure test factors with respect to maximum anticipated flight pressures

b. Post proof test history including pressurization time/cycle life, fluid exposure, testing technique and material review actions.

9.3.1 Continued

Detailed data are tabulated in Appendix D.

This reassessment indicated that three propellant tanks of the AS-503 Launch Vehicle and one J-2 engine start bottle were the only apparent areas of concern. Adequacy of these areas were verified by analyses and NDT inspection.

The four main propellant tanks in the CSM-103 SM/SPS were evaluated and considered adequate. Results of this assessment are tabulated in Appendix D.

9.3.2 Conclusions

All propellant tanks and auxiliary pressure vessels are within their minimum guaranteed life for C prime mission except one J-2 start bottle on the S-II stage which was considered an acceptable risk by the DCR board. No new evidence has been uncovered by JSAT which refutes this conclusion.

9.4 HONEYCOMB

9.4.1 Summary

Because of suspected damage to the SLA honeycomb structure as a result of the AS-502 anomalies, a detailed investigation was carried out on the honeycomb structures employed on AS-503. Examined in depth were adhesive bonding systems, pressure buildup within bonded structures, need for exterior insulation and interior venting of shells, and destructive and non-destructive testing. Appendix E reveals the results of this investigation.

9.4.2 Conclusion

The honeycomb structures making up the Instrument Unit (IU), the Command Module, the Spacecraft Lunar Module Adapter (SLA) and the Service Module (SM) were investigated. Anticipated flight temperatures and pressures are within the structural capabilities of these elements. Therefore, as presently designed, these elements are considered adequate for their assigned mission on AS-503.

9.5 MATERIALS ALLOWABLES

9.5.1 Summary

The various selected elements of the AS-503 Launch Vehicle have been reviewed from the standpoint of the material, sandwich (honeycomb) and weld design allowables employed. The review involved: identifying the materials in each of the critical elements, determining the design allowables for each material or welded joint and comparing these design allowables to those used in the original design. It was found that most of the allowables used are equivalent to or conservative as compared to those recommended and presented by JSAT in Appendix F.

9.5.2 Conclusions

The nonconservative design allowable discrepancies were investigated as to their impact on margins of safety. It was found that in no case did the employment of the nonconservative value result in a negative or zero margin of safety. It is therefore concluded that the material, sandwich and weld design allowables employed by the stage contractors in the design of the identified critical elements, are satisfactory.

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SECTION 10

SPACECRAFT SELECTED ELEMENT REPORT

10.0 SUMMARY

This section covers the detailed review of the fifteen (15) JSAT selected structural elements on the AS-503 Spacecraft.

The detailed review includes: stress analyses, design adequacy review, manufacturing and quality assurance information, MRB disposition reviews, and reference to material design allowables.

A materials evaluation study was also conducted with emphasis on stress corrosion, hydrogen embrittlement, and adhesive bonding. The structural adequacy of these elements for the AS-503 C prime mission is noted in the conclusion for each element.

The SPS tanks were reviewed for a fracture mechanics assessment. This element review is reported in D5-15780, Appendix D.

10.1 GENERAL

During the course of the assessment, a number of elements were identified as being of concern, either by reason of shortcoming in analysis, inadequacy of test, indicated lack of structural integrity, association with "popular problems", or the presence of MR's which could not be cleared by cursory examination. In addition, the SPS propellant tanks presented a special case by virtue of their requirement for a fracture mechanics investigation. The elements so identified are listed in Figure 10-1, in conjunction with their associated reasons for concern.

These elements were subjected to a detailed stress review. In addition, a general review was made of their associated manufacturing, quality control procedures, and, by inclusion in the overall review of manufacturing discrepancies, their outstanding MR's and module histories.

Stress Review

In the following sections, the reason for selecting the element is discussed in detail. The results of JSAT analyses are compared to those obtained by the contractor, and the JSAT assessment of the element is given. A summary form is presented for each element which was reviewed showing significant data comparisons. These summary forms show that no significant areas of concern exist for the selected spacecraft elements. With the exception of the X_A 1010 Interface, adequate factors of safety are indicated by test and analysis for all elements. The X_A 1010 Interface has shown positive margins by analysis, and awaits only the engine-out test to show adequate margins by test demonstration.

Manufacturing

This section describes the assessment of the materials and processes that were used in manufacturing the structure that is associated with the critical elements. As is shown in the previous section, the majority of the critical elements are, in fact, interfaces between spacecraft modules. There are critical elements identified in each of the spacecraft modules. Accordingly, discussions of the manufacture of the LES, CM, SM, and SLA are each described in the appropriate sections.

The manufacture of each of the spacecraft modules is assessed to be adequate. However, the following three areas of concern have been identified because of their potential influence on the behavior of the critical elements:

MODULE	ELEMENT	REASON FOR CONCERN
LES	LES/CM INTERFACE	INADEQUATE TEST, CRITICALITY FOR LIFTOFF AND ENGINE-OUT LOADS
CM	FORWARD BULKHEAD	SIGNIFICANT MR
CM	LONGERONS	ANALYSIS SHORTCOMING, CRITICALITY FOR LIFTOFF AND ENGINE-OUT LOADS
SM	CM/SM INTERFACE	LOW FACTOR OF SAFETY FOR NOMINAL FLIGHT, CRITICALITY FOR LIFTOFF AND ENGINE-OUT LOADS
SM	SHELL	SIGNIFICANT MR
SM	SPS FWD TANK SUPPORTS	THRUST-OSCILLATION INDUCED TANK VIBRATIONS
SM	SPS TANK SKIRTS	CONFIGURATION DIFFERENCES, END-BOOST LOADING
SM	SPS TANKS	REQUIRE FRACTURE MECHANICS ANALYSIS
SM	AFT BULKHEAD	CONFIGURATION DIFFERENCES, END-BOOST LOADING, SIGNIFICANT MR'S
SLA	SM/SLA INTERFACE	INADEQUATE TEST DATA, SIGNIFICANT MR'S
SLA	SHELL	AS-502 ANOMALY, SIGNIFICANT MR'S
SLA	X_A 709.9 SPLICE	AS-502 ANOMALY, SIGNIFICANT MR'S
SLA	X_A 585 JOINT	AS-502 ANOMALY, SIGNIFICANT MR'S
SLA	SLA/LM INTERFACE	INCOMPLETE ANALYSIS, SIGNIFICANT MR'S
SLA	X_A 502 INTERFACE	CRITICAL INTERFACE, AS-502 ANOMALY, INADEQUACY OF ANALYSIS, SIGNIFICANT MR'S

FIGURE 10-1 SELECTED CRITICAL ELEMENTS

10.1 GENERAL - Continued

A. Integrity of adhesive bonding in primary structure
B. Hydrogen embrittlement
C. Stress corrosion cracking

A. Adhesive Bonding

Specific concerns regarding adhesive bonding are discussed in 10.5.2 - SLA.

B. Hydrogen Embrittlement

Failure of nickel-tin (Ni-Sn) plated parts in a parachute assembly test article due to hydrogen embrittlement led to an investigation which revealed that 27 critical spacecraft parts plated with NI-SN are of uncertain quality with respect to hydrogen embrittlement. Fifteen of these parts are in the CM to SM Tension Tie Assembly and cannot be inspected nor replaced without destacking. The sustained tensile load that these critical parts can carry without brittle fracture is not known. An experimental program is being conducted by NR to establish the structural adequacy of these parts for the AS-503 mission. The approach is to establish the worst case stress threshold at which these parts exhibit hydrogen embrittlement, and to show that these thresholds are well above the sustained stresses applied to the parts of the spacecraft.

As of October 4, 1968, all phases of the NASA-MSC/NR test program were completed with the exception of the 350 hour sustained load tests. These tests, which were run at the spacecraft preload stress, were completed on October 7, 1968. The formal final report of the results is scheduled for release in a minimum of two weeks. Informal reports from SMD indicate adequacy of the critical parts for the AS-503 mission.

C. Stress Corrosion

NR has conducted a stress corrosion survey of 1501 drawings representing parts manufactured from 2000 and 7000 series aluminum alloys. The following information on the survey was taken from a letter report from I. J. Korb, Supervisor, NR Advanced M&P, to W. I. Castner, ES-8, NASA-MSC-SMD; this letter report was presented to H. W. Klopfenstein by J. N. Kotanchik on October 3, 1968.

a. The Apollo Stress Corrosion survey of the 2000 and 7000 series aluminum alloy parts has been completed for all structural parts of the CSM and SLA, and

10.1 GENERAL - Continued

for most of the non-structural parts. A few vendor supplied non-structural items have not been reviewed due to delays in obtaining drawings.

b. Twenty structural parts have been categorized as "Stress Corrosion possible" or "Stress Corrosion improbable (but possible)" based on maximum adverse conditions of manufacture, assembly, and environment that could be expected. These are presented in tabular form (in the final report) together with a listing of examination which has been made of these parts on various spacecrafts.

c. No evidence of stress corrosion has been found in any item examined. A report (SD6B-740) is currently in process of publication covering the details of the survey including a list of the 1501 drawings reviewed.

Quality Control Procedures

The quality control procedures that were stipulated for the manfuacture of AS-503 hardware were assessed and found adequate. Quality control requirements are incorporated in all manufacturing specifications. This includes the various aspects of fabrication and assembly from the procurement of raw material to the final inspection of flight hardware. Evidence that the quality control requirements have been met is found in the NR Fabrication and Inspection Records (FAIR Books), wherein the disposition of discrepancies in the structure is described. These discrepancy dispositions are the result of Materials Review (MR) actions which are described below. Provisions for AS-503 quality assurance are typified in the descriptions of quality assurance provisions for the CM and the SLA, presented in the appropriate sections which follow.

The assessment of the impact of Material Review Board (MRB) action on the selected critical elements is described in the JSAT Spacecraft As-Built Capability Document, D5-15781. A report of a complete review of MR's that pertain to the AS-503 spacecraft structure is contained in Boeing/Houston Document D2-118158-1, "AS-503 JSAT/ASSAT Spacecraft Material Review Assessment". This latter document is the record of the Joint Structural Assessment Team (JSAT) and Apollo Spacecraft Structural Assessment Team (ASSAT) review of the North American Rockwell Company (NR) Material Review (MR) documents that describe dispositions of discrepancies that were found in the AS-503 spacecraft structure.

10.1 GENERAL - Continued

Approximately 2500 MR dispositions were contained in the 787 MR documents that were reviewed. After assessing and evaluating each disposition, 2404 were determined to be adequate and 96 were determined to be questionable. These 96 dispositions were referred to JSAT stress for in-depth analysis and resolution. The stress analysis verified the adequacy of the 96 questionable dispositions. Thus, the 2500 MR dispositions that were reviewed were all finally assessed to be adequate.

These MR review results were used by JSAT in the final assessment of the flight readiness of the AS-503 Spacecraft.

The purpose of the review was to verify the adequacy of the dispositions of structural discrepancies that are described in the MR documents. At the outset the intent was to assess only those MR's that pertained to primary structure. However, the review encompassed not only all of the primary structure MR's but virtually all of the secondary structure MR's as well. Particular attention was given to the potential impact of MR's on previously identified selected critical elements.

The objective of the review was to assess the impact of the MR dispositions on the strength of the Spacecraft structure.

The original configuration of the AS-503 spacecraft structure was composed of five modules that included a Spacecraft Lunar Module Adapter (SLA-11), a Service Module (SM-103), a Command Module (CM-103), a Launch Escape System (LES), and a Lunar Module (LM-3). The plan was to assess the MR's that pertain to each of the above modules. Coincident with a change in the mission requirements for AS-503, a structure (LTA-B) which simulates the mass of a Lunar Module was substituted for LM-3. The flight worthiness of LTA-B was assessed to be adequate by inspection methods. There are no MR documents pertaining to this simulated spacecraft module. With the elimination of the requirement to assess the LM, this AS-503 ASSAT/JSAT Spacecraft Material Review assessment was accordingly limited to the SLA, SM, CM, and LES.

The MR review was conducted in three phases, as follows:

Phase	S/C Module	Location	Dates
I	SM	Downey, California	Sept. 3 - Oct. 4, 1968
II	CM/LES	Downey, California	Oct. 15 - Oct. 18, 1968
III	SLA	Houston, Texas	Oct. 22 - Oct. 26, 1968

10.1 GENERAL - Continued

The review was conducted by a review board which was composed of materials, quality control, structures, and stress specialists. The board was divided into several teams for each phase. Each team was led by either a structures or a stress specialist, who was responsible for the initial assessment of each MR disposition. When there was some doubt as to the adequacy of a disposition, the team leaders met and reviewed the problem and arrived at a consensus assessment.

Those MR dispositions that were not approved through the above sequential actions were labeled "questionable" and were referred to JSAT Stress for in-depth analysis and final resolution.

Identical procedures were followed in phases I, II, and III, of the review. A brief meeting was held at the beginning of each phase wherein specific work assignments were made, requirements and objectives were stated, and instructions were given. In addition, criteria for the assessment of all MR dispositions were specified. Throughout each phase a morning and afternoon meeting was held every day wherein accomplishments and problems were reported. Minutes were recorded and were signed by the attendees each day.

Data for Selected Elements

In the following sections, the individual elements are discussed. A stress section and summary chart are presented for each element. A materials section on each module is presented with discussion of the element in each module. The discussion of quality control follows a similar format.

10.2 LES 1083 INTERFACE

10.2.1 Design Adequacy Review

The X_A 1083 Interface was of concern because the ultimate capability of the pedestal in compression was not demonstrated by test to failure. The component test demonstrated only a 1.0 factor for AS-503 liftoff loads. Moreover, NR analysis (SD 67-1103) of the pedestal uses F_{cu} = 75,000 psi, which appears high. However, the ultimate compression allowable for a reinforced plastic is a function of the specific material system, including processing, and is difficult to establish in the absence of tests of the specific material. Since the allowable used to show the 1.62 factor is referenced to NR design data, and since the pedestal will be in place for the engine-out tests (which will demonstrate a 1.5 factor for liftoff, if successful), the analytically determined factor of 1.62 will be used for JSAT assessment. The NR/JSAT data comparison is shown in Figure 10-2.

ITEM OF COMPARISON	CONTRACTOR	JSAT
ENVIRONMENT	Tension: (1) Atmospheric Abort (2) 125° F. Compression: (1) Lift-off (2) 70° F.	SAME
LOADS @ X_A = 1083 Interface (Limit Loads)	Tension: S_X = 128,000 lb. S_Z = -9,000 lb. M_Y = 1,110,000 in-lb. Compression: S_X = -12,200 lb. S_Z = 10,300 lb. M_Y = 2,630,000 in-lb.	SAME
ALLOWABLE ASSUMPTIONS	Tension: P = 100,000 lb. Compression: F_{cu} = 75,000 psi The stud is assumed fixed at the nut.	Tension: Same Compression: $F_{cu} \cong$ 52,500 psi SAME
MINIMUM FACTOR OF SAFETY	Tension: 2.00 Compression: 1.62	Tension: Same Compression: Requires demonstration in the engine-out test
FAILURE MODE	Tension: Frangible nut cracking Compression: Pedestal crushing	SAME

FIGURE 10-2 SELECTED ELEMENT REVIEW DATA COMPARISON - LES/CM X_A 1083 INTERFACE

10.2.2 LES General Materials Usage

The LES is attached to the CM (Command Module) with AISI 4340 low alloy steel fittings and frangible nut assemblies (Figure 10-3). A strength range of 180 to 200 KSI is called out for the fittings while the studs are heat treated to 200-220 KSI. The higher strength range for this material does not provide as reliable a structure since 4340 parts heat treated over 200 KSI are most susceptible to hydrogen embrittlement and stress corrosion. See Fig. 10-3,-4 and -5 for typical LES material usage.
Typical heat treated strength requirements are as follows:

Inconel X - 750	= 165 to 190 KSI
17 -4PH	= 170 to 190 KSI
15 - 5PH	= 170 to 190 KSI
AISI-H-11	= 270 to 290 KSI

In general, the material selection appears satisfactory. The metallic materials are ordered to recognized federal specifications or adequate NR specifications. The launch escape motor and the pitch control motor are manufactured by Lockheed Propulsion under the requirements of MC 321-0001 and MC 321-0002, respectively. The current production of Lot 1 and Lot 2 of the launch escape motor cases are being used with a calculated risk due to incomplete production records. The tower jettison motor is manufactured by Thiokol under the requirements of MC 321-0003.

Material used in the LET is 6AL-4V titanium tubing with stress relief of the tower after welding. Allowables for the tower structure are for the annealed condition. Boeing experience indicates that welds in this material will sustain these allowables.

Finishes

Except as noted on the individual drawings, the finishes are controlled by V14-000024, "Finish Specification, Apollo Spacecraft." The rocket motor finish is covered by its individual procurement specification. The low alloy steel parts (except motors) are cadmium plated per OQ-P-416 when heat treated under 200 KSI and by vacuum cadmium process per MIL-C-8337 over 200 KSI. All corrosion resistant steels are cleaned and passivated and all titanium and nickel alloys are cleaned. One coat of white epoxy (MBO 125-012) is applied per MAO 108-013 when applicable. These finishing practices are common in aerospace usage and should satisfactorily control all modes of corrosion.

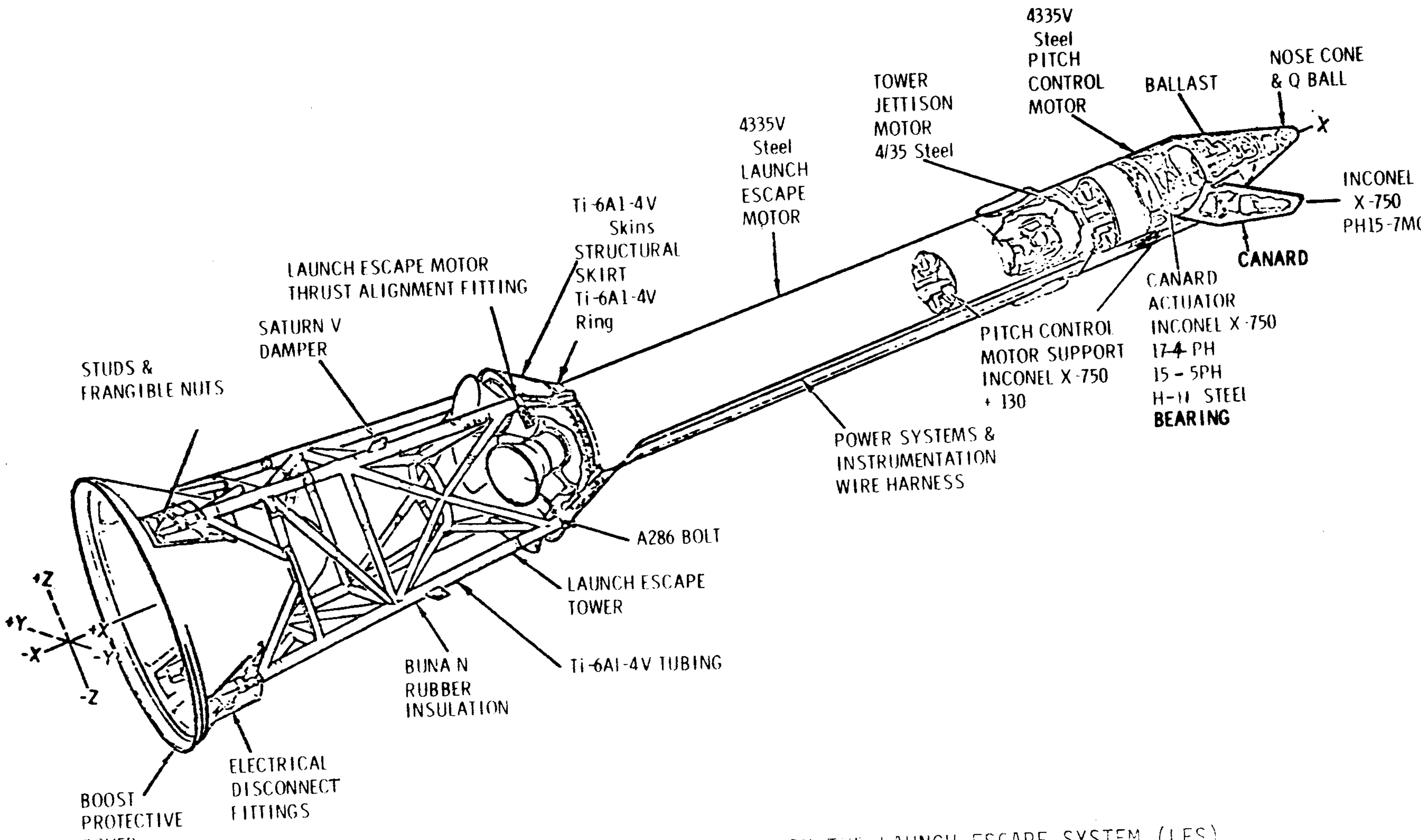

Figure 10-3 TYPICAL MATERIAL USAGE ON THE LAUNCH ESCAPE SYSTEM (LES)

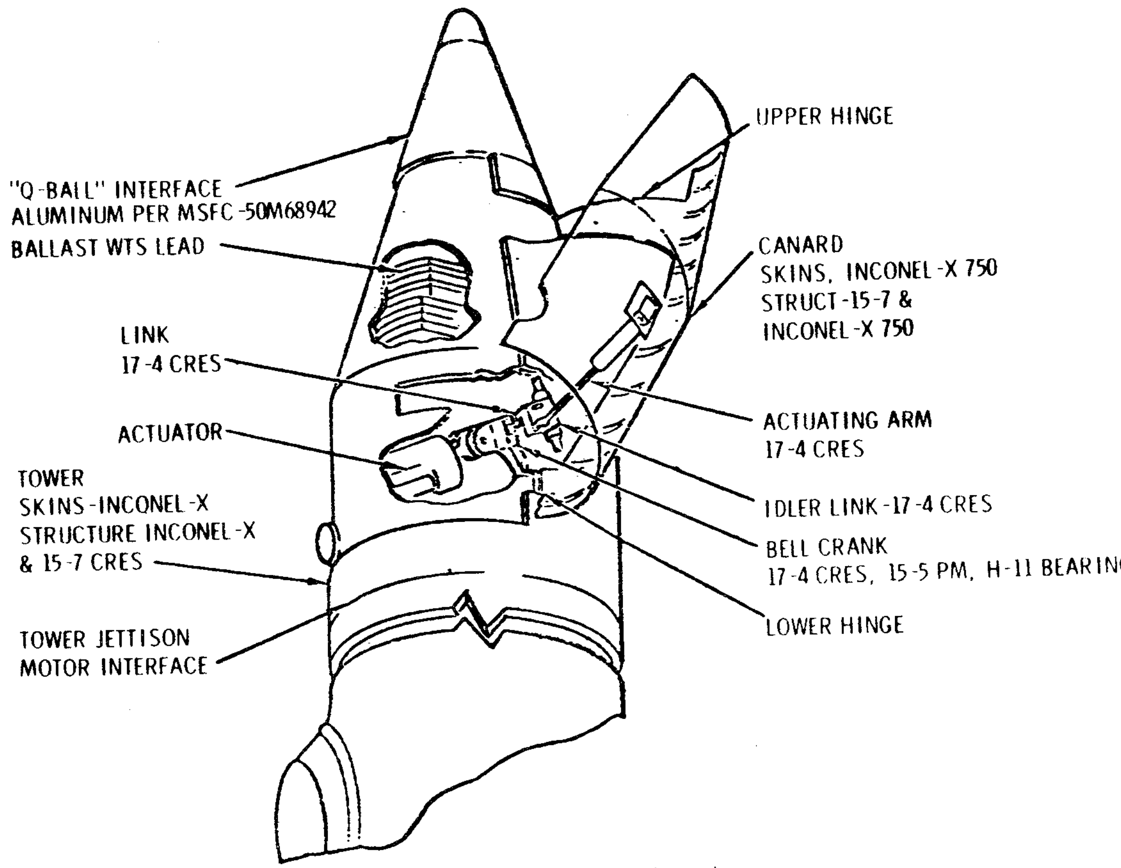

Figure 10-4 TYPICAL MATERIAL USAGE (LES)

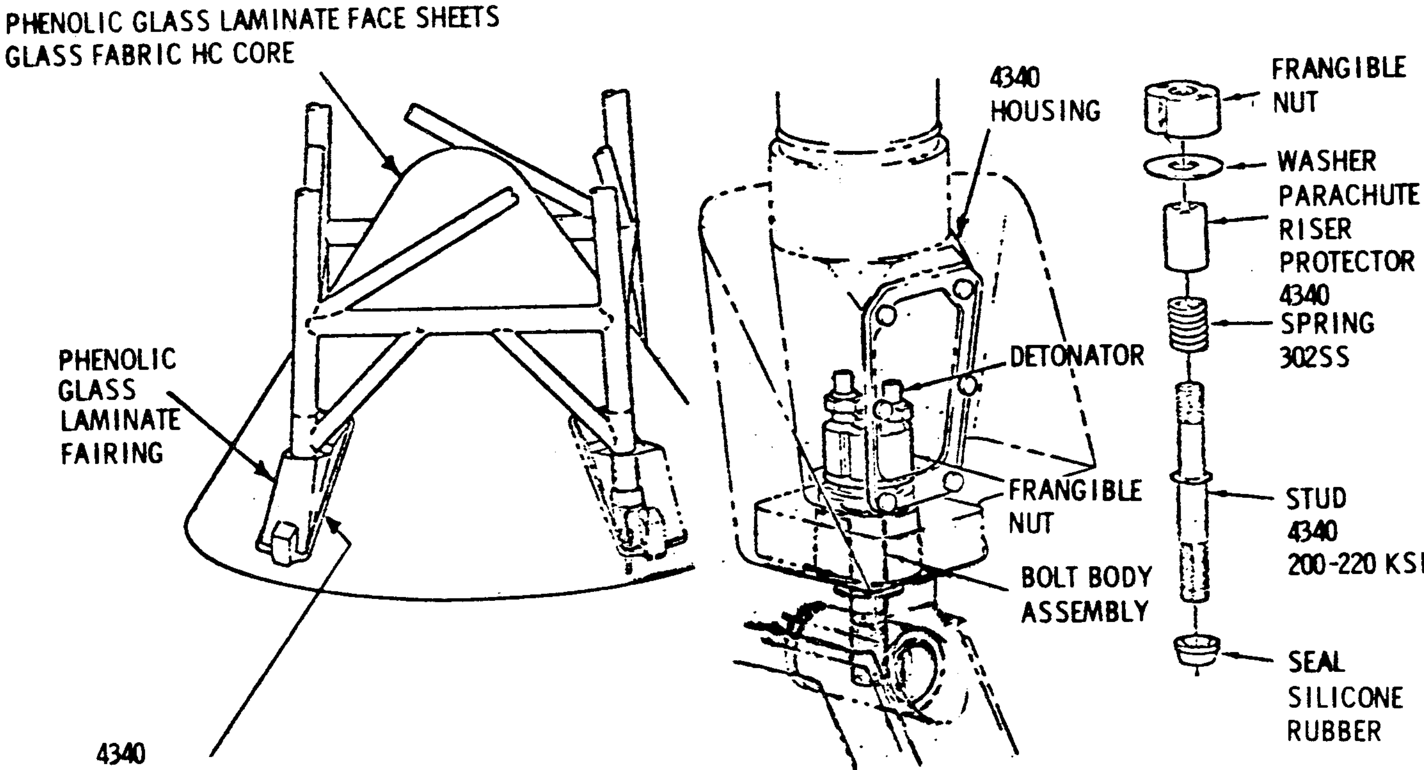

Figure 10-5 TYPICAL MATERIALS USAGE (LES)

10.2.2 Continued

Allowables

The allowables used for the LES were obtained from MIL-HDBK-5, NR Structures Manual, Materials and Producibility Bulletins 16, 44, 45, 46, 48, and 49, and Rocket Motor Vendors Design Documents.

10.3 CM FORWARD BULKHEAD

10.3.1 Design Adequacy Review

The CM Forward Bulkhead was chosen because an MR against it, MR No. 103605, could not be cleared by cursory examination. The adequacy of the design was not in question, as indicated by the factor of safety shown in Figure 10-6. The MR was cleared by in-depth stress analysis and the Forward Bulkhead judged adequate for the AS-503 flight.

10.3.2 CM General Materials Usage

A general picture of the CM metallic structural material usage on the CM and the applications of materials are shown in Figures 10-7 through 10-18. The inner structure, a welded pressure hull of 2014-T6 aluminum alloy, is rigidized and strengthened with adhesive bonded 5052-H39 aluminum honeycomb and 2014-T6 outer face sheets. The adhesive bonding of this inner structure and the secondary bonding of stringers, brackets, etc., is discussed to some extent under "Adhesive Bonding" in this section, he main emphasis being placed on adhesive bonding because it is basic to the structural design concept of the CM.

Metal parts such as sifffeners, brackets, fittings, etc., which are not attached by welding to the inner structure are heavily machined from 7075-T6 and 7079-T651 aluminum plates, extrusions, bars, or forgings. The alloys are known to be very susceptible to stress corrosion in the short transverse grain direction. The detail drawings do not specify the preferred grain direction in these parts. Attachment members of the outer structure, the docking system, forward pressure hatch, etc., use 17-4PH CRES Steel, A-286 CRES Steel, Inconel 718, PH15-7Mo, Ti-6Al-4V plate, rods, bars, forgings, extrusions, etc.

Insofar as could be determined, the selection and application of the structural materials appears to be satisfactory. The metallic materials are ordered to recognized federal specifications or adequate North American Rockwell specifications.

Adhesive Bonding

The principal adhesive bonding specification used on the CM is NR specification MA 0606-006, "Adhesive Bonding Apollo Command Module and Secondary Honeycomb Structure for Usage from -200° F to +250°F." A subsidiary specification is MA 0606-014, "Secondary Bonding of Stringers,

ITEM OF COMPARISON	CONTRACTOR	JSAT
ENVIRONMENT	80° F.	SAME
LOADS PARACHUTE SHEAR (LIMIT)	V = 31,200 LB. (3σ) V = 41,800 LB. (WORST-ON-WORST)	
ALLOWABLE	V = 52,100 LB.	
ASSUMPTIONS		
MINIMUM FACTOR OF SAFETY	1.4	
FAILURE MODE	LONGERON BENDING	

FIGURE 10-6 SELECTED ELEMENT REVIEW DATA COMPARISON - CM FORWARD BULKHEAD

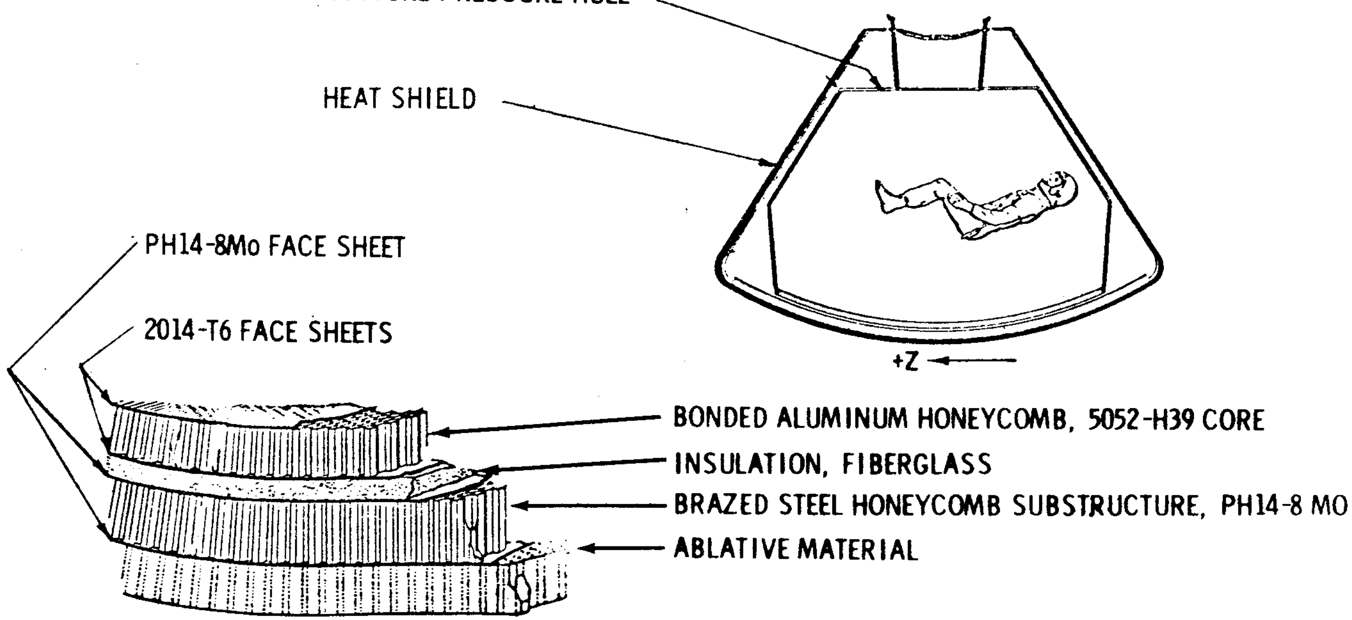

Figure 10-7 COMMAND MODULE SKIN CONFIGURATION MATERIAL USAGE

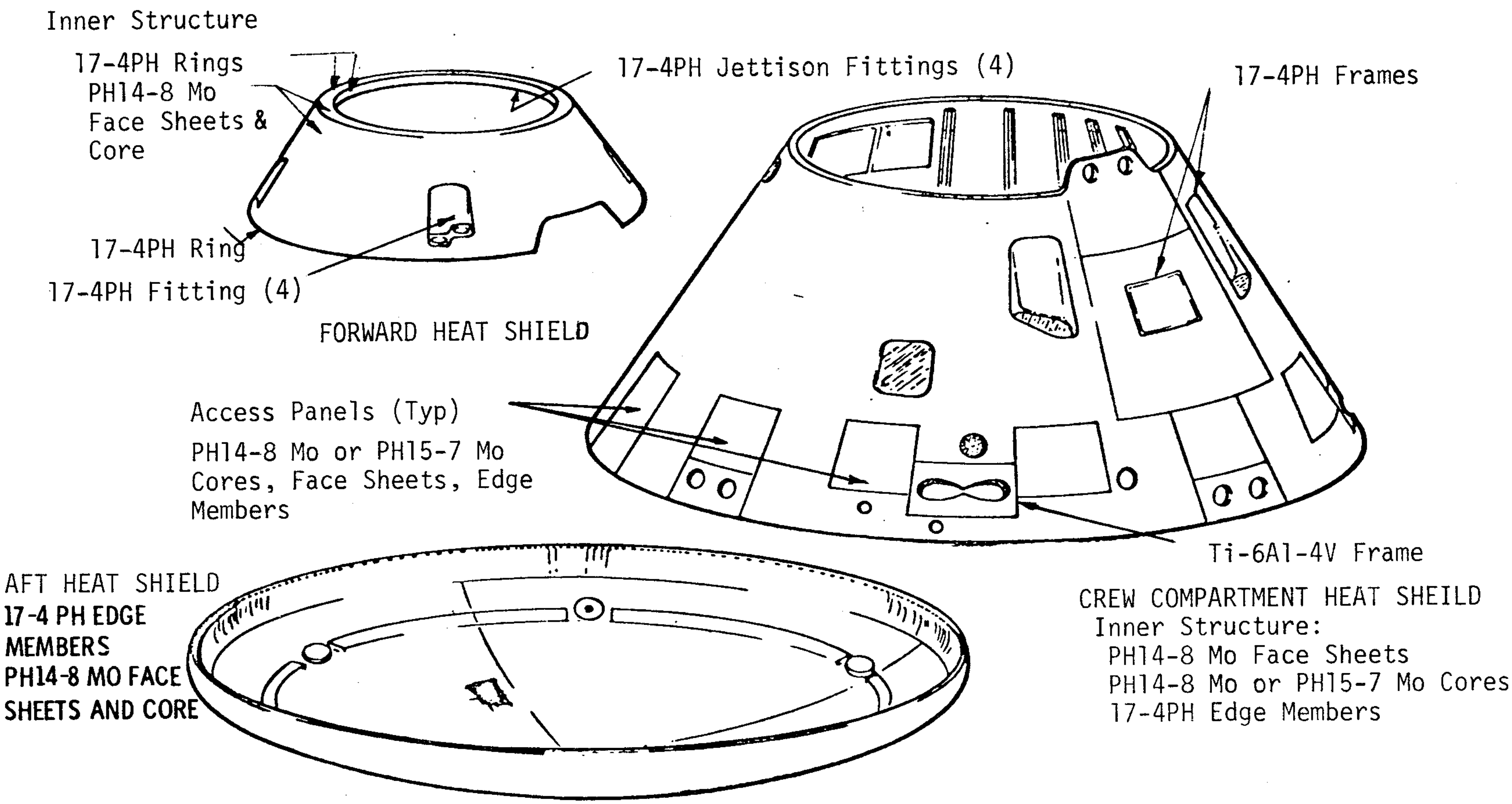

Figure 10-8 COMMAND MODULE HEAT SHIELD MATERIAL USAGE

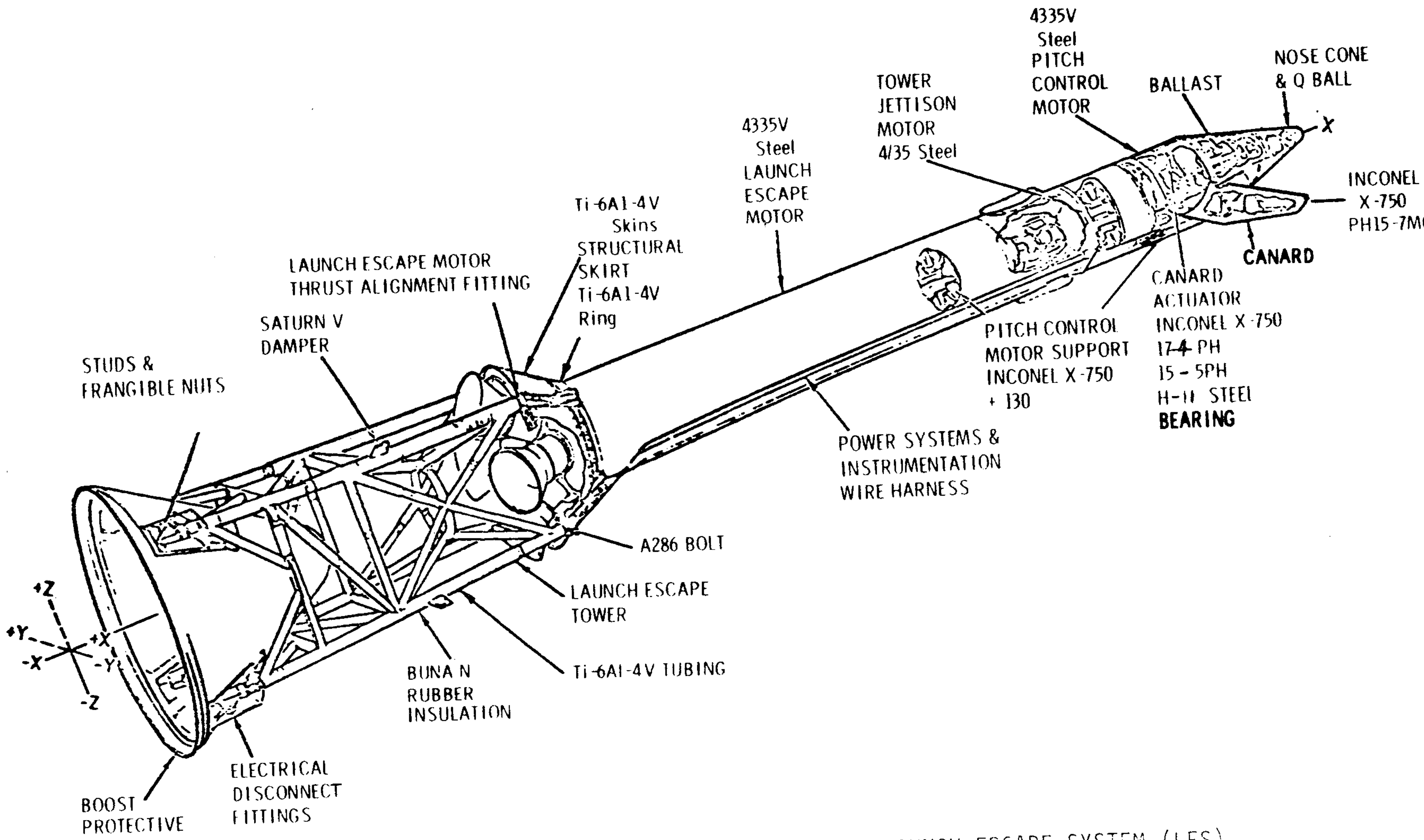

Figure 10-3 TYPICAL MATERIAL USAGE ON THE LAUNCH ESCAPE SYSTEM (LES)

CM FORWARD BULKHEAD

Design Adequacy Review

orward Bulkhead was chosen because an MR against lo. 103605, could not be cleared by cursory examina- he adequacy of the design was not in question, as d by the factor of safety shown in Figure 10-6. The leared by in-depth stress analysis and the Forward judged adequate for the AS-503 flight.

CM General Materials Usage

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rts such as sifffeners, brackets, fittings, etc., e not attached by welding to the inner structure ily machined from 7075-T6 and 7079-T651 aluminum extrusions, bars, or forgings. The alloys are be very susceptible to stress corrosion in the ransverse grain direction. The detail drawings pecify the preferred grain direction in these Attachment members of the outer structure, the system, forward pressure hatch, etc., use 17-4PH eel, A-286 CRES Steel, Inconel 718, PH15-7Mo, Ti- plate, rods, bars, forgings, extrusions, etc.

as could be determined, the selection and applica- the structural materials appears to be satisfactory. allic materials are ordered to recognized federal cations or adequate North American Rockwell speci- ns.

Figure 10-4 TYPICAL MATERIAL USAGE (LES)

e Bonding

ncipal adhesive bonding specification used on the R specification MA 0606-006, "Adhesive Bonding Command Module and Secondary Honeycomb Structure ge from -200° F to +250°F." A subsidiary specifi- is MA 0606-014, "Secondary Bonding of Stringers,

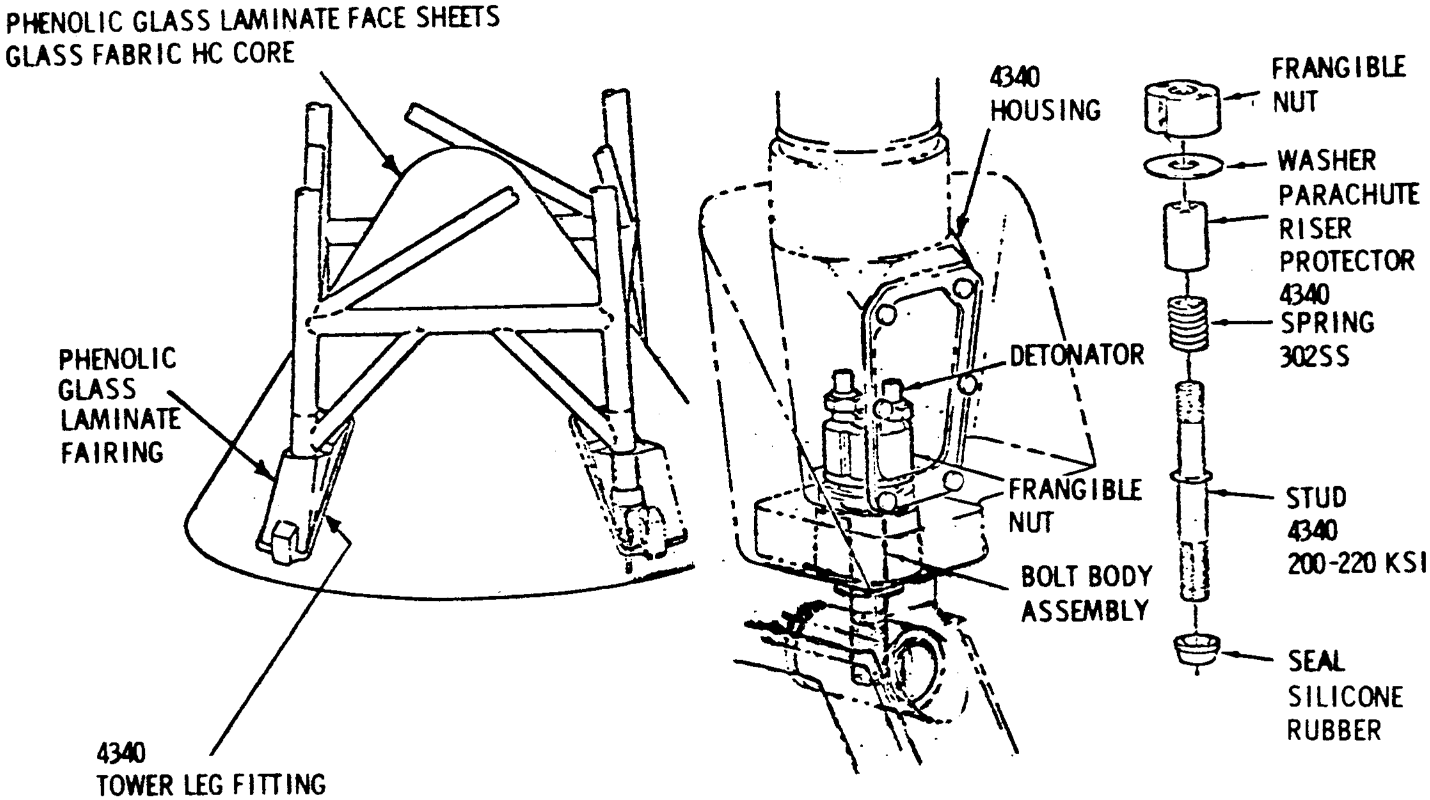

Figure 10-5 TYPICAL MATERIALS USAGE (LES)

ALLOWABLE	...,000 LB. (WORST-ON-WORST)	
	V = 52,100 LB.	
ASSUMPTIONS		
MINIMUM FACTOR OF SAFETY	1.4	
FAILURE MODE	LONGERON BENDING	

FIGURE 10-6 SELECTED ELEMENT REVIEW DATA COMPARISON - CM FORWARD BULKHEAD

were obtained from MIL-HDBK-
ls and Producibility Bul-
9, and Rocket Motor Vendors

10.3 CM FORWARD BULKHEAD

10.3.1 Design Adequacy Review

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10.3.2 CM General Materials Usage

A general picture of the CM metallic structural material usage on the CM and the applications of materials are shown in Figures 10-7 through 10-18. The inner structure, a welded pressure hull of 2014-T6 aluminum alloy, is rigidized and strengthened with adhesive bonded 5052-H39 aluminum honeycomb and 2014-T6 outer face sheets. The adhesive bonding of this inner structure and the secondary bonding of stringers, brackets, etc., is discussed to some extent under "Adhesive Bonding" in this section. he main emphasis being placed on adhesive bonding because it is basic to the structural design concept of the CM.

Metal parts such as sifffeners, brackets, fittings, etc., which are not attached by welding to the inner structure are heavily machined from 7075-T6 and 7079-T651 aluminum plates, extrusions, bars, or forgings. The alloys are known to be very susceptible to stress corrosion in the short transverse grain direction. The detail drawings do not specify the preferred grain direction in these parts. Attachment members of the outer structure, the docking system, forward pressure hatch, etc., use 17-4PH CRES Steel, A-286 CRES Steel, Inconel 718, PH15-7Mo, Ti-6Al-4V plate, rods, bars, forgings, extrusions, etc.

Insofar as could be determined, the selection and application of the structural materials appears to be satisfactory. The metallic materials are ordered to recognized federal specifications or adequate North American Rockwell specifications.

<u>Adhesive Bonding</u>

The principal adhesive bonding specification used on the CM is NR specification MA 0606-006, "Adhesive Bonding Apollo Command Module and Secondary Honeycomb Structure for Usage from -200° F to +250°F." A subsidiary specification is MA 0606-014, "Secondary Bonding of Stringers,

ITEM OF COMPARISON	CONTRACTOR	JSAT
ENVIRONMENT	80° F.	SAME
LOADS PARACHUTE SHEAR (LIMIT)	V = 31,200 LB. (3σ) V = 41,800 LB. (WORST-ON-WORST)	
ALLOWABLE	V = 52,100 LB.	
ASSUMPTIONS		
MINIMUM FACTOR OF SAFETY	1.4	
FAILURE MODE	LONGERON BENDING	

FIGURE 10-6 SELECTED ELEMENT REVIEW DATA COMPARISON - CM FORWARD BULKHEAD

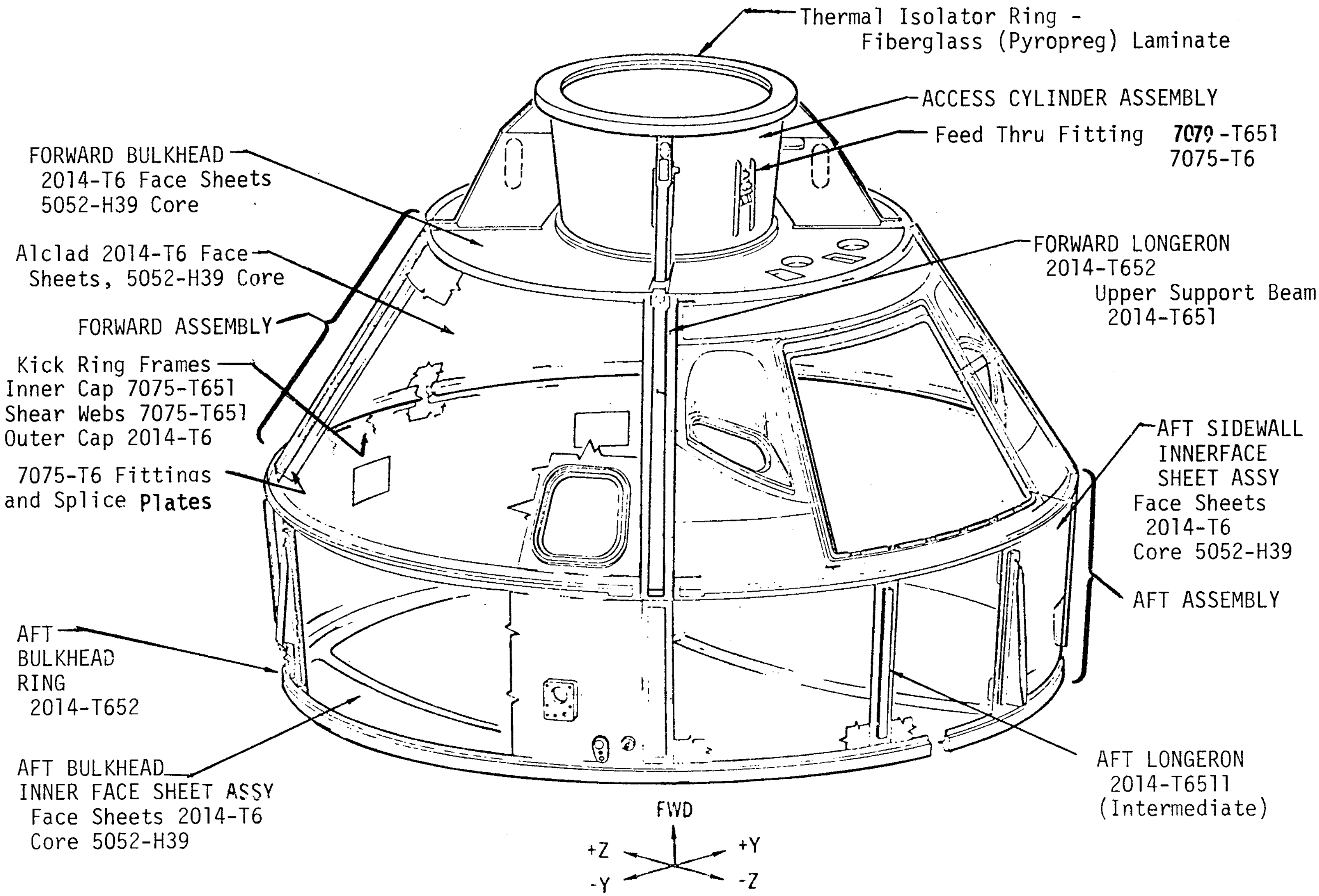

Figure 10-9 COMMAND MODULE INNER STRUCTURE MATERIAL USAGE

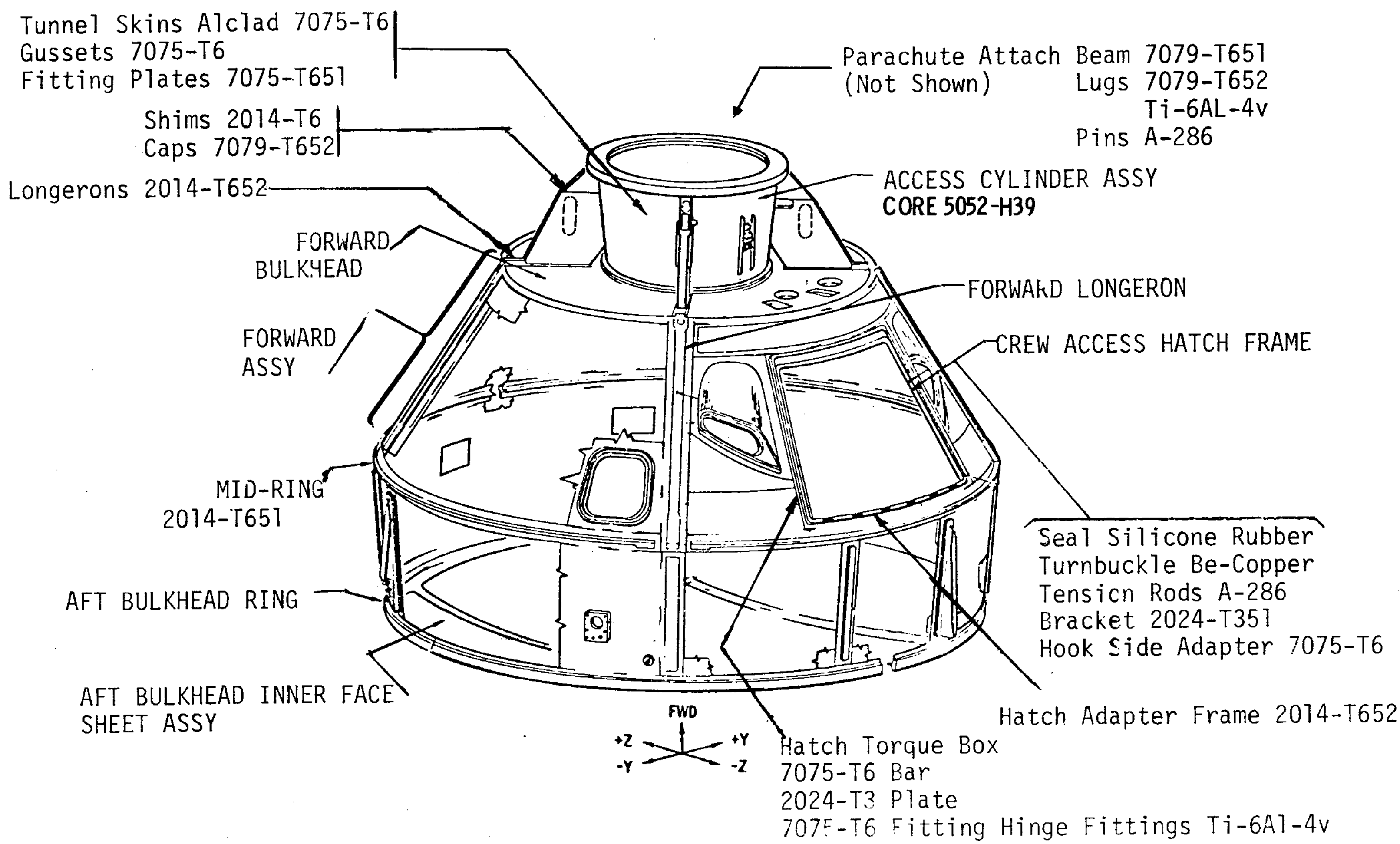

Figure 10-10 COMMAND MODULE INNER STRUCTURE MATERIAL USAGE

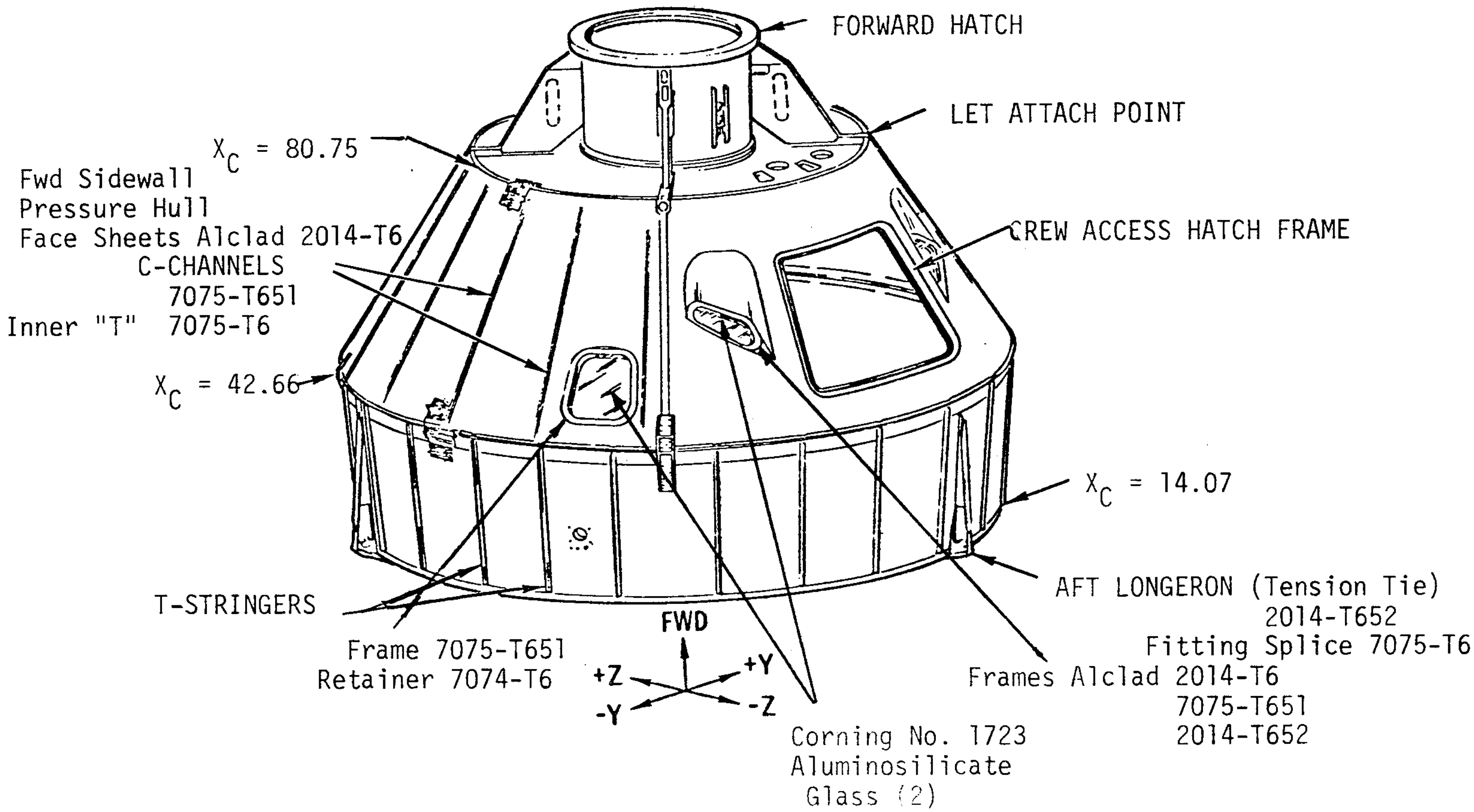

Figure 10-11 COMMAND MODULE INNER STRUCTURE MATERIAL USAGE

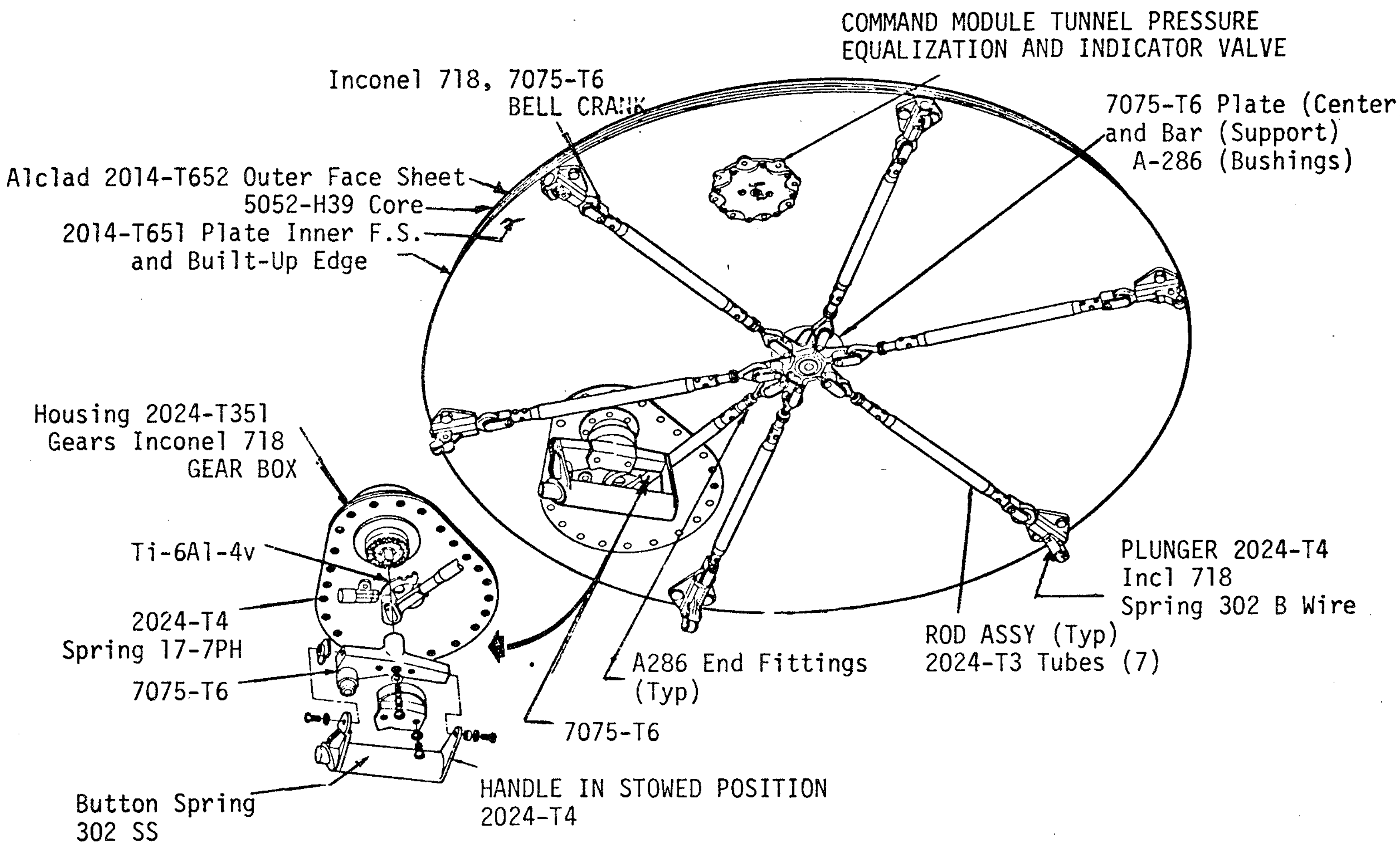

Figure 10-12 TYPICAL FORWARD PRESSURE HATCH MATERIALS

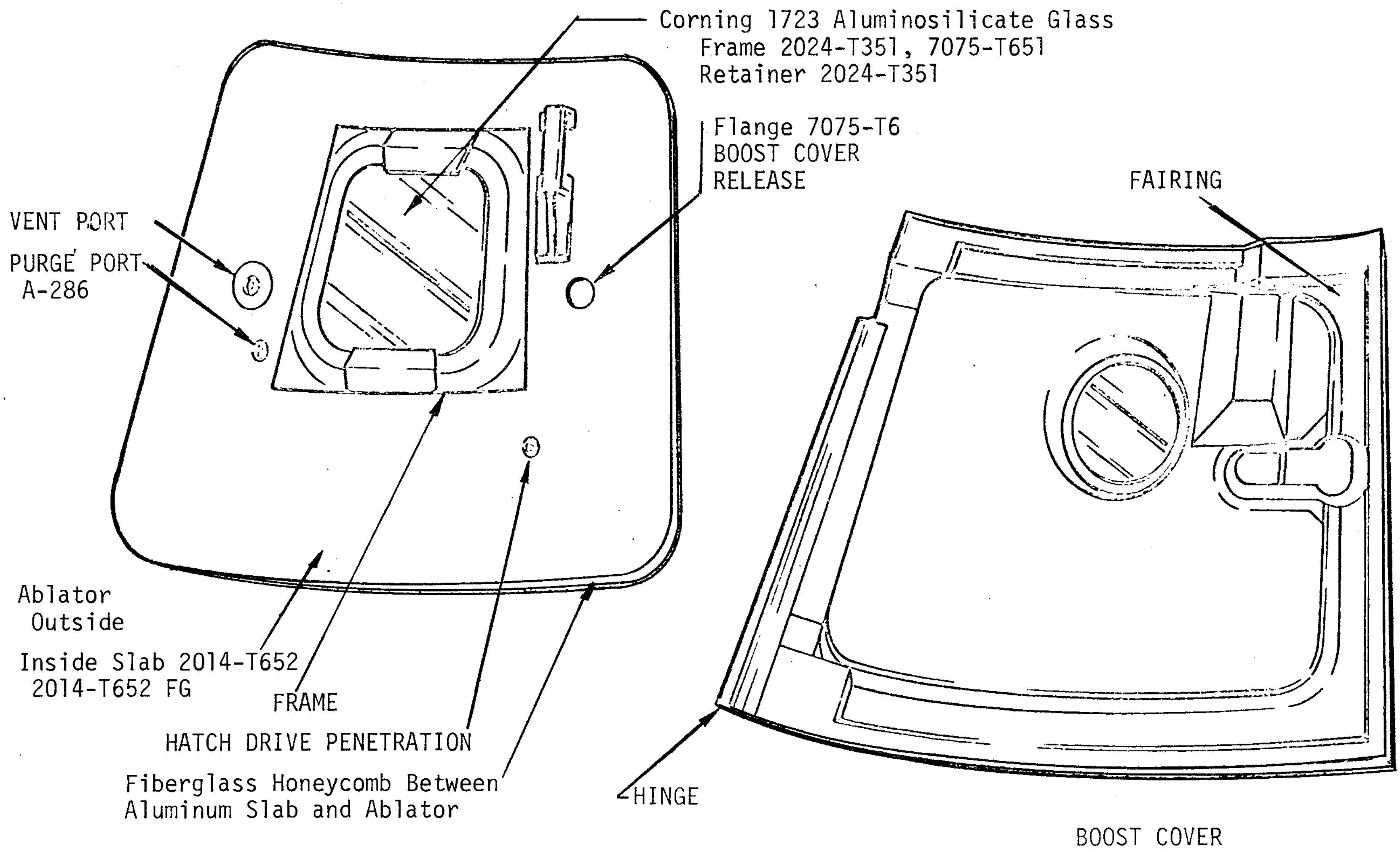

Figure 10-13 TYPICAL UNIFIED HATCH AND BOOST COVER MATERIALS

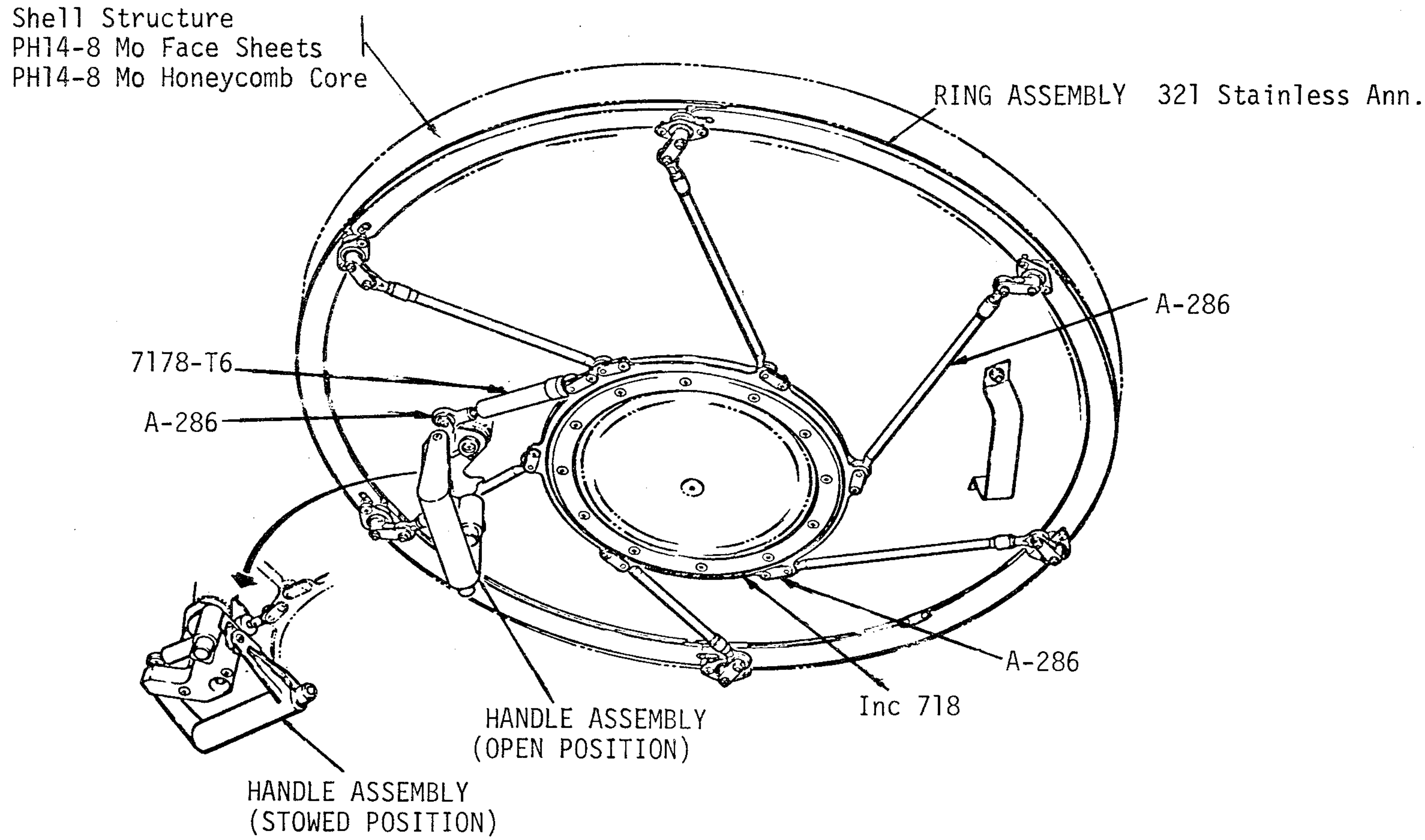

Figure 10-14 TYPICAL ABLATIVE HATCH MATERIALS

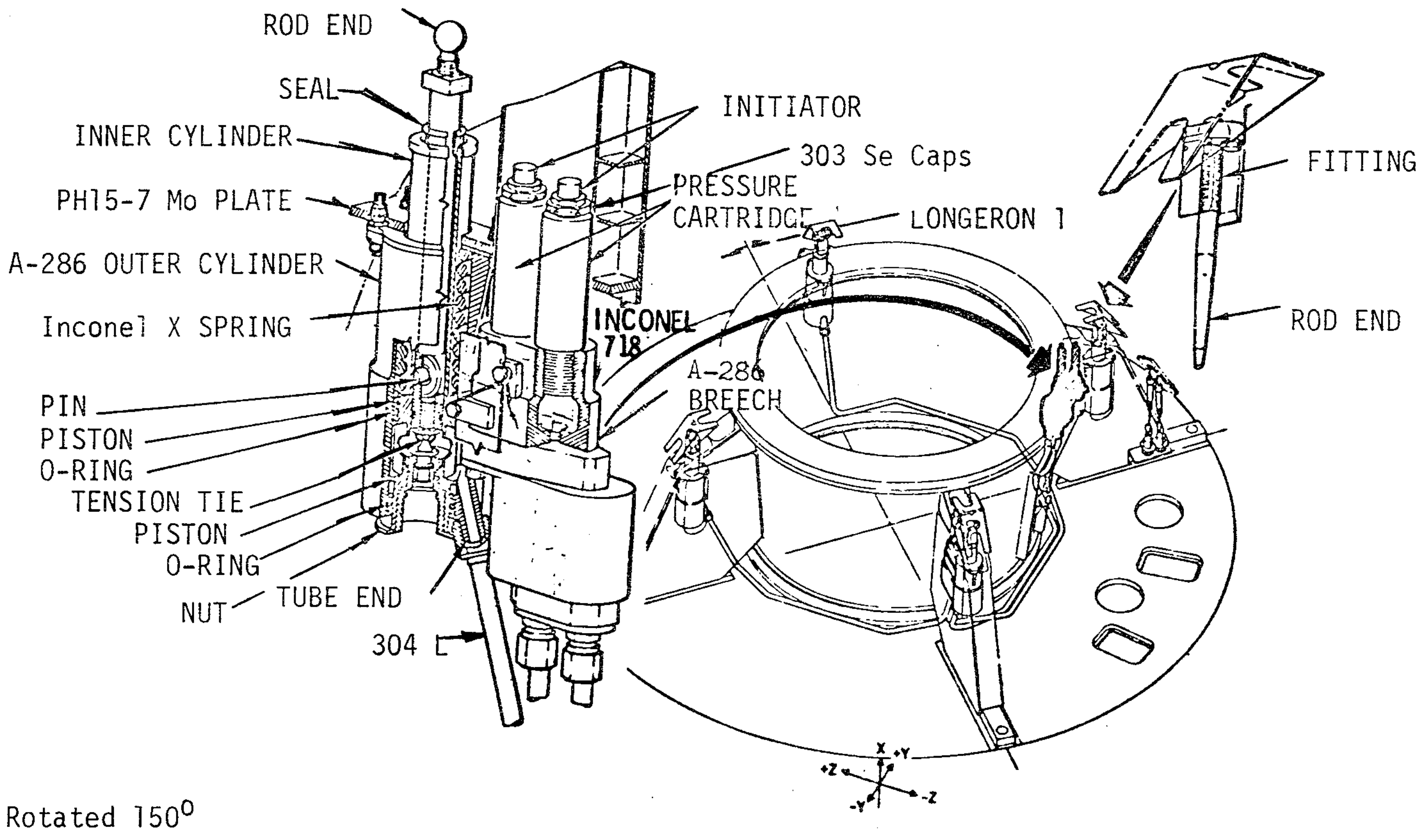

Figure 10-15 THRUSTER ASSEMBLY MATERIAL USAGE

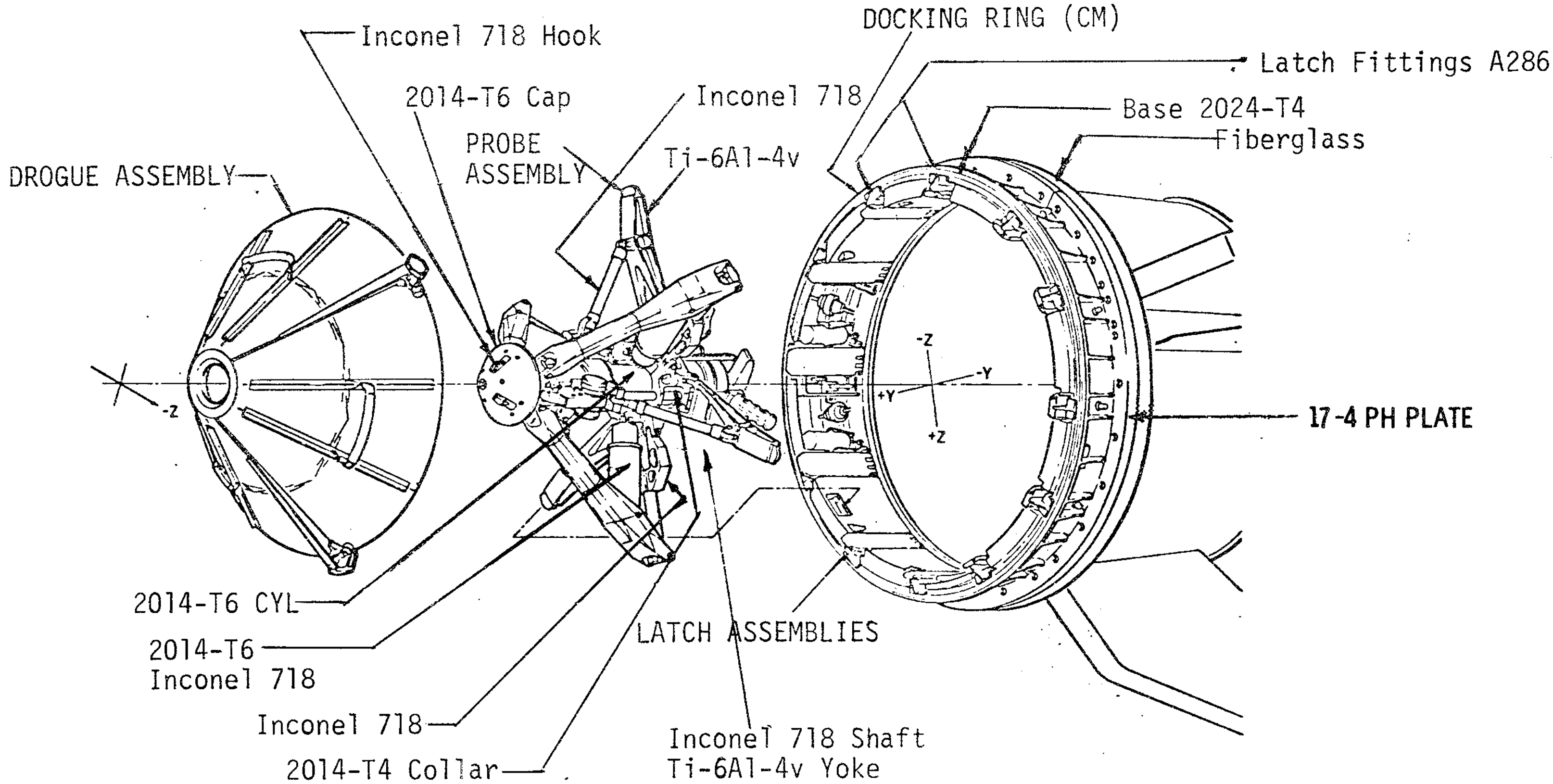

Figure 10-16 **DOCKING SYSTEM MATERIAL USAGE**

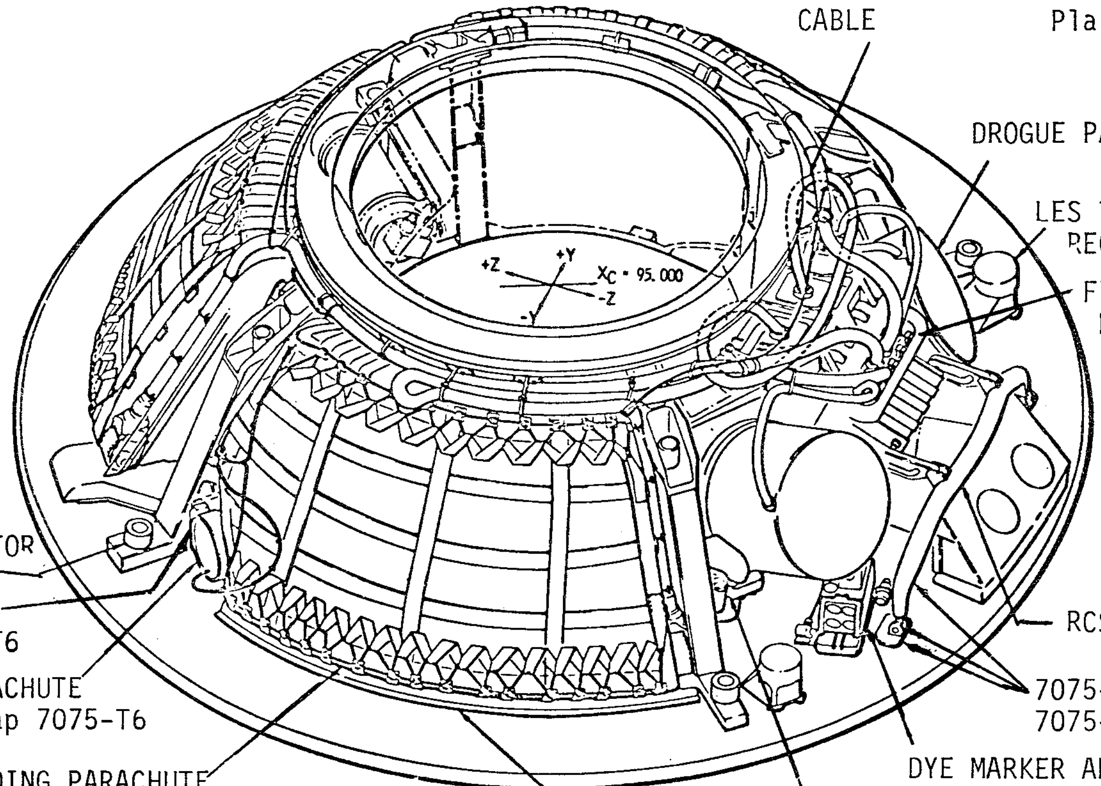

Figure 10-17 LES - EQUIPMENT MATERIAL USAGE

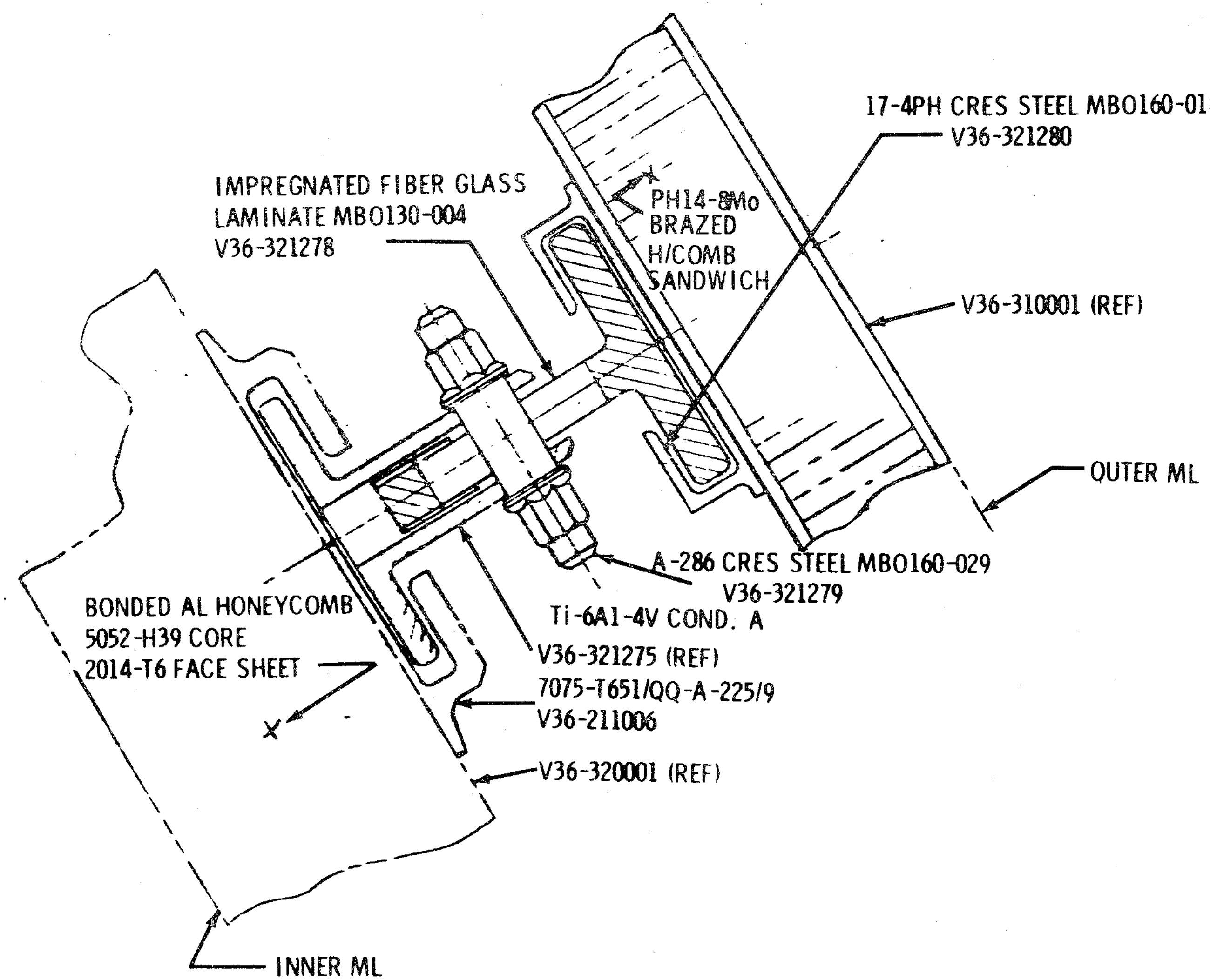

Figure 10-18 INNER TO OUTER SHELL ATTACHMENT MATERIAL USAGE

10.3.2 Continued

Adhesive Bonding (Continued)

Tie Brackets, Doublers, Etc. to Apollo Spacecraft." MA 0606-006 will be discussed first.

The primers, adhesives, and fillers for use with MA 0606-006 are epoxy-based. The primers are MB 0120-032 (Pittsburgh Plate Glass M-602 for -423° to 300°F), MB 0120-047 Type I (Am. Cyanamid HT-424B or Adhesive Engineering Aerobond P-413 for -423° to 180°F), and MB 0120-047 Type II (Am. Cyanamid HT-424F, or Adhesive Engineering Aerobond P-413 for -300° to 300°F. and short time to 500 °F).

MA 0606-006 makes use of four adhesives. MB 0120-048, the primary structural adhesive for honeycomb panel fabrication, is an epoxy-phenolic glass tape supported adhesive for -423° to 500°F service (HT-424 or Aerobond 430). For core-to-core splicing and for core-to-edge member or insert bonds, a thixotropic HT-424 paste, MB 0120-026, is used for -423° to 300°F, or short time to 500°F service. It is dyed blue to distinguish it from MB 0130-030. A foaming type adhesive, MB 0120-030 (HT-424, Type I) is used instead of the thixotropic paste where the core density is 4.4 lb. per cu. ft., or less, or where little or no pressure can be obtained during cure. It is also used as a stiffening medium to prevent edgewise collapse of core cells when inserting into channels, etc. As an alternate to the foaming type adhesive, a mineral-filled epoxy, MB 0120-037 (Epon 954, Reliabond 377), may be used to rigidize core edges. It is room-temperature curing. Figure 10-19 shows examples of adhesive selection.

For filling exposed core edges or core cells, where specified, three types of fillers are used: Type I consisting of 100 pbw MA 0120-039 (Am. Cyanamid Corfil 615) and 14 pbw Apco 320 hardener (Applied Plastics), Type II made up of 50 pbw LB 0120-012 (PPG Bondmaster M611/CH60) and 50 pbw Buehler 15-57AB alumina powder with 7 pbw Apco 320, and Type III composed of 100 pbw, MB 0120-039 with 7.5 pbw red di-ethylene triamine.

Details are fabricated for bonded honeycomb sandwich per LA 0102-004; surfaces are prepared for bonding per MA 0110-024; and process controls such as solution control, adhesive validation, production peel tests, etc., are covered in MQ 0103-001. The specification itself, MA 0606-006, includes general requirements, detail requirements, and quality assurance provisions.

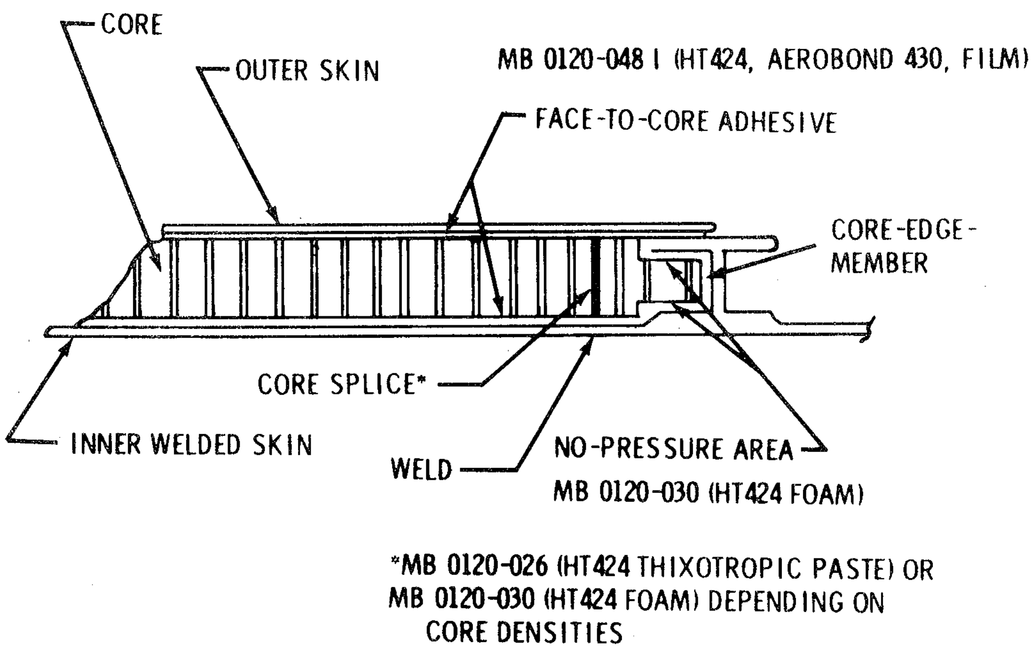

Figure 10-19 EXAMPLES OF ADHESIVE & FILLER SELECTION BASED ON MA 0606-006 ADHESIVE BONDING SPECIFICATION

10.3.2 Continued

General Requirements

Solution control; surface preparation and cleaning; storage and handling (cleaned details, primed details, materials - including storage temperature and life adhesive); temperature, humidity, and dust control; fabrication of details; treatment of torn cells or delaminated core bonds, etc.

Detail Requirements

Pre-fit of details (including straight edge, check fixture, or vinyl sheet impression check), primer application (including time limit after surface preparation, mixing instructions, life and storage parameters after mixing, application, curing, and handling of discrepant areas), honeycomb core splicing (including core-to-core and core-to-edge member bonding materials versus core densities and adhesive quantities), adhesive and filler selection (including film, foam, and thixotropic paste-up), adhesive and filler application (including patterns, gaps, overlaps, methods of application, dyeing for identification, adhesive flow control, ambient storage life), pressure application and curing (including pressure requirements and programming, provisions for thermocouples and vacuum lines, method of pressure application, temperature programming, and vacuum failure provisions), and multiple stage bonding (including primer application and drying).

Finishes

Except as noted on individual drawings, the finishes are controlled by V14-000024, "Finish Specification Apollo Spacecraft." For corrosion control of aluminum alloys during storage, manufacturing, and assembly, the controlling specification is MAO 609-002, "Corrosion Control of Apollo CSM Components."

The standard finish for all bonded aluminum parts of the CM is a chromate conversion coating per MAO 109-003, "Application of Chemical Films to Aluminum and Aluminum Alloys" (MIL-C-5541). The chemical film constituents are either Iridite 14-2 or Alodine 1200S. Some of the smaller aluminum parts, especially where painting would interfere with their function, are sulfuric acid anodized. The CM interior walls, including forward tunnel, (visible to crew), require one coat of MBO 125-019, light blue enamel, color 35622, per MAO 108-005. These finishes are common in aerospace usage and should satisfactorily control all modes of corrosion with the exception of stress corrosion.

10.3.2 Continued

Insulation

The insulation blanket installed between the inner and outer structure is an aluminum faced silica fibre matte known as TG-15000. The heat shield ablative material applied to the surface of the PH14-8Mo honeycomb sandwich of the outer structure, is AVCOAT 5026-39HCG. This is an epoxy-novolac with phenolic micro-balloons and random silica fibres in a phenolic fiberglass honeycomb. The phenolic honeycomb is bonded to the brazed steel honeycomb sandwich prior to filling with ablative material.

10.3.3 CM Quality Assurance

Quality Assurance covers process control specification, method of tool proofing, adhesive and filler evaluation prior to use (including peel and tensile strength requirements and others for MB 0120-039, MB 0120-012, MB 0120-030, MB 0120-030, and MB 0120-026), production testing (includes running test coupons with each production part - lap shear, if only metal-to-metal bonds; both lap shear and honeycomb peel if honeycomb bonds present - placement of test coupons and minimum test strengths; however, test coupons for foam and thixotropic adhesives not required), visual inspection (including adhesive primed surfaces and bonded parts), ultrasonic inspection ("where practicable," including rejection and drying requirements), sonic inspection (tap test where ultrasonic impracticable), X-ray inspection (core-to-core splices and core-to-edge member bonds single stage only to check maximum foam splice line width, core splice intersections, and repair of both), bondline thickness control, metal-to-metal adhesive defect inspection (visual for edge and corner lack of adhesive), and maintenance of records for each production part.

Radiographic inspection is controlled by NR specification MQ 0501-007 and ultrasonic inspection by MQ 050-010. One of the most important of the quality specifications is called out by number on drawing MQ 0501-026, "Production Quality Verification (PQV) Testing of Apollo Command Module Inner Structure Adhesive Bonds." This specification presents methods to locally destructive test production hardware to determine the strength of primary adhesive bonds. Four Block II tests are described: (1) face sheet-to-core tension (T_C), (2) metal-to-metal tension (T_M), (3) metal-to-metal shear (S_M), and (4) metal-to-metal Porta Shear. In the first three types, small grip pieces are bonded to the test surfaces, the test areas are trepanned by cutting through the skins and into the primary

10.3.3 Continued

bonds to isolate the areas, and the loads applied by suitable calibrated equipment. In the Porta Shear test a hollow cutter is used to cut through the metal and bond line and the shear load is then applied directly to the remaining circular piece of bonded metal. After testing the damaged areas are repaired.

Sketches define the locations of all test areas on the CM inner structure. Tables define the specimen types, locations, and loads required for the forward bulkhead, forward sidewall, aft sidewall, aft bulkhead, and bellyband. The number of tests to be performed are 16 T_C, 4 T_m, 16 S_m, and 21 Porta Shear, although current practice has eliminated S_m in favor of Porta Shear. These numbers are reduced to 5, 2, 5, and 5, respectively, if two successive spacecraft have met the P&V requirements of the more extensive test sequence.

MA 060-014, "Secondary Bonding of Stringers, Tie Brackets, Doublers, Etc., to Apollo Spacecraft" makes use of both the MB 0120-032 primer and the MB 0120-048 adhesive previously mentioned plus the MB 0120-053 high peel adhesive film (Am. Cyanamid FM-123-2). All CM details are required to be primed except shims which do not have to be primed if they are bonded within 24 hours after cleaning. Process verification coupons are run with the assembly when required by Quality Assurance. This option of process verification coupon testing could be a weakness in the specification.

The two quality specifications in MA 0606-014 are MO 0103-001 and MO 0501-024, the former being a general process control specification and the latter being specifically directed to the testing of MA 0606-014 bonded members. MQ 0501-024, "Verification Testing of Apollo Secondary Bonded Structures" is a 117 page document which shows in detail by means of sketches how each member such as channels, tees, and brackets is tested by using appropriate torque wrenches or tension scales with tools to grip the member under test. Test loads are those given on the engineering drawing.

In summary, it is difficult to pick an obvious weak spot in the adhesive bonding procedures. The adhesives are well known and acceptable. The specifications appear to be complete in their requirements for handling bonding surface preparation, validation procedures and storage life, and temperatures for primers and adhesives, fit checks, process validation test coupons, etc. The use of PQV (Production Quality Verification) testing (MQ 0501-026) of the honeycomb panels and the verification testing

10.3.3 Continued

of secondary bonded structural members (MQ 0501-024) denotes the extent to which quality assurance checking has been carried; although, of course, such tests are still in essence only sampling the structure to increase confidence in its reliability. PQV test reports for CM's No. 108, 109, and 110 were reviewed. In general, the test results were excellent with only two material review actions being required.

The problem of degrading the strengths of some heat treated aluminum alloys during bonding cure cycles was discussed with NR M&P allowables people. They were aware of the potential problem and claimed that necessary steps were taken to keep the designers informed and that degraded allowables were issued where necessary. Also, they indicated that they survey repair or rework bonding thermal cycles for the same reason.

Another potential problem area, that of the designer calling out the wrong specification for adhesive bonding (there being five MA 0606-XXX and five MA 0106-XXX specifications for adhesive bonding) was discussed with M&P. They indicated that the designer generally comes to the Project M&P group for consultation. Also, the Project M&P group receives one of four courtesy copies of all drawings for review. However, M&P does not have drawing sign-off rights and cases have occurred apparently where a drawing was released before M&P had reviewed their courtesy copy.

No amount of quality control nor sampling plans can substitute for good workmanship. This may be a problem area which could cause some trouble inasmuch as it is understood from NASA inspectors that (1) NR has no formal training program for shop bonding personnel and (2) periodic layoffs result in "bumping" which permits less qualified personnel with seniority to replace bonding shop personnel. This latter situation results in a measurable rise in bonded assembly rejections. It is conceivable that a greater number of marginal, or inadequate, parts are accepted despite the quality assurance provisions when "bumping" occurs.

One area of concern is the inadequate control over adhesive bonding process variables typified in the notes on drawing numbered V36-311001. This drawing authorized options resulting in bondline thicknesses up to 0.024 inches. The NR design allowables limit bondline thicknesses to 0.012 inches maximum. The NR document QEL-NMP-103-98, dated October 31, 1963, titled "Results of Lap Shear Strength vs. Glueline Thickness Tests," concludes that "gluelines"

10.3.3 Continued

for the HT 424 adhesive system below 0.014 inches will generally produce adequate bond strengths, which is in agreement with the NR allowables. Figure 10-20 obtained from the above document demonstrates that increasing the bondline thickness from 0.012 inches to 0.024 inches decreases lap shear strength at room temperature by 30 per cent and causes a 25 per cent reduction from design allowable.

Allowables

The allowables used for the CM were obtained from MIL-HDBK-5, North American Rockwell (NR) Structures Manual, and NR Material Producibility Bulletins 16, 44, 45, 46, 48, and 49. The allowables used for the PH14-8Mo brazed honeycomb were not available for assessment of this structure since NR considered these data proprietary.

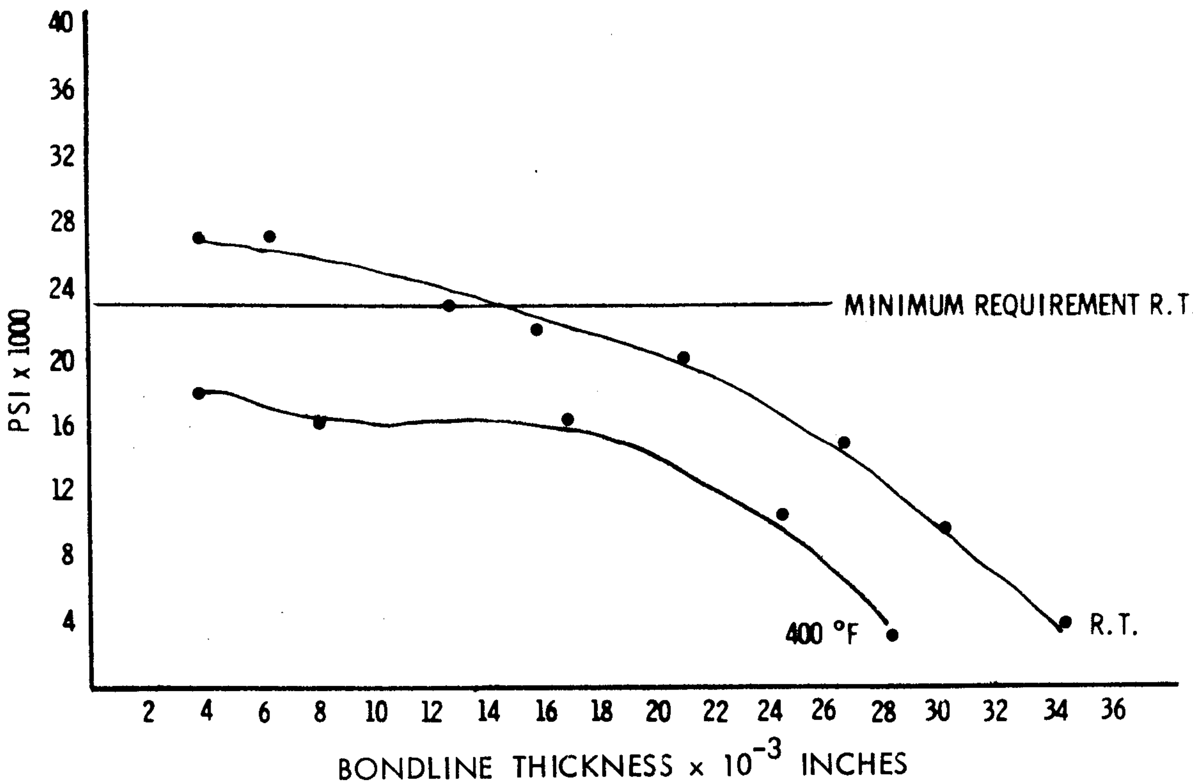

Figure 10-20 HT-424 ADHESIVE SYSTEM

10.4 CM LONGERONS

10.4.1 Design Adequacy Review

The reason for selecting the longerons was based on the low factor of safety reported in the NR analysis (F.S. = 1.53) coupled with the fact that the plastic bending part of the analysis was incorrectly handled. The analysis erred in computing the plastic bending section factor and in calculating a factor of safety based on stress allowables rather than based on bending moment allowables as is the required procedure for unsymmetrical sections (conservative in this case).

The longerons appear to be the controlling element of X_A 1083 interface capability for both liftoff and engine-out loads. Using the same internal loads, the plastic bending analysis was corrected with the result being that the error in the conservative direction was over-riding and that the factor of safety increased to 1.62. The corrected analysis demonstrates a higher factor of safety than was reported in the stress analysis. A summary of the review is presented in Figure 10-24.

10.5 CM/SM INTERFACE X_A 1010

10.5.1 Design Adequacy Review

The X_A = 1010 interface is made up of six radial beam trusses, six truss load pads, and 3 CSM tension ties. The outboard leg of the Radial Beam #3 Truss was selected as the critical element since the analysis indicated negative margins-of-safety in that area. Both the load pads and tension ties have been adequately demonstrated by test. Boeing analysis is in close agreement with the NR analysis. The conclusions as to the criticality of the Radial Beam #3 Truss are the same, both indicating an analytical factor of safety of about 1.47 for the AS-503 C-Prime flight loads. The comparison is shown in Figure 10-25.

There has been no structural test performed which adequately demonstrates the ultimate capability of Radial Beam #3. However, because of the similarity between Radial Beams #1 and #3, the ATR 222013 test demonstrates a Radial Beam #3 factor of safety $>$1.40 for the AS-503 C-Prime loads. Radial Beams #2 and #5 will be tested for engine-out loads before the AS-503 flight, and since Radial Beams #3 and #5 are similar, it will then be possible to determine a new test factor of safety for Radial Beam #3.

10.5.2 SM General Materials Usage

The SM outer structure is a one-inch thick, cylindrical, bonded aluminum honeycomb sandwich shell. This shell consists of four basic panels which are attached to six radial beams and to the forward and aft bulkheads, plus four smaller reaction control system panels. Except for the radiator panels, the outer face sheets are 2024-T81, the radiator panels outer face sheets being 6061-T6. The inner face sheets are 7178-T6. The honeycomb cores are 5052-H39 in two sizes, i.e., 3/16 x 0.0007 and 3/16 x 0.0015. The structure is bonded with epoxy-phenolic adhesives.

The inner structure consists of the six radial beams, forward and aft bulkheads, equipment shelves in one bay, and the various hardware associated with engine support, tank support, etc. Except for the bulkheads and shelves, the material used is generally 7075-T6, -T651. Some 2024-T3, -T4, -T42, and 2014-T6 are used also, but less extensively. The equipment shelves and forward and aft bulkheads are of bonded aluminum honeycomb structure.

The radial beams are machined and chem-milled from single plates of 2-1/2 inch thick 7075-T651 per NR specifications MA 0103-005 and MA 0103-004, respectively, to webs as thin

10.5.2 SM General Materials Usage - Continued

as 0.015 ± 0.003 inches in some areas. End grain pitting up to 0.005 in. with a surface of 300 RMS is permitted; however, the general surface finish is 180 RMS. Corner radii are 0.38 in. min., fillet radii 0.18 in. min., and all other 0.06 in. Because of the large amount of metal removed, it may be possible that large unbalanced internal stresses remain in the beams which could possibly lead to cracking. Some further investigation in this area may be warranted.

Typical material usage is shown in Figures 10-21, -22, and -23. The structure in the ECS and EPS radiator panel areas is complicated by the isolation of the radiators themselves from the rest of the panel with fiberglass laminate face sheets bonded to fiberglass honeycomb cores. The face sheets are phenolic resin impregnated glass fabric, elevated temperature resistant, per NR specification MB 0130-004. They are fabricated per NR specification MA 0105-002 into structural laminates. The cores are glass fabric impregnated with heat resistant phenolic resin for use up to 500°F. per NR specification MB 0130-014. The general arrangement and materials used in the EPS radiator area are shown in Figure 10-26 and 10-27.

Typical joint areas of the forward and aft bulkheads with the outer shells are shown in Figures 10-27 and 10-28. The EPS radiator arrangement shown is analogous to the ECS radiator system. The 6061-T6 alloy usage permits welding on fluid fittings and other manufacturing processes.

Adhesive Bonding

The principal bonding specification used on the SM is MA0606-010, "Adhesive Bonding, Apollo Space Vehicle Honeycomb Structure, for -300°F to 400°F Usage". Typical areas of use are the forward and aft bulkheads, the shelves, and the outer shell panels and radiators. While basically the same, this specification differs from MA 0606-006 (see CM) in several particulars among which are: 1) No multiple stage bonding is permitted, i.e., sandwich bonds are made in only one curing operation; 2) No primer is required on surface-prepared metal details assembled for bonding within 24 hours (except steel), metal-to-core within 36 hours, or on non-metal surfaces; 3) An optional cure cycle of one hour at 340°F was added to the 3-hour cure at 290°F; 4) Ultrasonically detected voids larger than one cell size are permitted for core densities less than 3 lbs. per cu. ft., providing they are less than 0.25 x 1.25 in. and spaced more than 5 in. apart; and, 5) Only lap shear and honeycomb

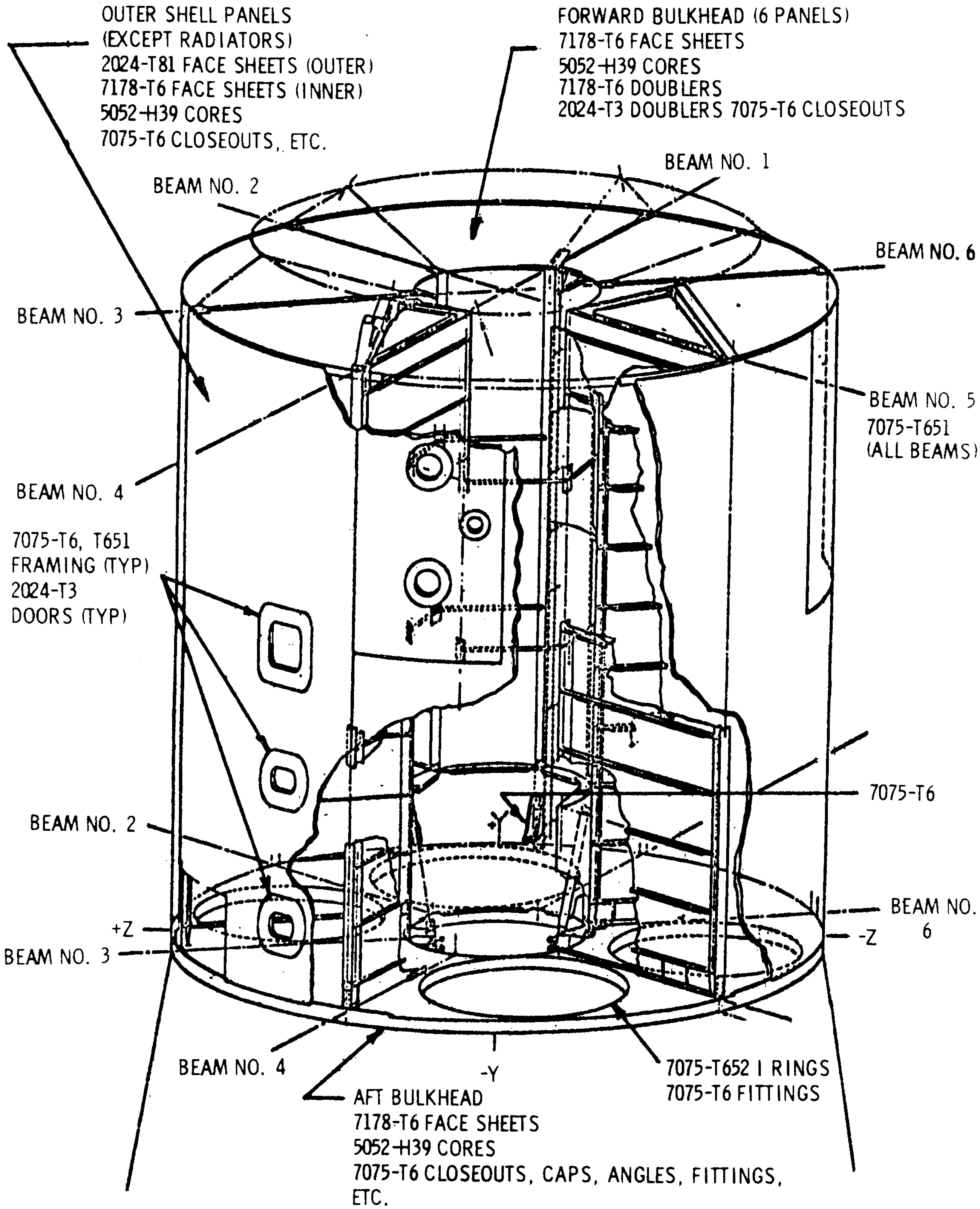

Figure 10-21 TYPICAL SM MATERIAL USAGE

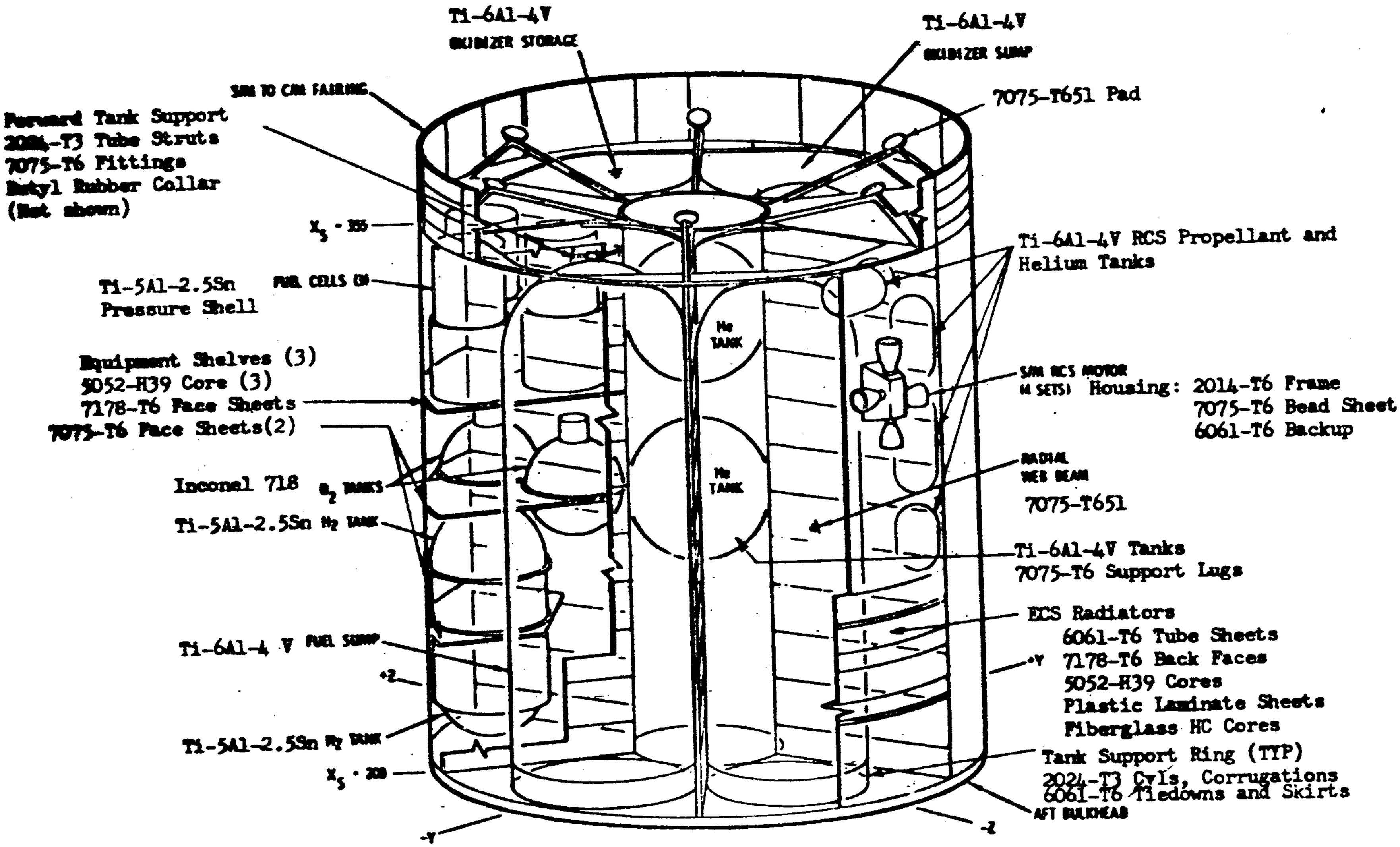

Figure 10-22 TYPICAL MATERIAL USAGE ON SERVICE MODULE

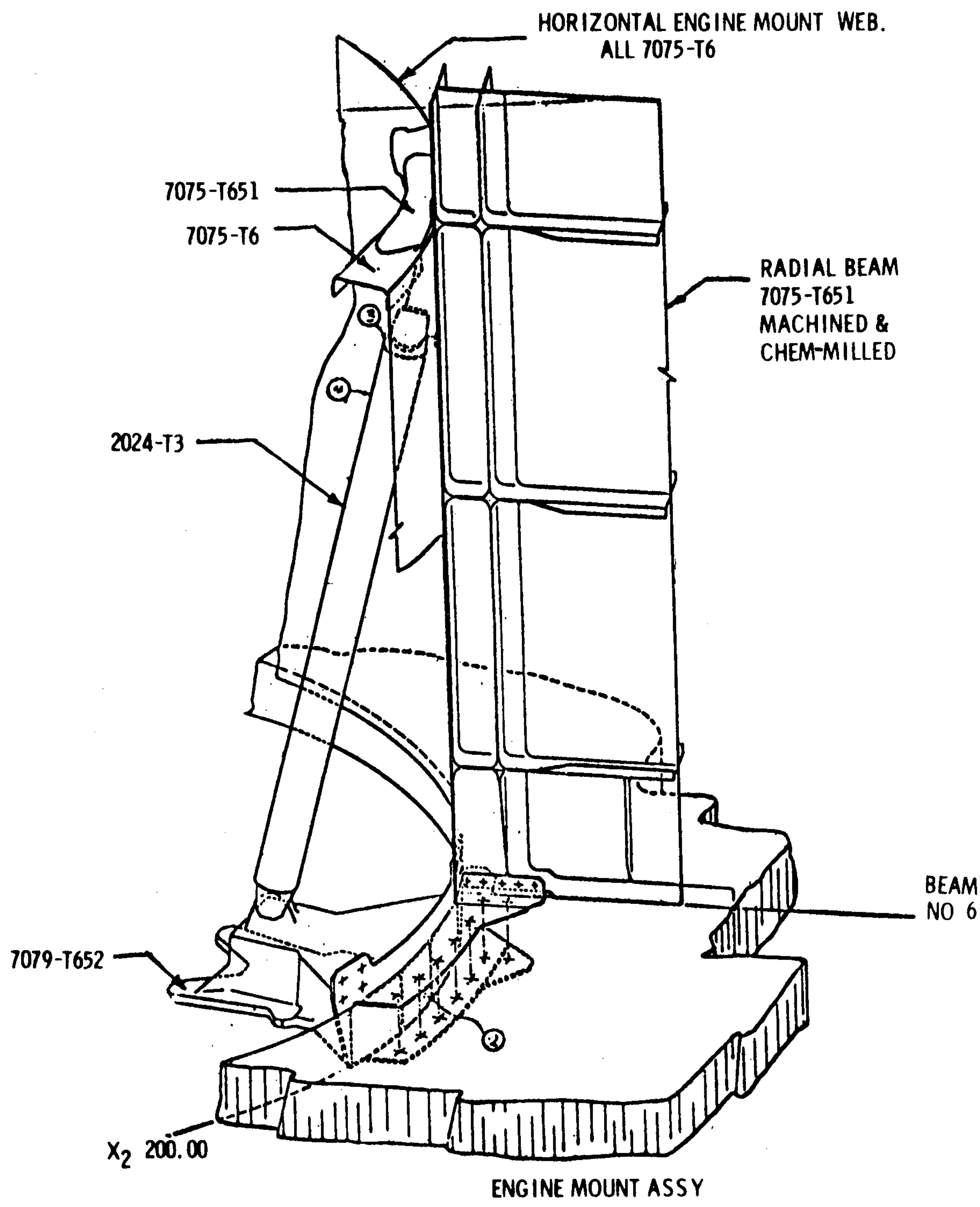

Figure 10-23 TYPICAL MATERIAL USAGE IN THE SERVICE MODULE ENGINE MOUNT ASSEMBLY

ITEM OF COMPARISON	CONTRACTOR	JSAT
ENVIRONMENT	Room Temperature	Room Temperature
LOADS Limit Loads at X_c 1083 Interface	$M = 1.03 \times 10^6$ in-lbs. $P = 122{,}000$ lbs.	$M = 1.03 \times 10^6$ in-lbs. $P = 122{,}000$ lbs.
ALLOWABLE	$F_{TU} = 60{,}000$ #/in^2 $F_{BU} = 87{,}550$ #/in^2	$F_{TU} = 60{,}000$ #/in^2 $M_{ALL} = 139{,}500$ in-lbs.
ASSUMPTIONS	Plastic bending	Plastic bending
MINIMUM FACTOR OF SAFETY	1.53	1.62
FAILURE MODE	Bending & tension on inner cap at Sta. $X_c = 71.5$	Bending & Tension on inner cap at Sta. $X_c = 71.5$

FIGURE 10-24 SELECTED ELEMENT REVIEW DATA COMPARISON - CM LONGERON

ITEM OF COMPARISON	CONTRACTOR	JSAT
ENVIRONMENT	Not applicable	Not applicable
LOADS (INTERNAL) LIMIT	Compression Pad Load P_c = 21060# Loads in Outboard Leg P = -24479# V = 871# M = 9281 in-lb	Compression Pad Load P_{cu} = 21060# Loads in Outboard Leg P = -24479# V = 871# M = 9281 in-lb
ALLOWABLE	Comp. Pad Allowable P_{cu} = 31000# Leg allowables F_{cc} = 58390 psi, F_{su} = 41000 psi M_u = 37170 in-lb	Comp. Pad Allowable P_{cu} = 31200# Leg allowables F_{cc} = 58000 psi F_{su} = 42000 psi M_u = 36900 in-lb
ASSUMPTIONS	1. Plastic bending in truss members 2. Moments from beam-column eccentricities neglected	1. Plastic bending in truss members 2. Moments from beam-column eccentricities neglected
MINIMUM FACTOR OF SAFETY	1.47	1.48
FAILURE MODE	Interaction of shear, bending, and compression stresses in outboard leg	Interaction of shear, bending, and compression stresses in outboard leg

FIGURE 10-25 SELECTED ELEMENT REVIEW DATA COMPARISON - CM/SM INTERFACE 1010

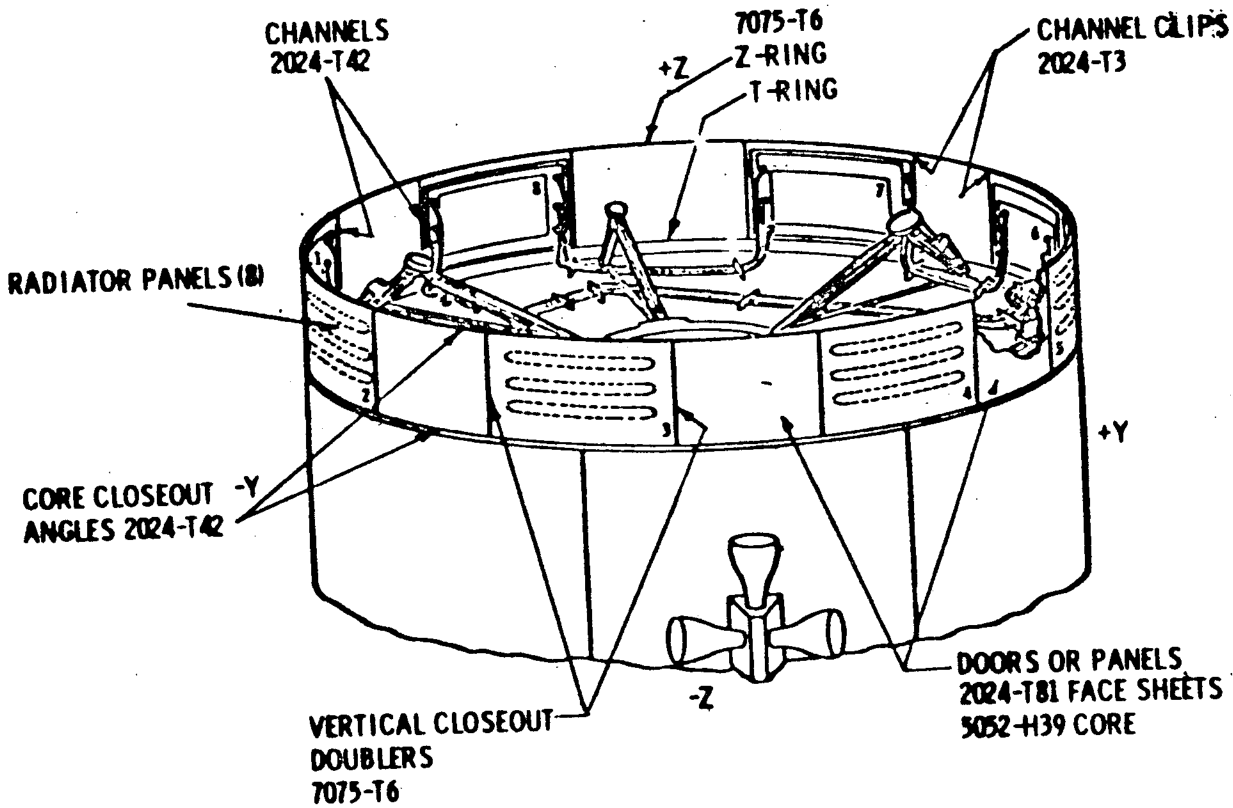

Figure 10-26 TYPICAL MATERIAL USAGE CSM FAIRING AND EPS RADIATOR AREA

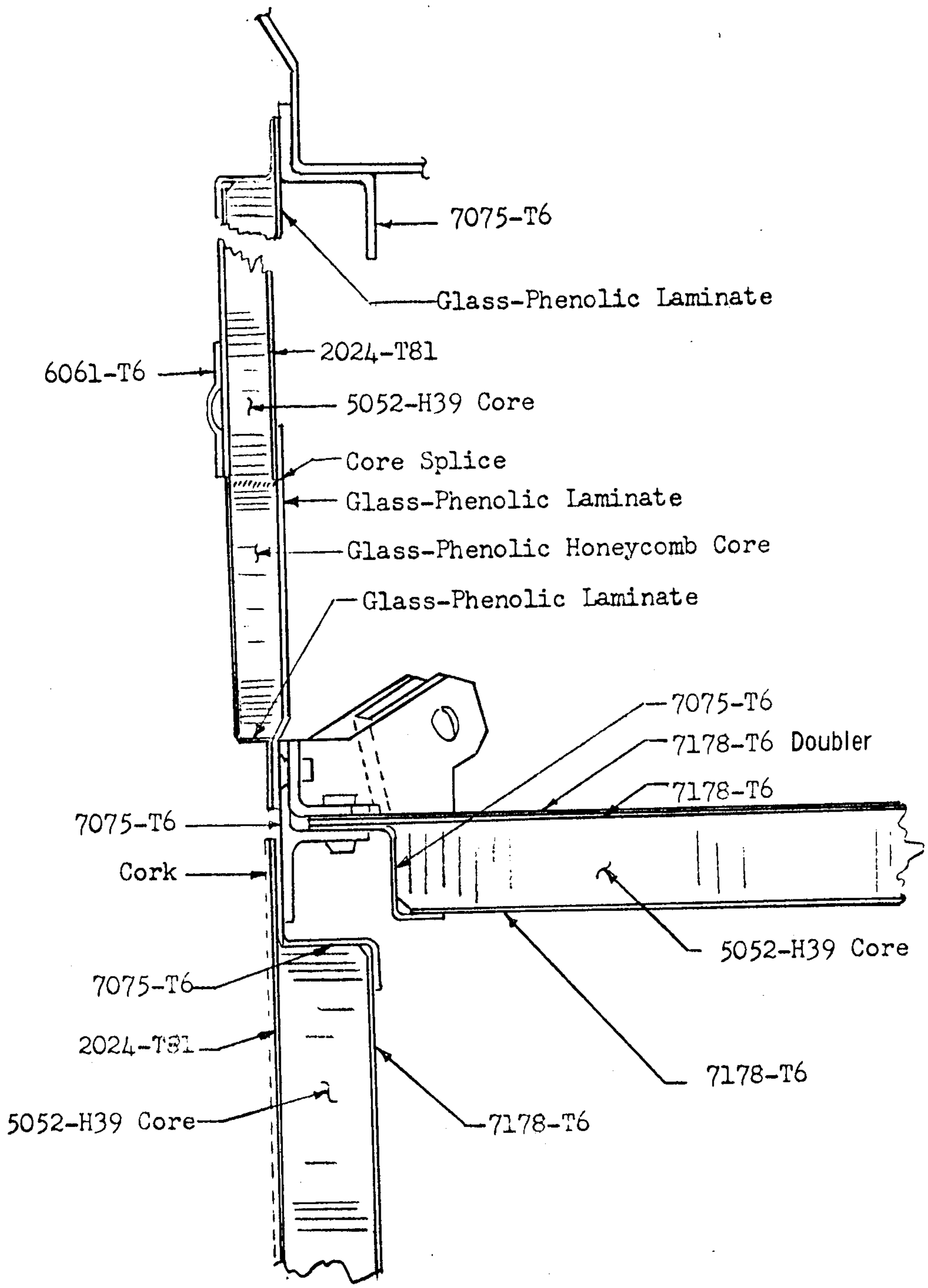

Figure 10-27 TYPICAL MATERIAL USAGE, FORWARD BULKHEAD - OUTER SHELL PANEL - CSM FAIRING AREA (ALL FASTENERS NOT SHOWN)

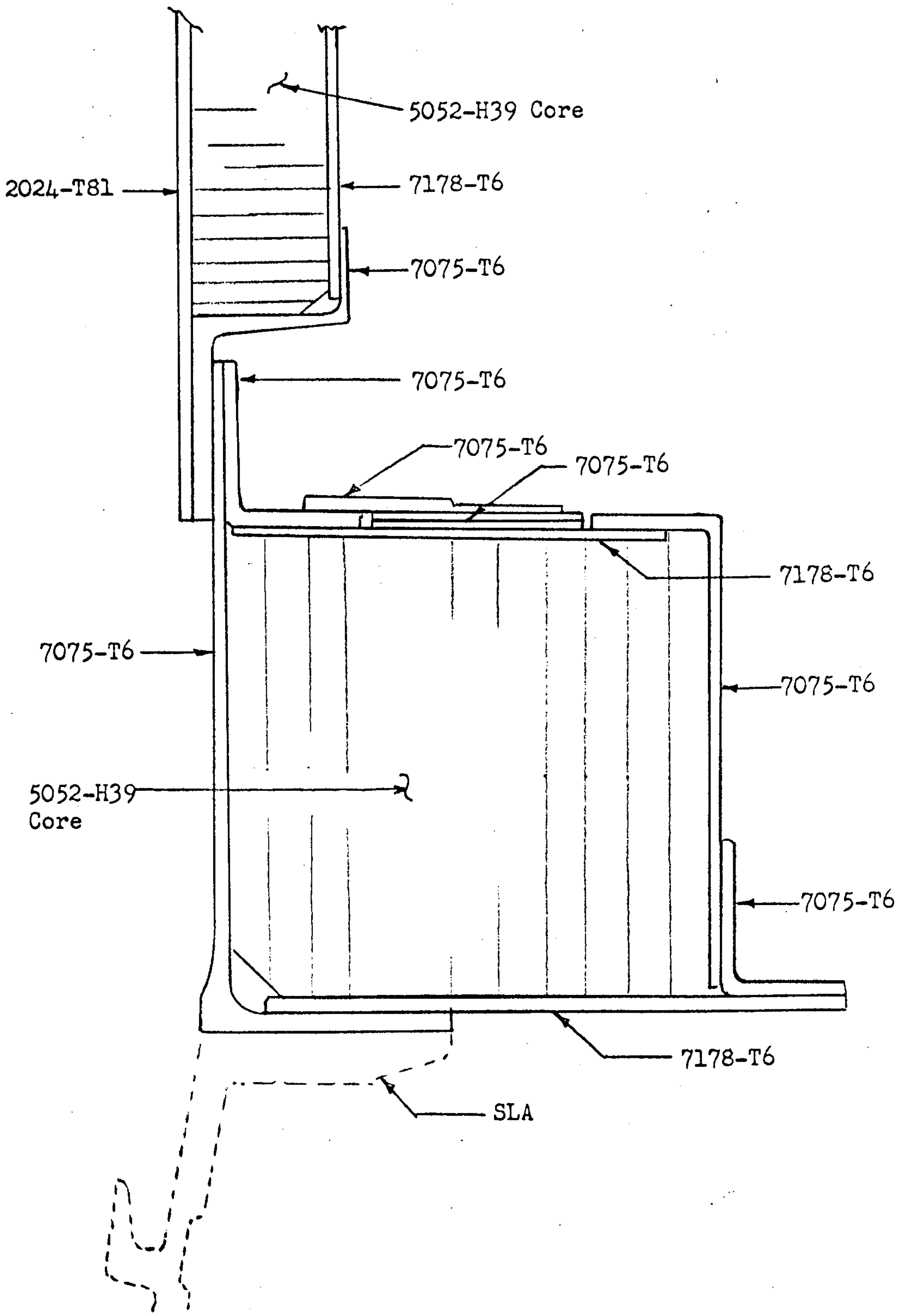

Figure 10-28 TYPICAL MATERIAL USAGE, AFT BULKHEAD - OUTER SHELL PANEL JOINT AREA (FASTENERS NOT SHOWN)

10.5.2 SM General Materials Usage - Continued

peel process verification test coupons are run with production parts- honeycomb tensile specimens not being required.

In general, the specification appears to be quite thorough in its coverage, being similar to MA0606-006. Test coupons are required to be run simultaneously with each production part to verify the bonding process. Also, production quality verification testing (a distinctive test of a small area of an actual production part to determine adhesive bond strength) is required. For example, the aft bulkhead drawing, V37-329810, requires eight Porta-Pull (tensile strength of honeycomb to face sheet bond) and two Porta-Shear (shear strength of metal-to-metal bond) tests. A check of other drawings shows single Porta-Pull tests usually are required for the various outer shell panels, although the forward bulkhead panels and shelves do not appear to require such tests.

Finishes

Part finishes generally are called out on the drawing by reference to V14-000-24, "Finish Specification Apollo Spacecraft". The standard finish for most of the SM is a chromate conversion coating per MA0109-003, "Application of Chemical Films to Aluminum and Aluminum Alloys" (MIL-C-5541), followed by one coat of clear epoxy. The chemical film constituents are either Iridite 14-2 or Alodine 1200S. Typically, this finish system is called out for the aft bulkhead, the forward bulkhead, the three shelves supporting the fuel cells, etc., the radial beams, the inside surfaces of the outer shells, and the outside surfaces of the outer shells except for the radiators and non-aluminum alloy surfaces. The radiators have a white inorganic temperature control coating, MB 0125-031, applied per MA 0108-022.

Some of the smaller aluminum alloy parts, especially where painting would interfere with their function, are sulfuric acid anodized. The CM/SM tension-tie bolts (4340 steel) are given a nickel-tin plated finish per MB 0125-041 which appears to have adequate hydrogen embrittlement relief coverage. Where aluminum and titanium alloys are in contact, special precautions are taken, e.g., in the assembly of the main propellant tank it is noted that both of the alloys contacting surfaces receive one coat of MB 0125-012 white epoxy primer per MA 0108-013 before assembly.

In general, the finishes appear to be adequate. The chromate conversion coatings were used successfully on the Boeing Lunar

10.5.2 SM General Materials Usage - Continued

Orbiter, the interior not receiving the clear epoxy paint specified for the Apollo SM.

Allowables

The allowables used for the SM come from the following sources: MIL-HDBK-5, NR Structures Manual, and NR Materials and Processes Bulletins 16, 44, 45, 46, 48, and 49. The presence of a member of the MIL-HDBK-5 Committee in the NR Allowables Group furnishes some assurance as to the reliability of the allowables. However, the NR people were questioned as to the reason for raising the Ti-6Al-4V tank allowables from 160 ksi ultimate and 150 ksi yield to 165 and 155 ksi, respectively. The basis for the change was a statistical analysis of data which had been accumulated during the Apollo program from a large number of tank head and cylinder tests. Therefore, the change appears to have been warranted.

10.6 SM/SPS PROPELLANT TANK UPPER SUPPORT

10.6.1 Design Adequacy Review

The adequacy of the SPS Forward Tank Supports was questioned because of the presence of thrust-oscillation induced tank vibrations. The effect of these dynamic loads for AS-503 was not considered in the design.

The Tank Supports were checked for tank lateral loads, including dynamic effects, as given in D5-15778 (Loads and Criteria Document). At the time the check was being made, the tanks were tested in the CM/SM End-Boost Stack Test (SD 67-554) for a tangential tank mode.

It was found that the Supports can be expected to show a factor of safety of at least 2.49, and thus are judged to be adequate for AS-503, see figure 10-29.

ITEM OF COMPARISON	CONTRACTOR	JSAT
ENVIRONMENT	Not applicable	SAME
LOADS	Ultimate column load = 1560 lbs.	Ultimate column load = 2020 lbs.
ALLOWABLE	Column buckling Allowable = 3600#	SAME
ASSUMPTIONS	Column load is determined from SD 67-554 End Boost Test and transverse accelerations	SAME
MINIMUM FACTOR OF SAFETY	3.20	2.49
FAILURE MODE	Column buckling	SAME

FIGURE 10-29 SELECTED ELEMENT REVIEW DATA COMPARISON - SM/SPS PROPELLANT TANK UPPER SUPPORT

10.7 SM SHELL

10.7.1 Design Adequacy Review

The SM Shell was chosen for examination because of an MR (No. 156214) which could not be cleared by a cursory examination. The design adequacy was not in question, as is indicated by the adequate factor of safety in Figure 10-30.

In-depth stress review of the MR disposition showed it to be adequate and the element was judged acceptable for AS-503 flight.

ITEM OF COMPARISON	CONTRACTOR	JSAT
ENVIRONMENT	88° F.	SAME
LOADS @ X_A 1010 (LIMIT)	S_A = 25,430 lb. M_A = 1.84×10^6 in-lb. P = -94,640 lb. T = 200,000 in-lb.	
ALLOWABLE		
ASSUMPTIONS		
MINIMUM FACTOR OF SAFETY	1.43	
FAILURE MODE	Compression yielding around cutout	

FIGURE 10-30 SELECTED ELEMENT REVIEW DATA COMPARISON - SM SHELL

10.8 SM/SPS TANK SKIRTS

10.8.1 Design Adequacy Review

The SPS Propellant Tank Skirts were of concern because their configuration is completely different for the Block II vehicle as compared to Block I. An analytically derived factor of safety of 1.48 for the 51-inch diameter oxidizer tank was shown by NR. The mode for this factor of safety is crippling.

The loads applied to the skirt were checked and found to be correct. A crippling analysis performed by JSAT produced the same 1.48 factor of safety. The compressive load in the tank skirt is a result of both axial and lateral acceleration. The comparison between contractor and JSAT data is shown in Figure 10-31.

The 51-inch diameter oxidizer tank skirt has demonstrated the required 1.40 factor of safety in test as well as the 1.48 analytical factor of safety. It is therefore considered structurally adequate for its design conditions.

ITEM OF COMPARISON	CONTRACTOR	JSAT
ENVIRONMENT	Room temperature considered	Room temperature considered
LOADS	Axial Load Factor = 4.032 g (limit) Lateral Load Factor = 0.236 g " Values include accelerations due to thrust oscillations. Internal tank pressure = 230 psi (limit)	Axial Load Factor = 4.027 g (limit) Lateral Load Factor = 0.150 g " Values include accelerations due to thrust oscillations. Internal tank pressure - 230 psi (limit)
ALLOWABLE	F_{cc} = 35,970 psi	F_{cc} = 35,970 psi
ASSUMPTIONS	Axial peaking factor = 1.83 Moment peaking factor = 1.42 Values determined by 2-S2 structural test.	Same
MINIMUM FACTOR OF SAFETY	1.40 (test)	1.42
FAILURE MODE	Meridional compressive stress on inner surface of the Skirt.	Same

FIGURE 10-31 SELECTED ELEMENT REVIEW DATA COMPARISON - SM SPS LOWER TANK SKIRT

10.9 SM AFT BULKHEAD

10.9.1 Design Adequacy Review

The critical area for the SM Aft Bulkhead is in Bay #5. Investigation into this area was initiated by an analytically derived factor of safety of 1.34, as shown in the NR stress analysis. The mode for this factor of safety is one of core shear stress.

The loads applied to the aft bulkhead were checked and found to be correct. A math model was set up by NR to simulate the highly redundant aft bulkhead structure. The stresses in the bulkhead, derived from the application of the internal loads, were assumed to be correct. The structural capability of the aft bulkhead was determined analytically by JSAT. The data comparison is shown in Figure 10-32.

The JSAT analysis demonstrates a higher factor of safety for the critical area than does NR. The aft bulkhead has successfully completed structural tests and is therefore considered structurally adequate for its design conditions.

ITEM OF COMPARISON	CONTRACTOR	JSAT
ENVIRONMENT	Room temperature considered	Room temperature considered
LOADS	Axial Load Factor = 4.036g (limit) Lateral Load Factor = 0.00 g (limit) Values include accelerations due to thrust oscillations.	Axial Load Factor - 4.042 g (limit) Lateral Load Factor = 0.025 g (limit) Values include accelerations due to thrust oscillations.
ALLOWABLE	Core shear = 251 psi	Core shear = 326 psi
ASSUMPTIONS	Loads applied to the tank structure were assumed to be distributed around the tank circumference.	Same
MINIMUM FACTOR OF SAFETY	1.40 (Test) 1.65 (Analytical)	1.40 (Test) 1.73 (Analytical)
FAILURE MODE	Core shear stress in Bay #5	Same

FIGURE 10-32 SELECTED ELEMENT REVIEW DATA COMPARISON - SM AFT BULKHEAD

10.10 SLA 838 INTERFACE

10.10.1 Design Adequacy Review

This element was selected due to the lack of tensile test data to qualify the interface, which was shown critical in tension by analysis. The SLA-2 test did not correctly simulate the Service Module tank loads, and was primarily a compressive test. Also, the SLA-2 test did not load the interface ring to a high enough running load to qualify it in tension. The SSSt test likewise was primarily a compressive test, which was intended to apply realistic SM loads to the 838 interface; however, the external loads were lower than the SLA-2 test loads. Therefore, this interface lacked tensile test qualification.

The NR analysis shows the ring reduced section tension critical. This conclusion is based on analysis which neglects the added effect of plastic bending on strength. JSAT analyses using plastic bending on the ring reduced section shows the interface to be compressive critical in the ring/SLA shell splice. A comparison of contractor and JSAT analyses is shown in Figure 10-33.

The interface (critical at the ring shell splice) is adequate for the AS-503loads with an analytical F.S. = 1.45. The SLA-2 test demonstrated a F.S. = 1.42.

10.10.2 SLA General Materials Usage

Basically the SLA structure is a truncated conical shell consisting of 2024-T81 face sheets bonded to 5052-H39 honeycomb core using epoxy-phenolic adhesives, the outer face sheets being covered with cork thermal insulation. Because of functional and manufacturing requirements, the honeycomb structure consists of a number of panels joined together with adhesive bonded 2024-T81 splice plates, or straps, to form quarter panels. Four of the quarter panels form the forward (upper) and four the aft (lower) conical sections, or shells; the quarter panels being joined both longitudinally and circumferentially with mechanical fasteners. The longitudinal close out members of the quarter panel honeycomb cores are typically 2024-T3 channels bonded in place. Other core close outs such as Z-sections around access holes and doors and irregular channel-like circumferential close out members of the quarter panel cores are typically 2024-T42, having been purchased in the annealed condition, formed, and heat treated prior to being bonded into the quarter panels. Doublers are usually bonded 2024-T81.

ITEM OF COMPARISON	CONTRACTOR	JSAT
ENVIRONMENT	156° F.	R.T.
LOADS (LIMIT)	First Stage separation N_T = 225 #/in(without peaking)	Max $q\alpha$ N_c = 807 #/in (without peaking)
ALLOWABLE (ULT.)	F_{TU} = 73,260 psi	F_{SU} = 2210 #/in
ASSUMPTIONS	No plastic bending.	Assume plastic bending on Ring reduced section; assume no shear strength through core bond.
MINIMUM FACTOR OF SAFETY	1.42 (Analytical)	1.45 (Analytical) 3.51 (Panel Test @ 505° F. - corrected to R.T.)
FAILURE MODE	Ring reduced section fails in tension (Analytical).	Lap shear splice with outer skin. (Analytical) Outer face sheet wrinkling (Test).

FIGURE 10-33 SELECTED ELEMENT REVIEW DATA COMPARISON - SLA 838 RING

10.10.2 Continued

The three ring frames - forward, aft, and at the L M support plane - are 7075-T6 extrusions which are part of the bonded quarter panel structures. Also, 7075-T6 is used for the heavier brackets and fittings and for the mechanically fastened straps along the separation lines between the quarter panels. The 7Al-4Mo titanium alloy finds use in some of the aft splice plates and in the L M tie down structure. Typical material usage is shown in Figure 10-34 through 10-38.

The honeycomb core is purchased to North American specification MB0170-027, "Core Material Aluminum Honeycomb, 5052-H39." Perforated core of 1/4-inch cell x 0.001-inch wall and 1/8-inch cell x 0.002-inch wall is used, the latter where greater compressive and/or shear strength is required, e.g., in the vicinity of cut outs.

Adhesive Bonding

The principal bonding specification for panel construction is North American MA 0606-012, "Adhesive Bonding, Apollo Space Vehicle Hoenycomb Structure, for -300°F to 500°F Usage." For core-to-face sheet bonding, epoxy-phenolic glass fabric supported tape adhesive per North American specification MB 0120-048 is used. For core splicing and core-to-edge member or insert bonds, epoxy-phenolic adhesive foam paste per MB 0120-030 or thixotropic paste adhesive per MB 0120-026 are specified. All three of these materials are typically American Cyanamid (Bloomingdale) HT424 adhesive, although Aerobond 430 tape adhesive has been qualified also. All metal parts including honeycomb cores are primed with MB 0120-031, American Cyanamid FM-47 liquid adhesive.

The materials and processing for adhesive bonded primary structure are assessed to be adequate to satisfy design requirements when in compliance with specifications. However, drawing authorized options and MR actions must be compatible with specification requirements to maintain this adequacy. Particular attention was directed to these items for SLA-11 because:

a. There were manufacturing difficulties on SLA-5 due to inadequate processing for adhesive bonding on AS-205.
b. A possible failure, as yet unexplained, occurred on SLA-9 on AS-502.
c. SLA-11 was fabricated like SLA-9 and is next in this series for flight.

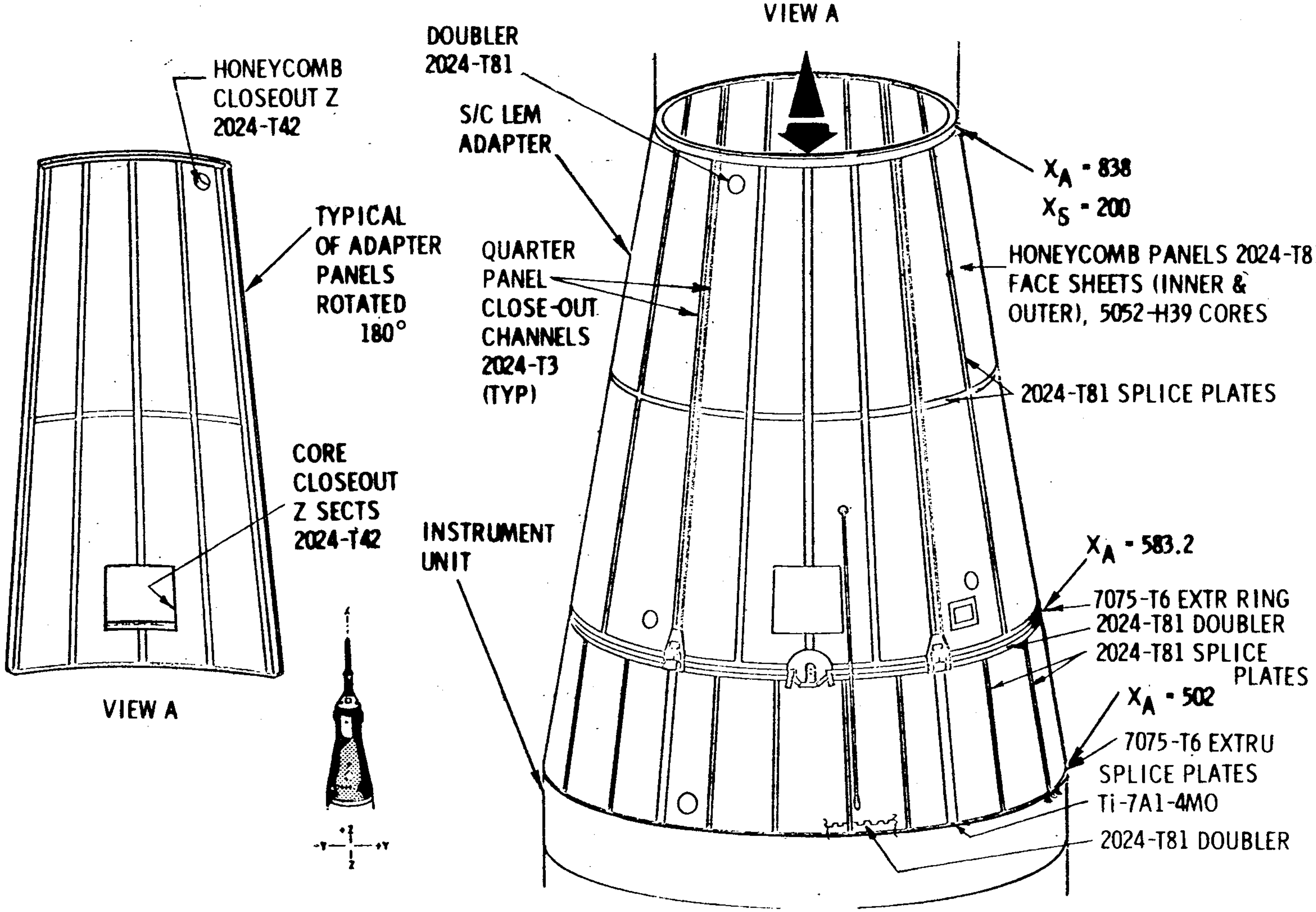

Figure 10-34 TYPICAL MATERIAL USAGE

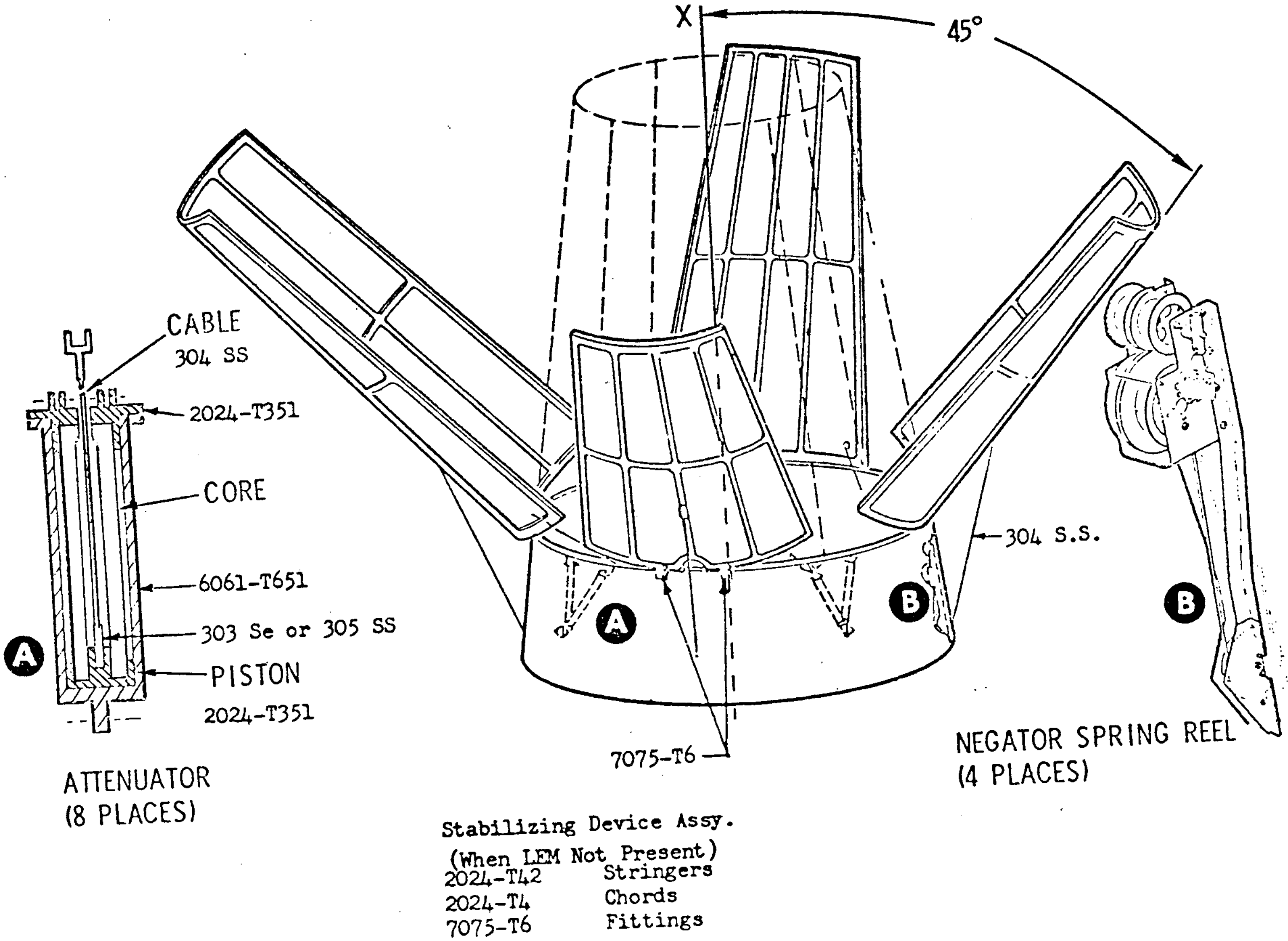

Figure 10-35 TYPICAL MATERIAL USAGE

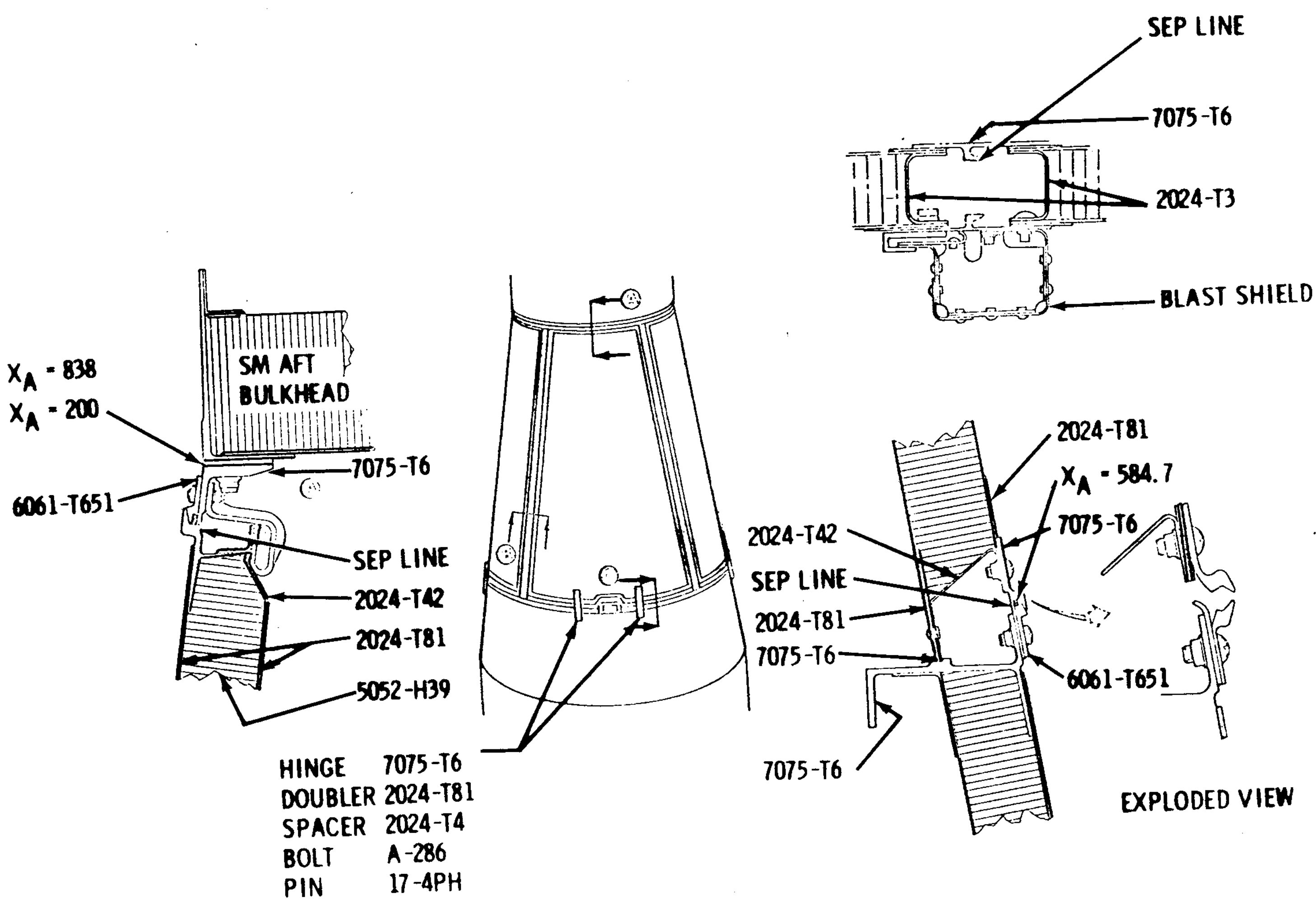

Figure 10-36 TYPICAL MATERIAL USAGE

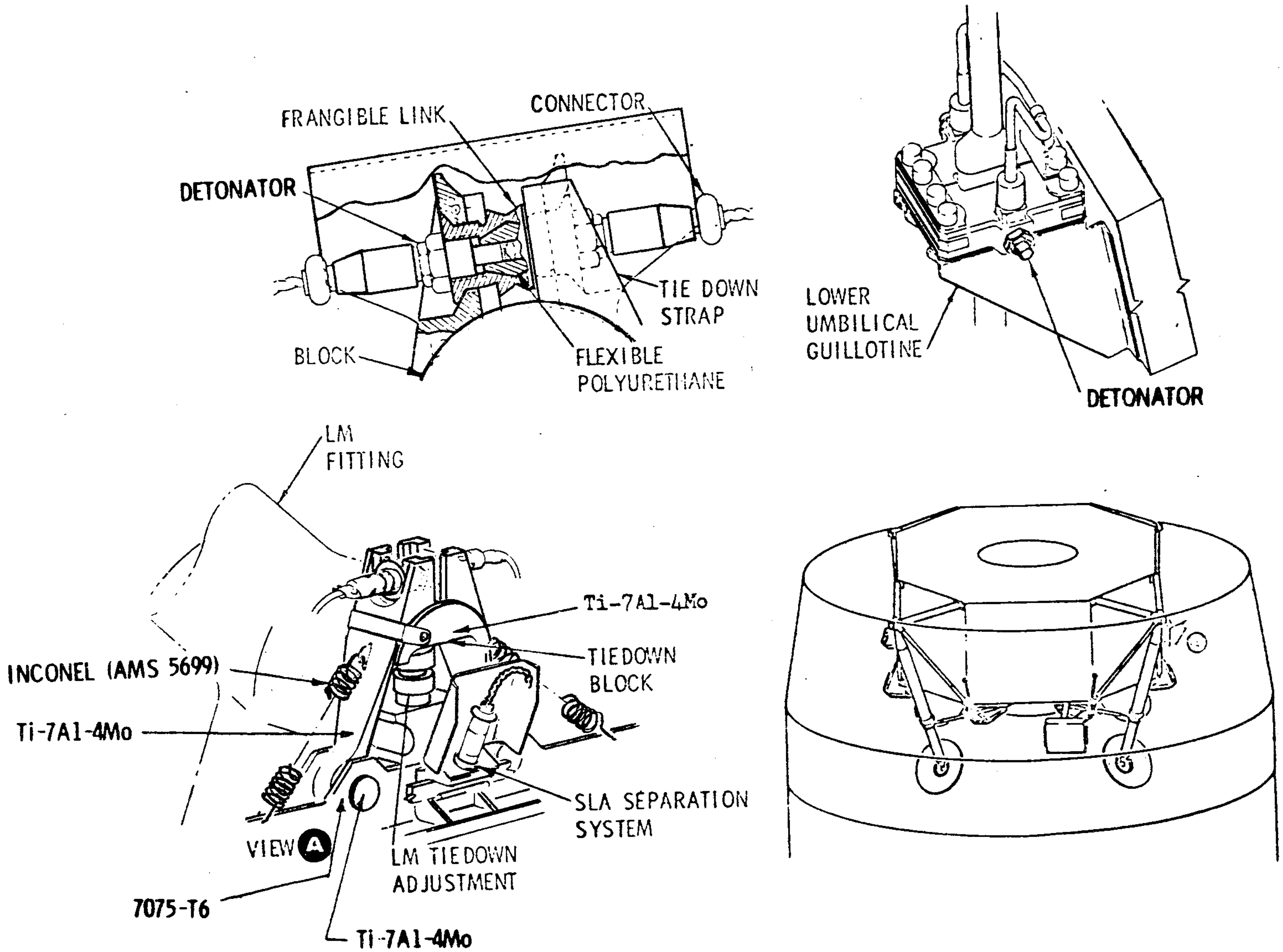

Figure 10-37 TYPICAL MATERIAL USAGE

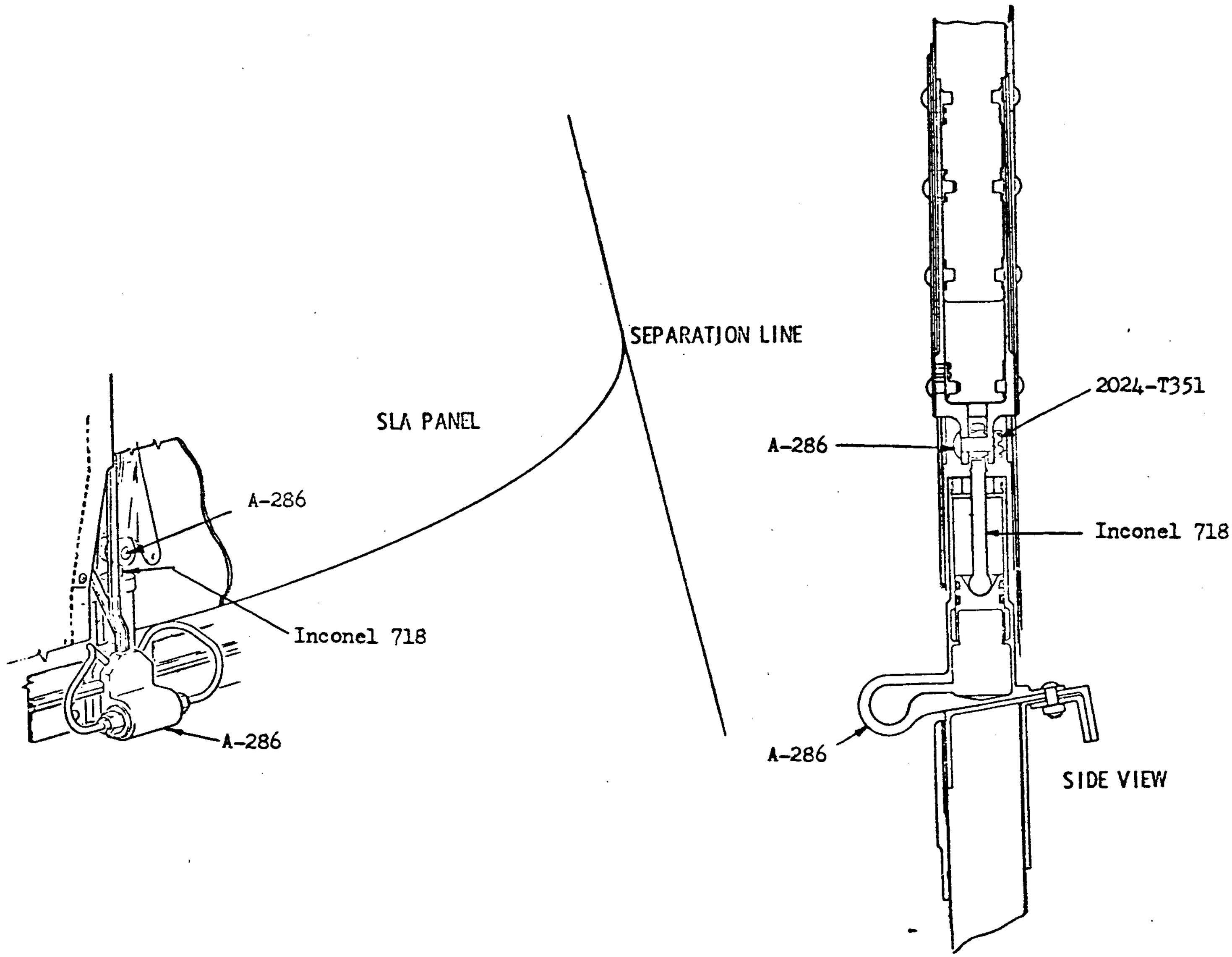

Figure 10-38 TYPICAL MATERIAL USAGE

10.10.2 Continued

Processing anomalies which have been identified on SLA-11 resulted in many flaws which were detected by nondestructive testing (NDT) techniques and subsequently repaired. The reliability of these repairs is assured primarily by process control.

The design of SLA-5 did not provide venting for relief of pressure due to water released during curing of the adhesive. The effect of this deficiency is particularly noticeable in large areas of metal-to-metal bondments, as indicated by the extensive repairs required for doubler and splice-to-face sheet bondments. Although NDT inspection will detect all unbonded areas, it will not verify bond strength. Processing anomalies which result in unbonded areas may also be expected to result in undetectable weak bonds. According to NR drawings, SLA-9 had venting holes for relief of pressure during the bonding process; forward panels 1 and 3 had core and doubler venting whereas forward panels 2 and 4 only had venting of stiffeners to the core at the LM attach point. Panel 1 was associated with the AS-502 anomaly. SLA-11 and SLA-9 have the same provision for relief of pressure during bonding.

A 12-man team headed by Mr. J. T. Doke evaluated SLA-5, 9, and 11, and IU honeycomb processing and inspection techniques at Tulsa. Results are given in Review of Honeycomb Structure, Apollo Spacecraft Adapter (SLA and IU), 9-16-68, J. T. Doke. Processing differences between SLA-5 and later SLA's are identified in regard to doubler venting. Boeing evaluation of SLA drawings showed more extensive venting differences than called out in the 12-man team report. Porta-Pull and Porta-Shear test results from testing at KSC on SLA-5 are given in the report. Although some test values fall below the specification levels, Boeing considers the test results showed adequate strength for the AS-503 mission in regions where test specimens were taken. However, the limited tests conducted do not verify adequate strength of bonding over the total panel surface. Eddysonic inspection also was done at KSC. The side loading of SLA-5 referred to in the report is understood by Boeing to consist of a 6000# load applied just above the CM/LES interface to provide strain gage calibration. Such a test would neither damage nor verify the SLA structure.

Vent holes were added to the inner face skins of SLA-5 and SLA-11 to reduce honeycomb internal pressure during boost. The effectiveness of these vent holes to reduce inflight pressures is still being evaluated by MSC at this time. The latest data from this evaluation shows maximum internal pressure of 16 to 20 psi.

10.10.2 Continued

Under C/S No. 5-2962-JB-083, Boeing recommended a SLA proof pressure test for increased confidence in structural integrity. An experimental program, conducted at Boeing-Kent facilities, established feasibility for such a test. In that program, failure of two SLA-2 panels occurred at 50 and 60 psig internal pressure. It was recommended that further development of the technique be carried out on a full scale SLA quarter panel.

NR-Tulsa performed a structural test which combined axial loads, internal pressure, and elevated temperature. A 12 x 12-inch flat panel simulating a SLA honeycomb panel was prepared. The panel was tested without failure with the outer face sheet at 275°F, honeycomb internal pressures of 15, 40, and 100 psig, and an axial load of 700 pounds/inch. The axial load was increased to 1500 pounds/inch and the panel was pressurized to 40 psig without failure. When the panel pressure was increased to 100 psi the RTV silicone rubber edge seal failed. Materials and processing used in fabrication of the test panel are unknown as of October 8, 1968.

In the case of the SLA, a check of several of the quarter panel drawing callouts indicates that only the foam paste is to be used for core-to-closeout and core-to-edge member bonding. The foam paste ashesive is used also for core-to-core splicing per MA 0606-012 because of the low density core material. Core-to-face sheet bonds where little or no pressure can be obtained during cure require the use of the adhesive foam paste.

The bonding specification, MA 0606-012, includes a listing of applicable documents and mateterials, general requirements, detail requirements, and quality assurance provisions. The general requirements cover solution control, pre-bond surface preparation, storage and handling (including storage temperature and time for adhesives), fabrication of details (including treatment of damaged cores) and bonding equipment verification.

The detail requirements cover pre-fit of details, primer application, honeycomb core splicing, adhesive selection, application of adhesives, and pressure application and curing. SLA quarter panel drawings call for priming detail parts. The primer per MA 0606-012 is thinned American Cyanamid vinyl-phenolic liquid adhesive FM 47 which is air dried after spraying and cured for one hour at 220-245°F. The amount of foam paste used for splicing or edge member bonding is specified in MA 0606-012 by weight for different core thicknesses.

In the pre-fit of details, core fit is checked at splices,

10.10.2 Continued

inserts, and edge members. A slight interference fit is required except at inserts where a maximum clearance of 0.25 inches is permitted. When the core details are installed in the assembly, visible gaps at core splices and edge member bonds (with the exception of inserts) should not exceed 0.375 inch when measured. Under Quality Assurance, X-ray Inspection, the splice and core-to-edge member bond widths are required to be measured after bonding. The maximum permitted widths are specified as a function of core density, the higher the core density the less the permitted gap. In honeycomb bonding, the minimum positive pressure is 15 psi, the maximum 60 psi, or not more than 50 percent of the core flatwise compressive strength. If vacuum is used, the vacuum cannot be increased beyond one to five inches of mercury until the temperature has been at 260°F, or above, for at least 30 minutes. Curing conditions are one hour at 340°F, or three hours at 290°F, the temperature increase being programmed. The bondline thickness for the adhesive tape (MB 0120-048) is generally limited to 0.012 inch. Bond strength requirements at this thickness level using 3/16-inch cell size x .002 or .003 inch thick perforated core are lap shear strength of 2500 psi, average, and 2250 psi, minimum, and honeycomb peel of 6 in-lb/inch average, and 5.4 in-lb/inch minimum.

Finishes

Except as noted on individual drawings, the finishes are controlled by drawing V14-000024, "Finish Specification Apollo Spacecraft." For corrosion control of aluminum alloys during storage, manufacturing, and assembly, the controlling specification is MA 0609-002, "Corrosion Control of Apollo CSM Components." All drawings call for finishing the exterior surfaces per MA 0109-003, "Application of Chemical Films to Aluminum and Aluminum Alloys" (or MIL-C-5541). The chemical films are Iridite 14-2 or Alodine 1200 S chromate conversion coatings, preferably applied by immersion or spraying rather than by manual application (per V14-000024). Sample panels are required to meet salt spray test requirements. An overcoat of clear epoxy is not required; however, it is noted that a 7075-T6 extruded forward-to-aft section splice requires the chromate conversion coating plus the epoxy per V14-000024, item 1-145.

The quarter panel drawing calls for most of the interior surfaces to be finished per MA 0109-801, "Application of Low Emissivity Chemical Film Coatings to Aluminum and Aluminum Alloys." To obtain a total emittance of less than 0.10, the aluminum is first subjected to a controlled polish followed by a sprayed Alodine 1200S conversion coating.

10.10.2 Continued

Other finish callouts on the drawing require that all drilled holes be chemically film treated per V14-000024, item 1-97 (actually MA 0109-003), omitting a specified clear epoxy coating. Also, all fasteners are required to be primed per V14-000024, item 2-5, after installation.

Insulation

As was previously noted, the exterior surfaces of the SLA are coated with 0.030 to 0.050 inch of cork ablative insulation. The cork is specified as MB 0130-020, "Resin Bonded Cork Insulation," Type I, which is 16-50 mesh ground cork in a thermosetting modified phenolic resin. The density is 30 lb/cu ft. The cork is bonded on the quarter panels with epoxy adhesive MB 0120-008 per MA 0106-027. The adhesive qualified to MB 0120-008, "Adhesive Room Temperature Curing, for Use From -250 to 500°F," is Epon 934.

Long time usage is only to 300°F, however. To prevent weather aging of the bonded cork sheets, they are coated with MB 0125-011, "Protective Coating, Ozone-and Weather-Resistant" per MA 0108-016. The coating is a chlorosulfonated polyethylene polymer, W. P. Fuller 150W-8. The process specification, MA 0108-016, "Application of Ozone-and Weather-Resistant Coating," requires a check for thickness (0.002-inch minimum) and adhesion (pull-off test using PPP-T-60, Type II, Class 1 tape).

Allowables

The allowables used for the SLA come from the following sources: MIL-HDBK-5, North American Rockwell (NR) Structures Manual; and NR Materials and Processes Bulletins 16, 44, 45, 46, 48, and 49.

10.10.3 SLA Quality Assurance

Quality Assurance provisions of MA 0606-012 cover process control, adhesive validation including a 0.375-inch wide core splice for a foam filling check, process verification (test coupons when required by Quality Assurance), visual inspection, non-destructive inspection (per MQ 0501-008), sonic inspection, X-ray inspection, bondline thickness, visual inspection of solid surface bonds for edge or corner defects, and maintenance of records. Adhesive film variation coupon (MB 0120-048) tests are required to show the following average and minimum strengths: honeycomb peel 7.0 and 6.3 in-lb/in. and honeycomb tensile 725 and 650 psi. Voids are determined by ultrasonic inspection. Critical assemblies (mission failure) are 100 percent inspected. Any voids in

10.10.3 Continued

metal-to-metal bonds are cause for part rejection as are voids larger than a nominal cell size in core-to-face sheet bonds where the core density is greater than three lbs/cu. ft. Where the density of the core is less, a part with a void containable in a rectangle 1.25 x 0.25 in. is acceptable providing the void is at least five inches from any other void. The specification provides that panels subjected to the entrance of water during ultrasonic inspection as determined by Quality Assurance must be dried for six hours at 230 ± 10°F in circulating air or for three hours at 230 ± 10°F in vacuum, the minimum heat up time being 45 minutes.

SLA quarter panel drawings for model numbers 7, 7A, 8, 9, 10, 11, etc., call for Hobott or Porta-Pull testing of core-to-face sheet adhesive bonds. Drawings for model numbers 1, 2, 3, 4, and 6 do not. The controlling specification is MQ 0501-801, "Production Quality Verification (PQV) Testing for the Spacecraft LM Adapter and Block II Service Module Primary Structure, Core-to-Metal Adhesive Bonds." In brief, the test consists of bonding a 1.116-inch diameter test lug to the face sheet, cutting the face sheet around the lug with a hole saw, and pulling the test lug until a tensile failure occurs in the honeycomb core or the adhesive bond between core and face sheet. After the test, the hole is repaired per the specification, essentially with filler and a doubler. Minimum pull-off values are specified. For the 1/4-inch cell x 0.001-inch wall, the minimum pull-off value is 400 psi tensile stress. One Porta-Pull test is required per quarter panel, the test being taken near the center of the panel.

10.11 SLA SHELL

10.11.1 Design Adequacy Review

NR defined the critical point in the shell as the outer face sheet at X_A=555 (face sheet wrinkling). This element was selected due to the reports of structural failure during the 502 anomaly.

JSAT analysis indicates the SLA shell is slightly more critical just below the X_A=709.9 splice in the inner face sheet (intercellular dimpling). The data comparison is shown in Figure 10-39.

This element is adequate for the AS-503 loads with an analytical F.S.=1.93. The SLA-2 test demonstrated a F.S.= 1.64, and the SSST demonstrated a F.S.=1.43.

ITEM OF COMPARISON	CONTRACTOR	JSAT
ENVIRONMENT	(Sta. 555) 211° F. outer 136 ° F. inner	(Below 709.9 splice) R.T.
LOADS (LIMIT)	End Boost N_c = 615 #/in (Without peaking)	Max q $\propto$ N_c = 754 #/in (Without peaking)
MOMENT - (IN-LBS)	3.626 x 10^6	11.308 x 10^6
AXIAL LOAD - (LBS)	-406,580	-221,740
ALLOWABLE (ULT.)	F_{cw} = 49,700 $F_{cw} = .430 \sqrt[3]{E_f E_c' G_c'}$	F_{cr} = 49,660 $F_{cr} = .0077\ E_F$ (Intercellular dimpling is critical)
ASSUMPTIONS		
MINIMUM FACTOR OF SAFETY	1.98 (Analysis) 1.91 (Test)	F.S. = 1.93 (Analysis) F.S. = 1.64 (Test)
FAILURE MODE	Outer face sheet wrinkling (analysis); no failure of SLA-2 test article in this area.	Inner face sheet intercellular buckling (analysis); no failure in this area in SLA-2 test article.

FIGURE 10-39 SELECTED ELEMENT REVIEW DATA COMPARISON - SLA SHELL

10.12 X_A=709.9 SPLICE

10.12.1 Design Adequacy Review

This element was selected due to the single critical load path nature of the joint. NR found the outer skin inner doubler critical neglecting the outer doubler entirely (conservative).

The JSAT analysis includes the outer skin outer splice plate and finds the joint better than the basic shell. Thus, the critical point shifts to the shell inner skin below the joint. The effects of this change are shown in Figure 10-40.

This element is adequate for the AS-503 loads with an analytical F.S.=1.93. The SLA-2 test demonstrated a F.S.=1.64, and the SSST demonstrated a F.S.=1.43.

ITEM OF COMPARISON	CONTRACTOR	JSAT
ENVIRONMENT	(Critical in splice) 164° F.	(Critical below 709.9 splice) R.T.
LOADS (LIMIT)	End Boost N_c = 627 #/in (Without peaking)	Max $q\alpha$ N_c = 754 #/in (Without peaking)
MOMENT (IN-LBS)	2.996×10^6	11.308×10^6
AXIAL LOAD (LBS)	-317,130	-221,740
ALLOWABLE	F_c = 53,080 psi	F_c = 49,660 psi
ASSUMPTIONS	Outer skin splice plate not effective.	Inter-cellular dimpling in the inner skin is more critical if both outer skin splice plates are considered effective.
MINIMUM FACTOR OF SAFETY	F.S. = 2.60 (Analysis) F.S. = 1.90 (Test)	F.S. = 1.93 (Analysis) F.S. = 1.64 (Test) Max $q\alpha$
FAILURE MODE	Comp. + bending of outer skin inner splice plate.	Intercellular dimpling of the inner skin (Analysis)

FIGURE 10-40 SELECTED ELEMENT REVIEW DATA COMPARISON - SLA X_A 709.9 SPLICE

10.13 585 INTERFACE

10.13.1 Design Adequacy Review

The reason for selecting this element is the key importance of this interface to the structural integrity of the SLA. NR shows the inner skin critical above the 3" doubler for Max q α loading.

The JSAT evaluation agrees with the NR choice of critical point. Minor differences change the analytical safety factor slightly as shown in Figure 10-41.

This element is adequate for the AS-503 loads with an analytical F.S.=1.73, the SLA-2 test demonstrated a F.S.= 1.68, and the SSST demonstrated a F.S.=1.45.

ITEM OF COMPARISON	CONTRACTOR	JSAT
ENVIRONMENT	R.T. Max $q\alpha$	Same
LOADS (LIMIT)	N_c = 687 #/in (without peaking)	↕
MOMENT - (IN-LBS)	15.48×10^6	↕
AXIAL FORCE - (LBS)	-234,450	↕
ALLOWABLE	F_{TU} = 52,900 psi	Same
ASSUMPTIONS		
MINIMUM FACTOR OF SAFETY	1.89 (Analysis) 1.68 (SLA-2 Test)	1.73 (Analysis) 1.68 (SLA-2 Test)
FAILURE MODE	Inner face sheet wrinkling at edge of doubler (Analysis); no failure in this area in SLA-2 Test.	Same

FIGURE 10-41 SELECTED ELEMENT REVIEW DATA COMPARISON - SLA X_A 585 INTERFACE

10.14 SLA/LM INTERFACE

10.14.1 Design Adequacy Review

Based on the analysis of the SLA/LM interface, the lug of the tie down strap appears to be the most critical element. The word "appears" must be used here as NR's SD 67-1103 report on this interface was not available. This conclusion is based on the loads in the SD 67-1103 report, the Block II analysis on this interface, and the V34-590XXX hardware geometry. NR has specified in an informal memo that Separation Condition 23251 is the critical load condition. However, based upon the load information in SD 67-1103, the Max $q\alpha$ condition 21253 appears to be the critical load condition.

Adequacy of element was demonstrated by test results in TR 322055. Although the test agency report has not yet been distributed, advance information indicates a F.S. of 2.19. Thus, the element is not of concern. See Figure 10-42.

ITEM OF COMPARISON	CONTRACTOR	JSAT
ENVIRONMENT	Ambient	Ambient
LOADS	LM attach point loads will not be available.	LM attach point loads will not be available.
ALLOWABLE	Not available	27 Kips Ult. load in strap leg.
ASSUMPTIONS		
MINIMUM FACTOR OF SAFETY	>1.59 (Analysis) >2.19 (Test)	>1.35 (Analysis) >2.19 (Test)
FAILURE MODE (TEST)	Frangible link of strap broke	Frangible link of strap broke.

FIGURE 10-42 SELECTED ELEMENT REVIEW DATA COMPARISON - SLA/LM INTERFACE

10.15 X_A=502 INTERFACE

10.15.1 Design Adequacy Review

This element was picked due to the single critical path nature of this element, and the reported structural failure during the AS-502 anomaly.

NR shows the outer face sheet compressive critical at X_A= 505.4. This is based on an assumed effective width of ring section of $30t_u$ for the tensile check of the X_A=502 ring. JSAT analysis finds the ring critical for local bending under tensile loads, using an effective width of 1" on a peak moment. A comparison of contractor and JSAT data is shown in Figure 10-43.

This element is adequate for the AS-503 loads with an analytic F.S.=1.76. The SLA-2 test demonstrated a F.S.= 1.41, and the SSST demonstrated a F.S.=.42.

ITEM OF COMPARISON	CONTRACTOR	JSAT
ENVIRONMENT	O/S - 173° F. I/S - 153° F.	156° F.
LOADS (LIMIT)	End Boost N_c = 581 #/in (Without peaking)	Separation NT = 163 #/in (Without peaking)
MOMENT - (IN-LBS)	3.864×10^6	7.20×10^6
AXIAL LOAD - (LBS)	-409,590	-40,000
ALLOWABLE	F_{cw} = 51,050 psi	F_{BU} = 99,200 psi Use plastic bending.
MINIMUM FACTOR OF SAFETY	2.32 (Analysis) 2.13 (SLA-2 Test)	1.76 (Analysis) Not tested in tension bending in transverse plane of SLA.
FAILURE MODE	Inner face sheet wrinkling.	

FIGURE 10-43 SELECTED ELEMENT REVIEW DATA COMPARISON - SLA X_A 502 RING

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SECTION 11

CONCLUSIONS

11.0 AS-503 S/V

The following conclusions resulted from the detailed review and assessment of the twenty-three (23) AS-503 Space Vehicle selected structural elements:

- On-site reviews and examination of documentation provided a high level of confidence in the contractors manufacturing and quality assurance procedures. Good traceability of records was noted.
- All discrepancies resulting in MRB action were dispositioned satisfactorily.
- No known stress corrosion problems remain in AS-503 primary structures other than as an acceptable risk.
- The primary structure of AS-503 has no open items associated with hydrogen embrittlement.
- Fracture mechanics analyses, including proof pressure testing, and NDT inspection verified the adequacy of pressure vessels to perform their required missions.
- Honeycomb structures employed in the AS-503 S/V are considered to be adequate to perform their intended mission in their present configuration.
- Adequate assurance was provided that the structural integrity of the selected elements is consistent with the AS-503 design objectives.

SECTION 12

RECOMMENDATIONS

12.0 AS-503 S/V

Any damage, repair, or modification made to these elements between the time of this review and launch time should be reported immediately to the JSAT chairman at MSFC.

APPENDIX A

AS-503 MRB ACTION ASSESSMENT

FOR THE

AS-BUILT L/V STRUCTURAL CAPABILITY

GENERAL

A total of 1336 MRB actions pertaining to the Launch Vehicle were reviewed and evaluated by Materials Engineering personnel. Of this number, 79 are considered significant for the final assessment of the "as-built" structural capability of the AS-503 Launch Vehicle. These MRB's are detailed in tables and stage sections within the body of this report.

Generally, weld discrepancies were the most prevalent. For this reason, weld maps have been included in this report to allow an evaluation of possible cumulative effects.

The Materials Engineering Group concludes that these 79 MRB actions require a stress review and evaluation to ascertain their individual or cumulative effect on the structural integrity of the AS-503 L/V.

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LIST OF ABBREVIATIONS

Abbreviations	Meanings
ABCL	As-Built Configuration List (MDC)
B/P	Blueprint (MDC)
CL	Centerline
CNC	Contract nonconformance (NR)
C/T	Common to (TBC)
DPS	Douglas Process Standard (MDC)
ECL	Engineering Configuration List
ECP	Engineering Change Proposals (TBC, NR, MDC)
ED	Edge distance
EM	Edge margin
EO	Engineering order (TBC)
FARR	Failure and Rejection Reports (MDC)
IBM	International Business Machines
IL	Internal Letter (NR)
inbd	Inboard
IU	Instrument Unit (IBM)
LH_2	Liquid Hydrogen
LOX	Liquid Oxygen
L/V	Launch Vehicle
MDC	McDonnell-Douglas Corporation
MRB	Material Review Board
MRD	Material Review Disposition (NR)
NR	North American Rockwell Corp.
NTL	Net Trim Line (NR)
outbd	Outboard

LIST OF ABBREVIATIONS (CONT'D)

PA	Plan of Action (NR)
psia	Pounds per square inch absolute
psig	Pounds per square inch gage
QEC	Quality Engineering Charts
S/B	Should be (MDC, NR)
S/C	Scope Change (MDC)
SED	Short edge distance (MDC)
TBC	The Boeing Company
TD	Technical Directive
UER	Unplanned Event Record (TBC)
VCL	Vehicle Checkout Laboratory (MDC)
WRO	Work Release Order

The company using the abbreviation is parenthetically shown after the meaning of the abbreviation. When the abbreviation is common to all the companies, no parenthetical identification is shown.

1.0 INTRODUCTION

The task of reviewing and evaluating MRB action taken on the AS-503 Launch Vehicle was performed in accordance with the "Technical Approach Plan for AS-503 Structural Integrity Assessment" under contract NAS8-5608, Schedule IV, Exhibit "A", Part IV, Task 1.0.

Criteria employed in this review was based on the assessment of corrective action taken on reported discrepancies as applied to the design configuration. Review considerations included:

1. Repair adequacy
2. Physical properties of repair materials
3. Compatibility of repair material with existing structure material
4. Possible change in load path or stress distribution
5. Possible effect of discrepancies or repairs on thermal gradients
6. Possible change in margin of safety due to repairs

2.0 SUMMARY OF MATERIAL REVIEW BOARD ACTIONS ON THE AS-503 LAUNCH VEHICLE

The structural capability of the AS-503 Launch Vehicle as-built configuration was established by evaluating the effect of MR actions against each stage and/or element and then applying the cumulative effect to the vehicle.

The as-built configuration for each stage was established by a total assessment of the MR actions, modifying the "as designed" stage, and determining the whole effect on the stage.

A similar procedure was followed for selected elements of each stage.

A total of 4348 MR actions were reviewed on this task. 1336 actions were identified as structural and of these, 79 were considered significant, and referred to stress for analysis. A summary of MR's for each stage is presented.

Stage	Total	Structural	Significant
S-IC	1870	686	48
S-II	1951	532	18
S-IVB	495	114	12
IU	32	4	1
	4348	1336	79

The cumulative effect of the actions was first visually established by preparing maps showing locations of significant MR's and "possible contributing" MR's.

A structural assessment was recommended when the number and/or pattern of MR's warranted this action.

Final analysis by the stress group will provide the structural capability of the L/V.

2.1 SUMMARY OF UNPLANNED EVENT RECORD (UER) DISPOSITIONS FOR THE S-IC-3

2.1.1 General

The "as-built" configuration of the S-IC-3 stage has been established for the AS-503 Structural Assessment Program by applying an evaluation of the significant UER's to the "as designed" stage.

The specific elements assessed included the stage assembly, the forward skirt, the LOX tank, the intertank, the fuel tank, the thrust structure, the fins, and the engine fairings.

Six hundred and eight-six (686) UER's on primary structure were reviewed of which 48 were considered significant for further analysis by the stress group. A summary of Significant UER's is presented in Table 2-1.I.

Sketches showing location of these UER's are presented as figures 2.1-II through 2.1-V.

2.1.2 Conclusions

Of the 48 significant MR's recommended for stress analysis, 30 (62%) resulted from misplaced or out-of-tolerance holes, 6(12.5%) actions resulted from weld porosity, pitting or mismatch, and the remainder from miscellaneous causes. Although the extent of damage described in these MR's could be considered of minor significance, there is insufficient evidence to support an unqualified approval without a stress analysis. Completion of the stress analysis of the significant MR's will establish the structural capability of this stage.

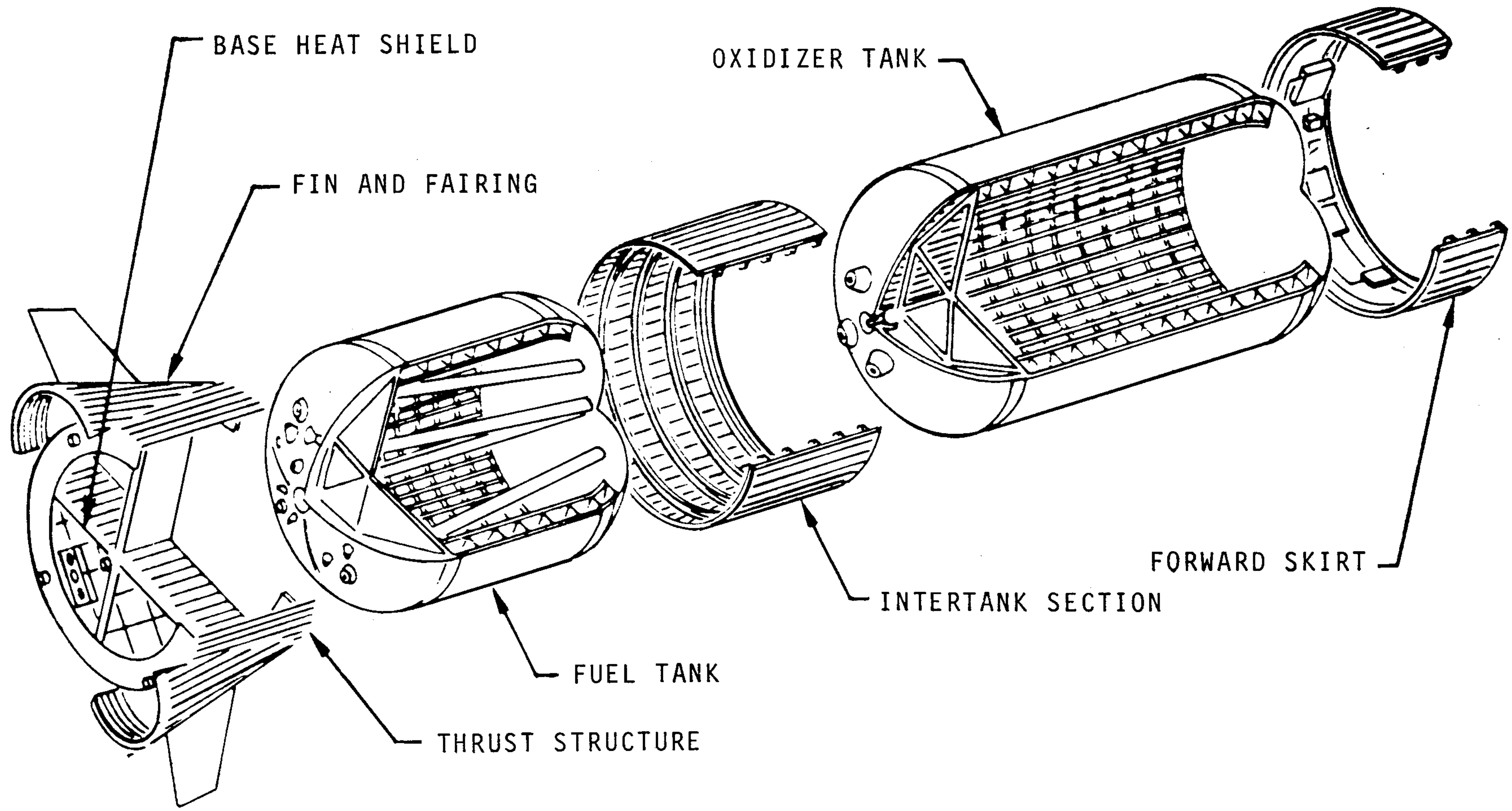


FIGURE 2.1-I STAGE ASSEMBLY, S-IC-3

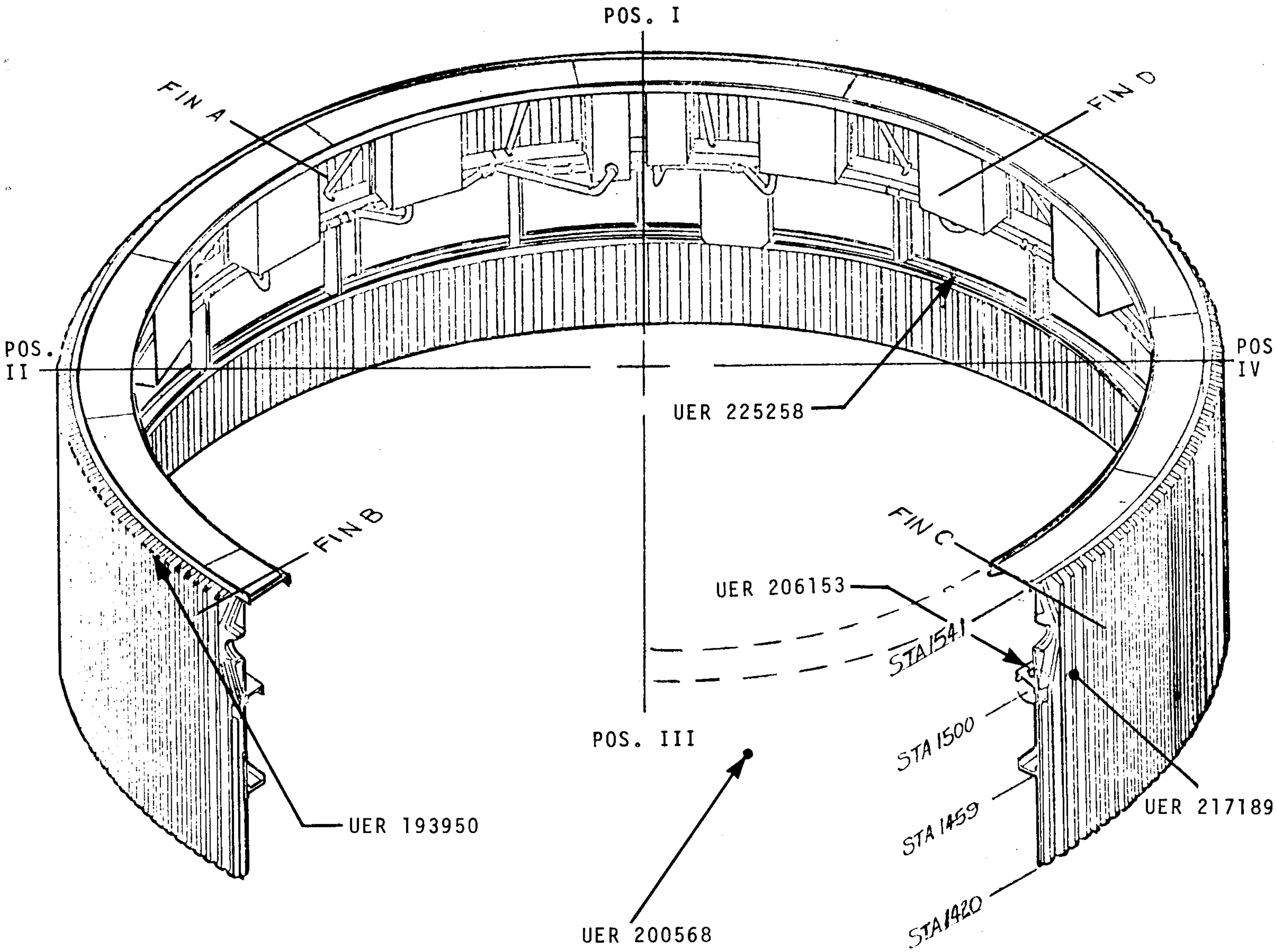


FIGURE 2.1-II UER MAP, FORWARD SKIRT, S-IC-3

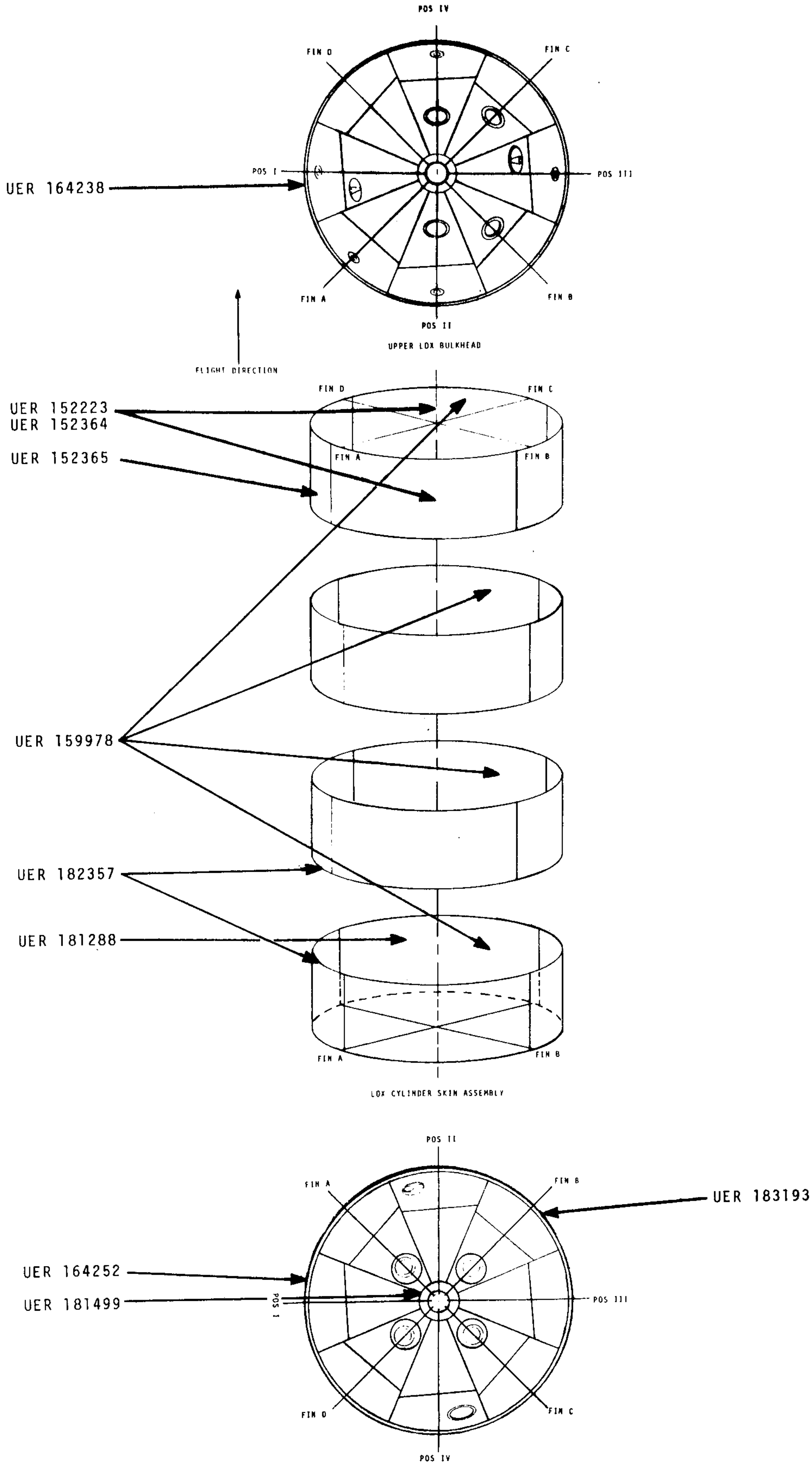


FIGURE 2.1-III UER MAP, LOX TANK, S-IC-3

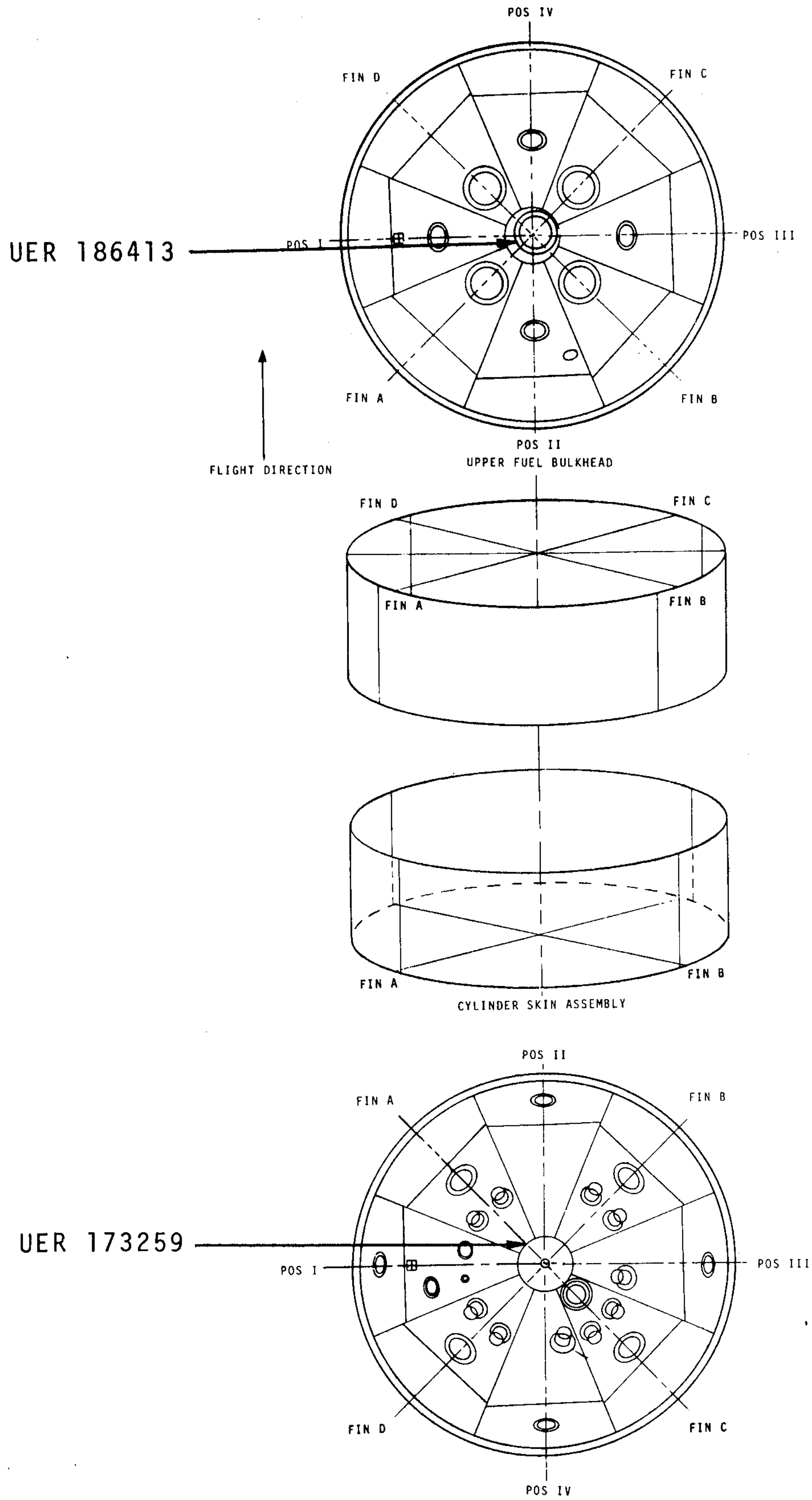
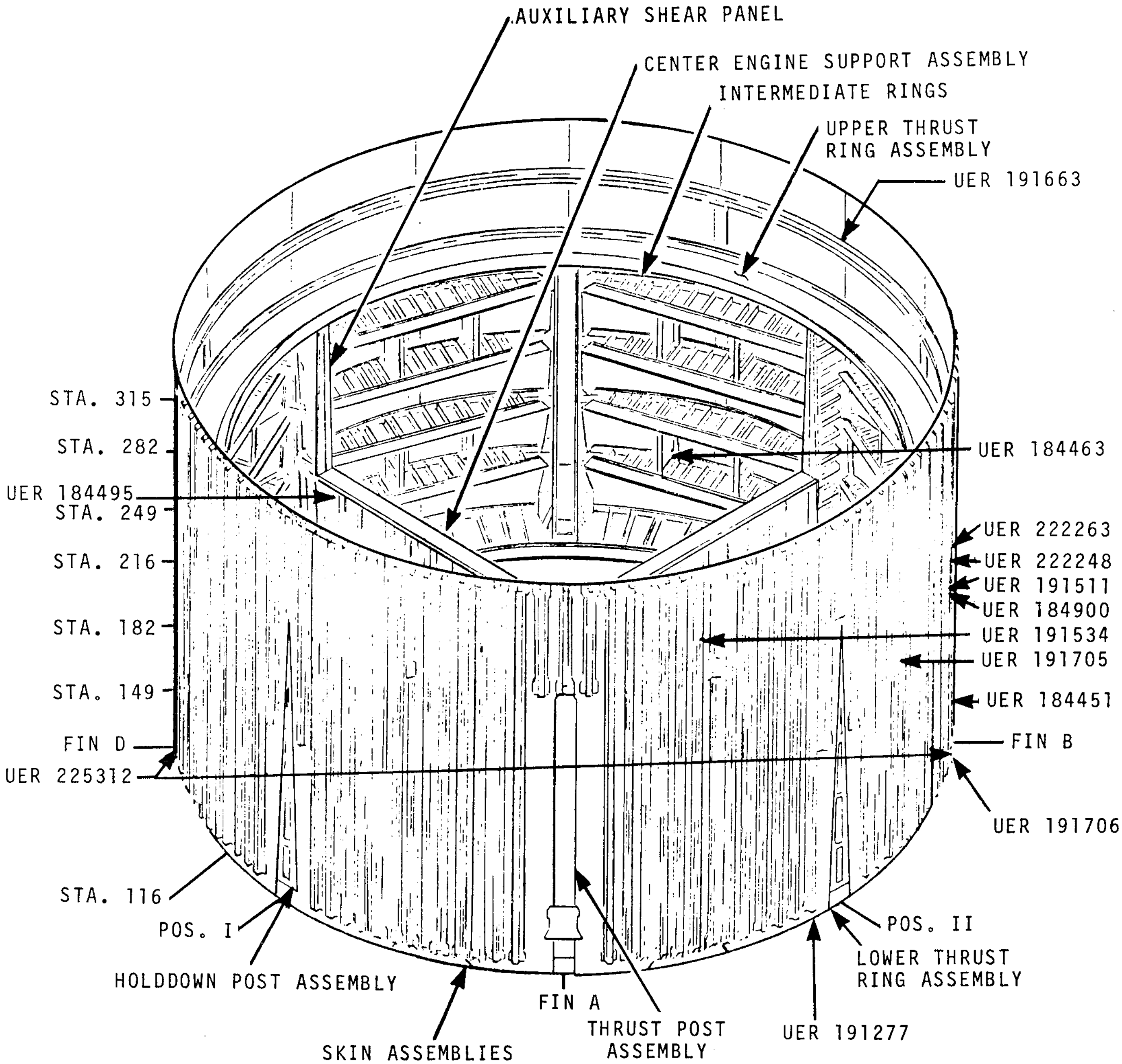


FIGURE 2.1-IV UER MAP, RP-1 FUEL TANK, S-IC-3



THE FOLLOWING UER'S WERE NOT LOCATED:

191574, 157286, 253473, 188987,
188988, 191662, 189332, 188978
155884, 170234

FIGURE 2.1-V UER MAP, THRUST STRUCTURE, S-IC-3

TABLE 2.1-I SUMMARY OF SIGNIFICANT MRB'S S-IC-3

STAGE: S-IC EFFECTIVITY AS-503 COMPONENT: FORWARD SKIRT

Element	MRB Number	Dwg/Part Number	Requirement	Deviation/Disposition	Reason for Concern
FORWARD SKIRT	UER193950	60B14200	Fasteners should be located as shown on the drawing.	1. One .190/.194 hole in a hat stiffener has a short edge margin. Disposition - plugged stiffener, skin and doubler separately.	Plugged hole could cause stress concentration.
				2. One .190/.198 hole in the 60-B14410-1 skin is elongated to .300. (For fastener common to hat stiffener). Disposition - Enlarged elongated hole to .375 and plugged.	
	217189	60B14800	.750 dia hole should be on Pos. 3 side of press tunnel C/L.	1. One .750 $^{+.02}_{-.00}$ hole mislocated to wrong side of C/L of press tunnel. Disposition - plugged hole with BMS5-62 sealant.	Doubler is a deviation from baseline. Possible load redistribution.
				2. A new hole has been drilled, mislocated 0.20. Disposition - installed doubler and located hole per drawing in doubler, leaving slotted hole in skirt.	
			E.O. 16 calls for removal of NAS1303-4H and NAS679A3W fasteners.	3. One NAS1303-4H Fastener has been located between two hat sections and is mislocated 1.06. Disposition - Use as is.	

TABLE 2.1-I SUMMARY OF SIGNIFICANT MRB'S S-IC-3

STAGE: S-IC-3 EFFECTIVITY: AS-503 COMPONENT: FORWARD SKIRT

Element	MRB Number	Dwg/Part Number	Requirement	Deviation/Disposition	Reason for Concern
FORWARD SKIRT	206153	60B14064	60B15863-1 tee should be attached to 60B14065-1 channel and ring.	The 60B15863-1 tee is attached to the 60B14065-2 channel. Disposition - Use as is.	This disposition changes the relative positions of the channel beam and intercostal, where they are no longer both attached to the ring with the same fasteners.
			60B15864-1 Clip should be attached to 60B14065-2 channel.	The 60B15864-1 clip is attached to the 60B14065-1 channel. Disposition - Use as is.	
			60B15833-1 intercostal should pick up existing holes in the 60B15863-1 angle.	Attach the 60B15833-1 intercostal to the channel ring with a new set of fasteners .	
	225258	60B14009	0.75 dia hole should be at 322° 30' at sta. 1500 only.	Extra hole was drilled at 322° 30' at station 1459. Disposition - Hole was plugged with 7075-T6 Material, immersed in LN_2 for insertion.	
	200568	60B14800		One .190/.194 hole drilled thru 60B14840-1 GOX fitting C/T 60B14430-1 doubler and hat stiffener, and 60B14410-1 skin did not clear under GOX fitting. Disposition - Faired in discrepant area	Removal of mat'l could decrease safety margin.

SUMMARY OF SIGNIFICANT MRB'S

STAGE: S-IC EFFECTIVITY: AS-503 COMPONENT: FORWARD SKIRT

Element	MRB (NCR) Number	Dwg/Part Number	Requirement	Deviation/Disposition	Reason For Concern
INTERFACE RING ASSY.	056717	60B15200-1	Countersinking of rivets	Eight holes countersunk on near side. Should have been on far side. Countersunk on far side and double flushed. In-process of doing this, rivet gun slipped, cracking the metal about 2" from edge and 1-1/4" long. Transfered to NCR 056497. Disposition - 3/16 hole drilled at both ends of crack. Bought off by Boeing QC and NASA QC (Telecon R. Pommenville, Cocoa Beach, 11-20-68)	Possible reduction in margin of safety.

TABLE 2.1-I SUMMARY OF SIGNIFICANT MRB'S S-IC-3

STAGE: S-IC EFFECTIVITY: AS-503 COMPONENT: OXIDIZER TANK

Element	MRB Number	Dwg/Part Number	Requirement	Deviation/Disposition	Reason for Concern
RING BAFFLE SEGMENT ASSY.	159978	60B12421-	Inst'l. of segment assembly	Excessive deburr throughout assembly (total of 824,0.190/0.194 and 0.250/0.254 holes). 25% are deburred 0.005/0.015 deep. Most of excessive deburr is on one side causing partial hole elongation. Use as is.	Possible reduction in safety factor.
CYL. SKIN SEC.	152223	60B12310-1A-902	Skin Sec. 4, Pos. II and IV	Manufactured for "F" effectivity and has E.O.'s 201 and 202 incorporated. 503 effectivity should have had E.O.'s 1, 201, 202, 204, and 205 configuration. Use as is.	Change in configuration.
	152364	60B12310-1A-902	Skin Sec. 4, Pos. II and IV	"	"
	152365	60B12316-1A-902	Skin Section 4, Pos. I	Manufactured for "F" effectivity with E.O.'s 201, 202, 203, 205, 1, 2, 3. 503 effectivity should have E.O.'s 201, 202, 203, 205 and 206. Use as is.	"
Y-RING, LWR.	164252	60B12201-1-900	Class II weld	X-ray of the machined Y-ring revealed porosity and gas holes at stations 1 and 3. Use as is.	Possible reduction in safety factor.
BAFFLE INST'L	181288	60B12401-1A-900	Baffle Inst'l.	Drill bit went through tee stiffener and into skin leaving pits .005,.010 and .025 deep & 0.175 in dia. in three locations. Use as is.	"

TABLE 2.1-I SUMMARY OF SIGNIFICANT MRB'S S-IC-3

STAGE: S-IC EFFECTIVITY: AS-503 COMPONENT: OXIDIZER TANK

Element	MRB (UER) Number	Dwg/Part Number	Requirement	Deviation/Disposition	Reason for Concern
Y-RING, UPPER	164238	60B12101-1-900		Thermocouple holes did not clean up on final O.D. cut of Y-ring. Weld #1-two holes 10.000 on either side of weld, 0.100 dia. and 0.200 deep. Weld #2-one hole 10.000 from weld in CW direction, 0.100 dia. and 0.050 deep. Use as is.	Possible reduction in safety factor.
BULKHEAD ASSY., LWR.	183193	60B12200-1B-988	Skin contour and fitting-contour, location and rotation.	The worst condition is at gore-to-gore weld between Fin B and Pos. II. Approx. arc length 20.500 to 30.500 has rate of change exceeding tolerance by 0.508. Use as is.	"
BULKHEAD ASSY., LWR.	181499	60B12200-1B-960	Max. Allowable mismatch 0.030.	Mismatch at polar cap to bulkhead weld of 0.045 at 5.000 and 0.045 at 13.000. From Fin A moving CW. Ok as is.	"
STRUCT. ASSY.	182357	60B12000-3A-947	Matching and weldment of tee stiffeners at juncture of #1 and #2 cyl. skin assys.	Tenth tee stiffener CCW from Pos. I was twisted. Stiffeners were clamped together to eliminate mismatch prior to welding. Use as reworked.	Stresses set up when straightened.
LOWER STRUCT. SUB. ASSY.	186810	60B12000-3A-950	Class III weld	Twelve tee stiffener welds rejected. Ten repaired and accepted Status of remaining two rejected welds unknown.	Reduced margin of safety (Possible)

SUMMARY OF SIGNIFICANT MRB'S

STAGE: S-IC   EFFECTIVITY: AS-503   COMPONENT: INTERTANK

Element	MRB (UER) Number	Dwg/Part Number	Requirement	Deviation/Disposition	Reason For Concern
INTERTANK ASSY.	157989	60B29800-1B-905	0.500 E/M	69 rivets in 5th skin splice between 60B28320 and 60B28380 rings have shy E/M. Disposition - Use as is	Reduction in margin of safety (Possible)

TABLE 2.1-I SUMMARY OF SIGNIFICANT MRB'S S-IC-3

STAGE: S-IC EFFECTIVITY: 503 COMPONENT: FUEL TANK

Element	MRB Number	Dwg/Part Number	Requirement	Deviation/Disposition	Reason for Concern
STRUCT. ASSY., FUEL TANK	186413	60B24000-1A-909	Max. allowable of wall thickness for grinding = 5%	Rework required more than 5% of wall thickness grinding out at 8 locations around tunnel to bulkhead weld.	Reduction of LOX tunnel fitting weld margin of safety
HEAD ASSY., LWR.	173259	60B24200-1C-985	60B32032 Class II	Excessive pitting and corrosion in welds. Reworked. Pitting heavier in previous repair areas. Disposition - Removed pitting by shaving weld bead. Was not shaved below base metal.	Insufficient evidence that all pitting was removed. Possible reduction in margin of safety.

TABLE 2.1-I SUMMARY OF SIGNIFICANT MRB'S S-IC-3

STAGE: S-IC EFFECTIVITY: AS-503 COMPONENT: THRUST STRUCT.

Element	MRB Number	Dwg/Part Number	Requirement	Deviation/Disposition	Reason for Concern
THRUST STRUCT.	191663	60B18054		STA. 315, Pos. III, (8) .375/.379 holes in splice, skin, & J-ring 60B18501-1 are loc. .50 low. Disposition - Plug holes with 7075-T6 special plugs, locate holes per drawing.	Plugged holes near fasteners could reduce strength
	191534	"	E/D = 1.5	Fin A to Pos. II, STA. 280, (4) .469 dia. holes C/T skin panel, intercostal assy. have edge margin of 0.45. Disposition - Use as is.	Reduction in M.S.
	184451	"		STA. 152, Fin B to Pos. III, 6th stringer has (1) .251 hole C/T skin panel & intermediate ring mislocated .50 high, resulting in hole in radius of ring lwr. cap. Disposition - Plugged hole with 7075-T6 & relocate fastener.	Reduction of cross section of intermediate ring cap.
	157286	60B18123-1	.250/.254 holes	Four 1/4 holes C/T 60B18127-1 skin, 60B18130-1 doubler, & 60B18136-1 str. are elongated. Disposition - Two holes were filed, plugged, & redrilled.	Skin discontinuity & stress concentration.
	225312	60B18700	Holes should be at STA. 117.79 Fin B	(2) holes were located at STA. 117.34. Disposition - Installed (2) interference fit 7075-T6 plugs.	Possible stress concentration.

TABLE 2.1-I SUMMARY OF SIGNIFICANT MRB'S S-IC-3

STAGE: S-IC EFFECTIVITY: AS-503n COMPONENT: THRUST STRUCT.

Element	MRB Number	Dwg/Part Number	Requirement	Deviation/Disposition	Reason for Concern
THRUST STRUCT.	191706	60B18054		STA. 116, Fin B, Pos. 2, hole elongated. Disposition - Enlarged hole to 1.00, installed cad. plated 4340 plug.	Skin discontinuity and possible reduction in skin thickness
	191705	60B18054		One 0.256/.265 hole in 60B19302-4 chord is damaged. 2nd hole, 0.256/0.265 hole damaged - cracked. Disposition - 1, 1st hole enlarged and larger rivet installed. 2, Removed cracked area. Replaced by 7075-T6 Al. alloy plug. A .020" steel doubler, 1.00 wide x length from front to back of angle stiffener was fastened to intercoastal by 7 fasteners.	Skin discontinuity and dissimilar metal corrosion.
	184463	"	Ref. Engr. Dwg. 60B18054 Sht. 6 detail DT-DG	STA. 184, Pos. III, two 1/2 dia. holes mislocated .5 C/T 60B191-26-2A outer chord of 60B19103-5 ring and 60B19323-1A gusset, creating E.M. of .150 and .075. Disposition - Installed 1/4 x 4.25 x 7.25 7075-T6 strap, picking up existing HI-LOCS, (8) places. (1/2 dia.)	Strap may cause load redistribution

TABLE 2.1-I SUMMARY OF SIGNIFICANT MRB'S S-IC-3

STAGE: S-IC EFFECTIVITY: AS-503 COMPONENT: AERODYNAMIC FINS

Element	MRB Number	Dwg/Part Number	Requirement	Deviation/Disposition	Reason for Concern
FIN ASSEMBLY	236893	60B30009-1		At tip beam & spar a .199 dia. hole is elongated to .22 UER list states "Use as is"	Reduction in safety factor.
	236955	60B30009-1		8 holes elongated in skin panel. Should be .199 dia. Disposition-Enlarge all holes to .260 dia.	This results in S.E.M. Reduction in safety factor, UER states "Holes are acceptable less installation of fasteners". Quality of assembly questionable.
BEAM ASSY.	236274	60B30217-1-900		Mislocation of 60B30201-1 web in assy. fixture resulted in a .10 misalignment.	Quality of assembly questionable.
FIN ASSEMBLY	236329	60B30005-1	.375 E.M. for the .25 dia. hole .28 E.M. for the .199 Holes	Eight skin to spar fastener holes have S.E.M.-two .250 dia. holes have actual .20 E.M. - six .199 dia. holes have between .20 and .28 E.M.	Reduction in M.S. due to S.E.M.
	236348	60B30005-1		151 hole discrepancies (136 holes are oversize, 7 holes are elongated, 7 holes are mislocated, 1 hole unauthorized)	Shy E/M. Reduced safety factor

TABLE 2.1-I SUMMARY OF SIGNIFICANT MRB'S S-IC-3

STAGE: S-IC EFFECTIVITY: AS-503 COMPONENT: AERODYNAMIC FINS

Element	MRB Number	Dwg/Part Number	Requirement	Deviation/Disposition	Reason for Concern
FIN ASSEMBLY	236235	60B30005-1		Six holes common to T.E. beam drilled oversize. Seven holes between spar & T.E. beam drilled oversize.	Shy E/M. Reduced safety factor.
	236370	60B30005-1		O/B most hole in 60B30114-2 angle close to far side skin is elongated.	Shy E/M. Reduced safety factor
	236324	60B30005-1		Eight holes in 60B30504-1A drilled oversize.	Shy E/M. Reduced safety factor
	264505	60B30008-1	E.O. 501 to be incorp.	Info. on hand (8-8-66) states that hand located holes were splitting edge margin but incorp. of E.O. 501 would increase E.M.	Insufficient E.M. on skin panel.
	236999	60B30008-1		8 holes in skin and L.E. enlarged or mislocated.	Shy E/M. Reduced safety factor Mislocated hole not accepted.

TABLE 2.1-I SUMMARY OF SIGNIFICANT MRB'S S-IC-3

STAGE: S-IC EFFECTIVITY: AS-503 COMPONENT: ENGINE FAIRING

Element	MRB Number	Dwg/Part Number	Requirement	Deviation/Disposition	Reason for Concern
FIN & FAIRING ASSEMBLY	400027	60B16020-1		Six .312 dia. bolt holes in "C" assembly are misaligned & bolts cannot be installed. Disposition - Ream holes to .374 dia. & install 4 NAS659V9 bolts.	Reduction in safety factor.
SEGMENT	181187	60B16153-2A		Machine cutter gouge 1.6 wide x .90 long x .14 deep in segment.	Reduction in safety factor.
ENG. FAIR. ASSY. LWR.	236354	60B16182-1-901		One hole in 60B16656-1, close out beam should be .190 dia. but is .30, double hole condition. Hole enlarged to .315 dia. and oversize fastener installed.	Reduced E.M. - Reduction in safety factor.
	228313	60B16183-1-900		One hole partially drilled through stringer and approx. 0.030 through skin. No edge margin in intercostal. Relocated hole to provide proper edge margin in intercostal. Plugged discrepant hole. One hole has no edge margin in chord. Installed fastener. Located new hole and fastener.	Reduced safety factor. Not clear what action taken.
	236268	60B16183-1-901		One 0.190/0.198 hole elongated to 0.250 and one to 0.245. Enlarged first hole to 0.256/0.265 and second hole to 0.250/0.254 and installed fasteners.	Reduction in safety factor.

TABLE 2.1-I SUMMARY OF SIGNIFICANT MRB'S S-IC-3

STAGE: S-IC EFFECTIVITY: AS-503 COMPONENT: ENGINE FAIRING

Element	MRB Number	Dwg/Part Number	Requirement	Deviation/Disposition	Reason for Concern
ENG. FAIR. ASSY. LWR.	236305	60B16183-1-900		One 0.190/0.194 hole elongated to 0.275. Installed fastener HL-13V-6-X with collars. Mfg. head to cover elongation. Use as reworked.	Reduction in safety factor.
	265547	60B16183-1-902		Twenty-three 0.190/0.194 holes in the air scoop sub assy., are oversize from 0.195 to 0.218. Fifteen holes enlarged to 0.203/0.207. Eight holes enlarged to 0.250/0.254. Use as reworked.	Reduction in safety factor.
ANGLE	213292	60B16313-1		Three dimensions on each of eleven parts are out of tolerance.	Possible reduction in safety factor (insufficient time to determine how these parts mate with others).
FIN & FAIRING	400028	60B16391-1		Six 0.312 holes between fin & fairing assembly D are misaligned and bolts will not fit in holes. Holes reamed to 0.374 & fasteners installed.	Reduction in safety factor
RETRO INSTL.	287526	60B16636-3A		Two holes common to 60B16014 ftg. on fairing assy. have been c'sk. C'sk is not required per dwg. Disposition - Use c'sk. fasteners.	Reduction in safety factor

2.2 SUMMARY OF MATERIAL REVIEW DISPOSITIONS FOR THE S-II-3

2.2.1 General

Five hundred thirty-two (532) Material Review Dispositions (MRD's) were reviewed to identify the "as built" configuration for determining the structural capability of the S-II-3 stage of the AS-503 Launch Vehicle. Of these, eighteen were considered significant. (These are summarized in Table 2.2-I.) Some of these MRD's were included because they did not show completion of repairs, or proof testing of repairs where required. Maps of discrepancies on the common bulkhead, aft LOX dome, and total stage are included, Figures 2.2-I thru 2.2-IV.

2.2.2 Conclusions

Assessment of the total discrepancies disclosed eighteen (18) actions which were considered significant enough to warrant a stress analysis. Although the proof test of the LH_2 tank at -423°F validates the tank (and adequacy of repairs) by a factor of 1.05 (as compared with anticipated flight loads) the analysis will provide additional quality assurance. A stress analysis of the significant discrepancies of the LOX tank is also considered mandatory as this structure was proof tested as subassemblies (aft, LOX and common bulkheads) and not as a complete unit. Integrity of the girth weld has not been established.

Upon completion of these tasks, the structural capability of the S-II-3 stage, as-built configuration will be established.

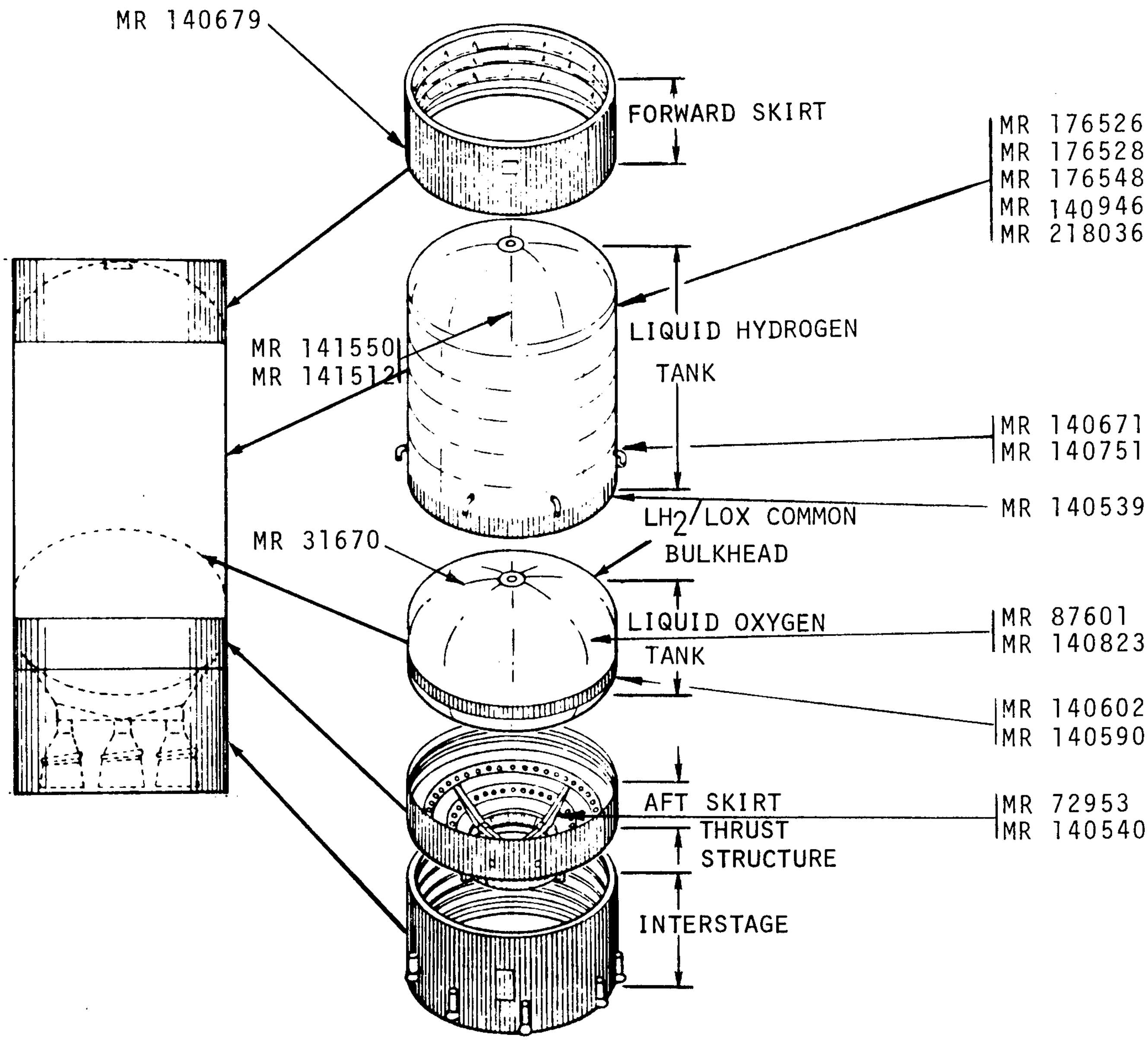
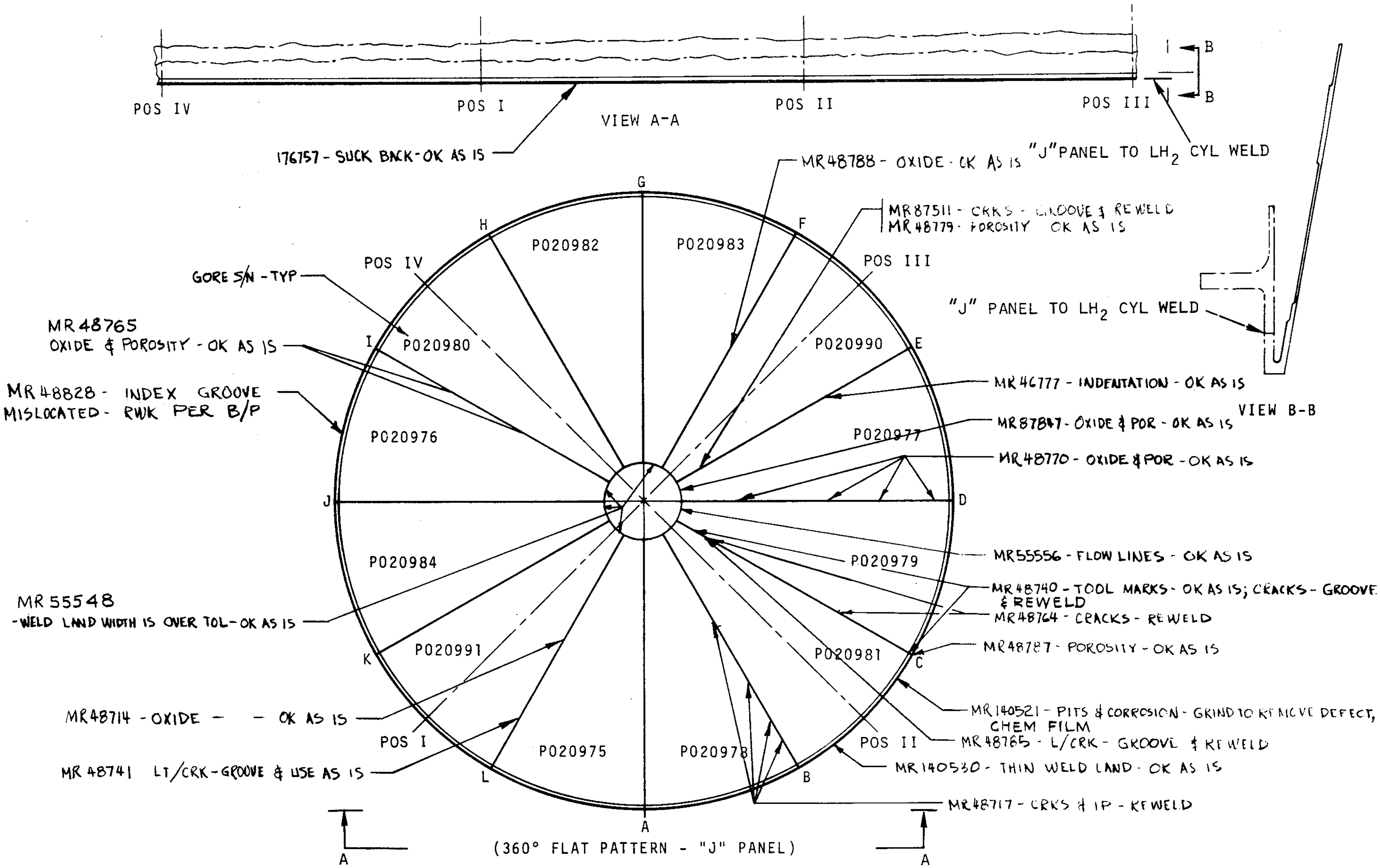


FIGURE 2.2-I MAP OF SIGNIFICANT MRD'S, STAGE ASSEMBLY, S-II-3



NOTE: VIEW LOOKING AFT

FIGURE 2.2-II MRD MAP, COMMON BULKHEAD FWD FACING SHEET & "J" PANEL, S-II-3

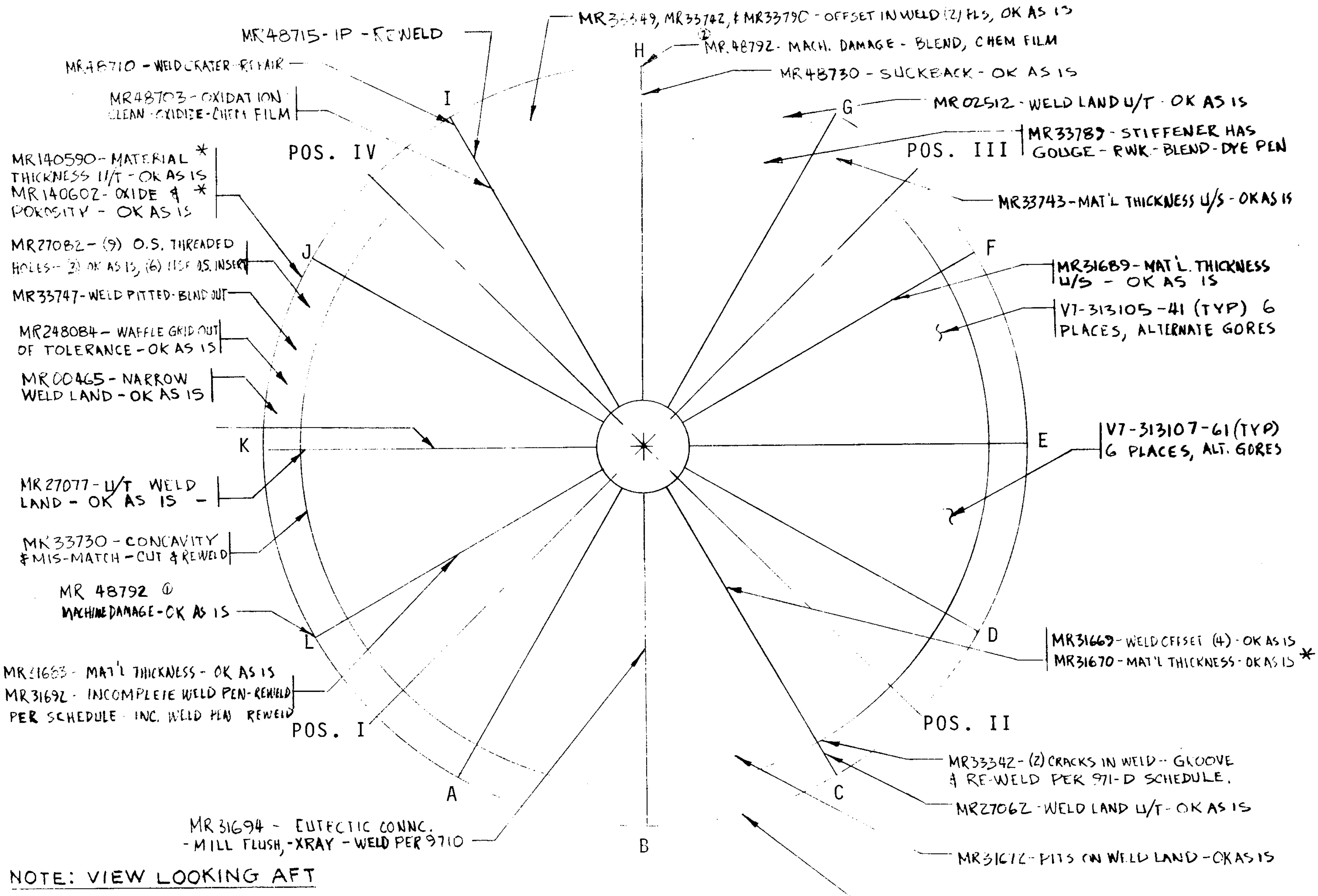


FIGURE 2.2-III MRD MAP, COMMON BULKHEAD AFT

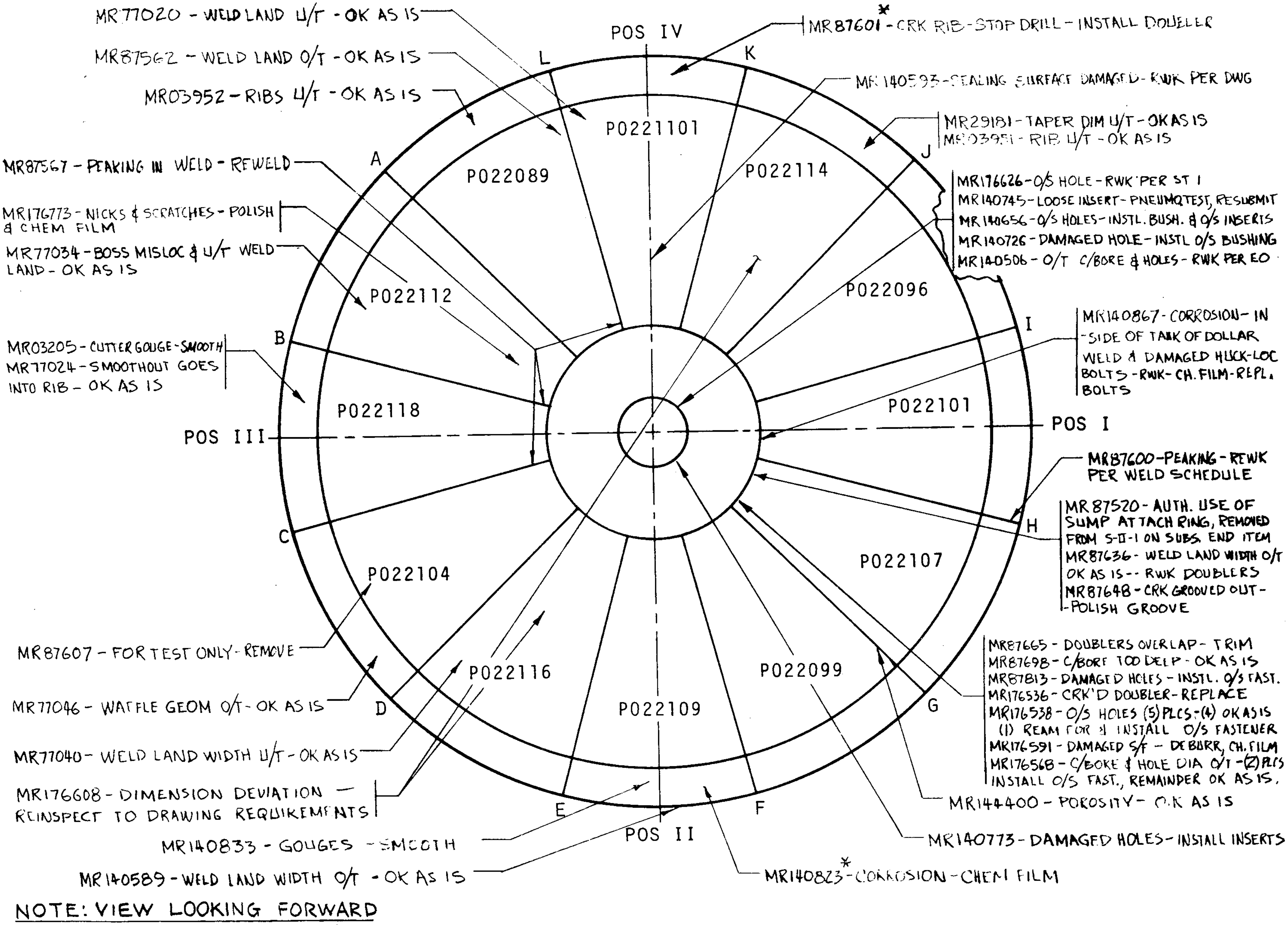


FIGURE 2.2-IV MRD MAP, LOX TANK AFT BULKHEAD, S-II-3

TABLE 2.2-I SUMMARY OF SIGNIFICANT MRB'S S-II-3

STAGE: S-II-3 EFFECTIVITY: AS-503 COMPONENT: FORWARD SKIRT

Element	MRB Number	Dwg/Part Number	Requirement	Deviation/Disposition	Reason for Concern
STRINGER	140679	V7-311002		At STA 848, Stringers 6-13, 20 holes were elongated in the stringers. Disposition - Eight 1/8 x 3/4 x 26-1/2 2024-T3 doublers were installed with (16) extra jo-bolts. Jo-bolt holes in stringers were re-drilled per hole pattern in insulation panel.	Load redistribution

TABLE 2.2-I SUMMARY OF SIGNIFICANT MRB'S S-II-3

STAGE: S-II-3 EFFECTIVITY: AS-503 COMPONENT: LH_2 TANK

Element	MRB Number	Dwg/Part Number	Requirement	Deviation/Disposition	Reason for Concern
FORWARD BULK-HEAD MERIDIAN WELD	141550	V7-312142		Offset in "I" meridian weld. Acceptable as is.	Reduce margin of safety.
	141512	V7-312142	.00196 inch ^{2}	Porosity and oxide, Acceptable as is.	Repetitive type defect.
FORWARD BULK-HEAD CIRCUM-FERENTIAL WELD	176526 176528 176548 140946 218036	V7-312002		Porosity and oxide, under tol-erance weld land, local offset, difference in mating weld 2 and some areas acceptable as is, other reworked.	Defects have an interaction on each other. Re-duce margin of safety.
TANK ASSY.	140671 140751	V7-300001	No cracks	Excessive cracks on stringers & ribs Repair by removing crack-ed areas, adding splices, dou-blers.	Repetitive type defect, load redistribution.
	140539	V7-313002	.045 inch^2 max.	Porosity and oxide, common bulk-head to Cyl. #1, J Section Weld.	Reduces margin of safety.

TABLE 2.2-I SUMMARY OF SIGNIFICANT MRB'S SII-3

STAGE: S-II-3 EFFECTIVITY: AS-503 COMPONENT: LOX TANK

Element	MRB Number	Dwg/Part Number	Requirement	Deviation/Disposition	Reason for Concern
AFT FACING SHEET, COMMON BULKHEAD	140602	V7-313002	.045 inch2 max.	At STA 282, a porosity of .099 exists at the girth weld. Disposition - Use as is.	Unproofed weld, repetitive defect, reduces margin of safety.
	140590	V7-313002	.484 inch min.	STA 282 LOX girth weld land thickness under tolerance. Disposition - Use as is.	Interaction with MR-140602 reduces margin of safety.
	31670	V7-313002	.152 thick	At "C" meridian weld, 54" above trim line, material thickness is under tolerance, measures 0.136 thick. Disposition - Use as is.	Thickness reduction reduces margin of safety.
AFT LOX BHD	87601	V7-313202	No cracks	At Pos. IV Gore, 1.5" crack in waffle rib. Disposition - Install 1/8 x 4 x 7, 2014-T6 doubler to opposite side of bhd.	Stress redistribution.
	140823	V7-30001		Corrosion of waffle surface at gore at Pos. II Disposition - Remove corrosion & protect surface.	Reduces margin of safety.

TABLE 2.2-I SUMMARY OF SIGNIFICANT MRB'S SII-3

STAGE: SII-3 EFFECTIVITY: AS-503 COMPONENT: THRUST STRUCTURE

Element	MRB Number	Dwg/Part Number	Requirement	Deviation/Disposition	Reason for Concern
FIN D, ARM 7 AFT	72953	V7-315367	.5000 ± .0005 dia hole	Two holes oversize through V7-315367-7 Cap. Disposition - Redrill for 9/16" bolt.	Oversize bolts in critical splices.
CENTER ENGINE BEAM	140540	V7-315252	.4375 ± .0005 dia hole	At STA 112, R.H. side of Fin D the L.H. outboard hole in V7-315252 fitting is oversize. Disposition - Redrill for 1/2" bolt.	Oversize bolts in critical splices.

2.3 SUMMARY OF FAILURE AND REJECTION REPORT (FARR) INSPECTION FOR THE S-IVB-3

2.3.1 General

One hundred fourteen (114) Failure and Rejection Reports (FARR's) on the primary structure were reviewed to identify the "as-built" configuration for the structural capability of the S-IVB stage of the AS-503 Launch Vehicle. Of these, twelve were considered singificant. These are summarized in Table 2.3-1. Nine of the significant discrepancies occurred on the tank assembly, and three on the aft inter-stage.

Contractor furnished maps, (Figures 2.3-II thru 2.3-X) of the tank FARR's are included. The nine significant tank FARR's are identified on the maps by asterisks next to the FARR numbers. Figure 2.3-I illustrates a stage as-sembly and locates the (3) FARR's on the aft interstage and nine (9) on the tank assembly.

2.3.2 Conclusions

Assessment of the total discrepancies resulted in the identification of 12 actions which were considered significant enough to warrant stress analysis.

A stress analysis of these discrepancies, including possible cumulative effects, will establish the structural capability of the S-IVB stage as-built configuration.

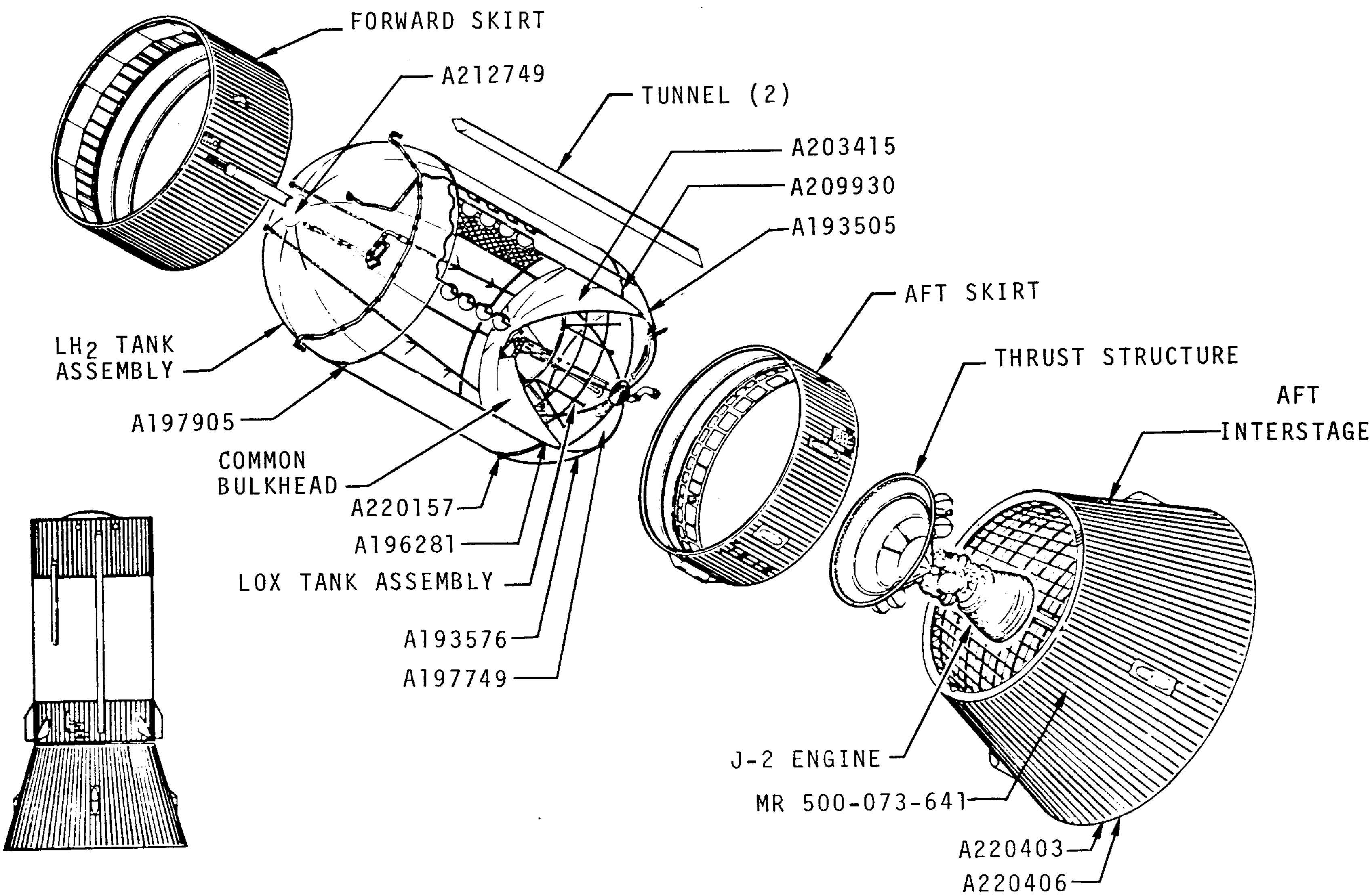
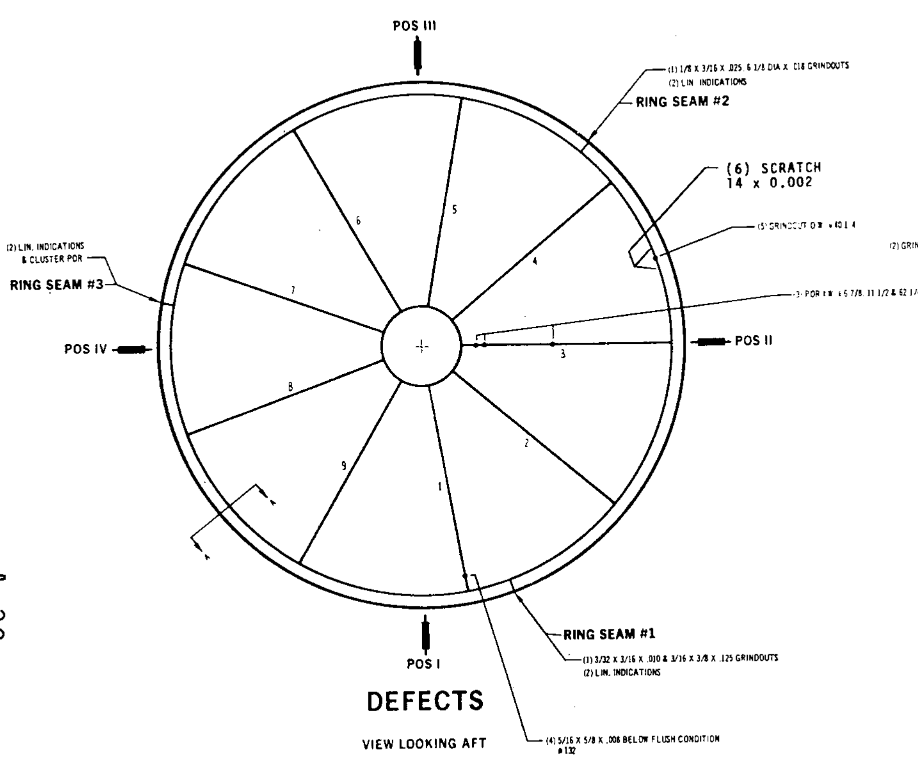
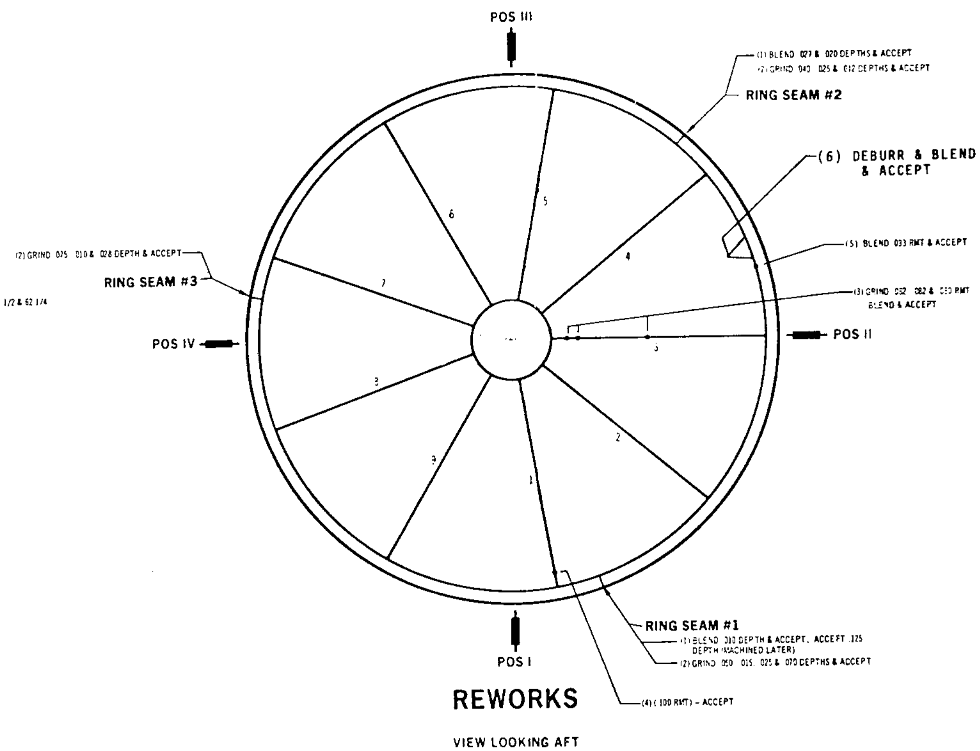
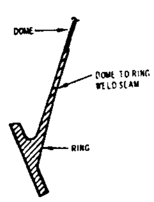
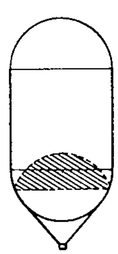


FIGURE 2.3-I MAP OF SIGNIFICANT FARR'S, STAGE ASSEMBLY, S-IVB





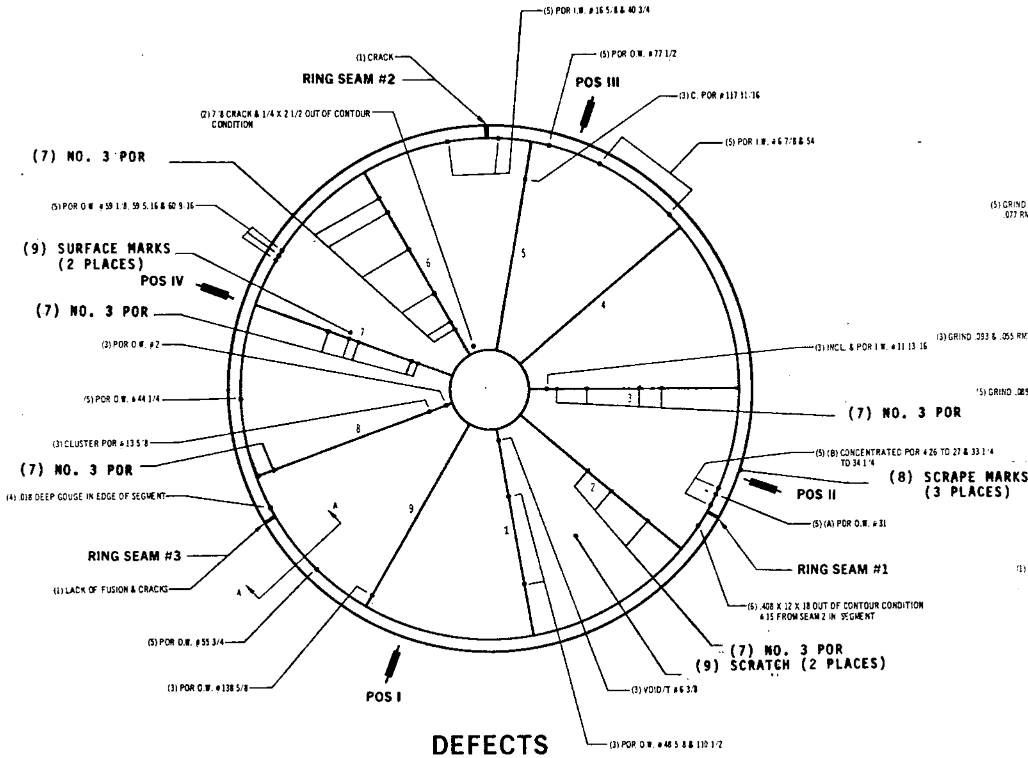




ITEM	FARR NUMBER	INITIATION DATE	DEFECTS	REWORKS REQUIRED	HOW REWORKED	REWELDS
1	A172131 AFTER MACHINING	11-11-65	4	3	N A	0
2	A171583	11-30-65	10	10	N A	0
3	A182656	1-19-66	3	3	N A	0
4	A182644	1-21-66	1	0	N A	0
5	A187019	1-29-66	1	1	N A	0
6	A198131	5-23-66	1	1	N/A	0

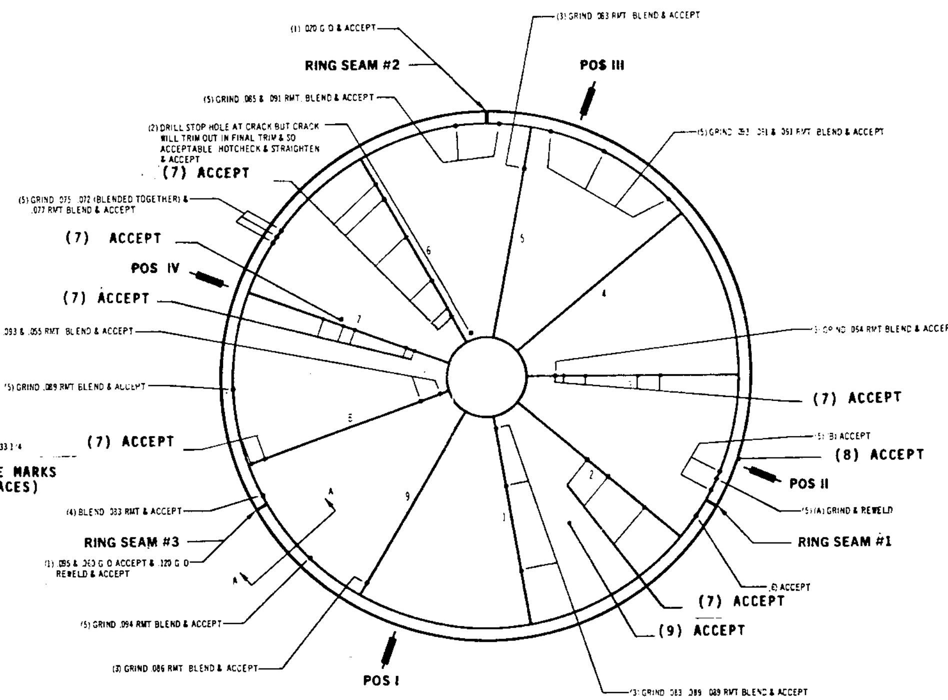
ITEM	FARR NUMBER	INITIATION DATE	DEFECTS	REWORKS REQ'D	WELDING REWORK	REWELDS

FIGURE 2.3-II FARR MAP, COMMON BULKHEAD, AFT FACING SHEET, S-IVB



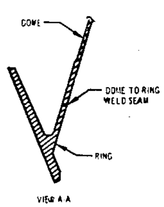
DEFECTS

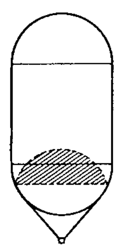
VIEW LOOKING AFT



REWORKS

VIEW LOOKING AFT

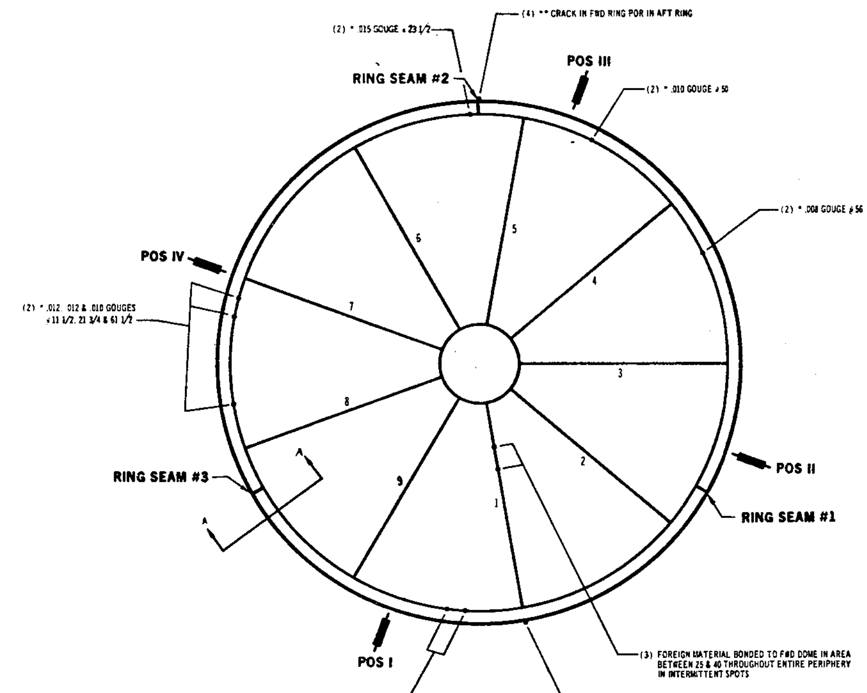




ITEM	FARR NUMBER	INITIATION DATE	DEFECTS	REWORKS REQUIRED	HOW REWORKED	REWELDS
1	A171578 BEFORE MACHINE	11-23-65	4	4	MANUAL MIG	1
2	A182633	1-18-66	2	1	N A	0
3	A182664	1-26-66	8	8	N A	0
4	A187028	1-31-66	1	1	N A	0
5	A189303	2-6-66	13	11	AUTO MIG	[illegible]
6	A189312	2-10-66	1	0	N A	0
* 7	A203415	6-20-66	22	0	N/A	0
8	A209703	4-11-66	3	0	N/A	0
9	A251464	4-26-67	4	0	N/A	0

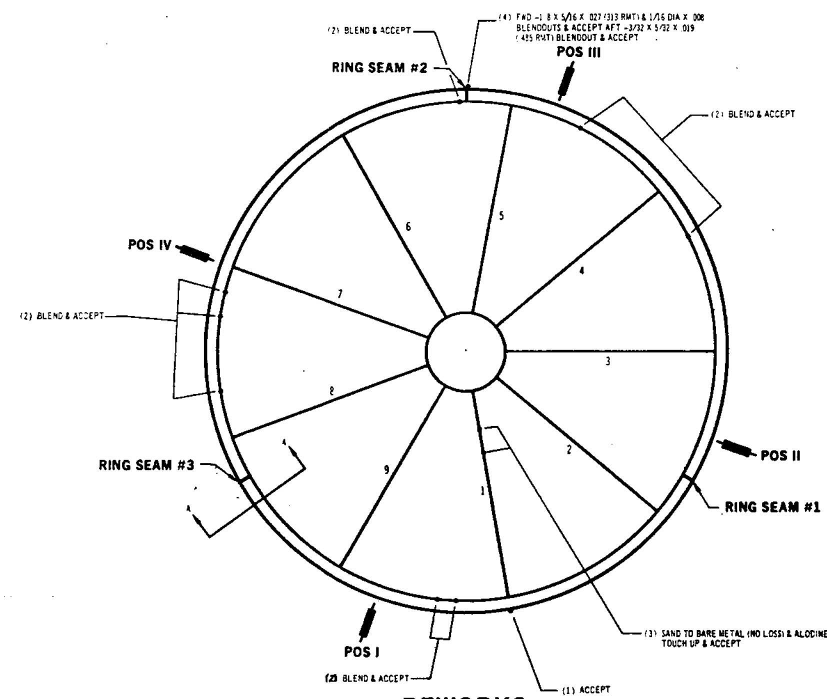
ITEM	FARR NUMBER	INITIATION DATE	DEFECTS	REWORK REQUIRED	WELDING REWORK	REWELDS

FIGURE 2.3-III FARR MAP, COMMON BULKHEAD, FWD FACING SHEET, S-IVB



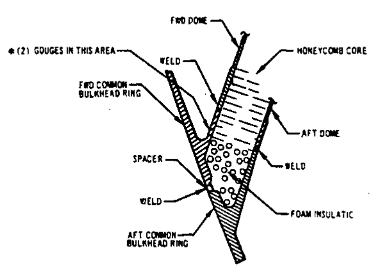
DEFECTS

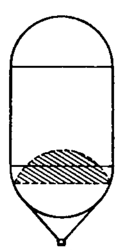
VIEW LOOKING AFT



REWORKS

VIEW LOOKING AFT



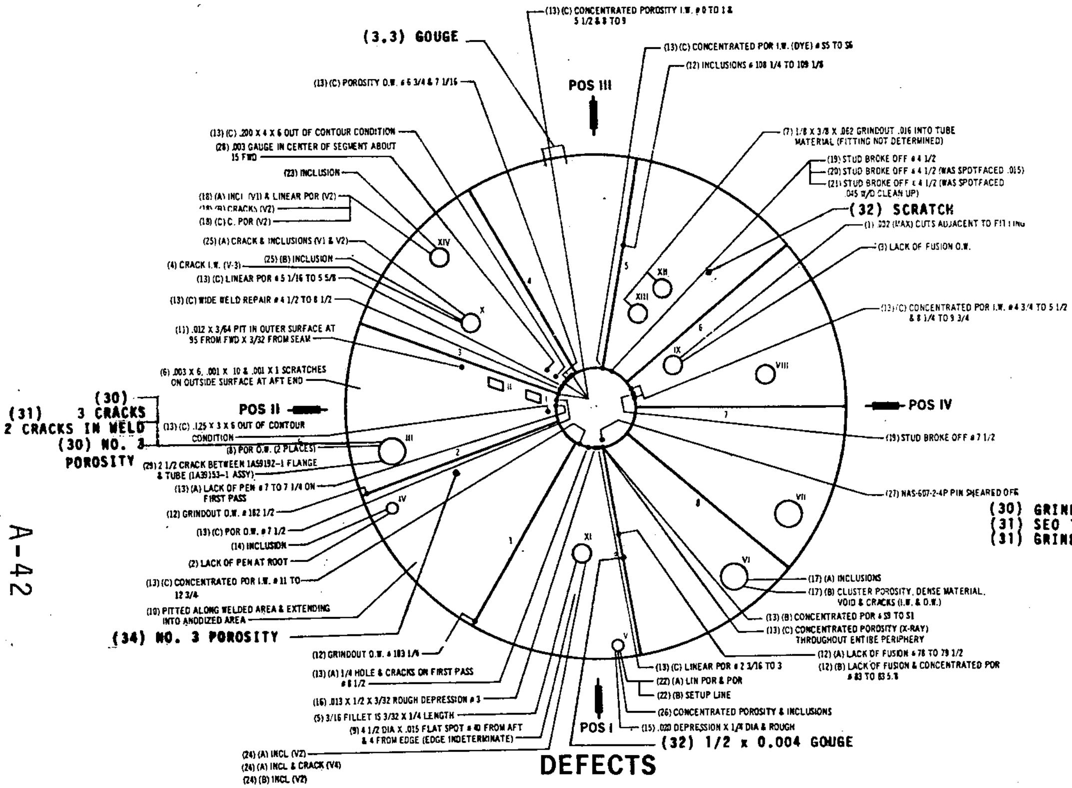


ITEM	FARR NUMBER	INITIATION DATE	DEFECTS	REWORKS REQUIRED	HOW REWORKED	REWELDS
(1)	A193505	3-11-66	1	0	N A	[illegible]
(2)	A189370 *	3-14-66	8	8	N A	[illegible]
(3)	A193579	3-29-66	1	1	N A	[illegible]
(4)	A193571 **	3-29-66	3	3	N A	0

** RING SEAMS ARE DISPLACED 60° BETWEEN FWD & AFT DISCREPANCY NOTED AFTER BONDING & BEFORE MACHINING

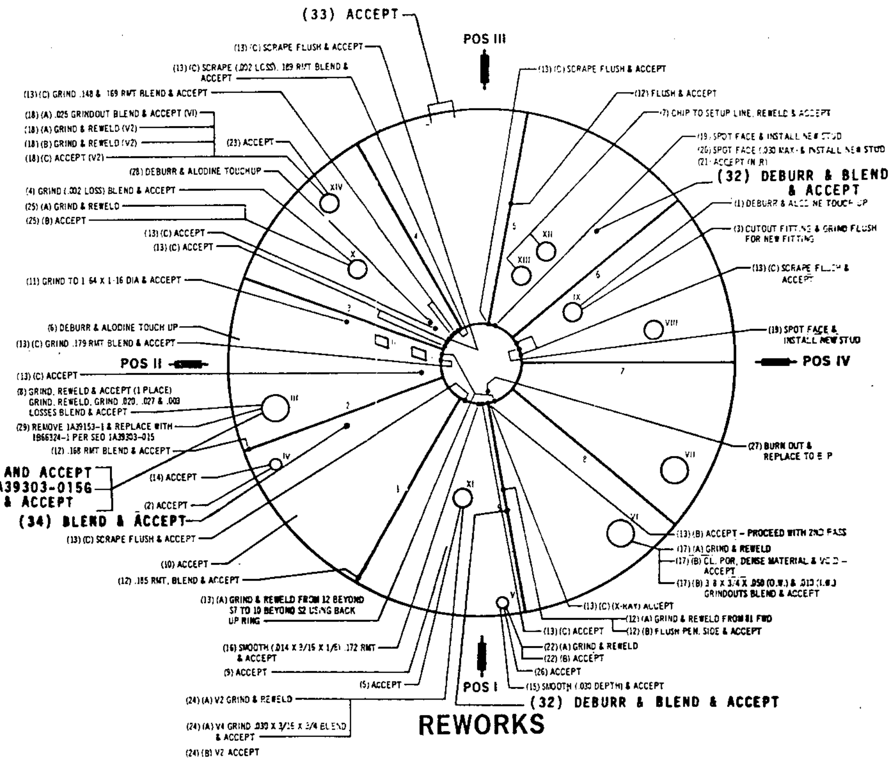
ITEM	FARR NUMBER	INITIATION DATE	DEFECTS	REWORKS REQUIRED	WELDING REWORK	REWELDS

FIGURE 2.3-IV FARR MAP, COMMON BULKHEAD ASSEMBLY, S-IVB



DEFECTS

VIEW LOOKING FWD



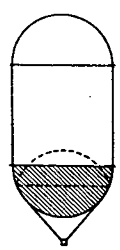
REWORKS

VIEW LOOKING FWD

ITEM	FARR NO.	DATE	DEFECTS
30	A197924	5-15-66	2
31	A197996	5-17-66	1
32	A198131	5-26-66	2
33	A209703	4-11-66	1
34	A209705	4-15-66	1

LEGEND

I-BRACKET
II-BRACKET
III-FITTING ASSY(LOX FILL LINE)
IV-ELBOW ASSY(LH_2 FILL LINE)
V-ELBOW ASSY(LH_2 CHILL RETURN)
VI-FITTING ASSY(LH_2 FEED LINE)
VII-FLANGE(LH_2 CHILL PUMP)
VIII-FLANGE(LOX VENT)
IX-LOX INSTR PROBE
X-LOX HELIUM HEATER
XI-LOX CHILL RETURN
XII-P.U. PROBE
XIII-WIRE LEADOUT PORT
XIV-LH_2 HELIUM HEATER



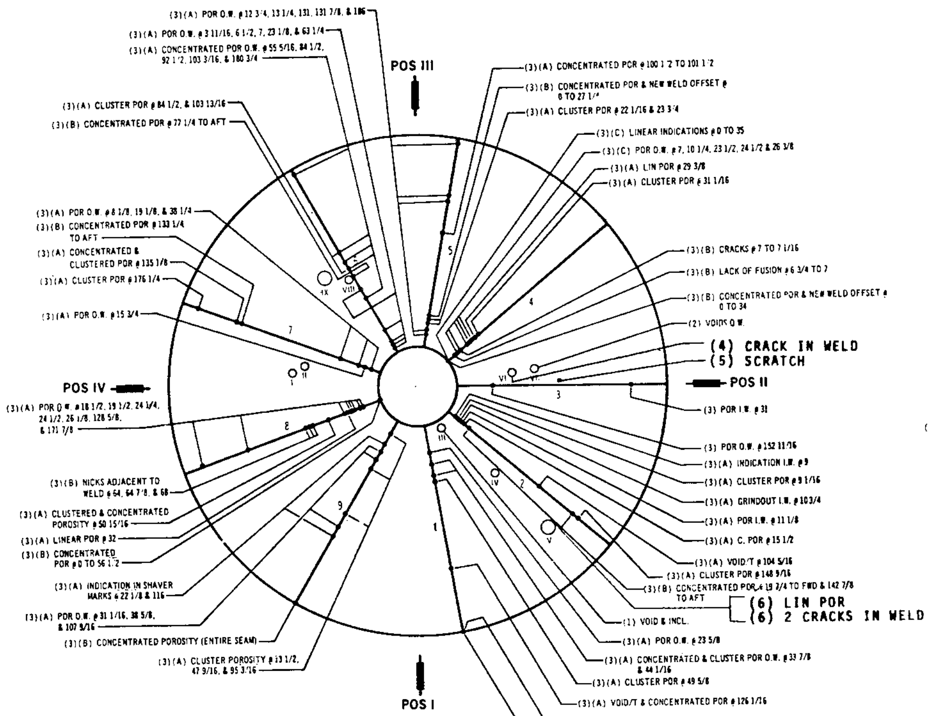
TANK ASSY

ITEM	FARR NUMBER	INITIATION DATE	DEFECTS	REWORKS REQUIRED	HOW REWORKED	REWELDS
1	A189341 LL	2-21-66	1	1	N/A	0
2	A187091 FF	2-27-66	1	0	N/A	0
3	A187092 LL	2-28-66	1	1	N/A	0
4	A187098 AT	3-3-66	1	1	N/A	0
5	A189363 AR	3-3-66	1	0	N/A	0
6	A189369 SEG 3	3-7-66	3	3	N/A	0
7	A189382 HH	3-9-66	1	1	AUTO TIG	1
8	A189385 BB	3-10-66	5	5	AUTO TIG	2
9	A193515 SEG 1	3-16-66	1	0	N/A	0
10	A193516 SEG 2	3-16-66	1	0	N/A	0
11	A193521 SEG 3	3-16-66	1	1	N/A	0
12	A189400 MER	3-21-66	5	5	AUTO MIG	1
* 13	A193576 JAMB	3-28-66	27	11	AUTO MIG	1
14	A212615 * FF	4-15-66	1	0	N/A	0
15	A212715 * AP	4-17-66	1	1	N/A	0

* HAND WELD

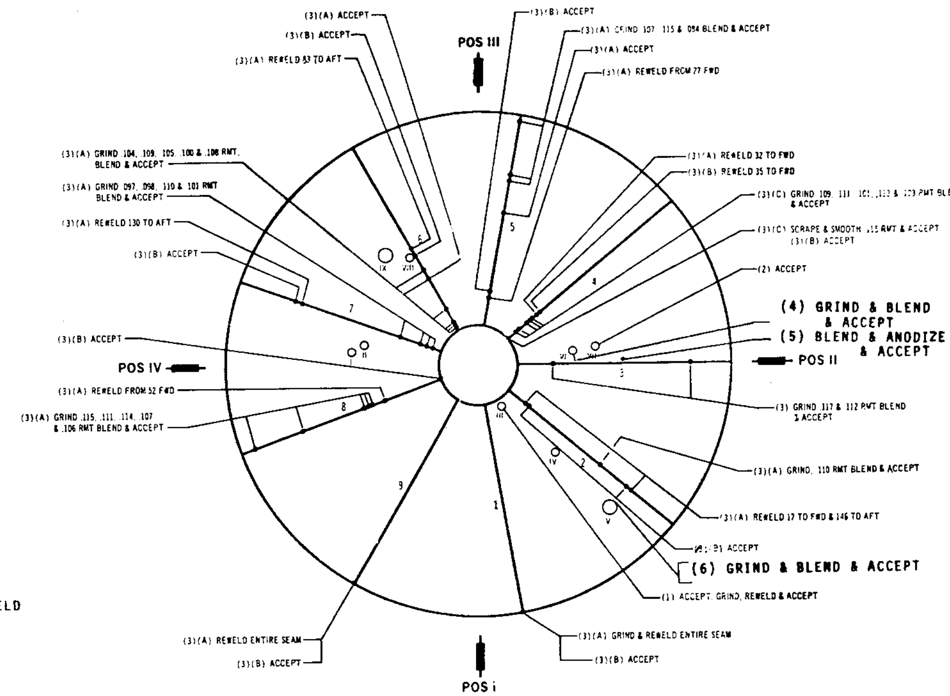
ITEM	FARR NUMBER	INITIATION DATE	DEFECTS	REWORKS REQUIRED	WELDING REWORK	REWELDS
16	A212716	4-18-66	1	1	N/A	0
17	A212519 * GG	4-18-66	6	3	MANUAL TIG	1
18	A212523 * AU	4-21-66	4	3	MANUAL TIG	2
19	A212727	4-21-66	2	2	STUD WELDER	2
20	A212730	4-22-66	1	1	STUD WELDER	1
21	A212733	4-22-66	1	0	N A	0
22	A212556 * AP	4-24-66	2	1	MANUAL TIG	1
23	A212661 * AU	4-26-66	1	0	N A	0
24	A212551 * AR	4-22-66	4	2	MANUAL TIG	1
25	A212652 * AT	4-22-66	4	3	MANUAL TIG	1
26	A212653 * AP	4-22-66	2	0	N A	0
27	A212754	5-5-66	1	1	N A	0
28	A197743	5-21-66	1	1	N A	0
* 29	A197749	5-21-66	1	1	MANUAL MECH MIG	1

FIGURE 2.3-V FARR MAP, LOX TANK AFT DOME, S-IVB



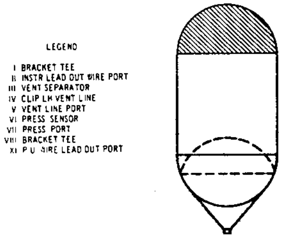
DEFECTS

VIEW LOOKING AFT



REWORKS

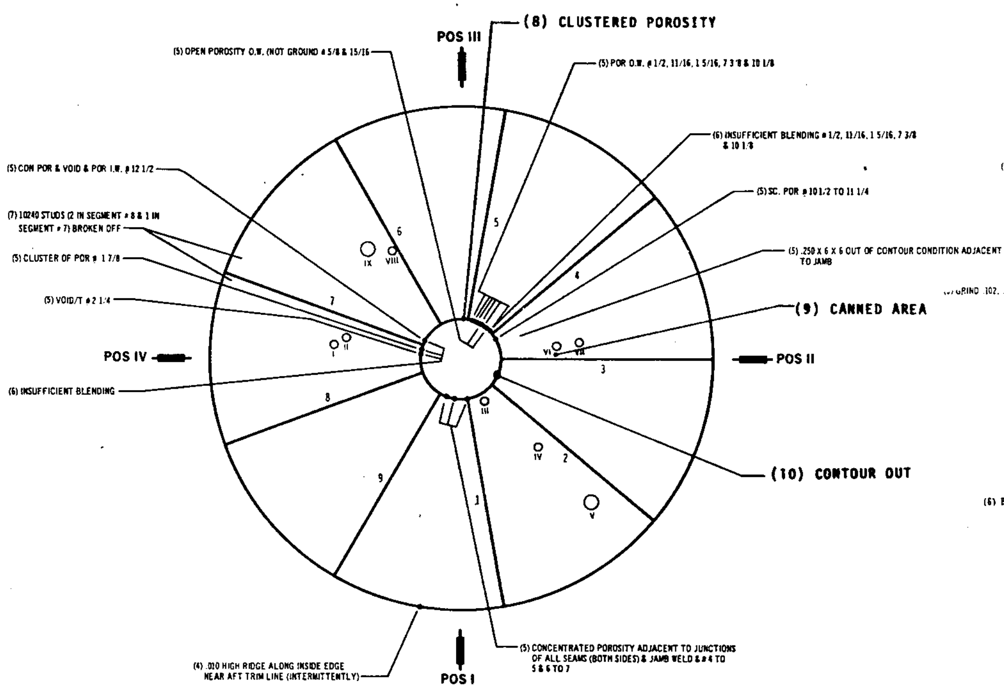
VIEW LOOKING AFT



ITEM	FARR NUMBER	INITIATION DATE	DEFECTS	REWORKS REQUIRED	HOW REWORKED	REWELDS
(1)	A189399 AC	3-21-66	2	1	AUTO TIG	1
(2)	A193552 AH	3-23-66	1	0	N A	0
(3)	A193569 MER	3-29-66	80	35	AUTO MIG	10
(4)	A197390	5-14-66	1	1		
(5)	A203426	6-21-66	1	1		
(6)	A197391	5-14-66	1	1		

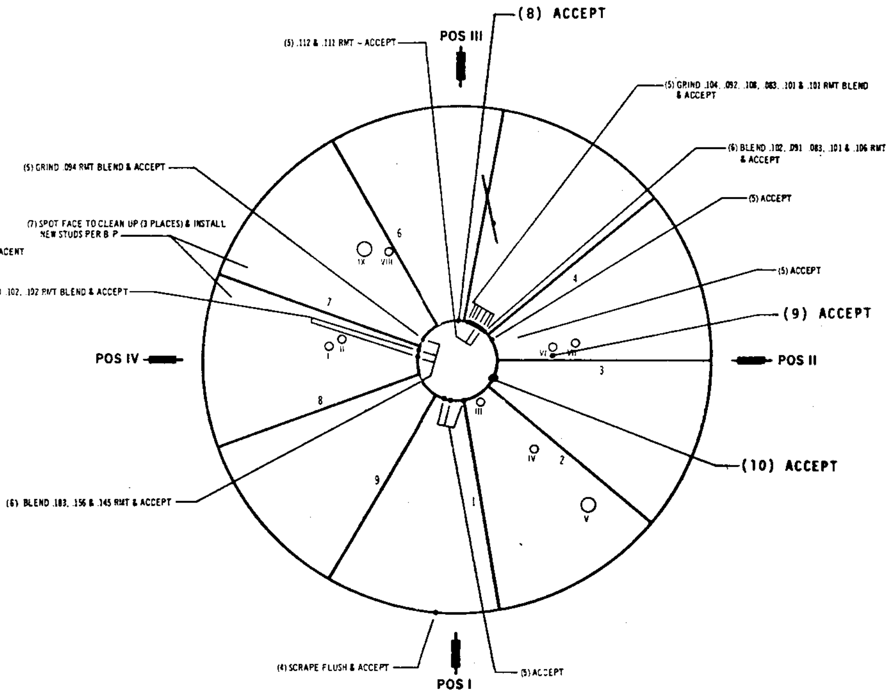
ITEM	FARR NUMBER	INITIATION DATE	DEFECTS	REWORKS REQUIRED	WELDING REWORK	REWELDS

FIGURE 2.3-VI FARR MAP, LH_2 TANK FWD DOME, MERIDIANS, S-IVB



DEFECTS

VIEW LOOKING AFT

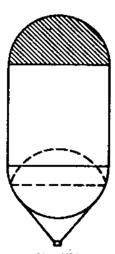


REWORKS

VIEW LOOKING AFT

LEGEND

I BRACKET TEE
II INSTR LEAD OUT WIRE PORT
III VENT SEPARATOR
IV CLIP LH VENT LINE
V VENT LINE PORT
VI PRESS SENSOR
VII PRESS PORT
VIII BRACKET TEE
XI P U WIRE LEAD OUT PORT

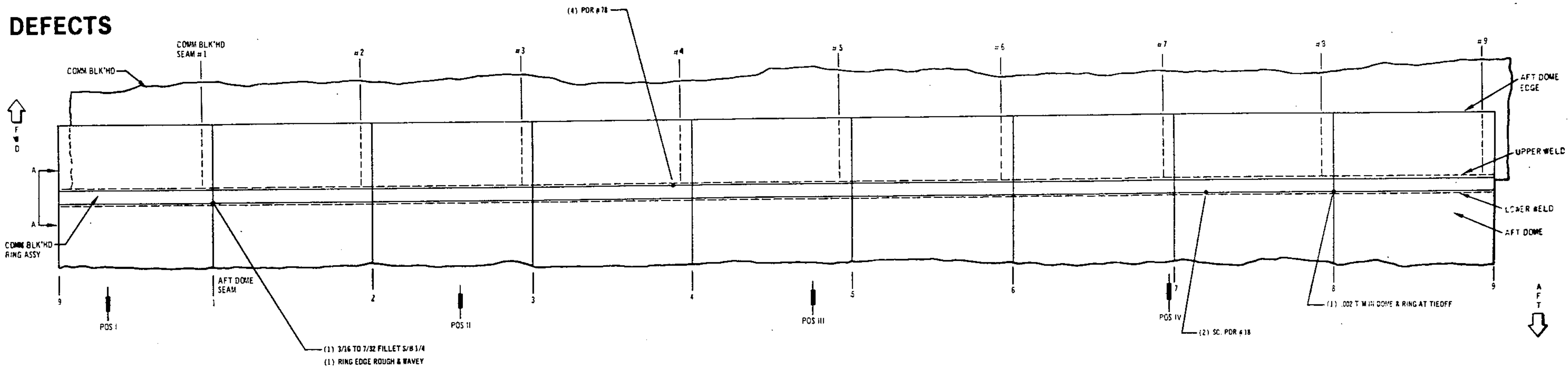


	ITEM	FARR NUMBER	INITIATION DATE	DEFECTS	REWORKS REQUIRED	HOW REWORKED	REWELDS
	4	A193597	4-7-66	1	1	N/A	0
	5	A212706	4-12-66	33	11	N/A	0
	6	A212724	4-20-66	8	8	N/A	0
	7	A212742	4-29-66	3	3	STUD WELDER	3
	8	A206344	8-17-66	1	0	N/A	0
	9	A 203426	6-21-66	1	0	N/A	0
*	10	A212749	5-3-66	1	0	N/A	0

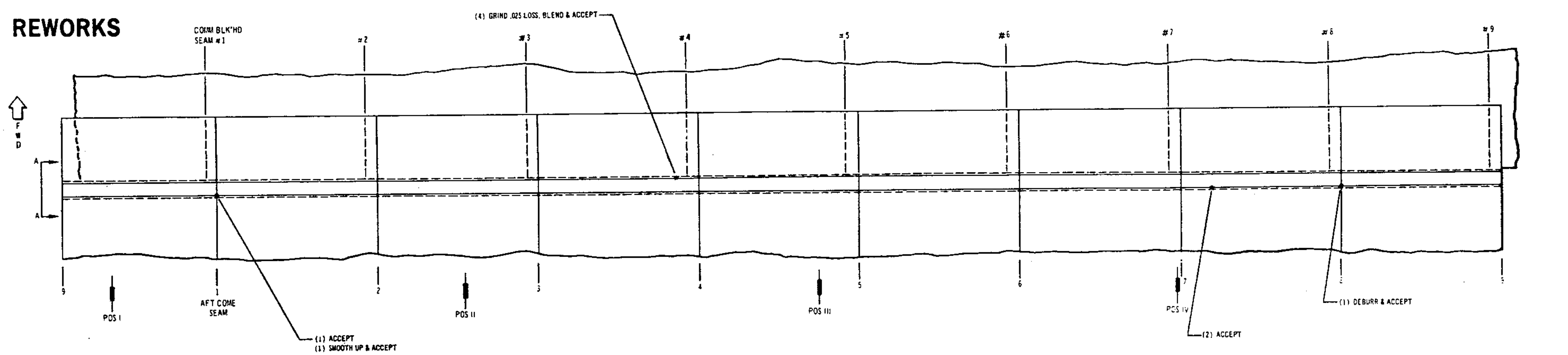
ITEM	FARR NUMBER	INITIATION DATE	DEFECTS	REWORKS REQUIRED	WELDING REWORK	REWELDS

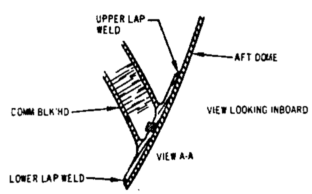
FIGURE 2.3-VII FARR MAP, LH_2 TANK FWD DOME, CENTER PLATE, S-IVB

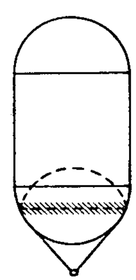
DEFECTS



REWORKS





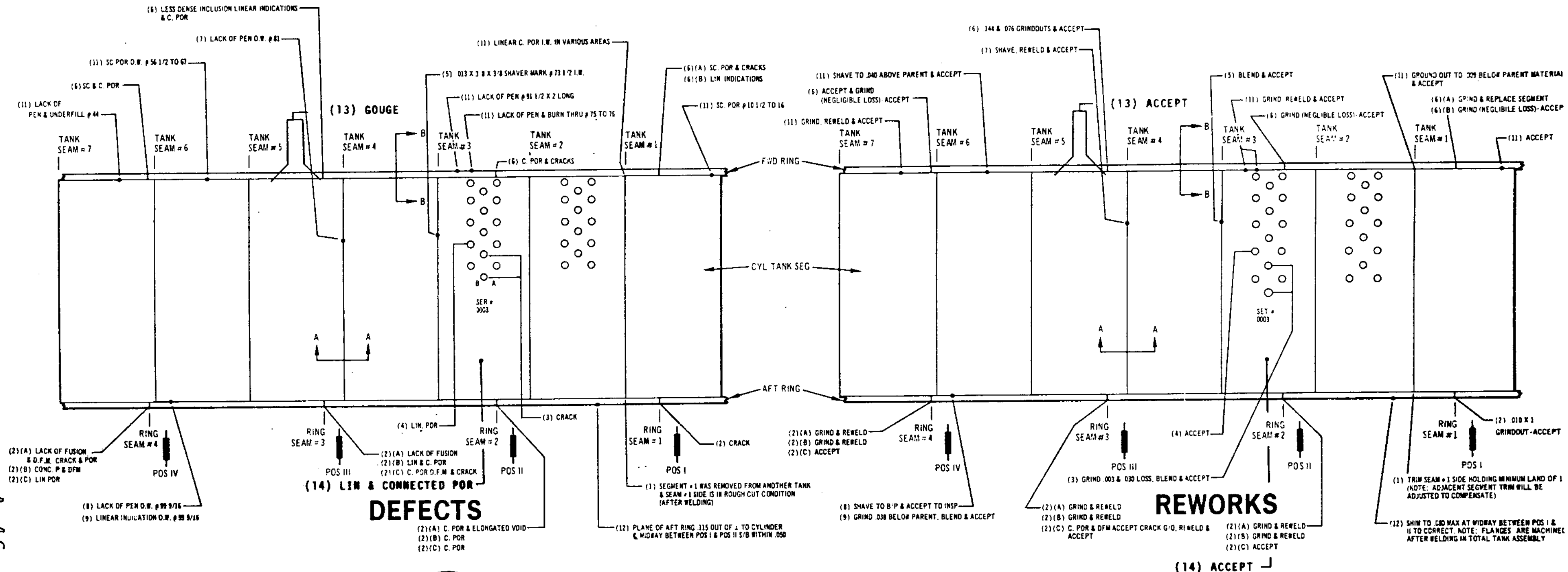


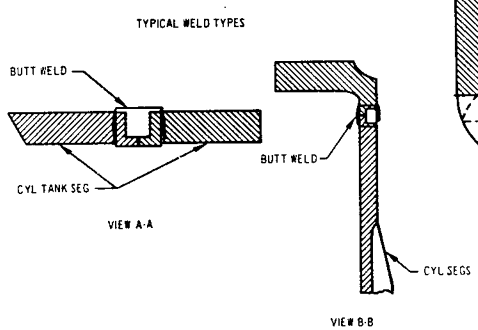
LEGEND

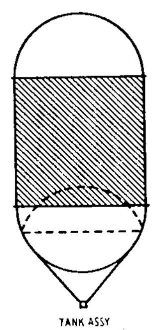
ITEM	FARR NUMBER	INITIATION DATE	DEFECTS	REWORKS REQUIRED	WELDING REWORK	REWELDS
(1)	A212748	5-3-66	3	2	N A	0
(2)	A212665	5-3-66	1	0	N A	0
(3)	A212754	5-5-66		SEE AFT DOME - ITEM 27		
(4)	A198219	5-22-66	1	1	N A	0

ITEM	FARR NUMBER	INITIATION DATE	DEFECTS	REWORKS REQUIRED	WELDING REWORK	REWELDS

FIGURE 2.3-VIII FARR MAP, COMMON BULKHEAD TO LOX TANK AFT DOME WELD, S-IVB





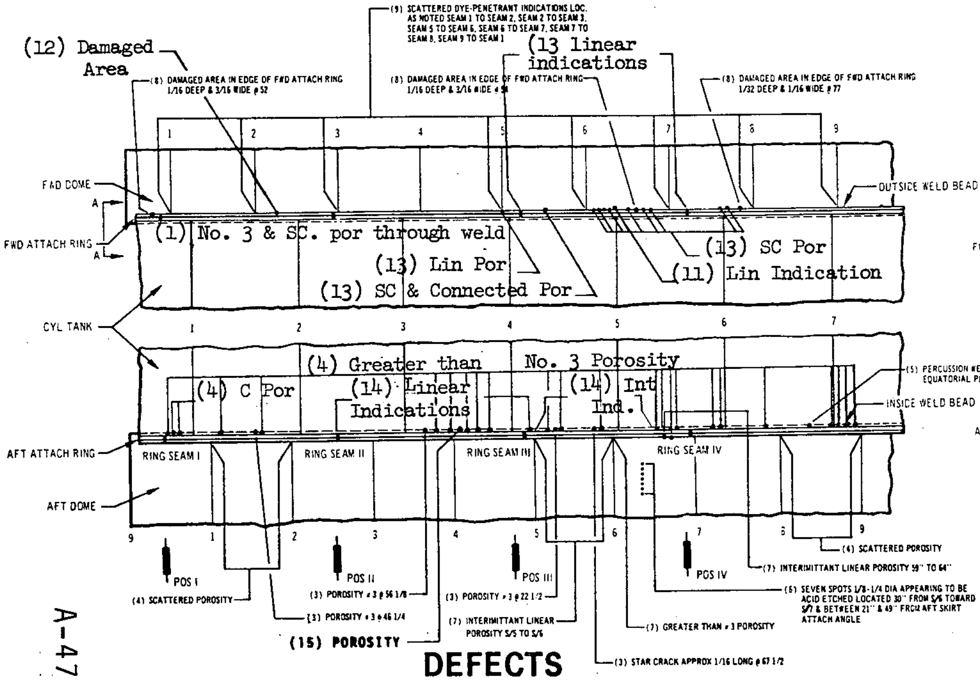


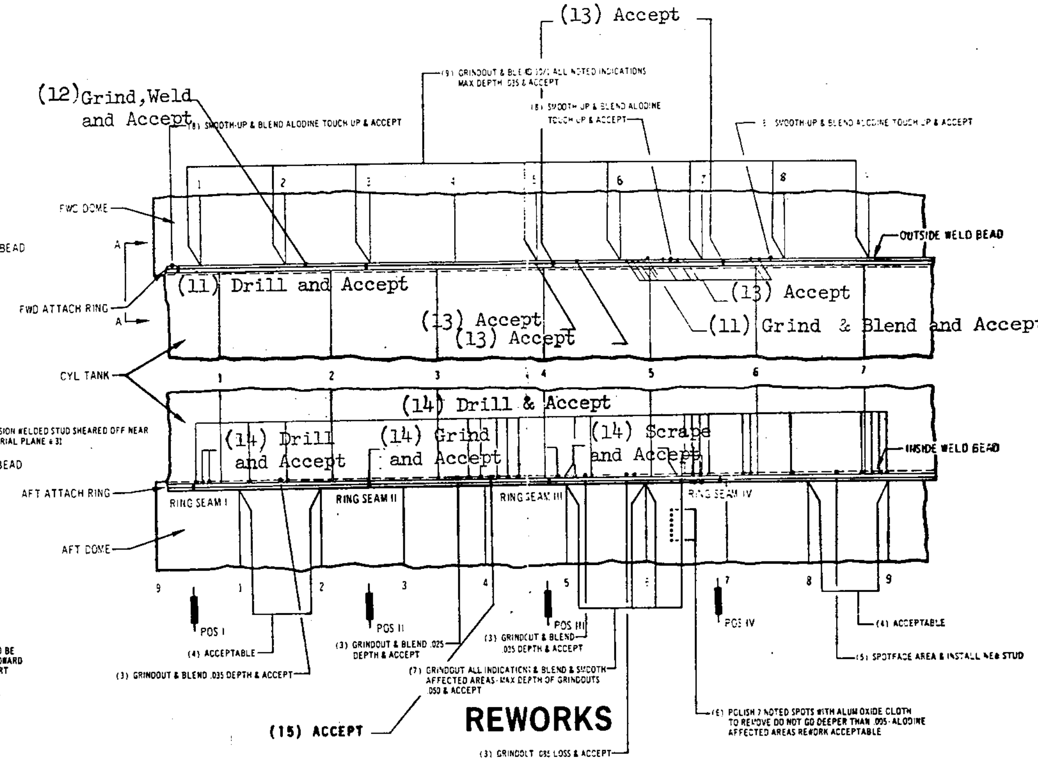
ITEM	FARR NUMBER	INITIATION DATE	DEFECTS	REWORKS REQUIRED	WELDING REWORK	REWELDS
(1)	A188729	3-3-66	1	1	N A	1
(2)	A189376 BEFORE MACH	3-4-66	18	8	MANUAL MIG	7
(3)	A189377	3-5-66	2	2	N A	0
(4)	A189378	3-7-66	1	0	N A	0
(5)	A209527	3-23-66	1	1	N A	0
(6)	A193551 BEFORE MACH	3-23-66	10	5	MANUAL MIG	1
(7)	A209530	3-24-66	1	1	AUTO MIG	1
(8)	A209895	4-22-66	1	1	N A	0
(9)	A209896	4-25-66	1	1	N A	0
(10)	A197901 *	4-28-66				

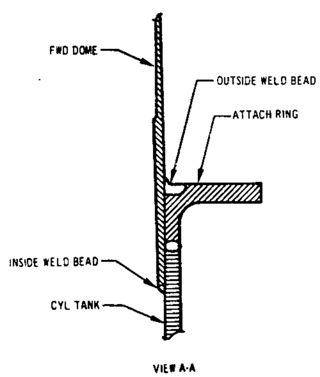
* SUPERSEDED BY A198153 (ITEM 11)

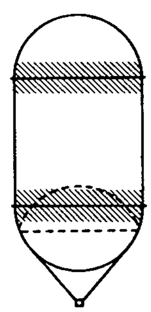
ITEM	FARR NUMBER	INITIATION DATE	DEFECTS	REWORKS REQUIRED	WELDING REWORK	REWELDS
(11)	A198153	5-17-66	6	5	AUTO MIG	3
(12)	A209901	5-24-66	1	1	N/A	0
(13)	A209703	4-11-66	1	0	N/A	0
(14)	A203416	7-1-66	1	0	N/A	0

FIGURE 2.3-IX FARR MAP, LH_2 CYLINDRICAL WELDS, S-IVB









	ITEM	FARR NUMBER	INITIATION DATE	DEFECTS	REWORKS REQUIRED	WELDING REWORK	REWELDS
	(1)	A197743	5-21-66	SEE AFT DOME ITEM 28			
	(2)	A198129	5-22-66	SEE COMMON ASSY TO AFT DOME - ITEM 4			
	(3)	A20990[illegible]	5-26-66	4	4	N/A	0
*	(4)	A209930	5-28-6[illegible]	2	0	N/A	0
	(5)	A198132	5-29-66	1	1	STUDWELDER	1
	(6)	A209932	5-31-66	7	7	N/A	0
*	(7)	A-196281	6-7-66	[illegible]	3	N/A	0
	(8)	A-209944	6-18-66	3	3	N/A	0
	(9)	A-209917	6-15-66	6	6	N/A	0
	(10)	A197749	6-21-66	SEE AFT DOME - ITEM 29			

	ITEM	FARR NUMBER	INITIATION DATE	DEFECTS	REWORKS REQUIRED	WELDING REWORK	REWELDS
*	(11)	A 197905	4-29-66	2	2	N/A	0
	(12)	A 207711	4-2[illegible]-66	1	1	N/A	0
	(13)	A 209712	4-27-66	4	0	N/A	0
	(14)	A 127779	4-19-66	25	25	N/A	0
*	(15)	A 220157	9-7-66	1	0	N/A	0

FIGURE 2.3-X FARR MAP, LOX TANK AFT DOME TO LH_2 CYL. & LH_2 TANK FWD DOME TO LH_2 CYL. WELD, S-IVB

TABLE 2.3-I SUMMARY OF SIGNIFICANT MRB'S, S-IVB

STAGE: S-IVB EFFECTIVITY: AS-503 COMPONENT: TANK ASSEMBLY

Element	MRB Number	Dwg/Part Number	Requirement	Deviation/Disposition	Reason for Concern
LH_2 TANK ASSEMBLY	A197905	1A39303-521	DPS-15104	Dye check of fwd. dome to ring weld shows numerous greater than #3 porosities. Defects were ground out, blended and refinished. Final inspection by dye check. "Acceptable to Engineering for use."	Repeated rework used to effect repair, but no x-ray inspection made during final inspection. Possible reduced safety factor from undetected flaws.
	A203415	1A39303-515	DPS-15104	Dye check of Common Bulkhead meridian welds (fwd. face) reveals numerous greater than #3 porosities. "Acceptable to Engineering for use"	No repair work attempted - Common Bhd. was fully assembled, flaws detected after Hydrostatic Test. Reduced safety factor.
	A196281	1A39303-521	DPS 10220 15104	Dye check of aft dome to ring weld shows intermittent linear defects and porosity. Defects were ground, blended and refinished.	Repeated rework, but no x-ray inspection was made to verify final integrity of welds or parent metal. Possible reduced safety factor from undetected defects.

TABLE 2.3-I SUMMARY OF SIGNIFICANT MRB'S S-IVB

STAGE: S-IVB EFFECTIVITY: AS-503 COMPONENT: TANK ASSEMBLY

Element	MRB Number	Dwg/Part Number	Requirement	Deviation/Disposition	Reason for Concern
LH_2 TANK ASSY. FWD. DOME ASSY.	A212749	1A39304	Welds should not shrink segments into an out-of-tolerance cond. Tolerances: +0.041 -0.139	Forward Dome Assy. contour of 82° latitude checks out of tolerance by following range: -.001 to -.240 Acceptable as is.	Reduction in safety factor.
LH_2 LOX TANK ASSY. COMMON BULKHEAD	A193505	1A39280-11	Two(2) 5/32" fillet welds required.	Seal weld, common bulkhead, aft dome joint. A third weld pass has been made covering center of -9 spacers. Acceptable as is.	Deviation from welding procedures.
LOX TANK AFT DOME & LH_2 CYLINDRICAL	A209930	1A39303 See A-A	Pre-production tensile coupons min. 30,000 PSI Panel #1.	Aft. dome to Cylindical skin weld. Three setstest specimens failed to meet required 30,000 PSI Disposition - Prepare new set of pre-production specimens. Result of this test is not documented.	Open item - "Inspection incomplete".
LOX TANK ASSY. FITTING ASSY.	A197749	1A39153-1	No cracks allowed.	Dye Penetrant Inspection DPS 15104 of fitting assembly 1A-39153-1 located in segment #3 of the aft dome O.D. side, has approx. 2-1/2" cracks at 6 o'clock in fillet weld of fitting assembly to flange. Disposition - Remove and replace fitting per salvage SEO 1A39-303-015 E.	No evidence of hydrostatic test or equivalent on new part.

TABLE 2.3-I SUMMARY OF SIGNIFICANT MRB'S S-IVB

STAGE: S-IVB EFFECTIVITY: AS-503 COMPONENT: TANK ASSEMBLY

Element	MRB Number	Dwg/Part Number	Requirement	Deviation/Disposition	Reason for Concern
LH_2 TANK ASSEMBLY	A220157	1A39306-511	DPS 14052	Aft ring to cylinder weld, 46-3/4" from seam 4 to seam 5. Linear porosity revealed by x-ray inspection of aft ring to cylinder tank. "Acceptable to Engineering for use".	Possible reduced factor of safety.
LOX TANK ASSY. AFT DOME	A193576	1A39308	Ultimate tensile strength should be 38,500 psi, (pre-production weld value), per DPS 14052	Aft. Dome, center flange weld. Results of pre-production test: #1 - 36,461 psi #2 - 36,162 psi #3 - 36,348 psi Also canned areas evident. Final disposition - Acceptable to Eng. for use.	Possible decrease in margin of safety.

TABLE 2.3-I SUMMARY OF SIGNIFICANT MRB'S S-IVB

STAGE: S-IVB EFFECTIVITY: AS-503 COMPONENT: INTERSTAGE ASSY.

Element	MRB Number	Dwg/Part Number	Requirement	Deviation/Disposition	Reason for Concern
AFT INTER-STAGE ASSY. SKIN PANEL AT STA. #132 & RING PLANE 5	500-073-641 "	1A71604-503 1A70707-464	No cracks allowed	STA 132, Ring Plane 5. 1/2" crack in length of skin panel. Disposition - Repaired cutout crack area, filled with a stainless steel 301-1/2 hard, 0.020" doubler. The doubler is fastened by removing and replacing fasteners in skin and stringer. All edges sealed and filled.	Reduced safety factor, load redistribution. (See notes 1, 2, and 3 below).

NOTES:

1. Potential hot spot from aerodynamic heating
2. The coeficients of linear expansion & thermal conductivity of Al & steel are incompatible. A thermal discontinuity was created.
3. Potential galvanic corrosion between Al. & CRES. should failure of edge seal occur.

Element	MRB Number	Dwg/Part Number	Requirement	Deviation/Disposition	Reason for Concern
INTERSTAGE ASSY.	A220403	1A71604	Tolerance-.240" ±.010	STA 2519, STR 6 to 126, under tolerance frame caps. Rework outlined. Inspection incomplete	Possible reduction in safety factor.
"	A220406	1B56534	"	STA 2519, STR 178 to 240, under tolerance frame caps milled. Rework and inspection incomplete.	"

2.4 SUMMARY OF MATERIAL REVIEW BOARD ACTIONS FOR THE IU-503

2.4.1 General

Thirty-two (32) Material Review Board reports were reviewed. Of this number, four are considered as being of a structural nature, and only one is significant. This MRB report is summarized in Table 2.4-I.

Figures 2.4-I and 2.4-II locate this discrepancy.

2.4.2 Conclusions

Assessment of the total discrepancies resulted in the identification of 1 action which was considered significant enough to warrant stress analysis.

Upon completion, this analysis will establish the structural capability of the IU as-built configuration.

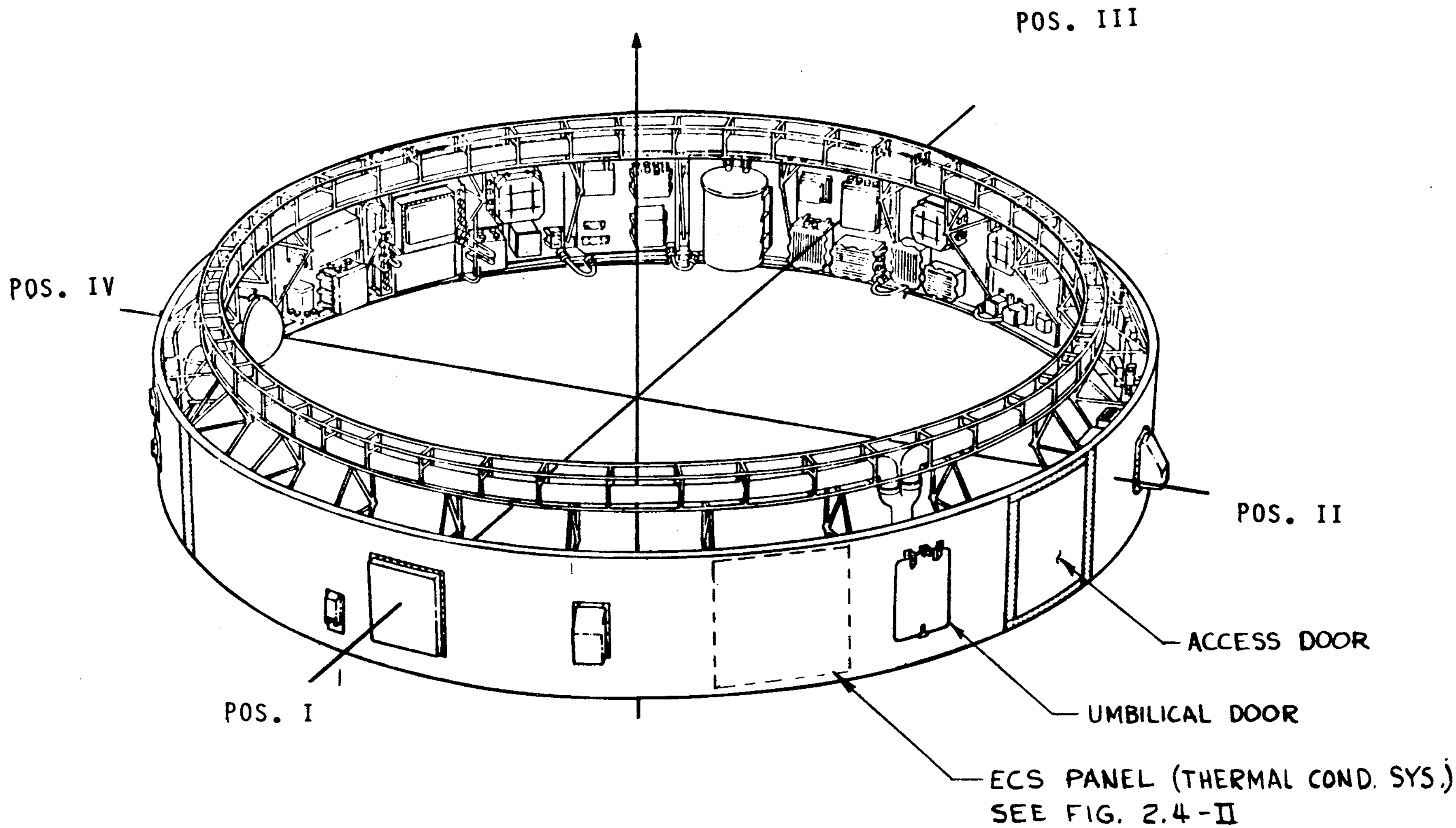


FIGURE 2.4-I INSTRUMENT UNIT

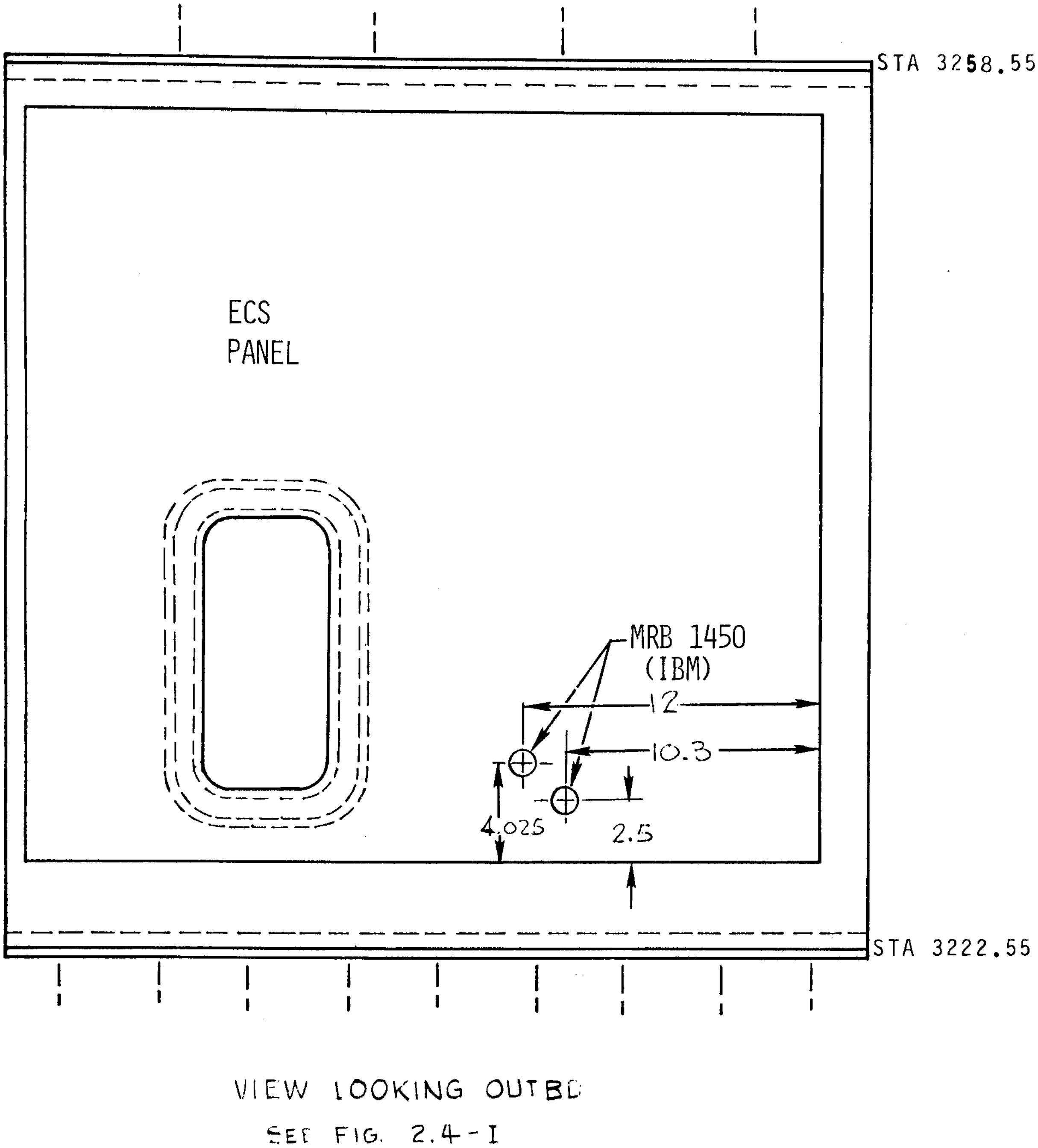


FIGURE 2.4-II SIGNIFICANT MRB, ECS PANEL, IU

TABLE 2.4-I SUMMARY OF SIGNIFICANT MRB'S - IU

STAGE: IU EFFECTIVITY: AS-503 COMPONENT: IU SHELL

Element	MRB Number	Dwg/Part Number	Requirement	Deviation/Disposition	Reason for Concern
SHELL	1450		Spec. 6009029	Slight circumferential scratch visible on base of insert, caused by screw that bottomed out. Use as is.	Two adjacent defects not repaired because damage was similar to that on test inserts which checked out as acceptable. X-ray would have revealed defects in flight hardware, if they existed, but none was run. Possible reduction in margin of safety from hidden damage to insert potting.

3.0 CONCLUSIONS

A total of 1336 discrepancies against the L/V were reviewed in this report. Of these, 79 were considered to have a potential significance on the structural integrity of the vehicle. Of the 79, twenty-two percent (22%) of these actions resulted from weld inadequacies such as inclusions, porosity, drop through and mismatch. Forty-four percent (44%) resulted from out-of-tolerance or misplaced holes; and the remaining actions (34%) resulted from dents, cracks and mismatch of parts. Although each of the 91 discrepancies could be considered minor, they were the most significant found and are being transmitted for stress analysis.

Completion of the stress analysis of these actions will establish the structural capability of the "as-built" vehicle. These data are reported in the "AS-503 S/V Structural Capability Report."

APPENDIX B

STRESS CORROSION

1.0 GENERAL

This appendix contains a presentation on stress corrosion which was prepared during the course of the AS-503 Structural Integrity Assessment.

DEFINITION OF STRESS CORROSION

- STRESS CORROSION IS A BRITTLE FAILURE OCCURRING IN NORMALLY DUCTILE MATERIALS RESULTING FROM THE COMBINED EFFECTS OF TENSILE STRESSES AND CORROSIVE ENVIRONMENT AND IS TIME DEPENDENT

FACTORS INFLUENCING STRESS CORROSION CRACKING

- MATERIAL SUSCEPTIBILITY
  - GRAIN DIRECTION
- TENSILE STRESSES & CORROSIVE ENVIRONMENT
  - SUSTAINED
  - COMBINED
- TIME DEPENDENCY
  - NUMBER OF FAILURES INCREASE WITH TIME

CRITERIA FOR THE ASSESSMENT OF STRESS CORROSION

- MATERIAL SUSCEPTIBILITY

  HIGH (SUSCEPTIBLE IN ALL CORROSIVE MEDIA)
  LOW (SUSCEPTIBLE IN LIMITED CORROSIVE MEDIA)

- CONDUCIVE ENVIRONMENT

  SUSTAINED TENSILE STRESS

  APPLIED LOAD INDUCING STRESSES
  PROCESS RESULTING IN RESIDUAL STRESSES
  ORIENTATION

  CORROSIVE MEDIA

  NORMAL ATMOSPHERE
  SPECIFIC PROTECTED ENVIRONMENT

- EFFECT OF FAILURE

  LOSS OF LIFE

  LOSS OF MISSION

  NO MAJOR IMPACT

PLAN AND APPROACH USED TO ASSESS STRESS CORROSION

- REVIEW SELECTED DRAWINGS AGAINST ESTABLISHED CRITERIA
- REVIEW MR'S FOR ASSESSMENT OF POTENTIAL STRESS CORROSION PROBLEM
- REVIEW AND ASSESS CONTRACTOR STRESS CORROSION SURVEYS AND INCORPORATE NASA ASSESSMENT OF CONTRACTOR SURVEYS

STRESS CORROSION ASSESSMENT TASKS PERFORMED

1. CONDUCTED LITERATURE SEARCH ON STRESS CORROSION AND ESTABLISHED ASSESSMENT CRITERIA
2. COMPILED AND ASSESSED AVAILABLE DATA FROM CONTRACTORS STRESS CORROSION SURVEY TO DETERMINE POTENTIAL PROBLEMS IN PRIMARY STRUCTURE
3. REVIEWED MR'S FOR ASSESSMENT OF POTENTIAL STRESS CORROSION PROBLEMS
4. REVIEWED FINDINGS OF STRESS CORROSION SURVEY AND MR ASSESSMENT WITH NASA FOR CONCURRENCE
5. PERFORMED DETAILED INVESTIGATION OF RING BAFFLE STRESS CORROSION PROBLEMS INCLUDING:
   - (A) REVIEW OF PERTINENT DOCUMENTATION
   - (B) ON-SITE REVIEW OF HARDWARE AT MTF
   - (C) REPORTED FINDINGS

STRESS CORROSION ASSESSMENT

- ONLY ACCESSIBLE PARTS WERE VISUALLY INSPECTED
- LIKE PARTS INSTALLED ON OTHER VEHICLES WERE INSPECTED
- NOT ALL AS-503 PARTS WERE INSPECTED
- VISUAL INSPECTION IS SUBJECTIVE
- PART REPLACEMENT NOT PROGRAM EFFECTIVE
- ASSESSMENT - LIMITED DEGREE OF ASSURANCE

SUMMARY OF CONTRACTOR STRESS CORROSION SURVEY

	S-IC	S-II	S-IVB	IU
NO. OF ITEMS REVIEWED FOR SUSCEPTIBILITY TO STRESS CORROSION	1849	*	1393	*
NO. OF ITEMS DETERMINED TO BE SUSCEPTIBLE	307	300	*	15
ACTION REQUIRED (BASED ON ANALYSIS)	NONE	*	NONE	NONE
FAILURE HISTORY (501, 502 AND TEST VEHICLES)	13	3	1	0
FAILURE HISTORY (503 PRIMARY STRUCTURE)	1**	0	0	0

* NOT ASSESSED
**ACCEPTED RISK

STRESS CORROSION ASSESSMENT

CONCLUSION

1. AS-503 IS A YOUNG VEHICLE

2. PRIMARY STRUCTURE IS MOSTLY IN COMPRESSION

3. KNOWN DISCREPANCIES HAVE BEEN CORRECTED OR THEIR RISK ACCEPTED

4. A REVIEW OF STRESS CORROSION SURVEYS PERFORMED BY THE CONTRACTORS SHOW THAT:

   A. CONTRACTORS HAVE PERFORMED A SURVEY OF SUSCEPTIBLE MATERIALS FOR EACH STAGE

   B. PRIMARY STRUCTURE HAS THE FEWEST SUSCEPTIBLE MATERIALS

   C. NO OPEN ITEMS EXIST ON PRIMARY STRUCTURE

5. PRESSURE VESSELS AND PROPELLANT TANKS ASSESSED FOR STRUCTURAL INTEGRITY, INCLUDING STRESS CORROSION AND FRACTURE MECHANICS, ARE CONSIDERED ADEQUATE.

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APPENDIX C

HYDROGEN EMBRITTLEMENT

1.0 GENERAL

This appendix contains a presentation on hydrogen embrittlement which was prepared during the course of the AS-503 Structural Integrity Assessment.

DEFINITION OF HYDROGEN EMBRITTLEMENT

- DELAYED BRITTLE FAILURE AT REDUCED TENSILE STRESS AS A RESULT OF ABSORBED HYDROGEN IN METALS

FACTORS INFLUENCING HYDROGEN EMBRITTLEMENT CRACKING

I SUSCEPTIBLE METALS

A. MICROSTRUCTURE

B. STRENGTH LEVEL

C. TEMPERATURE

II HYDROGEN

A. ATOMIC HYDROGEN

B. MOLECULAR HYDROGEN (AT EXTREME PRESSURE ONLY)

III STRESS

A. RESIDUAL

B. APPLIED

CRITERIA FOR THE ASSESSMENT OF HYDROGEN EMBRITTLEMENT

- MATERIAL SUSCEPTIBILITY
  - RESTRICTED TO HIGH STRENGTH STEEL ALLOY
- CONDUCIVE ENVIRONMENT
  - TENSILE STRESS
    - APPLIED
    - RESIDUAL
  - EXPOSED TO HYDROGEN PRODUCING PROCESS
  - EXPOSED TO HIGH PRESSURE GASEOUS HYDROGEN UNDER SERVICE CONDITIONS
- EFFECT OF FAILURE
  - LOSS OF LIFE
  - LOSS OF MISSION
  - NO MAJOR IMPACT

PLAN & APPROACH USED TO ASSESS HYDROGEN EMBRITTLEMENT

- REVIEW OF SELECTED DRAWINGS AGAINST ESTABLISHED CRITERIA
- REVIEW MR'S FOR FAILURES OF SUSCEPTIBLE MATERIALS
- REVIEW HISTORY OF SUSPECT PARTS FOR POSSIBLE EXPOSURE TO HYDROGEN
- REVIEW HISTORY FOR CORRECTIVE ACTION
- REVIEW AND ASSESS CONTRACTORS SURVEY OF HYDROGEN EMBRITTLEMENT PROBLEM
- INCORPORATE NASA ASSESSMENT OF CONTRACTOR REVIEW

HYDROGEN EMBRITTLEMENT

- AN NR HYDROGEN EMBRITTLEMENT SURVEY IDENTIFIED SEVEN TYPES OF PARTS INSTALLED IN CSM-103 AS HAVING POSSIBLE HYDROGEN EMBRITTLEMENT DUE TO AN IMPROPER NON-SPECIFIED BAKING PROCESS. THESE PARTS AND THE MSC DISPOSITION ARE AS FOLLOWS:

PART DESCRIPTION	ACTION TAKEN
(1) LES TOWER BOLT	REPLACED WITH QUALIFIED BOLTS
(2) CREWCOUCH BOLT	REMOVED PRELOAD 1
(3) TENSION TIE BOLT (CM)	ACCEPTED "AS IS" 2
(4) TENSION TIE STRAP	ACCEPTED "AS IS" 2
(5) TENSION TIE BOLT (SM)	ACCEPTED "AS IS" 2
(6) TENSION TIE NUT	ACCEPTED "AS IS" 2
(7) SLEEVE V & H ADD.	ACCEPTED "AS IS" 2

1 THESE BOLTS ARE USED IN SHEAR AND NEED NOT BE INSTALLED UNDER TENSION

2 THESE PARTS CANNOT BE READILY REPLACED. A TEST PROGRAM DEMONSTRATED THE ACCEPTABILITY OF THIS HARDWARE

ASSESSMENT - ADEQUATE ACTION TAKEN TO AVOID HYDROGEN EMBRITTLEMENT PROBLEM

D5-15782

HYDROGEN EMBRITTLEMENT ASSESSMENT

CONCLUSION

1. EVIDENCE HAS DISCLOSED THAT NO FAILURES HAVE BEEN ATTRIBUTED TO PURELY HYDROGEN EMBRITTLEMENT
2. PLATING PROCESS SPECIFICATIONS REQUIRE POST-PLATING BAKING OF PARTS TO DIFFUSE HYDROGEN
3. SUSPECT FAILURES ARE ASSOCIATED WITH STRESS CORROSION AND HAVE BEEN TREATED ACCORDINGLY
4. NO OPEN ITEMS EXIST ON PRIMARY STRUCTURE

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APPENDIX D

FRACTURE MECHANICS ASSESSMENT

1.0 GENERAL

This appendix contains fracture mechanics assessments on the space vehicle. Paragraph 1.1 contains a presentation prepared during the course of the assessment. Paragraph 1.2 presents a tabulation of fracture mechanics data for the AS-503 Launch Vehicle. Paragraph 1.3 contains a fracture mechanics evaluation of the Spacecraft SM/SPS propellant tanks.

SUMMARY OF

FRACTURE MECHANICS ASSESSMENT OF THE

AS-503 LAUNCH VEHICLE

PROPELLANT TANKS AND AUXILIARY PRESSURE VESSELS

FOR C PRIME MISSION

PURPOSE

- THE PURPOSE OF THIS PRESENTATION IS TO REPORT THE FRACTURE MECHANICS ASSESSMENT OF THE AS-503 LAUNCH VEHICLE PROPELLANT TANKS AND AUXILIARY PRESSURE VESSELS

BACKGROUND

PREVIOUS FRACTURE MECHANICS ASSESSMENTS ON NINETY-SEVEN (97) LAUNCH VEHICLE PRESSURE VESSELS AND PROPELLANT TANKS WERE REVIEWED AND UPDATED TO:

- REASSESS ADEQUACY OF PROOF PRESSURE TESTS BASED ON AS-503 C PRIME MISSION REQUIREMENTS
- REASSESS POST-PROOF TEST HISTORY INCLUDING:
  - PRESSURIZATION/TIME/CYCLE LIFE
  - FLUID EXPOSURE
  - MRB ACTIONS

CRITERIA FOR FRACTURE MECHANICS ASSESSMENT

- PROOF PRESSURE TEST
  - PROOF FACTOR ADEQUACY
  - MAXIMUM OPERATIONAL PRESSURES
  - PROOF TESTING TECHNIQUE
- CRITICAL FLAW SIZE DETERMINATION
  - PREDICTED FAILURE MODE
  - NDT DETECTION CAPABILITIES
- POST PROOF TEST HISTORY
  - PRESSURE/TIME/CYCLES
  - FLUID EXPOSURE
  - MRB ACTIONS

ASSESSMENT OF PROOF PRESSURE TESTING

AREA OF CONCERN	PROBLEM	SOLUTION
S-II LOX TANK DOLLAR WELD GIRTH WELD	PROOF TESTING OF WELDS CONSIDERED MARGINAL	• ANALYSES VERIFY ADEQUACY OF STRUCTURE • CRITICAL FLAW SIZE IS WITHIN NDT DETECTION CAPABILITIES • NO CRACKS WERE DETECTED • THE INSPECTION METHODS EMPLOYED IN EACH CASE WERE: X-RAY PENETRANT * EDDY-CURRENT
S-IVB LH_2 TANK LOWER VERTICAL WELDS	DITTO	
S-IVB LOX TANK GIRTH WELD AFT DOME	DITTO	
S-II STAGE J-2 ENGINE GH_2 START BOTTLE (S/N 4067991)	PROOF TEST BELOW MAXIMUM OPERATIONAL PRESSURE	

*USED ON J-2 ENGINE START BOTTLE FOR FILLER METAL ID.

ASSESSMENT OF POST-PROOF TEST HISTORY

- PRESSURIZATION/TIME/CYCLES (PROJECTED TO LAUNCH)

  ALL PRESSURE VESSELS AND PROPELLANT TANKS ARE WELL WITHIN THEIR MINIMUM GUARANTEED PRESSURE/TIME/CYCLE LIFE EXCEPT S-II, POSITION #1, J-2 - HYDROGEN START BOTTLE

- FLUID EXPOSURE

  PROCESSING AND PROOF TEST RECORDS INDICATE NO KNOWN EXPOSURE TO ADVERSE FLUIDS

- MRB ACTIONS

  MRB SUMMARIES INDICATE NO OPEN ITEMS ON PRESSURE VESSELS OR PROPELLANT TANK

FRACTURE MECHANICS ASSESSMENT SUMMARY

A REVIEW WAS MADE OF PREVIOUS FRACTURE MECHANICS ASSESSMENTS ON NINETY-NINE (99) PROPELLANT TANKS AND AUXILIARY PRESSURE VESSELS FOR THE SATURN V LAUNCH VEHICLE TO:

- DETERMINE ADEQUACY OF PROOF PRESSURE TESTING FOR AS-503 PROPELLANT TANKS AND AUXILIARY PRESSURE VESSELS FOR C PRIME MISSION
- ASSURE MINIMUM GUARANTEED PRESSURE/TIME/CYCLE LIFE FOR AS-503 PROPELLANT TANKS AND AUXILIARY PRESSURE VESSELS FOR C PRIME MISSION

CONCLUSIONS

PROOF PRESSURE TESTING

- PROOF PRESSURE TESTING CONSIDERED MARGINAL FOR:
  - S-II LOX TANK GIRTH AND DOLLAR WELDS
  - S-IVB LOX TANK GIRTH WELD AND AFT DOME
  - S-IVB LH_2 TANK LOWER VERTICAL WELDS
  - S-II STAGE J-2 ENGINE NO. 1 GH_2 START BOTTLE
- ADEQUACY OF THESE AREAS WAS VERIFIED BY ANALYSES AND NDT INSPECTION (X-RAY, PENETRANT, EDDY-CURRENT) AND ARE CONSIDERED ACCEPTABLE RISKS

MINIMUM GUARANTEED LIFE

- ALL PROPELLANT TANKS AND AUXILIARY PRESSURE VESSELS ARE WITHIN THEIR MINIMUM GUARANTEED LIFE FOR C PRIME MISSION EXCEPT THE J-2 START BOTTLE (S-II STAGE) WHICH IS CONSIDERED AN ACCEPTABLE RISK BY DCR BOARD DECISION AND JSAT CONCURRENCE

1.2 LAUNCH VEHICLE FRACTURE MECHANICS DATA

The following tables present the fracture mechanics data for each AS-503 L/V pressure vessel and propellant tank. These data have been assessed for the C prime mission and the conclusions noted in the "Remarks" column.

SUMMARY-SATURN V
AS-503
APOLLO LAUNCH VEHICLE PRESSURE VESSELS FRACTURE MECHANICS ASSESSMENT

NO.	VESSEL DESIGNATION	MATERIAL CONDITION			VESSEL CONFIGURATION AND DIMENSIONS				TEMPERATURE °F			PRESSURE (PSIG)				FLUID		ALLOWABLES USED BY DESIGN ACTIVITY	
	PART NUMBER NAME SERIAL NUMBER	BASE MATERIAL & CONDITION	WELD FILLER	WELD METHOD	SHAPE	DIA-METER (INCHES)	LENGTH (INCHES)	WALL THICK-NESS (INCHES)	DESIGN	OPER-ATION	PROOF	DESIGN	OPER-ATING MAX	PROOF	BURST	OPER-ATING	TEST PROOF	BASE METAL	WELD METAL
									S-IC BOEING										
1	S-IC Fuel Tank P/N60B24000-7B (1 per stage)																		
A	S/N 0000001	Al 2219-T87 60B32042	Al 2319 60B-32004	TIG and MIG	Domed Cylinder	396	517	D 0.128 DW 0.202 C 0.175	70°F	70°F	70°F	48.9	31.5 to 45.5	33.1 to 51.8	69.0	RP-1 JP-4	H_2O	MIL-HDBK-5A	31.5 KSI (RT) .9 factor of pre-production weld value in 60B-32-009
2	LOX Tank 60B12000-7B (1 per stage)																		
A	S/N 0000001	Al 2219-T87 60B32042	Al 2319 60B-32004	TIG and MIG	Domed Cylinder	396	769	D 0.152 DW 0.245 C 0.185 CW 0.254	70°F	-297°F	70°F	63.0	25.5 to 54.7	38.4 to 66.14	88.2	LOX	H_2O	MIL-HDBK-5A	31.5 KSI (RT) .9 factor as above
3	Helium Bottle in LOX P/N60B49031-1 (4 per stage)																		
A	S/N 0000055	Al 2014-T6 QQ-A-261 Extrusion	No Weld	--	Spher. Domed Cylinder	20.90	21.88	C 0.890	-320 to +250°F	-297 to +250°F	-320°F	3200 @-297°F 1500 @+250°F	3200@ -297°F	5000	6660	He	N2 He	MIL-HDBK-5A	No weld
B	S/N 0000059	↓	↓		↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
C	S/N 0000061	↓	↓		↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
D	S/N 0000063	Al 2014-T6 QQ-A-261 Extrusion	No Weld	--	Spher. Domed Cylinder	20.90	21.88	C 0.890	-320 to +250°F	-297 to +250°F	-320°F	3200 @-297°F 1500 @+250°F	3200@ -297°F	5000	6660	He	N2 He	MIL-HDBK-5A	No Weld

D= Dome Base Metal C= Cylinder Base Metal W= Weld

SUMMARY-SATURN V
AS-503
APOLLO LAUNCH VEHICLE PRESSURE VESSELS FRACTURE MECHANICS ASSESSMENT

NO.	K_{IC} KSI(IN)1/2 BASE METAL	K_{IC} KSI(IN)1/2 WELD METAL	K_{TH} Thresh'd Values (Oper. Fluid) KSI(IN)1/2 BASE METAL	K_{TH} Thresh'd Values (Oper. Fluid) KSI(IN)1/2 WELD METAL	FLAW SIZE (INCHES) SCREENED BY PROOF	FLAW SIZE (INCHES) CRIT	FLAW SIZE (INCHES) THRESHOLD CRITICAL OPERATING	PRESSURE CYCLES EXPERIENCED	SERVICE LIFE OPERATING PRESSURE (Operating Fluid) ANTICIPATED PRESSURE CYCLES	SERVICE LIFE OPERATING PRESSURE (Operating Fluid) GUARANTEED BY PROOF TEST	PROOF FACTOR MIN. PROOF PRESSURE / MAX. OPER. PRESSURE	PROOF FACTOR ADEQUACY	BURST FACTOR MIN. BURST PRESSURE / MAX. OPER. PRESSURE	PROBABLE FAILURE MODE	MANUFACTURER OR SOURCE	REMARKS
										S-IC BOEING						
1 A	35	28	28	22	(0.319) > T	N/A	N/A	1 - SF 20 psig max 2 - LC 14.5psig max	1 CDDT 20 psig max 2 - LC 14.5psig max	> 2.6 mins. at max. flight pressure	1.05 min.	Yes	1.52	Leak-Remote possibility of catastrophic	Boeing Michoud	No apparent problem for flight time
2 A	35 (RT)	28 (RT)	28 (-297°F)	22 (-297°F)	(0.286) > T	N/A	N/A	1 - SF 18 psig max 2 - LC 11.3 psig max	1 CDDT 18 psig max 2 - LC 11.3 psig max	> 2.6 mins. at max flight pressure	1.21 min.	Yes	1.61	Leak-Remote possibility of catastrophic	Boeing Michoud	No apparent problem for flight time
3 A	20	No Weld	18 -297°F	No Weld	0.032	N/A	0.074	1 6 A	1A	1950	1.56	Yes	2.08	Catastrophic	Martin-Marietta Corp Denver	OK. No apparent problems.
B	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
C	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
D	20	No Weld	18 -297° F	No Weld	0.032	N/A	0.074	1 6 A	1A	1950	1.56	Yes	2.08	Catastrophic	Martin-Marietta Corp Denver	OK. No apparent problems

SF Static Firing   CDDT Count Down Demonstration Test   LC Leak Check
A Maximum Operating Pressure Cycles Assumed

SUMMARY-SATURN V
AS-503
APOLLO LAUNCH VEHICLE PRESSURE VESSELS FRACTURE MECHANICS ASSESSMENT

NO.	VESSEL DESIGNATION: PART NUMBER / NAME / SERIAL NUMBER	MATERIAL CONDITION: BASE MATERIAL & CONDITION	MATERIAL CONDITION: WELD FILLER	MATERIAL CONDITION: WELD METHOD	VESSEL CONFIGURATION AND DIMENSIONS: SHAPE	DIAMETER (INCHES)	LENGTH (INCHES)	WALL THICKNESS (INCHES)	TEMPERATURE °F: DESIGN	TEMPERATURE °F: OPERATION	TEMPERATURE °F: PROOF	PRESSURE (PSIG): DESIGN	PRESSURE (PSIG): OPERATING MAX	PRESSURE (PSIG): PROOF	PRESSURE (PSIG): BURST	FLUID: OPERATING	FLUID: TEST PROOF	ALLOWABLES USED BY DESIGN ACTIVITY: BASE METAL	ALLOWABLES USED BY DESIGN ACTIVITY: WELD METAL
									S-IC	BOEING	(CONT'D)								
4	Helium Sphere High Pressure 60B52110-1B (7 per stage)																		
A	S/N 0000010	Forged Ti6Al4V STA 60B32534	Ti6Al-4V BAC 5947	TIG	Sphere	16.75	--	B 0.168 W 0.123	70	-65 to +165	77±18	3300	3000	5000	6600	He	H_2O He	MIL-HDBK-5A	MIL-HDBK-5A
B	S/N 0000016	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
C	S/N 0000017	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
D	S/N 0000022	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
E	S/N 0000027	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
F	S/N 0000028	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
G	60B52110-3 S/N 0000001	Forged Ti6Al4V STA 60B32534	Ti6Al-4V BAC 5947	TIG	Sphere	16.75	--	B 0.168 W 0.123	70	-65 to +165	77±18	3300	3000	5000	6600	He	H_2O He	MIL-HDBK-5A	MIL-HDBK-5A
5	Nitrogen Sphere 60B52111-1B (5 per stage)																		
A	S/N 0000017	Forged Ti6Al4V 60B32534	Ti6Al-4V BAC 5947	TIG	Sphere	12.33	--	B 0.110 W 0.124	70	-65 to +165	77±18	750 (3600)	750	1250	1650 (Actual 5300)	He	H_2O He	MIL-HDBK-5A	MIL-HDBK-5A
B	S/N 0000038	↓	↓	↓	↓	↓		↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
C	S/N 0000039	TI6AL4V	6AL-4V	TIG	Sphere	12.33	-	W.124	70	-	77±18	750	750	1250	1650	He	H_2O	MIL-HDBK-5A	MIL-HDBK-5A

D-12

D5-15782

SUMMARY-SATURN V
AS-503
APOLLO LAUNCH VEHICLE PRESSURE VESSELS FRACTURE MECHANICS ASSESSMENT

NO.	K_{IC} KSI(IN)1/2 BASE METAL	K_{IC} KSI(IN)1/2 WELD METAL	K_{TH} Thresh'd Values (Oper. Fluid) KSI(IN)1/2 BASE METAL	K_{TH} KSI(IN)1/2 WELD METAL	FLAW SIZE (INCHES) SCREENED BY PROOF	FLAW SIZE CRIT	FLAW SIZE THRESHOLD CRITICAL OPERATING	PRESSURE CYCLES EXPERIENCED	SERVICE LIFE OPERATING PRESSURE (Operating Fluid) ANTICIAPTED PRESSURE CYCLES	SERVICE LIFE GUARANTEED BY PROOF TEST	PROOF FACTOR MIN. PROOF PRESSURE / MAX. OPER. PRESSURE	PROOF FACTOR ADEQUACY	BURST FACTOR MIN. BURST PRESSURE / MAX. OPER. PRESSURE	PROBABLE FAILURE MODE	MANUFACTURER OR SOURCE	REMARKS
										S-IC BOEING (CONT'D)						
4																
A	44	39	40	35	B 0.032 W 0.040	NA	B.075 W.092	16 A	1A	73	1.67	Yes	2.2	Catastrophic	Airite	No apparent problem
B	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
C	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
D	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
E	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
F	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
G	44	39	40	35	B 0.032 W 0.040	NA	B.075 W.092	16A	1 A	73	1.67	Yes	2.2	Catastrophic	Airite	No apparent problem
5																
A	44	39	40	35	>T	>T	>T	16 A	1A	None	1.67	Yes	2.2	Leak	Airite	OK if no leak in pre-flight pressurization
B	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
C	44	39	40	35	>T	>T	>T	16 A	1A	NONE	1.67	Yes	2.2	Leak	Airite	OK if no leak in pre-flight pressurization

SUMMARY-SATURN V
AS-503
APOLLO LAUNCH VEHICLE PRESSURE VESSELS FRACTURE MECHANICS ASSESSMENT

NO.	VESSEL DESIGNATION: PART NUMBER / NAME / SERIAL NUMBER	MATERIAL CONDITION: BASE MATERIAL & CONDITION	WELD FILLER	WELD METHOD	VESSEL CONFIGURATION AND DIMENSIONS: SHAPE	DIAMETER (INCHES)	LENGTH (INCHES)	WALL THICKNESS (INCHES)	TEMPERATURE °F: DESIGN	OPERATION	PROOF	PRESSURE (PSIG): DESIGN	OPERATING MAX	PROOF	BURST	FLUID: OPERATING	TEST PROOF	ALLOWABLES USED BY DESIGN ACTIVITY: BASE METAL	WELD METAL
	S-IC BOEING (CONT'D)																		
5	Nitrogen Sphere 60B52111-1B (CONT)																		
D	S/N 0000042	Forged Ti6Al4V 60B32534	Ti6Al-4V BAC 5947	TIG	Sphere	12.33	--	B 0.110 W 0.124	70	-65 to +165	77+18	750 (3600)	750	1250	1650 (Actual 6300)	He	H_2O	MIL-HDBK-5A	MIL-HDBK-5A
E	S/N 0000070	Forged Ti6Al4V 60B32534	Ti6Al-4V BAC 5947	TIG	Sphere	12.33	--	B 0.110 W 0.124	70	-65 to +165	77+18	750 (3600)	750	1250	1650 (Actual 6300)	He	H_2O	MIL-HDBK-5A	MIL-HDBK-5A
6	Retro Rocket-Solid Prop. Motor Case TE 424 60B470001 (8 per stage)																		
A	S/N F7	Ladish D6AC Steel 200 KSI Yield	17-22 AS	TIG	Cylinder Eliptical 7.5 MA 4.7 mi	15.524	80.31	D 0.106 C 0.098 C 0.262 W 0.119	170	-65 to +170	AMB.	1862	1862	2175	2965	Solid Propellant	H_2O	MIL-HDBK-5A	MIL-HDBK-5A
B	S/N F10																		
C	S/N F11																		
D	S/N F12																		
E	S/N F14																		
F	S/N F15																		
G	S/N F16																		
H	S/N F17	D6AC STEEL	17-22	TIG	Cyl.	15.524	80.31	C.098 W.119	170	-65 to +170	AMB	1862	1862	2175	2965	S.P.	H_2O	MIL-HDBK-5A	MIL-HDBK-5A

SUMMARY-SATURN V
AS-503
APOLLO LAUNCH VEHICLE PRESSURE VESSELS FRACTURE MECHANICS ASSESSMENT

NO.	K_{IC} KSI(IN)1/2 BASE METAL	K_{IC} KSI(IN)1/2 WELD METAL	K_{TH} Thresh'd Values (Oper. Fluid) KSI(IN)1/2 BASE METAL	K_{TH} Thresh'd Values (Oper. Fluid) KSI(IN)1/2 WELD METAL	FLAW SIZE (INCHES) SCREENED BY PROOF	FLAW SIZE (INCHES) CRIT	FLAW SIZE (INCHES) THRESHOLD CRITICAL OPERATING	PRESSURE CYCLES EXPERIENCED	SERVICE LIFE OPERATING PRESSURE (Operating Fluid) ANTICIAPTED PRESSURE CYCLES	SERVICE LIFE OPERATING PRESSURE (Operating Fluid) GUARANTEED BY PROOF TEST	PROOF FACTOR MIN. PROOF PRESSURE / MAX. OPER. PRESSURE	PROOF FACTOR ADEQUACY	BURST FACTOR MIN. BURST PRESSURE / MAX. OPER. PRESSURE	PROBABLE FAILURE MODE	MANUFACTURER OR SOURCE	REMARKS
										S-IC	BOEING	(CONT'D)				
5	(CONT)															
D	44	39	40	35	> T	>T	>T	16 A	1A	NONE	1.67	YES	2.2	Leak	Airite	OK if no leak in pre-flight pressurization
E	44	39	40	35	>T	>T	>T	16 A	1A	NONE	1.67	YES	2.2	Leak	Airite	OK
6																
A	90	60	81	54	D 0.091 C 0.053 C 0.227 W 0.043	>T C 0.074 >T W 0.070	D >T C 0.062 C > T W 0.054	NA	NA	1	1.17	Yes	1.6	Catastrophic	Thiokol	Must be carefully protected from moisture
B	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
C	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
D	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
E	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
F	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
G	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
H	90	60	81	54	C.053 W.043	C.074 0.070	C.062 W.054	NA	NA	1	1.17	YES	1.6	Catastrophic	Thiokol	Must be carefully protected from moisture

SUMMARY-SATURN V
AS-503
APOLLO LAUNCH VEHICLE PRESSURE VESSELS FRACTURE MECHANICS ASSESSMENT

NO.	VESSEL DESIGNATION: PART NUMBER / NAME / SERIAL NUMBER	MATERIAL CONDITION: BASE MATERIAL & CONDITION	MATERIAL CONDITION: WELD FILLER	MATERIAL CONDITION: WELD METHOD	VESSEL CONFIGURATION AND DIMENSIONS: SHAPE	DIA-METER (INCHES)	LENGTH (INCHES)	WALL THICK-NESS (INCHES)	TEMPERATURE °F: DESIGN	TEMPERATURE °F: OPER-ATION	TEMPERATURE °F: PROOF	PRESSURE (PSIG): DESIGN	PRESSURE (PSIG): OPER-ATING MAX	PRESSURE (PSIG): PROOF	PRESSURE (PSIG): BURST	FLUID: OPER-ATING	FLUID: TEST PROOF	ALLOWABLES USED BY DESIGN ACTIVITY: BASE METAL	ALLOWABLES USED BY DESIGN ACTIVITY: WELD METAL
	S-II NORTH AMERICAN ROCKWELL																		
1	Liquid Hydrogen Propellant Tank P/N V7-312003 (1 per stage)																		
A	S/N 503	2014-T6	2319 4043	TIG MA01-0701-6F	Domed Cylin-der	396	623	FD B.122 (.102) W.245 CB.151 CW.310	-423	-423	-423	36.0 to 42.8	33.0 to 35.5	36.1 to 37.6	46.8 to 55.7	LH_2	Air LH_2	MIL-HDBK-5A	41 UTS @ -423°F (SID 65-1676)
2	Liquid Oxygen Propellant Tank P/N V7-313002-973																		
A	S/N 503	2014-T6	2319 4043	TIG MA01-0701-6F	Spher-oidal	396	392.6	B.141 W.235	-297	-297	RT	42.0 to 81.4	37.5 to 72.2	59.8 to 74.3	54.7 to 106	LOX	Air LN_2	MIL-HDBK-5A	33 UTS @ -300°F (SID 65-1676)
3	Helium Receiver ME 282-0010-0002 (Pneu. Control and He Injection)(2 per stage)																		
A	S/N 00407ABJ0013	Forged Ti6Al4V STA LA0111-008	Ti6Al 4V MA010 7-001	TIG	Sphere	16.928	--	B.230 W.326	-250 to +160	-50 to +160	RT	3250	3250	5000	8000	He	He H_2O	MIL-HDBK-5A	MIL-HDBK-5A
B	S/N 00407ABJ0007	T16AL4V	6AL 4V	TIG	Sphere	16928	--	B.230 W.326	+160 max	+160 max	RT	3250	3250	5000	8000	He	He H_2O	MIL-HDBK-5A	MIL-HDBK-5A
4	Helium Surge Press. Receiver ME 282-0036-0002 (Pneu. Control) (2 per stage)																		
A	S/N 1010AD00022	Forged Ti6Al4V STA LA0111-008	Ti6Al 4V MA010 7-001	TIG	Sphere	10050	--	B.072 W.096	-50 to +160	-50 to +160	RT	800	800	2000	4000	He	He N_2 H_2O	155 KSI UTS 145 KSI Yield 10% Elong	130 UTS
B	S/N 10106AD00046																		

F D = Forward Dome   C = Cylinder   B = Base Metal   W = Weld and Haz

SUMMARY-SATURN V
AS-503
APOLLO LAUNCH VEHICLE PRESSURE VESSELS FRACTURE MECHANICS ASSESSMENT

NO.	K_{IC} KSI(IN)1/2 BASE METAL	K_{IC} KSI(IN)1/2 WELD METAL	K_{TH} Thresh'd Values (Oper. Fluid) KSI(IN)1/2 BASE METAL	K_{TH} Thresh'd Values (Oper. Fluid) KSI(IN)1/2 WELD METAL	FLAW SIZE (INCHES) SCREENED BY PROOF	FLAW SIZE (INCHES) CRIT	FLAW SIZE (INCHES) THRESHOLD CRITICAL OPERATING	PRESSURE CYCLES EXPERIENCED	SERVICE LIFE OPERATING PRESSURE (Operating Fluid) ANTICIAPTED PRESSURE CYCLES	SERVICE LIFE OPERATING PRESSURE (Operating Fluid) GUARANTEED BY PROOF TEST	PROOF FACTOR MIN.PROOF PRESSURE / MAX. OPER.PRESSURE	PROOF FACTOR ADEQUACY	BURST FACTOR MIN.BURST PRESSURE / MAX. OPER-PRESSURE	PROBABLE FAILURE MODE	MANUFACTURER OR SOURCE	REMARKS
									S-II NORTH AMERICAN ROCKWELL							
1																
A	40 (-423 °F)	16.5 (-423 °F)	40 (-423 °F)	16.5 (-423 °F)	.077	N/A	.084	None after Cryogenic pfoof test	1 CDDT 80 sec max at 18 psi max	1 Cycle to operating pressure for flight time	1.06	Yes	1.57	Catastropic	NR Seal Beach	No apparent problem for flight time
2																
A	27 (-297 °F)	14.5 (-297 °F)	27 (-297 °F)	14.5 (-297 °F)	NA	N/A	NA	1 S.F.cycle 280 sec. at 26.8 pst max. 1-C.P.cycle a 24.3 psi max.	1 CDDT 150 sec. at 26.8 psi max.	NONE	1.03	No	1.47	Catastropic	NR Seal Beach	Adequacy verified by analyses and NDT inspection
3																
A	44 RT 40 -50°F	39 RT 34 -50°F	36 -50°F	31 -50°F	B 0.060 W 0.090	B .117 W .170	B0.096 W0.140	16 A	1 A	48	1.54	Yes	2.46	Catastropic	Airite	Appears OK
B	44	39	36	31	B.060 W.090	B .117 W .170	B.096 W.140	16 A	1 A	48	1.54	Yes	2.46	Catastropic	Airite	Appears OK
4																
A	44 RT 40 -50°F	39 RT 34 -50°F	36 -50°F	31 -50°F	B .053 W .073	>T >T	>T >T	16 A	1 A	161	2.5	Yes	5.0	Leak	Airtek	Appears OK
B																

S.F. = Static Firing CDDT = Count Down Demonstration Test C.P. = Cryogenic Proof Test B = Base Metal W = Weld & HAZ

D5-15782

SUMMARY-SATURN V
AS-503
APOLLO LAUNCH VEHICLE PRESSURE VESSELS FRACTURE MECHANICS ASSESSMENT

NO.	VESSEL DESIGNATION (PART NUMBER / NAME / SERIAL NUMBER)	MATERIAL CONDITION: BASE MATERIAL & CONDITION	MATERIAL CONDITION: WELD FILLER	MATERIAL CONDITION: WELD METHOD	VESSEL CONFIGURATION AND DIMENSIONS: SHAPE	DIAMETER (INCHES)	LENGTH (INCHES)	WALL THICKNESS (INCHES)	TEMPERATURE °F: DESIGN	TEMPERATURE °F: OPERATION	TEMPERATURE °F: PROOF	PRESSURE (PSIG): DESIGN	PRESSURE (PSIG): OPERATING MAX	PRESSURE (PSIG): PROOF	PRESSURE (PSIG): BURST	FLUID: OPERATING	FLUID: TEST PROOF	ALLOWABLES USED BY DESIGN ACTIVITY: BASE METAL	ALLOWABLES USED BY DESIGN ACTIVITY: WELD METAL
	S-II NORTH AMERICAN ROCKWELL (CONT'D)																		
5	Accumulator Reservoir MC282-0028 (Hydraulic System)(4 per stage)																		
A	S/N 06553C101736	Forged SAE4340 MIL-A-7190A 195 KSI-UTS	No Weld	--	Capped Cylinder	5.808	20.6	0.167	-65 to +275	0 to +200	RT	3650	3650	5500 (3 min	9200	N_2 (Oil)	N_2 (Oil)	MIL-HDBK-5A	NO WELD
B	S/N 06553C101739	↓	↓		↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
C	S/N 06553C101740	↓	↓		↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
D	S/N 06553C101743	Forged SAE 4340 MIL-A-7190A 195 KSI	No Weld	--	Capped Cylinder	5.808	20.6	0.167	-65 to +275	0 to +200	RT	3650	3650	5500 (3 min	9200	N_2 (Oil)	N_2 (Oil)	MIL-HDBK-5A	NO WELD
6	Accumulator Reservoir MC 282-0028A (Hydraulic System)(4 per stage)																		
A	S/N 06553C101736A	Forged 6061-T6 QQ-A-367	No Weld	--	Capped Cylinder	8.62	8.5	0.094	-65 to +275	0 to +200	RT	100	100	300	600	N_2 Oil	N_2 Oil	MIL-HDBK-5A	NO WELD
B	S/N 06553C101739A	↓	↓		↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
C	S/N 06553C101740A	↓	↓		↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
D	S/N 06553C101743A	Forged 6061-T6 QQ-A-367	No Weld	--	Capped Cylinder	8.62	8.5	0.094	-65 to +275	0 to +200	RT	100	100	300	600	N_2 Oil	N_2 Oil	MIL-HDBK-5A	NO WELD

B = Base Weld W = Weld STA = Solution Treated and Aged Ann = Annealed

SUMMARY-SATURN V
AS-503
APOLLO LAUNCH VEHICLE PRESSURE VESSELS FRACTURE MECHANICS ASSESSMENT

NO.	K_{IC} KSI(IN)1/2 BASE METAL	K_{IC} KSI(IN)1/2 WELD METAL	K_{TH} Thresh'd Values (Oper. Fluid) KSI(IN)1/2 BASE METAL	K_{TH} KSI(IN)1/2 WELD METAL	FLAW SIZE (INCHES) SCREENED BY PROOF	FLAW SIZE CRIT	FLAW SIZE THRESHOLD CRITICAL OPERATING	PRESSURE CYCLES EXPERIENCED	SERVICE LIFE OPERATING PRESSURE (Operating Fluid) ANTICIAPTED PRESSURE CYCLES	SERVICE LIFE GUARANTEED BY PROOF TEST	PROOF FACTOR MIN.PROOF PRESSURE / MAX. OPER.PRESSURE	PROOF FACTOR ADEQUACY	BURST FACTOR MIN.BURST PRESSURE / MAX. OPER.PRESSURE	PROBABLE FAILURE MODE	MANUFACTURER OR SOURCE	REMARKS
									S-II NORTH AMERICAN ROCKWELL (CONT'D)							
5																
A	120	--	108	-	.162	>T	>T	16 A	1 A	NONE	1.5	Yes	2.5	Leak	North American Rockwell	Leak should not occur during the sustained load of flight
B																
C																
D	120	--	108	-	.162	>T	>T	16 A	1 A	NONE	1.5	Yes	2.5	Leak	NR	No leak will develop
6																
A	50	--	45	--	>T	>T	>T	16 A	1 A	NONE	3.0	Yes	6.0	Leak	NR	No leak will develop during flight
B																
C																
D	50	--	45	--	>T	T	>T	16 A	1 A	NONE	3.0	Yes	6.0	Leak	NR	No leak will develop

T = Thickness W = Weld B = Base Metal

SUMMARY-SATURN V
AS-503
APOLLO LAUNCH VEHICLE PRESSURE VESSELS FRACTURE MECHANICS ASSESSMENT

NO.	VESSEL DESIGNATION: PART NUMBER / NAME / SERIAL NUMBER	MATERIAL CONDITION: BASE MATERIAL & CONDITION	MATERIAL CONDITION: WELD FILLER	MATERIAL CONDITION: WELD METHOD	VESSEL CONFIGURATION AND DIMENSIONS: SHAPE	DIA-METER (INCHES)	LENGTH (INCHES)	WALL THICK-NESS (INCHES) (min)	TEMPERATURE °F: DESIGN	TEMPERATURE °F: OPER-ATION	TEMPERATURE °F: PROOF	PRESSURE (PSIG): DESIGN	PRESSURE (PSIG): OPER-ATING MAX	PRESSURE (PSIG): PROOF	PRESSURE (PSIG): BURST	FLUID: OPER-ATING	FLUID: TEST PROOF	ALLOWABLES USED BY DESIGN ACTIVITY: BASE METAL	ALLOWABLES USED BY DESIGN ACTIVITY: WELD METAL
	S-II NORTH AMERICAN ROCKWELL (CONT'D)																		
7	Ullage Motor Solid Propellant Motor Case ME901-0089E (4 per stage)																		
A	S/N 06-357-014-4200	Forged SAE 4130 Steel 180 KSI Yield	17-22AS	TIG Girth Welds	Domed Cylinder 2-1 Elipse	12.60	68.2	D 0.075 C 0.075 C 0.194 C 0.290 W 0.194	-30 to +155	-30 to +155	RT	1250	1250	1450	1820	Solid Propellant	H_2O	MIL-HDBK-5A	MIL-HDBK-5A
B	S/N 06-357-015-4200	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
C	S/N 06-357-016-4200	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
D	S/N 06-357-016-4200	SAE 4130 18 KSI Yd.	17-22 AS	TIG	Cylinder	12.60	68.2	C.075 W.194	155 max.	155 max.	RT	1250	1250	1450	1820	S.P.	H_2O	MIL-HDBK-5A	MIL-HDBK-5A
8	S-II Retro Rocket-Solid Propellant Motor Case T 15179 1A59670* (4 per stage)																		
A	S/N 6-745-10	Forged SAE 4130 Steel 150 KSI Yield	MIL-W-8611	TIG Girth Welds	Domed Cylinder	9.00	90.65	D 0.130 C 0.077	-10 to +155	-10 to +145	RT	2138	2138	2700	--	Solid Propellant	H_2O	MIL-HDBK-5A	MIL-HDBK-5A
B	S/N 6-745-11	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓		↓	↓	↓	↓
C	S/N 6-745-07	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓		↓	↓	↓	↓
D	S/N 6-756-06	SAE 4130 150 KSI Yield	MIL-W 8611	TIG	Cylinder	9.00	90.65	D 0.130 C 0.077	-10 to +155	-10 to +145	RT	2138	2138	2700	--	S.P.	H_2O	MIL-HDBK-5A	MIL-HDBK-5A

B = Base Metal W = Weld D = Dome Base Metal C = Cylinder Base Metal

SUMMARY-SATURN V
AS-503
APOLLO LAUNCH VEHICLE PRESSURE VESSELS FRACTURE MECHANICS ASSESSMENT

NO.	K_{IC} KSI(IN)1/2 BASE METAL	K_{IC} KSI(IN)1/2 WELD METAL	K_{TH} Thresh'd Values (Oper. Fluid) KSI(IN)1/2 BASE METAL	K_{TH} Thresh'd Values (Oper. Fluid) KSI(IN)1/2 WELD METAL	FLAW SIZE (INCHES) SCREENED BY PROOF	FLAW SIZE (INCHES) CRIT	FLAW SIZE (INCHES) THRESHOLD CRITICAL OPERATING	PRESSURE CYCLES EXPERIENCED	SERVICE LIFE OPERATING PRESSURE (Operating Fluid) ANTICIAPTED PRESSURE CYCLES	SERVICE LIFE OPERATING PRESSURE (Operating Fluid) GUARANTEED BY PROOF TEST	PROOF FACTOR MIN. PROOF PRESSURE / MAX. OPER. PRESSURE	PROOF FACTOR ADEQUACY	BURST FACTOR MIN. BURST PRESSURE / MAX. OPER. PRESSURE	PROBABLE FAILURE MODE	MANUFACTURER OR SOURCE	REMARKS
								S-II NORTH AMERICAN ROCKWELL (CONT'D)								
7																
A	130	120	117	108	>T	>T	>T	NA	NA	NA	1.26	Yes	1.46	Leak **	Rocketdyne	Appears OK
B																
C																
D	130	120	117	108	>T	>T	>T	NA	NA	NA	1.26	Yes	1.46	Leak **	Rocketdyne	OK
8																
A	150	140	135	126	>T	>T	>T	NA	NA	NA	1.26	Yes	1.46	Leak **	Thiokol	*McDonnell-Douglas provides retro-rocket for S-II **Catastrophic failure at dis-continuities possible
B																
C																
D	150	140	135	126	>T	>T	>T	NA	NA	NA	1.26	Yes	1.46	Leak	Thiokol	OK

T=THICKNESS NA=NOT APPLICABLE

SUMMARY-SATURN V
AS-503
APOLLO LAUNCH VEHICLE PRESSURE VESSELS FRACTURE MECHANICS ASSESSMENT

NO.	VESSEL DESIGNATION: PART NUMBER / NAME / SERIAL NUMBER	MATERIAL CONDITION: BASE MATERIAL & CONDITION	WELD FILLER	WELD METHOD	VESSEL CONFIGURATION AND DIMENSIONS: SHAPE	DIAMETER (INCHES)	LENGTH (INCHES)	WALL THICKNESS (INCHES) (min)	TEMPERATURE °F: DESIGN	OPERATION	PROOF	PRESSURE (PSIG): DESIGN	OPERATING MAX	PROOF	BURST	FLUID: OPERATING	TEST PROOF	ALLOWABLES USED BY DESIGN ACTIVITY: BASE METAL	WELD METAL
	S-IVB MCDONNELL DOUGLAS PRESSURE VESSELS																		
1	Liquid Hydrogen Tank P/N 1A39300-509 (1 per stage)																		
A	S/N 1008	Plate 2014-T6	AL4043	MIG DPS 14042	Domed Cyl.	260	429	CB.123 CW.246 DB.060	RT	-75 to +110	RT	37 to 41.5	34.0 to 38.3	38.0	53.1 61.4 Actual	LH_2 Insulated	H_2O Air	MIL-HDBK-5A	32.o UTS at RT .8 of values in SM45961
2	Liquid Oxygen Tank P/N 1A39300-509 (1 per stage)																		
A	S/N 1008	Plate 2014-T6	AL4043	MIG DPS 14042	Spheroidal	260	176.7	B.086 W.191	-297	-270 to -297	RT	44 to 74	41.0 to 68.6	51.6 to 54.2	88.2	LOX	H_2O Air	MIL-HDBK-5A	37.6 UTS at -300° F .8 of values in SM45961
3	Helium Storage Sphere 1B66868 (Repressurization System--1 per stage)																		
A	S/N 115	Forged Ti6Al4V STA 1P20047	Ti6AL 4V-STP 0308	TIG 1P00 128	Sphere	25.268	--	B .334 W .452	-40 to +210	-40 to +120	-40 to +210	3200	3200	4800	8000	He	He H_2O	MIL-HDBK-5A	MIL-HDBK-5A
4	Helium Storage Sphere 1A49990 (Propellant Repressurization System) 8 Per Stage																		
A	S/N 15	Forged Ti6AL4V STA 1P20047	Ti6AL 4V STP 0308	TIG 1P00 128	Sphere	25.268	--	B .334 W .452	-40 to +210	-40 to +120	-40 to +210	3200	3200	4800	8000	He	He H_2O	MIL-HDBK-5A	Mil-HDBK-5A
B	S/N 16	Forged Ti6AL4V STA 1P20047	Ti6AL 4V-STP 0308	TIG 1P00 128	Sphere	25.268	--	B .334 W .452	-40 to +210	-40 to +120	-40 to +210	3200	3200	4800	8000	He	He H_2O	MIL-HDBK-5A	MIL-HDBK-5A

C=CYLINDRICAL B=BASE METAL W=WELD AND WELD HAZ D=DOME

SUMMARY-SATURN V
AS-503
APOLLO LAUNCH VEHICLE PRESSURE VESSELS FRACTURE MECHANICS ASSESSMENT

NO.	K_{IC} KSI(IN)1/2 BASE METAL	K_{IC} KSI(IN)1/2 WELD METAL	K_{TH} Thresh'd Values (Oper. Fluid) KSI(IN)1/2 BASE METAL	K_{TH} KSI(IN)1/2 WELD METAL	FLAW SIZE (INCHES) SCREENED BY PROOF	FLAW SIZE CRIT	FLAW SIZE THRESHOLD CRITICAL OPERATING	PRESSURE CYCLES EXPERIENCED	SERVICE LIFE OPERATING PRESSURE (Operating Fluid) ANTICIAPTED PRESSURE CYCLES	SERVICE LIFE GUARANTEED BY PROOF TEST	PROOF FACTOR MIN. PROOF PRESSURE / MAX. OPER. PRESSURE	PROOF FACTOR ADEQUACY	BURST FACTOR MIN. BURST PRESSURE / MAX. OPER. PRESSURE	PROBABLE FAILURE MODE	MANUFACTURER OR SOURCE	REMARKS
										S-IVB MC	DONNELL	DOUGLAS				
1																
A	27 (RT)	14.6 (RT)	(27) (RT)	(14.6) (RT)	0.139	0.137	.137	1 S.F.Cycle	1 CDDT Cycle	NONE	.99	NO	1.39	Catastrophic	McDonnell Douglas Corp.	Adequacy verified by analyses and NDT inspection
2																
A	27 RT	16.5 (RT)	(40) (-297 °F)	(16.5) (-297 °F)	0.170	124	.124	1 S.F.Cycle	1 CDDT Cycle	NONE	.79	NO	1.28	Leak	McDonnell Douglas Corp.	Adequacy verified by analyses and NDT inspection
3																
A	44 (RT) 41(-400°F)	39RT 34(-400°F)	40RT 37 (-40°F)	35RT 31 (-40°F)	B .062 W .091	B .142 W .202	B .120 W .160	16 A	1 A	32	1.5	YES	2.5	Catastrophic	Airtek McDonnell-Douglas	Looks o.k.
4																
A	44 (RT) 41 (-400°F)	39RT 34 (-40°F)	40RT 37 (-40°F)	35RT 31 (-40°F)	B .062 W .091	B .142 W .202	B .120 W .160	16 A	1 A	32	1.5	YES	2.5	Catastrophic	Airtek McDonnell-Douglas	Looks o.k.
B	44 (RT) 41 (-40°F)	39RT 34 (-40°F)	40RT 37 (-40°F)	35RT 31 (-40°F)	B .062 W .091	B .142 W .202	B .120 W .160	16 A	1 A	32	1.5	YES	2.5	Catastrophic	Airtek McDonnell-Douglas	Looks o.k.

S.F. = STATIC FIRING   CDDT = COUNT DOWN DEMONSTRATION   B= BASE METAL   W = WELD OR WELD HAZ
A=ASSUMED CYCLES

SUMMARY-SATURN V
AS-503
APOLLO LAUNCH VEHICLE PRESSURE VESSELS FRACTURE MECHANICS ASSESSMENT

NO.	VESSEL DESIGNATION: PART NUMBER / NAME / SERIAL NUMBER	MATERIAL CONDITION: BASE MATERIAL & CONDITION	MATERIAL CONDITION: WELD FILLER	MATERIAL CONDITION: WELD METHOD	VESSEL CONFIGURATION AND DIMENSIONS: SHAPE	DIA-METER (INCHES)	LENGTH (INCHES)	WALL THICK-NESS (INCHES)	TEMPERATURE °F: DESIGN	TEMPERATURE °F: OPER-ATION	TEMPERATURE °F: PROOF	PRESSURE (PSIG): DESIGN	PRESSURE (PSIG): OPER-ATING MAX	PRESSURE (PSIG): PROOF	PRESSURE (PSIG): BURST	FLUID: OPER-ATING	FLUID: TEST PROOF	ALLOWABLES USED BY DESIGN ACTIVITY: BASE METAL	ALLOWABLES USED BY DESIGN ACTIVITY: WELD METAL
	S-IVB MCDONNELL DOUGLAS (CONTINUED)																		
4 CONT	Helium Storage Sphere 1A49990 (Repressurization System--8 per stage)																		
C	S/N 22	Forged Ti6AL4V STA 1P20047	Ti6AL 4V-STP 0308	TIG 1P00 128	Sphere	25.268	--	B .334 W .452	-40 to +210	-40 to +120	-40 to +210	3200	3200	4800	8000	He	He H_2O	MIL-HDBK-5A	MIL-HDBK-5A
D	S/N 78	↓	↓	↓	↓	↓		↓	↓	↓	↓	↓	↓	↓	↓		↓	↓	↓
E	S/N 80	↓	↓	↓	↓	↓		↓	↓	↓	↓	↓	↓	↓	↓		↓	↓	↓
F	S/N 81	↓	↓	↓	↓	↓		↓	↓	↓	↓	↓	↓	↓	↓		↓	↓	↓
G	S/N 83	↓	↓	↓	↓	↓		↓	↓	↓	↓	↓	↓	↓	↓		↓	↓	↓
H	S/N 97	Forged Ti6AL4V STA 1P20047	Ti6AL 4V-STP 0308	TIG 1P00 128	Sphere	25.268	--	B .334 W .452	-40 to +210	-40 to _120	-40 to +210	3200	3200	4800	8000	He	He H_2O	MIL-HDBK-5A	MIL-HDBK-5A
5	Helium Control Sphere 1A43857-501 (Pneu. Control System--1 per stage)																		
A	S/N 33	Forged Ti6AL4V Ann. 1P20047	Ti6AL 4V--STP 0308	TIG 1P00 077	Sphere	5.830	--	B .040 W .054	-125 to +160	-125 to +160	RT	1600	1600	2400	4000	He	N_2 H_2O	MIL-HDBK-5A	MIL-HDBK-5A
6	Helium Storage Sphere (COLD) 1A48858-1 (LOX Pressurization and LH_2 LOX Burner Systems--9 per stage)	↓	↓	↓	↓	↓		↓	↓	↓	↓	↓	↓	↓		↓	↓	↓	↓
A	S/N 1107	Forged Ti6AL4V Ann. 1P20047	NO Filler	Pres. Butt Weld 1P00 076	Sphere	8.064	--	B .170 W .182	-412 ±12 to +70	-412 ±12	-423	3200 at -412 ±12°F 750 @ RT	3200	5340 at -423 °F 3500 at RT	7100 at -423 °F	He LH_2	He LH_2	MIL-HDBK-5A	MIL-HDBK-5A

SUMMARY-SATURN V
AS-503
APOLLO LAUNCH VEHICLE PRESSURE VESSELS FRACTURE MECHANICS ASSESSMENT

NO.	K_{IC} KSI(IN)1/2 BASE METAL	K_{IC} KSI(IN)1/2 WELD METAL	K_{TH} Thresh'd Values (Oper. Fluid) KSI(IN)1/2 BASE METAL	K_{TH} Thresh'd Values (Oper. Fluid) KSI(IN)1/2 WELD METAL	FLAW SIZE (INCHES) SCREENED BY PROOF	FLAW SIZE (INCHES) CRIT	FLAW SIZE (INCHES) THRESHOLD CRITICAL OPERATING	PRESSURE CYCLES EXPERIENCED	SERVICE LIFE OPERATING PRESSURE (Operating Fluid) ANTICIPATED PRESSURE CYCLES	SERVICE LIFE OPERATING PRESSURE (Operating Fluid) GUARANTEED BY PROOF TEST	PROOF FACTOR MIN. PROOF PRESSURE / MAX. OPER. PRESSURE	PROOF FACTOR ADEQUACY	BURST FACTOR MIN. BURST PRESSURE / MAX. OPER. PRESSURE	PROBABLE FAILURE MODE	MANUFACTURER OR SOURCE	REMARKS
4								S-IVB	MCDONNELL	DOUGLAS	(CONTINUED)					
C	44 (RT) 41(-40°F)	39RT 34 (-40°F)	40RT 37(-40°F)	35RT 31(-40°F)	B .062 W .091	B .142 W .202	B .120 W .160	16 A	1A	32	1.5	YES	2.5	Catastrophic	Airtek McDonnell-Douglas	Looks OK
D																
E																
F																
G	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
H	44 (RT) 41(-40°F)	39RT 34(-40°F)	40RT 37(-40°F)	35RT 31(-40°F)	B .062 W .091	B .142 W .202	B .120 W .160	16 A	1A	32	1.5	YES	2.5	Catastrophic	Airtek McDonnell-Douglas	Looks OK
5																
A	44RT 40(-25°F)	39RT 33(-125°F)	40RT 36(-125°F)	35RT 30(-125°F)	B .029 W .039	B .053 W .072	BO .038 W .050	16 A	1A	22	1.5	YES	2.5	Catastrophic	Airtek McDonnell-Douglas	Looks OK
6	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
A	71RT 53(-423°F)	50RT 40(-423°F)	64RT 48(-423°F)	45RT 36(-423°F)	B .022 W .015	B .072 W .055	B .063 W .041	7	1	297	1.67	YES	2.2	Catastrophic	Menasco	Looks OK

B=BASE METAL A=ASSUMED CYCLES W=WELD AND WELD HAZ

SUMMARY-SATURN V
AS-503
APOLLO LAUNCH VEHICLE PRESSURE VESSELS FRACTURE MECHANICS ASSESSMENT

NO.	VESSEL DESIGNATION: PART NUMBER / NAME / SERIAL NUMBER	MATERIAL CONDITION: BASE MATERIAL & CONDITION	MATERIAL CONDITION: WELD FILLER	MATERIAL CONDITION: WELD METHOD	VESSEL CONFIGURATION AND DIMENSIONS: SHAPE	DIA-METER (INCHES)	LENGTH (INCHES)	WALL THICK-NESS (INCHES)	TEMPERATURE °F: DESIGN	TEMPERATURE °F: OPER-ATION	TEMPERATURE °F: PROOF	PRESSURE (PSIG): DESIGN	PRESSURE (PSIG): OPER-ATING MAX	PRESSURE (PSIG): PROOF	PRESSURE (PSIG): BURST	FLUID: OPER-ATING	FLUID: TEST PROOF	ALLOWABLES USED BY DESIGN ACTIVITY: BASE METAL	ALLOWABLES USED BY DESIGN ACTIVITY: WELD METAL
							S-IVB MCDONNELL DOUGLAS (CONTINUED)												
6	Helium Storage Sphere (COLD) 1A48858-1 (LOX Pressurization and LH_2 LOX Burner Systems -- 9 per stage)																		
B	S/N 1117	Forged Ti6A14V Ann. 1P20047	No Filler	Pres. Butt Weld 1P00 076	Sphere	8.064	--	B.170 W.182	-412 ± 12 to +70	-412 ± 12	-423	3200 at -412 ±12°F 750 @ RT	3200	5340 at -423 °F 3500 at RT	7100 at -423 °F	He LH_2	He LH_2	MIL-HDBK-5A	MIL-HDBK-5A
C	S/N 1121																		
D	S/N 1124																		
E	S/N 1136																		
F	S/N 1142																		
G	S/N 1144																		
H	S/N 1149																		
I	S/N 1152	Forged Ti6A14V Ann. 1P20047	No Filler	Pres. Butt Weld 1P00 076	Sphere	8.064	--	B.170 W.182	-412 ±12 to +70	-412 ±12	-423	3200 at -412 ±12°F 750 @ RT	3200	5340 at -423 °F 3500 at RT	7100 at -423 °F	He LH_2	He LH_2	MIL-HDBK-5A	MIL-HDBK-5A
7	Helium Cold Sphere 1A49991 (LOX Pressurization and LH_2/LOX Burner Systems---3 per stage)																		
A	S/N 24	Forged Ti6A14V Ann. 1P20047	No Filler	Pres. Butt Weld 1P00 076	Sphere	8.064	--	B.082 W.082	-423 to +160	-423	-423	2000	2000	3000	5000@ -423 °F	He LH_2	He LH_2	MIL-HDBK-5A	MIL-HDBK-5A

B=BASE METAL W=WELD AND WELD HAZ

SUMMARY-SATURN V
AS-503
APOLLO LAUNCH VEHICLE PRESSURE VESSELS FRACTURE MECHANICS ASSESSMENT

NO.	K_{IC} KSI(IN)1/2 BASE METAL	K_{IC} KSI(IN)1/2 WELD METAL	K_{TH} Thresh'd Values (Oper. Fluid) KSI(IN)1/2 BASE METAL	K_{TH} Thresh'd Values (Oper. Fluid) KSI(IN)1/2 WELD METAL	FLAW SIZE (INCHES) SCREENED BY PROOF	FLAW SIZE (INCHES) CRIT	FLAW SIZE (INCHES) THRESHOLD CRITICAL OPERATING	PRESSURE CYCLES EXPERIENCED	SERVICE LIFE OPERATING PRESSURE (Operating Fluid) ANTICIAPTED PRESSURE CYCLES	SERVICE LIFE OPERATING PRESSURE (Operating Fluid) GUARANTEED BY PROOF TEST	PROOF FACTOR MIN. PROOF PRESSURE / MAX. OPER. PRESSURE	PROOF FACTOR ADEQUACY	BURST FACTOR MIN. BURST PRESSURE / MAX. OPER. PRESSURE	PROBABLE FAILURE MODE	MANUFACTURER OR SOURCE	REMARKS
6	S-IVB MCDONNELL DOUGLAS (CONTINUED)															
B	71 RT 53(-423 °F)	50RT 40(-423 °F)	64RT 48(-423 °F)	45RT 36(-423 °F)	B .022 W .015	B .072 W .055	B .063 W .041	7	1	297	1.67	YES	2.2	Catastrophic	Menasco	Looks o.k.
C																
D																
E																
F																
G																
H																
I	71RT 53(-423 °F)	50RT 40(-423 °F)	64RT 48(-423 °F)	45RT 36(-423 °F)	B .022 W .015	B .072 W .055	B .063 W .041	7	1	297	1.67	YES	2.2	Castastrophic	Menasco	Looks o.k.
7																
A	71RT 53(-423 °F)	50RT 40(-423 °F)	64RT 48(-423 °F)	45RT 36(-423 °F)	B .065 W .050	>T >T	B >T W .073	16A	1A	38	1.5	YES	2.5	Catastrophic	Menasco	Looks o.k.

T=Thickness C=Cylinder Base Metal A=Assumed Cycles

SUMMARY-SATURN V
AS-503
APOLLO LAUNCH VEHICLE PRESSURE VESSELS FRACTURE MECHANICS ASSESSMENT

NO.	VESSEL DESIGNATION: PART NUMBER / NAME / SERIAL NUMBER	MATERIAL CONDITION: BASE MATERIAL & CONDITION	MATERIAL CONDITION: WELD FILLER	MATERIAL CONDITION: WELD METHOD	VESSEL CONFIGURATION AND DIMENSIONS: SHAPE	DIAMETER (INCHES)	LENGTH (INCHES)	WALL THICKNESS (INCHES)	TEMPERATURE °F: DESIGN	TEMPERATURE °F: OPERATION	TEMPERATURE °F: PROOF	PRESSURE (PSIG): DESIGN	PRESSURE (PSIG): OPERATING MAX	PRESSURE (PSIG): PROOF	PRESSURE (PSIG): BURST	FLUID: OPERATING	FLUID: TEST PROOF	ALLOWABLES USED BY DESIGN ACTIVITY: BASE METAL	ALLOWABLES USED BY DESIGN ACTIVITY: WELD METAL
	S-IVB MCDONNELL DOUGLAS (CONTINUED)																		
7	Helium Cold Sphere 1A49991 (LOX Pressurization and LH_2/LOX Burner Systems--3 per stage)																		
B	S/N 77	Forged Ti6Al4V Ann. 1P20047	No Filler	Pres. Butt Weld 1P00 076	Sphere	8.064	--	B.082 W.082	-423 to +160	-423	-423	2000	2000	3000	5000@ -423 °F	He LH_2	He LH_2	MIL-HDBK-5A	MIL-HDBK-5A
C	S/N 80	Forged Ti6Al4V Ann. 1P20047	No Filler	Pres. Butt Weld 1P00 076	Sphere	8.064	--	B.082 W.082	-423 to +160	-423	-423	2000	2000	3000	5000@ -423 °F	He LH_2	He LH_2	MIL-HDBK-5A	MIL-HDBK-5A
8	Air Tank 1B55725-1 1B55408 (Auxiliary Hydraulic System---1 per stage)																		
A	S/N 11	Forged Ti6Al4V Ann. 1P20047	No filler	Pres. Butt WELD 1P00 076	Sphere	8.064	--	B.072 W.072	-80 to +160	-80 to +160	RT	600	600	1200	2400	Air	H_2O Air	MIL-HDBK-5A	MIL-HDBK-5A
9	Accumulator 1B29312 (Hydraulic System--High Pressure--1 per stage)																		
A	S/N 54	Forged Ti6Al4V Ann, 1P20047	No Weld	No Weld	Domed cyl.	5.00	19	D.285 C.260	-35 to +275	-35 to +275	RT	3650	3650	7300	14000	N_2 (Oil)	H_2O N_2	MIL-HDBK-5A	NO WELD

SUMMARY-SATURN V
AS-503
APOLLO LAUNCH VEHICLE PRESSURE VESSELS FRACTURE MECHANICS ASSESSMENT

NO.	K_{IC} KSI(IN)1/2 BASE METAL	K_{IC} KSI(IN)1/2 WELD METAL	K_{TH} Thresh'd Values (Oper. Fluid) KSI(IN)1/2 BASE METAL	K_{TH} KSI(IN)1/2 WELD METAL	FLAW SIZE (INCHES) SCREENED BY PROOF	FLAW SIZE CRIT	FLAW SIZE THRESHOLD CRITICAL OPERATING	PRESSURE CYCLES EXPERIENCED	SERVICE LIFE OPERATING PRESSURE (Operating Fluid) ANTICIAPTED PRESSURE CYCLES	SERVICE LIFE GUARANTEED BY PROOF TEST	PROOF FACTOR MIN. PROOF PRESSURE / MAX. OPER. PRESSURE	PROOF FACTOR ADEQUACY	BURST FACTOR MIN. BURST PRESSURE / MAX. OPER. PRESSURE	PROBABLE FAILURE MODE	MANUFACTURER OR SOURCE	REMARKS
									S-IVB MCDONNELL DOUGLAS (CONTINUED)							
7																
B	71RT 53(-423 °F)	50RT 40(-423 °F)	64RT 48(-423 °F)	45RT 36(-423 °F)	B .022 W .015	B .072 W .055	B .063 W .041	16A	1A	38	1.5	YES	2.5	Catastrophic	Menasco	looks o.k.
C	71RT 53(-423 °F)	50RT 40(-423 °F)	64RT 48(-423 °F)	45RT 36(-423 °F)	B .022 W .015	B .072 W .055	B .063 W .041	16A	1A	38	1.5	YES	2.5	Catastrophic	Menasco	looks o.k.
8																
A	71RT 71(-80°F)	50RT 50(-80°F)	64	45	B>T W>T	B>T W>T	B>T W>T	16A	1A	NONE	2.0	YES	4.0	Leak	Menasco	if bottle does not leak during pre-flight pres.- leak should not develop during flight.
9																
A	44	-	40	-	D>T C .165	D>T C>T	D>T C>T	16A	1A	NONE	2.0	YES	3.9	Leak	Bertea Products	if cylinder does not leak in preflight pressurization no leak in flight should occur.

T=THICKNESS C=CYLINDER BASE METAL D=DOME B=BASE METAL W=WELD AND WELD HAZ A=ASSUMED CYCLES

SUMMARY-SATURN V
AS-503
APOLLO LAUNCH VEHICLE PRESSURE VESSELS FRACTURE MECHANICS ASSESSMENT

NO.	VESSEL DESIGNATION: PART NUMBER / NAME / SERIAL NUMBER	MATERIAL CONDITION: BASE MATERIAL & CONDITION	WELD FILLER	WELD METHOD	VESSEL CONFIGURATION AND DIMENSIONS: SHAPE	DIAMETER (INCHES)	LENGTH (INCHES)	WALL THICKNESS (INCHES)	TEMPERATURE °F: DESIGN	OPERATION	PROOF	PRESSURE (PSIG): DESIGN	OPERATING MAX	PROOF	BURST	FLUID: OPERATING	TEST PROOF	ALLOWABLES USED BY DESIGN ACTIVITY: BASE METAL	WELD METAL
	S-IVB MCDONNELL DOUGLAS (CONTINUED)																		
10	Accumulator Housing and Cap 1A83362-501 1A83361-1 (Hydraulic System Low Pressure-- 1 per stage)																		
A	S/N50	Forged Al2014 -T652 QQ-A-367	No Weld	No Weld	Domed cyl. 3.56D Dome	7.874	7.00	D.198 C.218	-35 to +275	-35 to +275	RT	180	180	465	775	Oil	N_2	MIL-HDBK-5A	
11	Helium Expulsion Tank (Teflon Bladder) N_2O_4 - MMH 1B39468 (Auxiliary Propulsion System--2 per stage)																		
A	S/N 21	Forged Dome Sheet Cyl. Ti6Al4V STA	No filler	TIG 1P00 077	Domed Cyl.	12.50	39	D.040 W.040 C.025	+40 to +105	-40 to +105	RT	200	200	413	550	He (MMH) (N_2O_4)	He H_2O	MIL-HDBK-5A	MIL-HDBK-5A
B	S/N 22	Forged Dome Sheet Cyl. Ti6Al4V STA	No Filler	TIG 1P00 077	Domed Cyl.	12.50	39	D.040 W.040 C.025	+40 to +105	-40 to +105	RT	200	200	413	550	He (MMH) (N_2O_4)	He H_2O	MIL-HDBK-5A	Mil-HDBK-5A
12	Helium Tank 1B39317 (Auxiliary Propulsion System, Pressurization --2 per stage)																		
A	S/N12	Forged Dome Ti6Al4V STA Cyl. Ann.	Ti6Al 4V AMS 4954	TIG 1P00 077	Dome Cyl.	8.0	32	D 194 W.194 C.185	+70 to +165	+70 to +165	RT	3100	3100	4800	7200	He	He H_2O	Mil-HDBK-5A	MIL-HDBK-5A

D=DOME C=CYLINDER SECTION W=WELD AND WELD HAZ

SUMMARY-SATURN V
AS-503
APOLLO LAUNCH VEHICLE PRESSURE VESSELS FRACTURE MECHANICS ASSESSMENT

NO.	K_{IC} KSI(IN)1/2		K_{TH} Thresh'd Values (Oper. Fluid) KSI(IN)1/2		FLAW SIZE (INCHES)			PRESSURE CYCLES EXPERIENCED	SERVICE LIFE OPERATING PRESSURE (Operating Fluid)		PROOF FACTOR		BURST FACTOR	PROBABLE FAILURE MODE	MANUFACTURER OR SOURCE	REMARKS
	BASE METAL	WELD METAL	BASE METAL	WELD METAL	SCREENED BY PROOF	CRIT	THRESHOLD CRITICAL OPERATING		ANTICIAPTED PRESSURE CYCLES	GUARANTEED BY PROOF TEST	MIN. PROOF PRESSURE / MAX. OPER. PRESSURE	ADEQUACY	MIN. BURST PRESSURE / MAX. OPER. PRESSURE			
10									S-IVB MCDONNELL DOUGLAS (CONTINUED)							
A	25	-	22	-	D>T C>T	D>T C>T	D>T C>T	16A	1A	NONE	2.57	YES	4.3	Leak	Bertea Products	if tank does not leak in preflight pressurization it should be o.k. for flight.
11																
A	44	39	31	27	D>T W.038 C.021	D>T W>T C>T	D>T W>T C T	16A	1A	NONE	2.06	YES	2.75	Leak	Bell Aerospace Systems	if tank does not leak in preflight pressurization it should be o.k. for flight.
B	44	39	31	27	D>T W.038 C.021	D>T W>T C>T	D>T W>T C>T	16A	1A	NONE	2.06	YES	2.75	Leak	Bell Aerospace Systems	if tank does not leak in preflight pressurization it should be o.k. for flight.
12																
A	44	39	40	36	D T W.142 C.045	D T W>T C .097	D>T W>T C.088	16A	1A	C 158 W 60	1.55	YES	2.3	Catastrophic	1. Pressure systems 2. McDonnell Douglas	looks o.k.

D=Dome W=Weld and Weld Haz A=Assumed Cycles
T=Thickness C=Cylinder Base Metal NA=Not Applicable

SUMMARY-SATURN V
AS-503
APOLLO LAUNCH VEHICLE PRESSURE VESSELS FRACTURE MECHANICS ASSESSMENT

NO.	VESSEL DESIGNATION: PART NUMBER / NAME / SERIAL NUMBER	MATERIAL CONDITION: BASE MATERIAL & CONDITION	WELD FILLER	WELD METHOD	VESSEL CONFIGURATION AND DIMENSIONS: SHAPE	DIA-METER (INCHES)	LENGTH (INCHES)	WALL THICK-NESS (INCHES)	TEMPERATURE °F: DESIGN	OPER-ATION	PROOF	PRESSURE (PSIG): DESIGN	OPER-ATING MAX	PROOF	BURST	FLUID: OPER-ATING	TEST PROOF	ALLOWABLES USED BY DESIGN ACTIVITY: BASE METAL	WELD METAL
							S-IVB MCDONNELL DOUGLAS (CONTINUED)												
12	Helium Tank 1B39317 (Auxiliary Propulsion System, Pressurization --2 per stage)																		
B	S/N 09	Forged Dome Ti6Al4V STA Cyl. Ann.	Ti6Al 4V AMS 4954	TIG 1P00 077	Dome Cyl	8 0	32	D.194 W.194 C 185	+70 to +165	+70 to +165	RT	3100	3100	4800	7200	He	He	MIL-HDBK-5A	MIL-HDBK-5A
13	Solid Propellant Motor Case 1A81960 Thiokol FR280 (Ullage Motor-G Force for start up--2 per stage)																		
A	S/N K 801-7	Forged SAE4135 190 KSI Yd MIL-T-6735	17-22 AS Girth Weld	TIG	Dome Cyl. Elips-oidal Dome 2:1	8.313	22.92	D.054 C.054 C.-79	-30 to +155	-30 to +145	RT	1390	1390	2200	--	Solid Pro-pell-ant	H_2O	MIL-HDBK-5A	Mil-HDBK-5A
B	S/N K 801-8	Forged SAE4135 190 KSI Yd MIL-T-6735	17-22 AS Girth Weld	TIG	Dome Cyl. Elips-oidal Dome	8.313	22.92	D.054 C.054 C.-79	-30 to +155	-30 to +145	RT	1390	1390	2200	--	S.P.	H_2O	MIL-HDBK-5A	MIL-HDBK-5A

SUMMARY-SATURN V
AS-503
APOLLO LAUNCH VEHICLE PRESSURE VESSELS FRACTURE MECHANICS ASSESSMENT

NO.	K_{IC} KSI(IN)1/2 BASE METAL	K_{IC} KSI(IN)1/2 WELD METAL	K_{TH} Thresh'd Values (Oper. Fluid) KSI(IN)1/2 BASE METAL	K_{TH} KSI(IN)1/2 WELD METAL	FLAW SIZE (INCHES) SCREENED BY PROOF	FLAW SIZE CRIT	FLAW SIZE THRESHOLD CRITICAL OPERATING	PRESSURE CYCLES EXPERIENCED	SERVICE LIFE OPERATING PRESSURE (Operating Fluid) ANTICIAPTED PRESSURE CYCLES	SERVICE LIFE GUARANTEED BY PROOF TEST	PROOF FACTOR MIN. PROOF PRESSURE / MAX. OPER. PRESSURE	PROOF FACTOR ADEQUACY	BURST FACTOR MIN. BURST PRESSURE / MAX. OPER. PRESSURE	PROBABLE FAILURE MODE	MANUFACTURER OR SOURCE	REMARKS
12									S-IVB MCDONNELL DOUGLAS (CONTINUED)							
B	44	39	40	36	D->T W.142 C.045	D->T W>T C.097	D->T W->T C.088	16A	1A	C 158	1.55	YES	2.3	Catastrophic	1. Pressure systems 2. McDonnell Douglas	looks o.k.
13																
A	90	60	81	54	D.040 C.068	D>T C>T	D->T C->T	NA	NA	NA	1.58	YES	NA	Leak	Thiokol	looks o.k.
B	90	60	81	54	D.040 C.068	D>T C>T	D->T C->T	NA	NA	NA	1.58	YES	NA	Leak	Thiokol	looks o.k.

T=Thickness C=Cylindrical Base Metal NA=Not Applicable

SUMMARY-SATURN V
AS-503
APOLLO LAUNCH VEHICLE PRESSURE VESSELS FRACTURE MECHANICS ASSESSMENT

NO.	VESSEL DESIGNATION: PART NUMBER / NAME / SERIAL NUMBER	MATERIAL CONDITION: BASE MATERIAL & CONDITION	WELD FILLER	WELD METHOD	VESSEL CONFIGURATION AND DIMENSIONS: SHAPE	DIA-METER (INCHES)	LENGTH (INCHES)	WALL THICK-NESS (INCHES)	TEMPERATURE °F: DESIGN	OPER-ATION	PROOF	PRESSURE (PSIG): DESIGN	OPER-ATING MAX	PROOF	BURST	FLUID: OPER-ATING	TEST PROOF	ALLOWABLES USED BY DESIGN ACTIVITY: BASE METAL	WELD METAL
									IU - IBM										
1 A	Gas bearing sphere 2 ft^3 20Z32013 (1 per stage) S/N 24	Ti6Al4V STA MIL-T 9047 Class 5	Ti6Al-4V AMS 4954	TIG	Sphere	18.76	--	B 0.226 W. 0.226	+200 Expos -65 to +140	20-200 Fluid 60±20 AMB	+200	3200 at +200°F	3000 60±20°F	5346 at 200°F	7100 at 200°F	N_2	H_2O N_2	MIL-HDBK-5A	MIL-HDBK-5A
2 A	Gaseous N_2 sphere 165 in^3 7909919 (1 per stage) S/N 8	Ti6Al4V STA MIL-T-9047 Class 5	Ti6Al-4V AMS 4954	TIG	Sphere	6 838	--	B. 0.099 W. 0.132	+200 Expos -65 to +140	20-200 Fluid 60±20 AMB	+200	3200 at +200°F	3000 60±20°F	5000 at +200°F	6400 at +200°F	N2	H_2O N_2	Mil-HDBK-5A	MIL-HDBK-5A
3 A	Methanol-water accumulator 20Z4207 (1 per stage) S/N	Al 6061-T6 QQ-A-250/11	No Weld	Mech. Fast-ened	Sphere	5.00	--	B. 0.059-	70	70	70	16	16	75	--	H_2O CH_3OH	H_2O Air	MIL-HDBK-5A	NO WELD
4 A	Water Accumulator with Polyurethane Bladder 20A42122 (1 per stage) S/N	Al 5052-0 QQ-A-250/8	Al 4043	TIG	Cylin-der Flat Head	10.5	25	B. 0.059 W. 0.059	70	70	70	5	5	17	(210 act.)	H_2O	H_2O Air	MIL-HDBK-5A	MIL-HDBK-5A

B = BASE METAL W = WELD AND HAZ

SUMMARY-SATURN V
AS-503
APOLLO LAUNCH VEHICLE PRESSURE VESSELS FRACTURE MECHANICS ASSESSMENT

NO.	K_{IC} KSI(IN)1/2 BASE METAL	K_{IC} KSI(IN)1/2 WELD METAL	K_{TH} Thresh'd Values (Oper. Fluid) KSI(IN)1/2 BASE METAL	K_{TH} Thresh'd Values (Oper. Fluid) KSI(IN)1/2 WELD METAL	FLAW SIZE (INCHES) SCREENED BY PROOF	FLAW SIZE (INCHES) CRIT	FLAW SIZE (INCHES) THRESHOLD CRITICAL OPERATING	PRESSURE CYCLES EXPERIENCED	SERVICE LIFE OPERATING PRESSURE (Operating Fluid) ANTICIAPTED PRESSURE CYCLES	SERVICE LIFE OPERATING PRESSURE (Operating Fluid) GUARANTEED BY PROOF TEST	PROOF FACTOR MIN. PROOF PRESSURE / MAX. OPER. PRESSURE	PROOF FACTOR ADEQUACY	BURST FACTOR MIN. BURST PRESSURE / MAX. OPER. PRESSURE	PROBABLE FAILURE MODE	MANUFACTURER OR SOURCE	REMARKS
1 A	44	39	40	35	B.042 W.033	.116 .092	.094 .074	16 A	1 A	246	1.66	YES	2.2	Catastropic	(Airtek)	Glass bead peened 4% each side. Appears OK
2 A	44	39	40	35	B.038 W.050	.168	.084 .114	16 A	1 A	40	1.66	YES	2.0	Catastropic	(Airtek)	Glass bead peened 4% each side. Appears OK
3 A	50	No Weld	45	No Weld	<T	>T	>T	16 A	1 A	(NA)	4.7	YES	No test req'd	Leak	IBM	Low pressure tanks not serialized. Appears o.k.
4 A	50	45	45	40	<T	>T	>T	16 A	1 A	(NA)	3.4	YES	No test req'd	Leak	IBM	Low pressure tanks not serialized. Appears o.k.

T = THICKNESS NA = NOT APPLICABLE

SUMMARY-SATURN V
AS-503
APOLLO LAUNCH VEHICLE PRESSURE VESSELS FRACTURE MECHANICS ASSESSMENT

NO.	VESSEL DESIGNATION: PART NUMBER / NAME / SERIAL NUMBER	MATERIAL CONDITION: BASE MATERIAL & CONDITION	MATERIAL CONDITION: WELD FILLER	MATERIAL CONDITION: WELD METHOD	VESSEL CONFIGURATION AND DIMENSIONS: SHAPE	DIA-METER (INCHES)	LENGTH (INCHES)	WALL THICK-NESS (INCHES)	TEMPERATURE °F: DESIGN	TEMPERATURE °F: OPER-ATION	TEMPERATURE °F: PROOF	PRESSURE (PSIG): DESIGN	PRESSURE (PSIG): OPER-ATING MAX	PRESSURE (PSIG): PROOF	PRESSURE (PSIG): BURST	FLUID: OPER-ATING	FLUID: TEST PROOF	ALLOWABLES USED BY DESIGN ACTIVITY: BASE METAL	ALLOWABLES USED BY DESIGN ACTIVITY: WELD METAL
	J-2 ENGINE - ROCKETDYNE DIV. OF NR (ON S-II AND S-IVB)																		
1	Start Bottle Gaseous Hydrogen 307562 (5 per S-II Stage)																		
A	S-II Position #1 J2051-4067991	Forged Ti6AL4V STA	Ti6AL 4V	TIG	Sphere	25.316	--	B.097 W.210	-300 to -140	-300 to -140	70^{+20}_{-0}	1400	1400	1410	2800	Gas H2 AIR	H_2O	MIL-HDBK-5A	MIL-HDBK-5A
B	S-II Position #2 J2053-0062							B.097 W.138						1786					
C	S-II Position #3 J2059-0075													1800					
D	S-II Position #4 J2045-0042													1786					
E	S-II Position #5 J2055-4076660							B.097 W.210	-300 to -140					1800					
F	S-IVB J2071-4068446	Forged Ti6AL4V	Ti6AL 4V	TIG	Sphere	25.316	--	B.097 W.210	-300 to -140	-200 to -140	70^{+20}_{-0}	1400	1400	1800	2800	Gas. H_2	H_2O	MIL-HDBK-5A	MIL-HDBK-5A

B=BASE METAL W=WELD AND WELD HAZ

SUMMARY-SATURN V
AS-503
APOLLO LAUNCH VEHICLE PRESSURE VESSELS FRACTURE MECHANICS ASSESSMENT

NO.	K_{IC} KSI(IN)1/2 BASE METAL	K_{IC} KSI(IN)1/2 WELD METAL	K_{TH} Thresh'd Values (Oper. Fluid) KSI(IN)1/2 BASE METAL	K_{TH} Thresh'd Values (Oper. Fluid) KSI(IN)1/2 WELD METAL	FLAW SIZE (INCHES) SCREENED BY PROOF	FLAW SIZE (INCHES) CRIT	FLAW SIZE (INCHES) THRESHOLD CRITICAL OPERATING	PRESSURE CYCLES EXPERIENCED (note 1)	SERVICE LIFE OPERATING PRESSURE (Operating Fluid) ANTICIAPTED PRESSURE CYCLES	SERVICE LIFE OPERATING PRESSURE (Operating Fluid) GUARANTEED BY PROOF TEST Remaining (note 1)	PROOF FACTOR MIN. PROOF PRESSURE / MAX. OPER. PRESSURE	PROOF FACTOR ADEQUACY	BURST FACTOR MIN. BURST PRESSURE / MAX. OPER. PRESSURE	PROBABLE FAILURE MODE	MANUFACTURER OR SOURCE	REMARKS
1	J-2 ENGINE - ROCKETDYNE DIV. OF NR (ON S-II AND S-IVB)															
A	49.05 RT 52.33 (-200 °F)	61.5 (RT) 65.19 (-200 °F)	40.55 (-200 °F)	54.11 (-200 °F)	B.0422 W.1840	NA NA	B.0422 W.1840	NA	NA	NONE	.975	NO	2.0	1. Weld Leak 2. Possible Catastrophic	NR (Col)	Adequacy verified by analyses and NDT inspection
B					B.0388 W.089	NA NA	B.0422 W.100	7 at 1400 psi	1(1440 psi)	16 1400 psi	1.28	YES		Catastrophic	Airtite	Appears o.k.
C					B.0388 W.089	NA NA	B.0422 W.100	7 at 1400 psi	1(1493 psi)	16 at 1400 psi				Catastrophic	Airtite	
D					B.0388 W.089	NA NA	B.0422 W.100	11 at 1400 psi	1(1455 psi)	12 at 1400 psi				Catastrophic	Airtite	
E					B.0388 W.164	NA NA	B.0422 W.1840	9 at 1400 psi	1(1485 psi)	12 at 1400 psi				1. Weld Leak 2. Possible Catastrophic	NR (Col)	
F	49.05 (RT) 52.33 (-200 °F)	61.5 (RT) 65.19 (-200 °F)	40.55 (-200 °F)	54.11 (-200 °F)	B.0388 W.164	NA NA	B.0422 W.1840	11 at 1400 psi	1(1500 psi)	10 at 1400 psi	1.28	YES	2.0	1. Weld Leak 2. Possible Catastrophic	NR (Col)	Appears o.k.

NOTE 1: Assumed that time at relief pressure is minimum. If relief valve pressure is held one hour, all tanks except 0042 and 0062 will have zero guaranteed life.

B=BASE METAL W=WELD AND WELD HAZ NA=NOT APPLICABLE

SUMMARY-SATURN V
AS-503
APOLLO LAUNCH VEHICLE PRESSURE VESSELS FRACTURE MECHANICS ASSESSMENT

NO.	VESSEL DESIGNATION: PART NUMBER / NAME / SERIAL NUMBER	MATERIAL CONDITION: BASE MATERIAL & CONDITION	MATERIAL CONDITION: WELD FILLER	MATERIAL CONDITION: WELD METHOD	VESSEL CONFIGURATION AND DIMENSIONS: SHAPE	VESSEL CONFIGURATION AND DIMENSIONS: DIA-METER (INCHES)	VESSEL CONFIGURATION AND DIMENSIONS: LENGTH (INCHES)	VESSEL CONFIGURATION AND DIMENSIONS: WALL THICK-NESS (INCHES)	TEMPERATURE °F: DESIGN	TEMPERATURE °F: OPER-ATION	TEMPERATURE °F: PROOF	PRESSURE (PSIG): DESIGN	PRESSURE (PSIG): OPER-ATING MAX	PRESSURE (PSIG): PROOF	PRESSURE (PSIG): BURST	FLUID: OPER-ATING	FLUID: TEST PROOF	ALLOWABLES USED BY DESIGN ACTIVITY: BASE METAL	ALLOWABLES USED BY DESIGN ACTIVITY: WELD METAL
	J-2 ENGINE - ROCKETDYNE DIVISION OF NR (ON S-II AND S-IVB) (CONTINUED)																		
2	Start Bottle Gaseous Helium (Inner) 307562 (5 per S-II Stage) (1 per S-IVB Stage)																		
A	S-II Position #1 J2051-4067991	Forged Ti6AL4V STA	Ti6AL 4V	TIG	Sphere	12.464	--	B.153 W.218	-300 to -140	-300 to -140	70^{+20}_{-0}	3200	3200	5700	7750	Gas. He; Gas. H_2	H_2O	MIL-HDBK-5A	MIL-HDBK-5A
B	S-II Position #2 J2053-0062																		
C	S-II Position #3 J2059-0075																		
D	S-II Position #4 J2045-0042																		
E	S-II Position #5 J2055-4076660																		
F	S-IVB J2071-4068446	Forged Ti6AL4V STA	Ti6AL 4V	TIG	Sphere	12.464	--	B.153 W.218	-300 to -140	-300 to -140	70^{+20}_{-0}	3200	3200	5700	7750	Gas. He; Gas H_2	H_2O	MIL-HDBK-5A	MIL-HDBK-5A

B=BASE METAL W=WELD AND WELD HAZ

SUMMARY-SATURN V
AS-503
APOLLO LAUNCH VEHICLE PRESSURE VESSELS FRACTURE MECHANICS ASSESSMENT

NO.	K_{IC} KSI(IN)1/2 BASE METAL	K_{IC} KSI(IN)1/2 WELD METAL	K_{TH} Thresh'd Values (Oper. Fluid) KSI(IN)1/2 BASE METAL	K_{TH} Thresh'd Values (Oper. Fluid) KSI(IN)1/2 WELD METAL	FLAW SIZE (INCHES) SCREENED BY PROOF	FLAW SIZE (INCHES) CRIT	FLAW SIZE (INCHES) THRESHOLD CRITICAL OPERATING	PRESSURE CYCLES EXPERIENCED	SERVICE LIFE OPERATING PRESSURE (Operating Fluid) ANTICIAPTED PRESSURE CYCLES	SERVICE LIFE OPERATING PRESSURE (Operating Fluid) GUARANTEED BY PROOF TEST	PROOF FACTOR MIN. PROOF PRESSURE / MAX. OPER. PRESSURE	PROOF FACTOR ADEQUACY	BURST FACTOR MIN. BURST PRESSURE / MAX. OPER. PRESSURE	PROBABLE FAILURE MODE	MANUFACTURER OR SOURCE	REMARKS
									J-2 ENGINE - ROCKETDYNE DIV. OF NR (ON S-II AND S-IVB) (CONTINUED)							
2																
A	38	33	34	30	B.037 W.060	NA NA	B.072 W.114	16A	1A	51	1.78	YES	2.4	Catastrophic	NR (Col)	Appears o.k.
B															Airite	
C															Airite	
D															Airite	
E															NR (Col)	
F	38	33	34	30	B.037 W.060	NA NA	B.072 W.114	16A	1A	51	1.78	YES	2.4	Catastrophic	NR (Col)	Appears o.k.

B=BASE METAL W=WELD AND WELD HAZ A=ASSUMED CYCLES NA=NOT APPLICABLE

1.3 SM/SPS PROPELLANT TANKS EVALUATION

The four main propellant tanks in the CSM-103 SM/SPS were evaluated as part of the JSAT study. Tank integrity can be assured by fracture mechanics analysis provided the following tank temperatures are not exceeded at S-IC End Boost:

TANK	MAX. SAFE TEMP. ($^{\circ}$ F.)
Oxidizer Sump	107
Oxidizer Storage	107
Fuel Sump	120*
Fuel Storage	120*

*120° F. is the limit of the evaluation data.

The basis for this evaluation is:

a. An acceleration load effect which increases the membrane stress in the lower dome as shown in Table D-I.

b. Tank pressure at launch is 160 psig which results in 175 psi pressure difference at S-IC End Boost.

c. Tank cyclic pressure history from Vendor plus 3 cycles to 182 psig at KSC in the OCP procedures and pressurization to 160 psig for launch.

d. Flaw growth during depressurization from 300 psig proof test assumed to be zero.

Table D-I is a summary of stresses, flaw sizes, and maximum acceptable temperatures. The applicable fracture mechanics curves for the four tanks are presented in Figures D-1 through D-4.

TABLE D-1. SUMMARY OF AS-503 SM/SPS PROPELLANT TANKS FRACTURE MECHANICS EVALUATION

	51" DIA OXIDIZER SUMP S/N 200061	45" DIA OXIDIZER STORAGE S/N 300061	51" DIA FUEL SUMP S/N 200058	45" DIA FUEL STORAGE S/N 300058
Propellant Density @ 70°F (#/ft^3)	90.05	90.05	56.33	56.33
Internal Pressure (Psia)	175.0	175.0	175.0	175.0
Pressure Due to "g" Load (4.1 g's) (Psi)	32.4	32.5	20.7	20.3
Total Internal Pressure on Dome (Max) (Psia)	207.4	207.5	195.2	195.3
Maximum Membrane Stress in Dome (KSI)	94.6	93.5	89.0	88.0
[1] Maximum Potential Flaw at Launch (Inches)	.0142	0.0137	0.0143	0.0138
Critical Stress at Max. Potential Flaw (KSI)	136.6	135.3	136.5	135.5
Stress Intensity Ratio $\frac{K_{Ii}}{K_{Ic}}$ with Maximum Potential Flaw and Maximum Membrane Stress	.694	.691	.652	.649
Maximum Safe Operating Temp. (°F)	107°F	107°	120°+	120°+

[1] Assuming No Flaw Growth During Depressurization From Proof Test

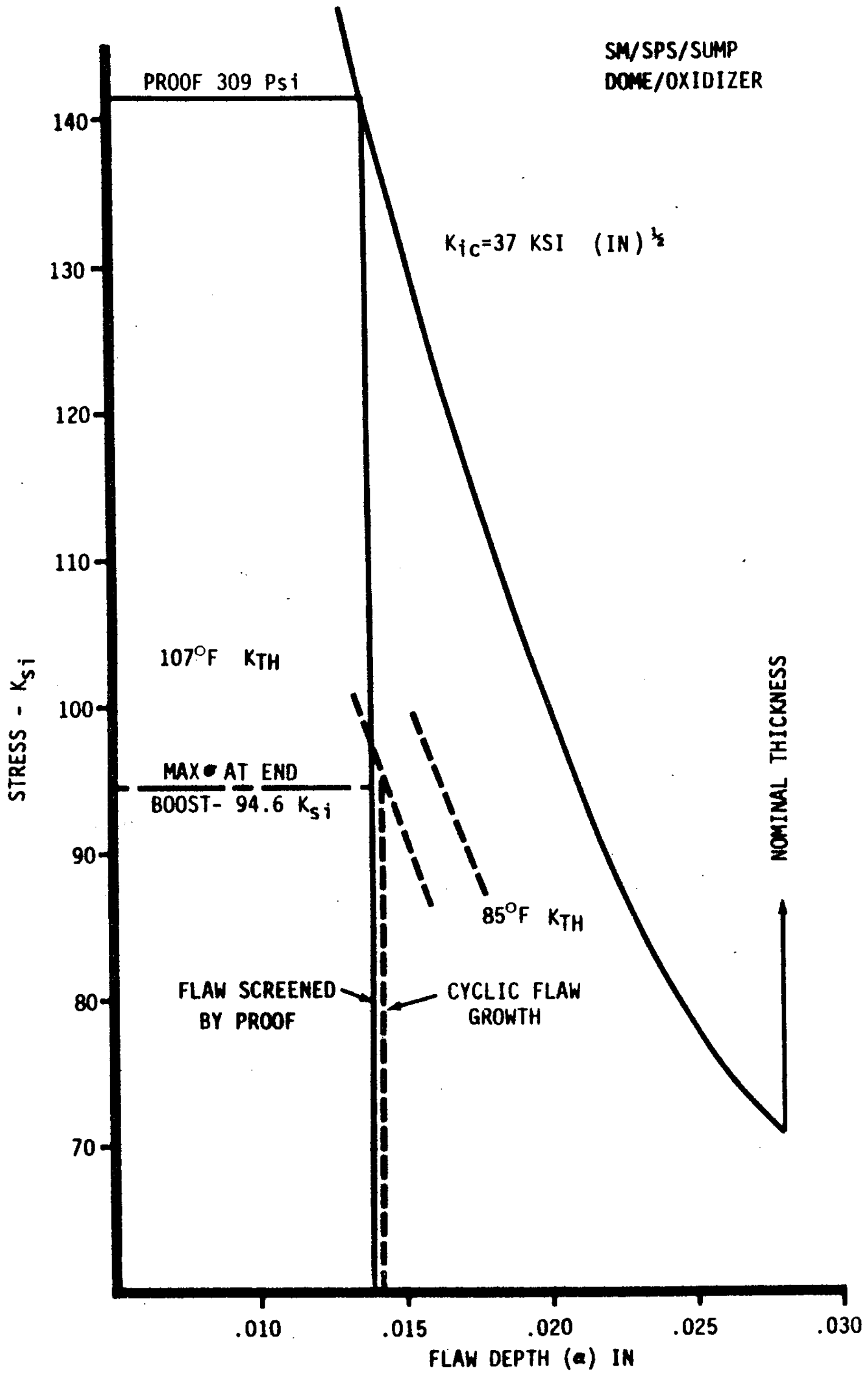

FIGURE D-1. OXIDIZER SUMP TANK CRITICAL FLAW SIZE

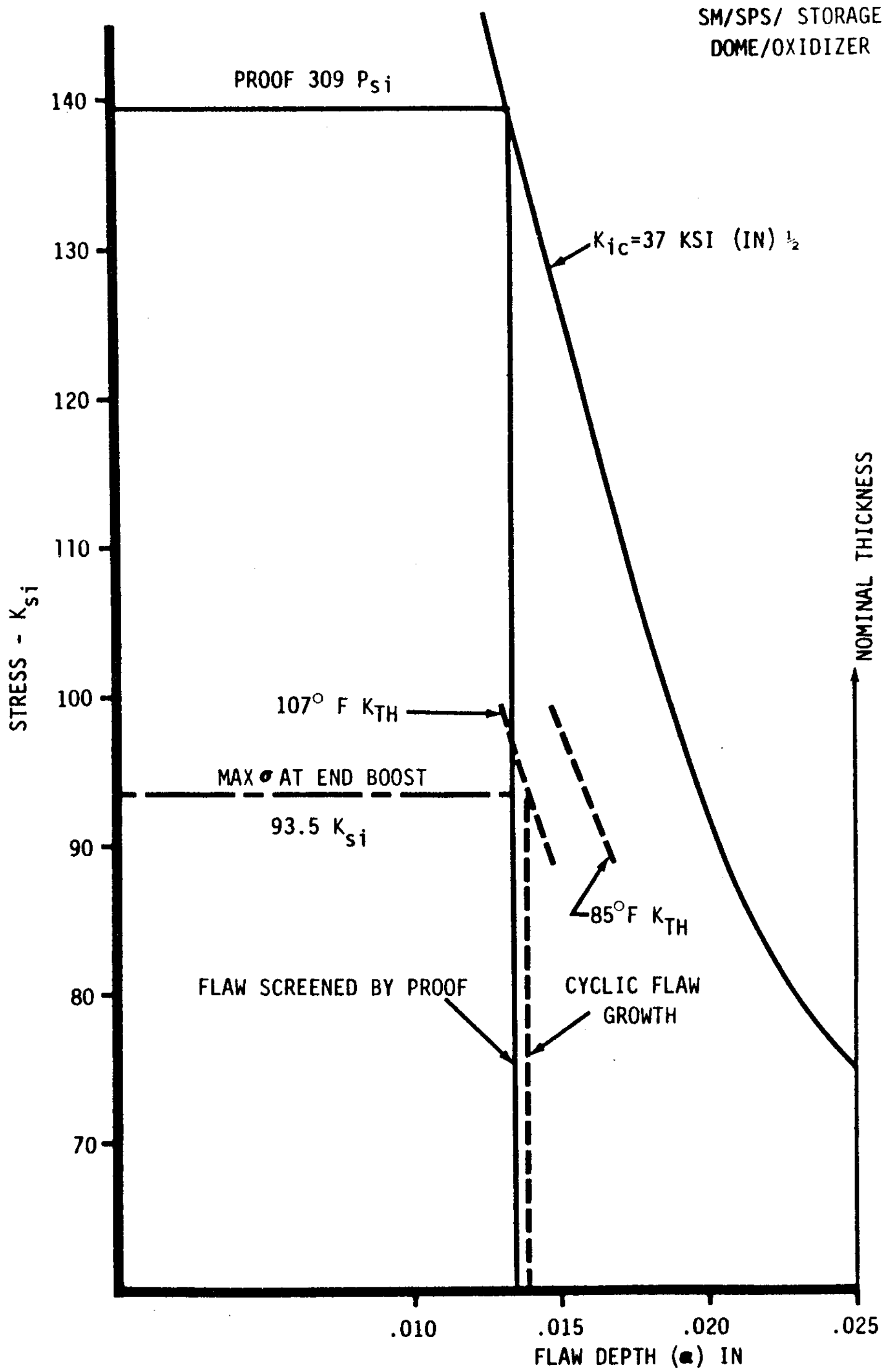

FIGURE D-2. OXIDIZER STORAGE TANK CRITICAL FLAW SIZE

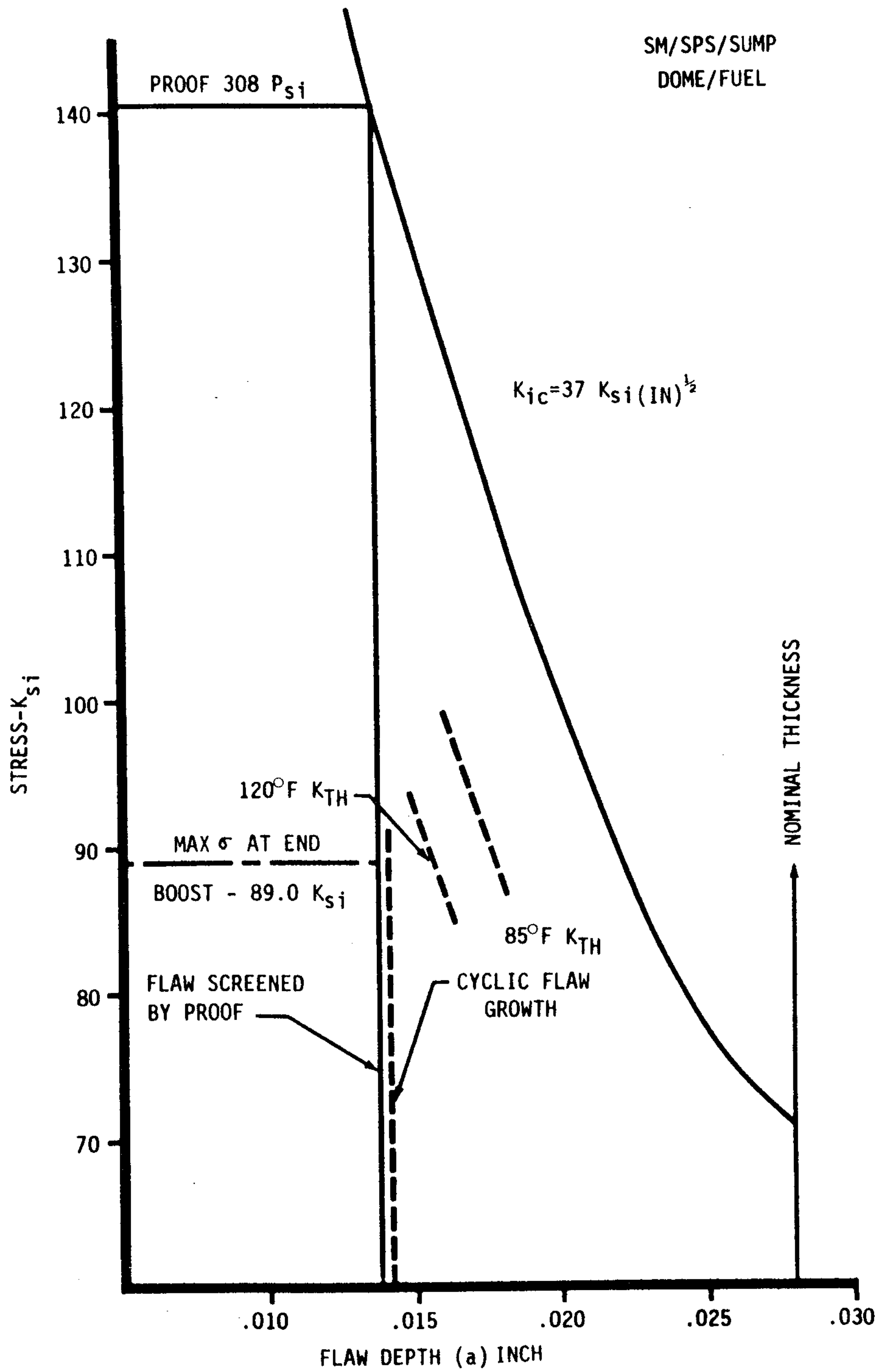

FIGURE D-3. FUEL SUMP TANK CRITICAL FLAW SIZE

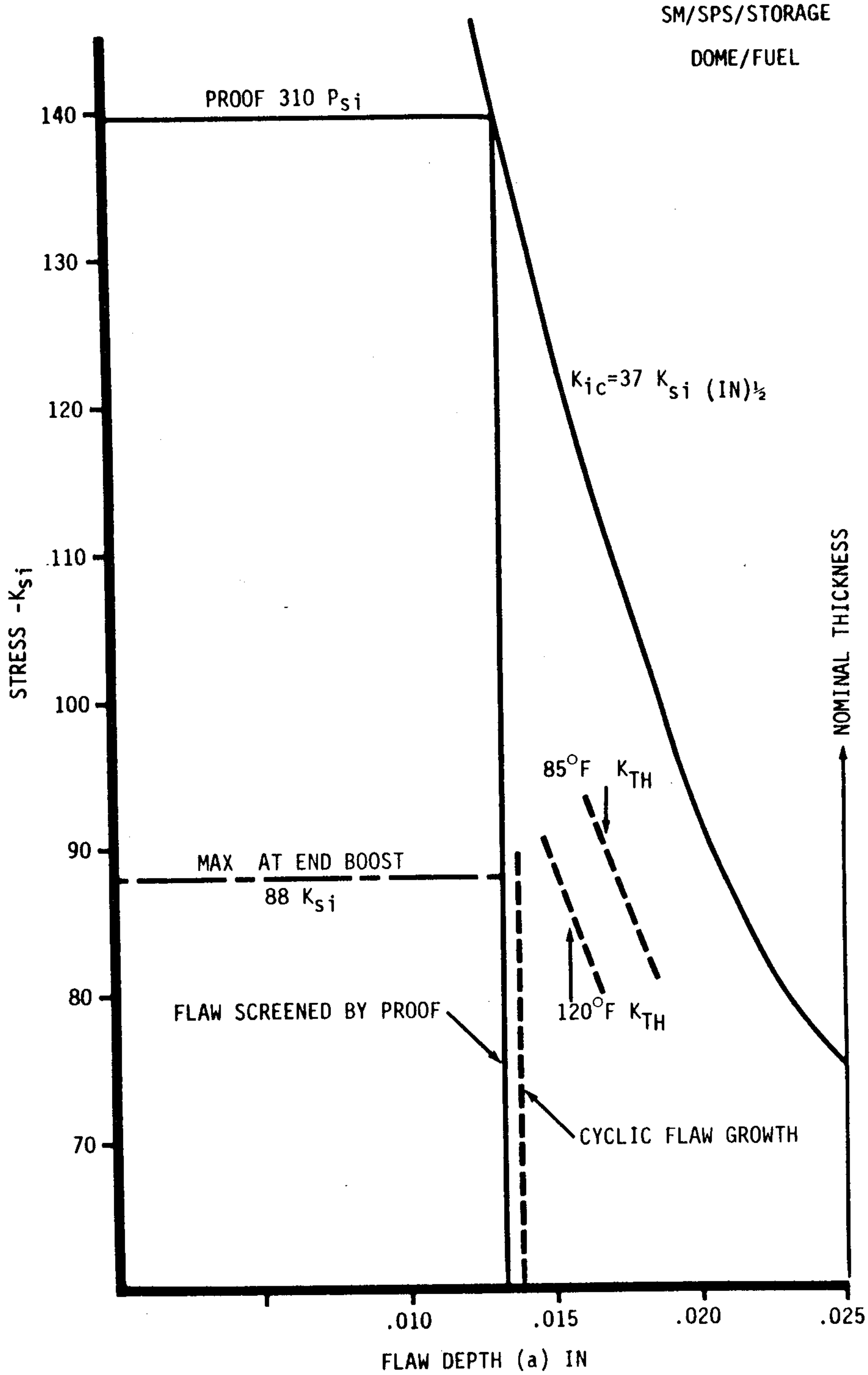

FIGURE D-4. FUEL STORAGE TANK CRITICAL FLAW SIZE

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APPENDIX E

HONEYCOMB ASSESSMENT

1.0 GENERAL

This appendix contains a presentation of a honeycomb material assessment made during the course of the AS-503 Structural Integrity Assessment.

CRITERIA FOR THE ASSESSMENT OF HONEYCOMB

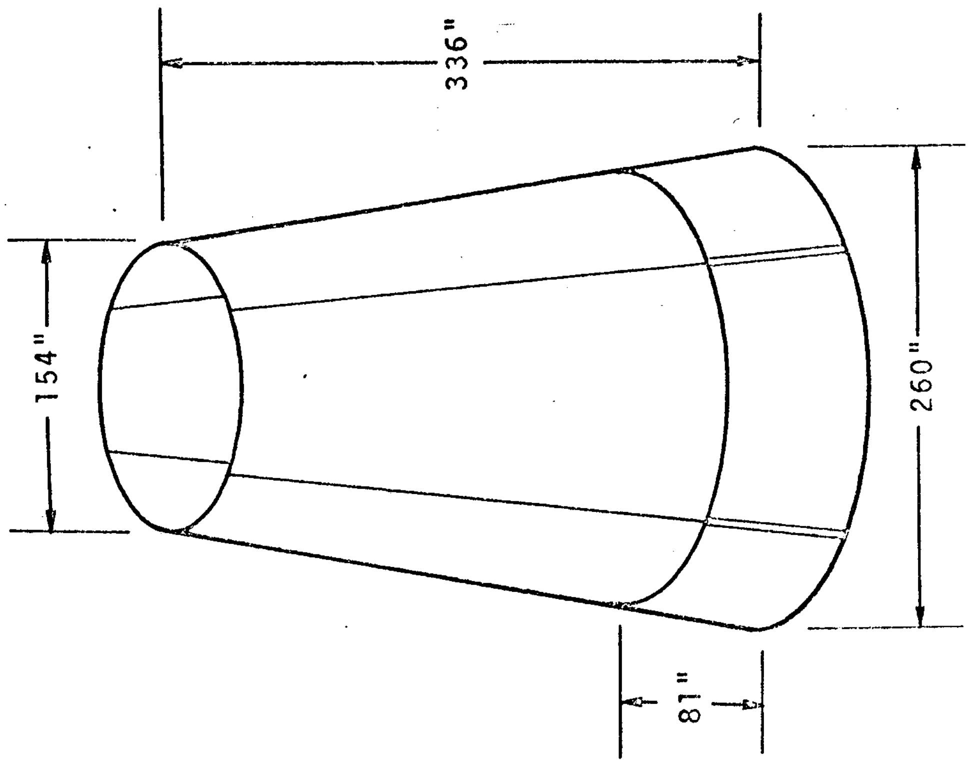
- QUALIFICATION REQUIREMENTS ESTABLISHED & DEMONSTRATED
- "IN-PROCESS" CONTROL REQUIREMENTS ESTABLISHED AND SATISFIED
- "IN-PROCESS" TEST REQUIREMENTS ESTABLISHED AND SATISFIED
- FINAL ACCEPTANCE TEST REQUIREMENTS ESTABLISHED & DEMONSTRATED

PLAN & APPROACH TO ASSESS HONEYCOMB STRUCTURE

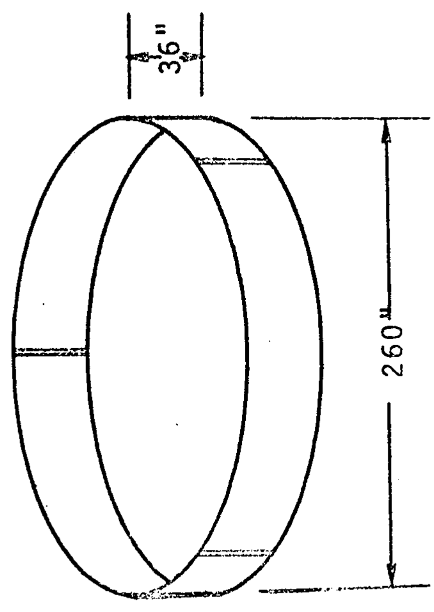
- DOCUMENTATION REVIEW AND ASSESSMENT
  - MRB ACTION
- ON-SITE REVIEW
  - MATERIALS
  - MANUFACTURING
  - QUALITY ASSURANCE
- ASSESSMENT OF "IN-PROCESS" AND END ITEM STORAGE & HANDLING

AREAS PRESENTED FOR COMPARISON OF IU & SLA HONEYCOMB STRUCTURES

- CONFIGURATION
    - PANELS
    - SHELL
    - MATERIALS
- QUALITY ASSURANCE
    - NDT & DESTRUCTIVE TECHNIQUES
- ENVIRONMENTAL REQUIREMENTS
- MANUFACTURING PROCEDURES
- STORAGE & HANDLING



SLA



IU

COMPARISON OF IU AND SLA HONEYCOMB STRUCTURES

CONFIGURATION	IU	REMARKS	SLA	REMARKS
PANELS	3 REQUIRED, APPROX. 25' LONG X 3' HIGH	ESSENTIALLY A SEALED UNIT. DIFFERENCES IN PANEL DUE TO ACCESS OPENINGS AND SPECIAL BRACKETRY.	TWO SETS OF 4 PANELS EACH REQUIRED: LOWER SET - APPROX. 7' HIGH UPPER SET - APPROX. 21' HIGH	LOWER SET OF PANELS IDENTICAL. TWO OF UPPER SET OF PANELS CONTAIN ACCESS DOORS. METAL-TO-METAL OVERLAPS PERFORATED TO VENT WATER VAPOR PRODUCED DURING CURE.
SHELLS	SIMPLE CYLINDER - 260" DIA. X 36" HIGH	CONSISTS OF PANELS RIGIDLY JOINED. INTERIOR SURFACE NOT VENTED. EXTERIOR SURFACE NOT INSULATED	TRUNCATED CONE - 336" HIGH X 260" TO 154" DIA.	LOWER PANELS RIGIDLY JOINED. UPPER PANELS HINGED, DESIGNED TO DEPLOY. INTERIOR SKIN VENTED EXTERIOR SKIN HAS 0.030" CORK INSULATION.

COMPARISON OF IU AND SLA HONEYCOMB STRUCTURES

MATERIAL	IU	SLA
ADHESIVE SYSTEM	METLBOND 329 IS QUALIFIED TO MIL-A-25463, TYPE II AND MMM-A-132, TYPE II.	
ALUMINUM CORE	5052-H39 CORE MATERIAL IS QUALIFIED TO MIL-C-7438	5052-H39 CORE MATERIAL IS QUALIFIED TO MIL-C-7438
ALUMINUM FACE SHEETS	7075-T6 CLAD FACE SHEET IS QUALIFIED TO QQ-A-250/12C	2024-T81 CLAD FACE SHEET IS QUALIFIED TO QQ-A-250/5D
QUALITY		
	IBM DEMONSTRATES CONFORMANCE TO THESE SPECIFICATIONS BY CONDUCTING THE FOLLOWING TESTS: LAP SHEAR, PI-TENSION, PORTASHEAR } TABS & PANEL SANDWICH BEAM SHEAR, EDGE COMPRESSION, EDGE TENSION, DRUM PEEL } PANELS N.D.T. ULTRASONIC, RADIOGRAPHIC, PORTASHEAR } FLIGHT PANELS	NR CONDUCTS THE FOLLOWING TESTS: LAP SHEAR, DRUM PEEL } TABS NO TESTS ARE RUN ON FULL SIZE PANELS TO DEMONSTRATE LOAD BEARING CAPABILITY ULTRASONIC, RADIOGRAPHIC } FLIGHT PANELS

COMPARISON OF SM, SLA, AND IU HONEYCOMB STRUCTURES

	SM	SLA	IU
ADHESIVE PRIMER	HT 424 HT 424	HT-424 FM-47	METLBOND 329 NONE
LAP SHEAR STRENGTH (RM. TEMP.)	2300 PSI	1900 PSI	2223 PSI MIN 2720 PSI AVE
EXPERIENCE	EXTENSIVE PRIOR INDUSTRY USAGE	NO PRIOR INDUSTRY USAGE	EXTENSIVE PRIOR INDUSTRY USAGE
CORK AREA	90 PERCENT	100 PERCENT	NONE
MAX TEMPERATURE	223°F AVG. MAX SKIN TEMP 225°F AVG. CORE TEMP	211°F	255°F
VENTED	NO	YES	NO
MAX. PRESSURE	37 PSI AVG. CORE PRESS	18 PSI	19.8 PSI

*BARE 220°F, CORKED 230°F, RADIATOR 232°F

COMPARISON OF IU AND SLA HONEYCOMB STRUCTURES

ENVIRONMENT	IU	SLA	REMARKS
TEMPERATURE	255°F MAX ADHESIVE QUALIFIED TO 300°F	211°F MAX ADHESIVE QUALIFIED TO 300°F	SLA TEMP. IS SKIN TEMP. BENEATH INSULATION. IU TEMP. IS SKIN TEMP. WITHOUT INSULATION.
ATMOSPHERE	SEA COAST	SEA COAST	
MANUFACTURING			
	NO PRIMER USED. ONE STEP BONDING	FACE SHEETS PRIMED WITH FM47, MAY BE STORED UP TO 9 MNS. BEFORE BONDING.	STORED PRIMED PANELS ARE PROTECTED BY WRAPPING IN CLEAN KRAFT PAPER.
	CURE CYCLE-RT TO 350°F IN 110 MIN., HOLD AT 350°F FOR 60 MIN.	CURE CYCLE - RT TO 350°F IN 120 to 240 MIN., HOLD AT 350°F FOR 60 MIN.	SLA CURE TEMP RANGE IS IN BONDING SPEC.
	PRESSURE-Δp=45 PSI ($\pm$5)-VACUUM & AUTO-CLAVE PRESSURE	PRESSURE-Δp=15 TO 60 PSI VACUUM & AUTO-CLAVE PRESSURE	SLA CURE PRESSURE RANGE IS IN BONDING SPEC.
	TEMP. & PRESS. ARE MONITORED AND RECORDED	TEMP. & PRESS. ARE MONITORED AND RECORDED	PART OF PERMANENT MFG. RE-CORD.
	TEST TAB MFG. WITH EACH FLIGHT PANEL	TEST TAB MFG. WITH EACH FLIGHT PANEL.	IN-PROCESS QC.
	TEST PANEL MFG. WITH EVERY SET OF 15 FLIGHT PANELS		NO FULL SIZE SLA TEST PANELS PRODUCED.

PRESSURE CAPABILITY		
TEST	MAX. PRESSURE (PSI)	COMMENTS
SLA-9 @ 133 SEC.	UP TO 38	NO VENTING FREE WATER
NR PANEL TESTS	>100	1.0 IN. DIA. VOIDS
BOEING PANEL TESTS	>100	1.0 IN. DIA. VOIDS
SLA-2 PANEL TESTS	50 TO 60	EXTENSIVE PRIOR TESTING

AS-503 PRESSURES		
MODULE	MAX. PRESSURE (PSI)	COMMENTS
CM	UP TO 14.7	NO SIGNIFICANT TEMPERATURE RISE FREE WATER
SM	37	224°F NO VENTING CORKED FREE WATER S/M HONEY-COMB 20% STRONGER THAN SLA
SLA	18	211°F. VENTED & CORKED FREE WATER
IU	19.8	255°F. NO VENTING NO WATER

ASSESSMENT OF SM AND SLA HONEYCOMB STRUCTURES

SM

POTENTIAL FOR PRESSURIZATION

CORKED AREA - 90 PERCENT

RADIATOR SURFACE TEMPERATURE = 232°F

SANDWICH TEMPERATURE CORKED AREA = 230°F. **

SANDWICH TEMPERATURE BARE AREA = 220°F.

SANDWICH PANEL SKINS NOT VENTED

APPROXIMATE EQUALIZED PRESSURE = 37 PSI*

ASSESSMENT - ADEQUATE BASED ON HIGHER ADHESIVE STRENGTH OF SM THAN SLA AND AVAILABLE PRESSURE TEST DATA.

*WITH ENTRAPPED WATER

**THIS IS THE TEMPERATURE UNDER THE CORK WHERE THERE IS PROTUBERANCE HEATING, SUCH AS THE RCS QUADS AREAS.

SLA-11

POTENTIAL FOR PRESSURIZATION

CORK LIMITS TEMPERATURE TO 211°F.

VENTING LIMITS PRESSURE TO 18 PSI*

DEMONSTRATED CAPABILITY = 38 PSI (SLA-9)

ASSESSMENT - ADEQUATE

FINAL ASSESSMENT DEPENDENT ON MR REVIEW RESULTS

ASSESSMENT OF IU AND SLA HONEYCOMB STRUCTURES

IU

POTENTIAL FOR PRESSURIZATION
- NO CORK - TEMPERATURE - 255°F.*
- NO OUTGASSING OF ADHESIVES
- NO WICKING BY ADHESIVE SKRIM
- NO WATER USED IN NDT
- NO WATER INGESTED - SEALED
- PRESSURE OF ENTRAPPED AIR - 19.8 PSI MAX

ASSESSMENT - ADEQUATE

SLA-11

POTENTIAL FOR PRESSURIZATION

CORK LIMITS TEMPERATURE TO 211°F*

VENTING LIMITS PRESSURE TO 18 PSI**

DEMONSTRATED CAPABILITY - 38 PSI (SLA-9)

PRELIMINARY ASSESSMENT - ADEQUATE

* OUTER SKIN TEMPERATURE
** WITH ENTRAPPED WATER

HONEYCOMB STRUCTURES

AREAS INVESTIGATED:

- INSTRUMENT UNIT (IU)
- SPACECRAFT LUNAR MODULE ADAPTER (SLA)
- SERVICE MODULE (SM)
- COMMAND MODULE (CM)

CONCLUSIONS:

ANTICIPATED FLIGHT TEMPERATURES AND PRESSURES ARE WITHIN STRUCTURAL CAPABILITIES OF THESE ELEMENTS

THESE ELEMENTS, IN THEIR PRESENT CONFIGURATIONS, ARE ADEQUATE FOR THEIR ASSIGNED MISSION ON AS-503

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APPENDIX F

MATERIAL DESIGN ALLOWABLES

1.0 GENERAL

This section contains the material and sandwich (honeycomb) design allowables, and typical weld strengths recommended for each of the critical elements of the AS-503 launch vehicle. The presentation is broken down according to launch vehicle stage and the critical elements identified with each stage.

The design allowables were obtained from MIL-Handbook-5A, MIL-Handbook-23 and Aerospace Structural Metals Handbook. The typical weld strengths were obtained from the above when possible and from welding handbooks and reports. The presentations are made in tabular form followed by lists of parts or elements to which the allowables are applicable.

1.1 S-IC-3 STAGE

1.1.1 LOX Tank, Lower Bulkhead

The material design allowables for each structural element of the S-IC-3 aft LOX Bulkhead are presented in the following tabulations. Design allowables for the weldments are also presented. All allowables shown are "A" values.

Following each set of material design allowables is a list of part numbers, including part name, for which the allowables are applicable.

2219-T87 Sheet and Plate .040-2.500

	-297°F	RT
F_{tu} KSI (L)	74.4	62
F_{ty} KSI (L)	58.5	50
E 10^6 psi	11.3	10.5

These material design allowables are applicable to the following elements:

60B12202	Gore Apex
60B12204	Gore Base
60B12206	Centerpiece
60B12209	Transition Cone
60B12213	Fitting, Drain and Fill, LOX
60B12223	LOX Fill Fitting
60B12203	Gore Apex Suction Fitting

2219-T851 Plate, 5.001-6.000

	-297°F	RT
F_{tu} KSI (T)	N/A	54
F_{ty} KSI (T)	"	41
E 10^6 psi	"	10.5

These material design allowables are applicable to the following elements:

60B12201	Y-ring

2219-T852 Forging ≦4.000

	-297°F	RT
F_{tu} KSI (L)	N/A	62
F_{ty} KSI (L)	"	50
E 10^6 psi	"	10.5

These material design allowables are applicable to the following elements:

60B12207 Fitting, Center Suction Duct

All welds of the Aft LOX Bulkhead Assembly (60B12200) other than the Y-ring welds are according to ABMA-PD-W-45A using 2319 filler wire per 60B32004. Typical weldment strengths follow:

1. Transverse Butt Welds, sheet and plate (.063-1.000) [1]

(a) 2219-T87, T851 as welded with 2319 wire

	-297°F	RT
F_{tu}	31.5	28
F_{ty}	18	16

(b) 2219-T37, T351 as welded with 2319 wire then aged to T87 and T851

	-297°F	RT
F_{tu}	37.5	32.5
F_{ty}	27.0	24.5

2. TIG and MIG Butt Joints [2]

(a) 2219-T87, room temperature properties

		F_{tu}	F_{ty}	Elong(in 2")
Base Metal	KSI	66	50	10%
As welded with 2319 wire	KSI	35	26	3%
Postweld H.T. and aged	KSI	43	37	2%

[1] Design allowables from Boeing Design Manual

[2] Data from Kaiser Aluminum (not design allowables)

(b) 2219-T81, room temperature properties

		F_{tu}	F_{ty}	Elong (in 2")
Base Metal	KSI	61	44	6%
Transverse tensile properties of MIG weldments (flush)	KSI	38	26	3%

All Y-ring welds are according to 10M01648B and use 2319 filler wire. The shielding gas may be any one of argon, argon/oxygen, argon/helium or helium. The welds are butt fusion welds by mechanized MIG. Test specimens must meet the following strength requirements:

	F_{tu}
Un-notched	30 KSI
Notched	34 "
Notched and stress relieved	36 "

1.1.2 Forward Skirt

The material design allowables for each structural element of the S-IC-3 Forward Skirt are shown in the following tabulations. All allowables shown are "A" values except where noted otherwise. In the case of extruded shapes, the allowables were selected after crippling factors were calculated for each segment of a structural shape.

Following each set of material design allowables is a list of part numbers, including part name, for which the allowables are applicable.

7075-T6 Sheet and Plate $< .500$

	RT	150°F	200°F
F_{tu} KSI (L)	77	73	68
F_{ty} KSI (L)	67	64	62
E 10^6 psi	10.3	10.0	9.8

These material design allowables are applicable to the following elements:

60B15820-1	Skin Splice, Outer
60B14420-1	Skin Panel, Cylinder
60B14450-1, -3	Doubler, Skin Splice
60B14321-1, -2	Bracket, Door Support, Umbilical Door
60B14232-1	Doubler
60B14460-1	Doubler, Skin Splice, Center
60B14490-1, -3	Doubler, Skin
60B14240-1	Doubler, Access Door
60B14206-1	Ring, Electrical Cut-out
60B14268-1	Filler, Radius
60B14231-1	Bracket, Umbilical Support
60B14830-1	Doubler, Fitting, GOX Line Opening
60B14822-5, -7	Guide Bracket Assy., GOX Line
60B02734-1	Cover Assy., Ordnance, Stage Assy.
60B14410-1	Skin Panel, Conical
60B14640-1	Doubler, Fitting, Electrical Cable Inlet
60B14618-1	Doubler, Detonating Fuse Cut-out
60B14221-1	Stiffener, Hat, Access Door
60B14263-1	Skin, Umbilical Door
60B14264-1	Angle, Umbilical Door

60B15842-1	Gusset, Struct.	
60B14067-1, -3	Zee, LOX Vent	
60B14068-1, -3	Angle	
60B15864-1, -3	Angle	
60B14222-1	Skin, Access Door	
60B14066 -1, -3	Beam, LOX Vent	
60B14069-1	Hat	
60B14070-1	Angle	
60B14831-1	Doubler	
60B14004-1, -2	Filler, N_2 Bottle Support	
60B14004-3	Filler, N_2 Bottle Support	
60B15650-1	Plate, Splice, Leg, J-ring	1
60B15833-1, -3	Intercostal	
60B15831-1, -3	Angle	
60B15864-1, -3	Angle	
60B14822-1, -3	Guide Bracket Assy., GOX Line	
60B15040-1	Doubler, LOX Vent Fitting	
60B14019-1	Stiffener, N_2 Bottle Support	

7075-T6, T6511 Extrusions $<$.250
& 7079-T6 Extrusions $<$1.5000

	RT	150°F	200°F
F_{tu} KSI (L)	78	74	69
F_{ty} KSI (L)	70	67	64
E 10^6 psi	10.3	10.0	9.8

These material design allowables are applicable to the following elements:

60B14430-1	Stiffener, Hat, Skin Panel
60B14230-1	Stiffener, Hat, STA 1420 to 1459
60B14233-1	Zee
60B15210-1	Ring Segment, Interface Ring
60B15230-1, -3	Angle, Splice, Outer, Interface Ring
60B14233-1	Zee
60B14201-1, -2	Stiffener Assy., Umbilical Door
60B15863-1	Tee
60B14224-1	Angle, Access Door
60B14227-1	Stiffener, Angle, Access Door
60B15050-1	Stiffener, Hat, Fitting Tie
60B15210-1	Ring Segment, Interface Ring
60B14650-1	Stiffener, Hat, Upper
60B14820-1	Stiffener, Hat, Fitting

1 Applicable when 7075-T6 material is used.

7079-T6 Sheet $<.250$ and Forgings <2.000

	RT	150°F	200°F
F_{tu} KSI (L)	72	70	68
F_{ty} KSI (L)	63	62	60
E 10^6 psi	10.3	10.2	10.1

These material design allowables are applicable to the following elements:

60B15201-1	Web, Interface Ring
60B15202-1	Stiffener, Angle, Interface Ring
60B15204-1	Gusset, Interface Ring
60B15207-1	Plate, Splice
60B15220-1, -3	Plate, Splice, Interface Ring
60B14620-1	Forging, Electrical and GOX Line Fitting

7079-T6 Extrusions $<.250$

	RT	150°F	200°F
F_{tu} KSI (L)	75	73	71
F_{ty} KSI (L)	67	66	64
E 10^6 psi	10.3	10.2	10.1

These material design allowables are applicable to the following elements:

60B15203-1	Stiffener, Tee, Interface Ring
60B15205-1	Ring Segment, Inner, Interface Ring
60B15610-1	Ring Segment, J-Ring
60B15410-1	Ring Segment, Channel

7079-T651 Plate <2.500

	RT	150°F	200°F
F_{tu} KSI (L)	71	69	67
F_{ty} KSI (L)	64	63	61
E 10^6 psi	10.3	10.2	10.1

These material design allowables are applicable to the following elements:

60B15221-1	Plate, Splice, Interface Ring

7075-T651 Plate < 2.000

	RT	150°F	200°F
F_{tu} KSI (L)	76	72	67
F_{ty} KSI (L)	68	65	63
E 10^6 psi	10.3	10.0	9.8

These material design allowables are applicable to the following elements:

60B02721-1	Block Assy., Support, Stage Assy.
60B15650-1	Plate, Splice, Leg, J-Ring [2]
60B14026-1	Fitting, Camera Support

7075-T73 Sheet .040-.250

	RT	150°F	200°F
F_{tu} KSI (L)	67	64	60
F_{ty} KSI (L)	56	55	54
E 10^6 psi	10.3	10.0	9.8

These material design allowables are applicable to the following elements:

60B14218-1 Channel, Umbilical Door

7075-T6 Clad Sheet < .040

	RT	150°F	200°F
F_{tu} KSI (L)	70	67	62
F_{ty} KSI (L)	61	58	56
E 10^6 psi	10.3	10.0	9.8

These material design allowables are applicable to the following elements:

60B14262-1, -3 Stiffener, Hat, Door

[2] Applicable when 7075-T651 material is used.

6061-0 Plate <3.000

	RT	150°F	200°F
F_{tu} KSI (L)	16	16	16
F_{ty} KSI (L)	6	6	6
E 106 psi	9.9	N/A	N/A

These material design allowables are applicable to the following elements: [3]

60B14328-1 Plate, Umbilical Frame

2024-T4 Drawn Tube <.5000

	RT	150°F	200°F
F_{tu} KSI (L)	64	61	59
F_{ty} KSI (L)	40	39	38
E 10^6 psi	10.5	10.4	10.3

These material design allowables are applicable to the following elements:

60B15846-1 Struct.

2024-T351 Rod <6.500

	RT	150°F	200°F
F_{tu} KSI (L)	62	60	58
F_{ty} KSI (L)	40	39	38
E 10^6 psi	10.5	10.4	10.3

These material design allowables are applicable to the following elements: [4]

60B15847-1 End Fitting

[3] The allowables shown for 150°F and 200°F are based on data from the Aerospace Structural Metals Handbook, Vol.II

[4] The RT allowables are "S" values from MIL-HDBK-5A. The 150°F and 200°F allowables are percentages of RT figures based on data from the Boeing Design Manual.

2024-0 Clad Sheet and Plate <1.750

	RT	150°F	200°F
F_{tu} KSI (L)	22	NA	NA
F_{ty} KSI (L)	8	NA	NA
E 10^6 psi	10.5	NA	NA

These material design allowables are applicable to the following elements:

60B14605-1, -2 Cover Assy., Electrical Opening

7079-T6 Forgings 3.001-4.000

	RT	150°F	200°F
F_{tu} KSI (L)	71	71	71
F_{ty} KSI (L)	61	61	61
E 10^6 psi	10.3	10.2	10.1

These material design allowables are applicable to the following elements: 5

60B15020-1 Forging, Frame, LOX Vent

7075-T6 Extrusions .250-.499

	RT	150°F	200°F
F_{tu} KSI (L)	81	77	71
F_{ty} KSI (L)	73	69	67
E 10^6 psi	10.3	10.0	9.8

These material design allowables are applicable to the following elements:

60B15620-1 Angle Splice, Inner, J-ring
60B15420-1 Angle Splice, Inner, Channel

5 These allowables are "S" values from MIL-HDBK-5A

7075-T6 Extrusions .5000-2.999

	RT	150°F	200°F
F_{tu} KSI (L)	81	77	71
F_{ty} KSI (L)	72	68	66
E 10^6 psi	10.3	10.0	9.8

These material design allowables are applicable to the following elements:

60B14324-1	Angle, Upper Header, Umbilical Opening
60B14290-1	Channel, Frame, Access and Umbilical Opening

7079-T6 Extrusions .250-.499

	RT	150°F	200°F
F_{tu} KSI (L)	77	75	72
F_{ty} KSI (L)	68	67	65
E 10^6 psi	10.3	10.2	10.1

These material design allowables are applicable to the following elements:

60B15630-1	Angle, Splice, Outer, J-Ring
60B15430	Angle, Splice, Outer, Channel

6061-0 Extrusions, All

	RT	150°F	200°F
F_{tu} KSI (L)	14	14	14
F_{ty} KSI (L)	5	5	5
E 10^6 psi	9.9	NA	NA

These material design allowables are applicable to the following elements: (6)

60B14327-1	Angle, Lower, Umbilical Frame
60B14326-1, -2	Angle, Side, Umbilical Frame
60B14329-1	Angle, Upper, Umbilical Frame

(6) Allowables at 150°F and 200°F are based on data from the Aerospace Structural Metals Handbook, Vol. II

7075-0 Sheet and Plate $\leq$2.000

		RT	150°F	200°F
F_{tu}	KSI (L)	29	NA	NA
F_{ty}	KSI (L)	12	NA	NA
E	10^6 psi	10.3	NA	NA

These material design allowables are applicable to the following elements:

60B14024-7	Filler

7075-0 Extrusions, All

		RT	150°F	200°F
F_{tu}	KSI (L)	29	NA	NA
F_{ty}	KSI (L)	11	NA	NA
E	10^6 psi	10.3	NA	NA

These material design allowables are applicable to the following elements:

60B14024-3, -5, -9	Filler
60B14020-1	Extrusion, Spacer, Y-Ring
60B14021-1	Extrusion, Filler, Y-Ring
60B14022-1	Extrusion, Filler, Upper Ring

1.2 S-II-3 STAGE

1.2.1 LOX Tank Girth Weld

The following material design allowables for the S-II-3 LOX tank material joined at the girth weld are "A" values in all cases:

2014-T651 Plate, 1.001-2.000

	-300°F	75°F
F_{tu} KSI (L)	75	66
F_{ty} KSI (L)	68	60
E 10^6 psi	11.7	10.5

The girth weld is made according to NAA specification MA0107-016. This specification covers both MIG and TIG welding processes of 2014 with 2319, 4043 and 716 filler wire. It calls out a weldment tensile strength of 38 KSI for 2014-T6 greater than .250 inch thickness, as part of the butt weld test requirements.

The book, Welding Kaiser Aluminum, shows filler wire 2319 as a substitute for 4043. Since typical mechanical properties are available for 2014-T6 weldments using 4043 filler but not for similar weldments using 2319 filler, those of the former are shown in the following tabulation. [1]

Typical Weld Strengths
2014-T6 MIG or TIG Butt Welds, 4043 Filler

	F_{tu}	F_{ty}	Elong in 2"
As Welded Properties	34 KSI	28 KSI	4%
Postweld Heat Treated and Aged Properties [2]	50 KSI	N/A	2%

[1] Data was obtained from the Welding Handbook, Amer. Welding Society, and Welding Kaiser Aluminum, Kaiser Aluminum and Chemical Sales, Inc.

[2] Solution heat treated; aged to T62

The typical weld strengths shown in the preceding and the following listings are presented to allow an approximation of the strength of fusion welded 2014-T651. These listings are for 2014-T6 welds; however the mechanical strengths of 2014 in the T6 and T651 conditions are nearly equal (within 5%).

The following tabulation contains weldment data from document NASA-CR-77511, Development of Welding Techniques and Filler Metals for High Strength Aluminum Alloys, Southwest Research Institute. The data shows the comparative strength of MIG versus TIG welds and 2319 versus 4043 filler wire.

Average Uniaxial Ultimate Strengths for MIG and TIG Weldments

Weld Process	Base Material	Filler Wire	Strength, KSI
MIG	2014-T6	4043	42
TIG	2014-T6	4043	47
TIG	2014-T6	2319	50

1.2.2 Forward LH_2 Bulkhead

The material design allowables for each element of the S-II-3, LH_2 Tank, Forward Bulkhead are shown in the following tabulations. All allowables are "A" values.

2014-T62 Plate, .250-1.000

	250°F	RT
F_{tu} KSI (L)	75	68
F_{ty} KSI (L)	67	60
E 10^6 psi	11.6	10.5

These material design allowables are applicable to the following elements:

V7-312143	Panel, Skin, Systems Attach, Bulkhead, Upper, LH_2 Tank, Assy of
V7-312144	Panel, Skin, Bulkhead, Upper, LH_2 Tank
V7-312145	Panel, Skin, Electrical and Probe Attach, Bulkhead, Upper, LH_2 Tank, Assy. of

2014-T651 Plate, 1.001-2.000

		250°F	RT
F_{tu}	KSI (L)	73	66
F_{ty}	KSI (L)	67	60
E	10^6 psi	11.6	10.5

These material design allowables are applicable to the following elements:

V7-312147	Ring, Door, Access, Bulkhead, Upper, LH_2 Tank, Assy. of

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Typical weldment strengths of 2014-T6, butt welds using 4043 filler wire are shown as follows. The data was acquired from the Welding Handbook and Welding Kaiser Aluminum.

Typical 2014 Weldment Strength

Alloy & Temper	Filler Alloy	As Welded Properties F_{tu}	F_{ty}	Elong*	Postweld Heat Treat & Aged Properties F_{tu}	F_{ty}	Elong*
2014-T6	4043	34	28	4	50	NA	2

Heat Treatment
T62

*Percent in 2 inches

1.2.3 Forward Skirt

The material design allowables for each structural element of the S-II-3 Forward Skirt are presented in the following tabulations. The values shown are "A" values in all cases.

Following each tabulation is a list of elements to which the material design allowables are applicable. Wherever possible, the list of elements is broken down according to the four, 90° segments or panels making up the forward skirt.

1.2.3 (Continued)

<u>7075-T6 Sheet T=.040-.062</u>

	RT	350°F
F_{tu} KSI (L)	72	43
F_{ty} KSI (L)	63	39
E 10^6 psi	10.3	8.8

These material design allowables are applicable to the following elements:

V7-311022	Web
V7-311164	Doubler

V7-311102-151 Panel No. 1	V7-311202-21 Panel No. 2	V7-311302-801 Panel No. 3	V7-311402-181 Panel No. 4
V7-311102-7 Skin	V7-311202-3 Skin	V7-311302-3 Skin	V7-311402-3 Skin
V7-311102-41 Skin	V7-311202-5 Skin	V7-311302-7 Skin	V7-311402-5 Skin
V7-311026 Intercostal	V7-311202-7 Skin	V7-311420 Intercostal	V7-311402-7 Skin
V7-311159 Doubler	V7-311420-1 Intercostal	V7-311159 Doubler	V7-311420 Intercostal
	V7-311420-2 Intercostal	V7-311302-19 Skin	V7-311159 Doubler
	V7-311159 Doubler	V7-311307 Frame	V7-311160 Doubler
	V7-311207 Frame	V7-311306 Frame	V7-311406 Frame
	V7-311206-3 Web		
	V7-311206-15 Web		
	V7-311206-17 Web		
	V7-311206-9 Tee		
	V7-311206-13 Stiffener		
	V7-311206-19 Tee		

7075-T6 Sheet T=.063-.187, Extrusions T ≤.249

	RT	350°F
F_{tu} KSI (L)	73	44
F_{ty} KSI (L)	64	40
E 10^6 psi	10.3	8.8

These material design allowables are applicable to the following elements:

V7-311044	Plate
V7-311036	Plate
V7-311037	Plate
V7-311007	Door

V7-311102-151 Panel No. 1	V7-311202-21 Panel No. 2	V7-311302-801 Panel No. 3	V7-311402-181 Panel No. 4
V7-311102-19 Plate	V7-311203-3 Skin	V7-311303 Skin	V7-311403 Skin
V7-311103 Skin	V7-311165 Doubler	V7-311165 Doubler	V7-311165 Doubler
V7-311104 Frame	V7-751106 Bracket	V7-311178 Doubler	V7-311178 Doubler
V7-311157 Doubler	V7-311207-7 Cap	V7-311122 Strap	
V7-311165 Doubler	V7-311207-9 Cap	V7-311522 Bracket	
V7-311178 Doubler	V7-311178 Doubler		
V7-311179 Doubler	V7-311206-5 Cap		
	V7-311206-7 Cap		

7075-T6 Sheet T= .188 - .249

	RT	350°F
F_{tu} KSI (L)	75	45
F_{ty} KSI (L)	65	40
E 10^6 PSI	10.3	8.8

These material design allowables are applicable to the following elements:

V7-311043 Plate
V7-311040 Plate

V7-311102-151 Panel No. 1	V7-311202-21 Panel No. 2	V7-311302-801 Panel No. 3	V7-311402-181 Panel No. 4
V7-311102-23 Plate	-	-	-

7075-T651 Plate T= .250 - 2.00

	RT	350°F
F_{tu} KSI (L)	74	44
F_{ty} KSI (L)	66	41
E 10^6 PSI	10.3	8.8

These material design allowables are applicable to the following elements:

V7-311021 Tee
V7-311011 Plate
V7-311172 Fitting
V7-311174 Fitting

7075-T6511 Extrusion T = .249

	RT	350°F
F_{tu} KSI (L)	78	47
F_{ty} KSI (L)	70	43
E 10^6 psi	10.3	8.8

These material design allowables are applicable to the following elements:

V7-311102-151 Panel No. 1	V7-311202-21 Panel No. 2	V7-311302-801 Panel No. 3	V7-311402-181 Panel No. 4
V7-311109 Stringer	V7-311408 Stringer	V7-311304 Frame	V7-311109 Stringer
V7-311102-49 Angle	V7-311409 Stringer	V7-31109 Stringer	V7-311408 Stringer
V7-311110 Stringer	V7-311410 Stringer	V7-311408 Stringer	V7-311409 Stringer
V7-311120 Stringer	-	V7-311410 Stringer	V7-311413 Stringer
V7-311123 Stringer	-	V7-311141 Stringer	V7-311140 Stringer
V7-311135 Stringer	-	-	V7-311141 Stringer
V7-311136 Stringer	-	-	V7-311161 Stringer
V7-311137 Stringer	-	-	V7-311410 Stringer
V7-311138 Stringer	-	-	-
V7-311184 Stringer	-	-	-
V7-311408 Stringer	-	-	-
V7-311140 Stringer	-	-	-
V7-311155 Stringer	-	-	-
V7-311409 Stringer	-	-	-
V7-311410 Stringer	-	-	-

7075-T6511 Extrusion T=.250-.499

	RT	350°F
F_{tu} KSI (L)	81	49
F_{ty} KSI (L)	73	45
E 10 psi	10.3	8.8

These material design allowables are applicable to the following elements:

V7-311102-151 Panel No. 1	V7-311202-21 Panel No. 2	V7-311302-801 Panel No. 3	V7-311402-181 Panel No. 4
-	V7-311155 Stringer	V7-311155 Stringer	V7-311155 Stringer
-	V7-311109 Stringer	V7-311109 Stringer	-

2024-T3 Sheet T=.063-.249

	RT	350°F
F_{tu} KSI (L)	63	50
F_{ty} KSI (L)	46	39
E 10^6 psi	10.5	9.8

These material design allowables are applicable to the following elements:

V7-311180 Strap

V7-311102-151 Panel No. 1	V7-311202-21 Panel No.2	V7-311302-801 Panel No. 3	V7-311402-181 Panel No. 4
V7-311122 Strap	V7-311181 Strap	V7-311059 Angle	V7-311122 Strap
-	V7-311059 Angle	V7-311050 Intercostal	V7-311050 Intercostal

V7-311102-151 Panel No. 1	V7-311202-21 Panel No. 2	V7-311302-801 Panel No. 3	V7-311402-181 Panel No. 4
-	V7-311058 Angle	V7-311058 Angle	V7-311051 Frame
-	V7-311122 Strap	-	V7-311052 Frame
-	-	-	V7-311053 Intercostal
-	-	-	V7-311058 Angle
-	-	-	V7-311059 Angle

2024-T4, T3511 Extrusions, T=.050-.249

	RT	350°F
F_{tu} KSI (L)	57	47
F_{ty} KSI (L)	42	38
E 10^6 psi	10.5	9.8

These material design allowables are applicable to the following elements:

V7-311102-151 Panel No. 1	V7-311202-21 Panel No. 2	V7-311302-801 Panel No. 3	V7-311402-181 Panel No. 4
V7-311124 Stiffener	V7-311124 Stiffener	V7-311124 Stiffener	V7-311124 Stiffener
V7-311125 Stiffener	-	V7-311125 Stiffener	V7-311125 Stiffener
V7-311176 Stiffener	-	V7-311054 Tee	V7-311176 Stiffener
V7-311177 Stiffener	-	V7-311055 Tee	V7-311054 Tee
-	-	V7-311056 Tee	V7-311055 Tee
-	-	-	V7-311056 Tee
-	-	-	V7-311057 Tee

1.3 S-IVB-503 STAGE

1.3.1 Common Bulkhead/Aft Bulkhead-Aft Bulkhead/Thrust Structure Joints

The following information relates to material design allowables, sandwich design allowables, and typical weld strengths for the S-IVB-503-Common Bulkhead/Aft Bulkhead-Aft Bulkhead/Thrust Structure joints. The allowables are "A" values in all cases.

The typical weld strengths shown in the last tabulations were obtained from reliable sources such as the Welding Handbook, Welding Kaiser Aluminum and reports from Douglas Aircraft Company and NASA.

Following each group of material and sandwich design allowables is a list of S-IVB-503 elements to which the allowables are applicable.

7075-T6 Extrusion, .500-.749

	RT	250°F
F_{tu} KSI (L)	81	66
F_{ty} KSI (L)	72	60
E 10^6 psi	10.3	9.5

These material design allowables are applicable to the following elements:

1A39316-101	Stringer, Thrust Structure
" -103	" " "
" -105	" " "
" -115	" " "
" -117	" " "
" -119	" " "
" -133	" " "
" -139	" " "
" -141	" " "
" -143	" " "
" -145	" " "
" -153	" " "
" -155	" " "
" -73	" " "
" -75	" " "
" -77	" " "
" -79	" " "

1A39316-81	Stringer,	Thrust	Structure	
" -83	"	"	"	
" -85	"	"	"	
" -89	"	"	"	
" -91	"	"	"	
" -93	"	"	"	
" -95	"	"	"	
" -97	"	"	"	
" -99	"	"	"	
1B28969-1	Stringer	"	"	

7075-T6 Extrusion, ≤.249

	RT	250°F
F_{tu} KSI (L)	78	63
F_{ty} KSI (L)	70	58
E 10^6 PSI	10.3	9.5

These material design allowables are applicable to the following elements:

1A39316-121	Tee,	Thrust	Structure
" -123	"	"	"
" -125	"	"	"
" -135	"	"	"
1A39316-51	Brace	"	"

7075-T6 Clad Sheet, .040-.062

	RT	250°F
F_{tu} KSI (L)	72	58
F_{ty} KSI (L)	63	52
E 10^6 PSI	10.3	9.5

These material design allowables are applicable to the following elements:

1A39316-59	Intercostal,	Thrust	Structure
" -61	"	"	"
" -137	Doubler,	"	"
" -191			

1A39316-131 Doubler, Thrust Structure

7075-T6 Clad Sheet .063 to .187

	RT	250°F
F_{tu} KSI (L)	73	59
F_{ty} KSI (L)	64	53
E 10^6 PSI	10.3	9.5

These material design allowables are applicable to the following elements:

1A39316-11 Channel, Thrust Structure
-3 Splice Plate, Thrust Structure
" -47 Gusset, Thrust Structure
" -57 Stiffener, Thrust Structure
" -58 " , " "
" -9 Channel, Thrust Structure

1A67503-1 Frame Assy, Thrust Structure

1A68349-1 Segment, Thrust Structure
-503 " " "

1A68381-1 Frame, Thrust Structure

1B52893-501 Frame, Thrust Structure

7075-T651 Sheet, .040-.499

	RT	250°F
F_{tu} KSI (L)	72	58
F_{ty} KSI (L)	62	52
E 10^6 PSI	10.3	9.5

These material design allowables are applicable to the following elements:

1A68314-1 Skin, Thrust Structure
-503 " " "

1A68549-501	Skin,	Thrust	Structure
1A68666-1	"	"	"
1A68951-1	"	"	"

7075-T651 BAR, ≤ 3.000

	RT	250°F
F_{tu} KSI (L)	77	62
F_{ty} KSI (L)	66	55
E 10^6 PSI	10.3	9.5

These material design allowables are applicable to the following elements:

1A78017-1	Stringer,	Thrust	Structure
1A78148-1	"	"	"
1B28151-1	"	"	"
1B38077-1	Bracket,	"	"
1B38078-1	"	"	"
-2	"	"	"
1B42261-1	Fitting	"	"
-2	"	"	"
1B64597-1	Stringer,	"	"

A356-T61 Al. Casting Class 2

	RT	250°F
F_{tu} KSI (L)	40	36
F_{ty} KSI (L)	30	28
E 10^6 PSI	10.4	9.9

These material design allowables are applicable to the following elements:

1A57487-503 Fitting, Thrust Structure

2014-T6 Sheet, .040-.249

	RT	-300°F
F_{tu} KSI (L)	67	76
F_{ty} KSI (L)	59	67
E 10^6 PSI	10.5	11.6

These material design allowables are applicable to the following elements:

1A39286-13	Segment, Aft Common Bulkhead
1A39286-15	Plate, " " "
1A39280-13	Segment, Fwd " "
1A39280-7	Plate, " " "
1A39308-41	Segment, Dome Assy., Aft, LOX Tank
" -43	" " " " " "
" -45	" " " " " "
" -47	" " " " " "
" -49	" " " " " "
" -51	" " " " " "
" -53	" " " " " "
" -55	" " " " " "

2014-T6 Extrusion, .500-.749

		RT	-300°F
F_{tu}	KSI (L)	64	72
F_{ty}	KSI (L)	58	66
E	10^6 PSI	10.5	11.6

These material design allowables are applicable to the following elements:

1A39286-9	Ring, Aft, Common Bulkhead
1A39280-11	Ring, Fwd, Common Bulkhead

Heat Resistant Phenolic, Glass Reinforced Honeycomb Core
Room Temperature Mechanical Properties

Core Designation	Longitudinal Properties		Transverse Properties		Compression Properties	
	Shear Strength	Shear Modulus	Shear Strength	Shear Modulus	Com. Strength	Com. Modulus
Class I, Type I, Grade 4 [1]	180 PSI	10,800 PSI	85 PSI	5117 PSI	410 PSI	42,000 PSI
Class I, Type I, Grade 6 [2]	265 "	15,400 PSI	136 "	7610 PSI	800 "	72,000 PSI

The Class I, Type I, Grade 4 core is equivalent to HRP-3/16-GF11-4.0 core while the Class I, Type I, Grade 6 is nearly

[1] Density is 4.0 pcf
[2] Density is 5.5 pcf

equivalent to HRP-3/16-GF 12-6.0 core. The cores with the beginning designation "HRP" are used in the S-IVB -503.

These sandwich design allowables are applicable to the following elements:

1A39292-1	Core, Common Bulkhead (HRP-3/16-GF 12-6.0)
1A39292-501	Core, Common Bulkhead (HRP-3/16-GF 11-4.0)

Typical strength of 2014-T6 butt welds similar to those in the S-IVB common bulkhead are presented in the next three data listings.

Typical Weld Strengths [3]

2014-T6, MIG or TIG Butt Welds, 4043 Filler

	F_{tu}	F_{ty}	Elong.
As welded properties at room temp.	34 KSI	28 KSI	4% in 2 in.

NOTE: These are general values for both MIG and TIG weldments in 2014-T6 aluminum of any thickness

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Typical Weld Strengths [4]

2014-T6 Sheet, .100 thick, MIG Butt Welds, 4043 Filler

	F_{tu}	F_{ty}	Elong.
Transverse Welds			
(a) Room temp.	45.0 KSI	32.5 KSI	4% in 1 in.
(b) -423°F	55.5 "	46.1 "	1.7 "
Longitudinal Welds			
(a) Room temp.	60.0 "	40.0 "	9.4 "
(b) -423 °F	79.2 "	61.2 "	5.0 "

NOTE: These weld strengths are undoubtedly more representative of S-IVB weldments since the values were obtained from a Douglas report in which MIG and TIG welds were evaluated in an attempt to improve tankage welds.

[3] From The Welding Handbook, American Welding Society and Welding Kaiser Aluminum, Kaiser Aluminum & Chem. Sales Inc.

[4] Douglas Aircraft Co., Rpt. SM48383, "Evaluation of MIG & TIG Welding Processes for Joining 2014-T6 Aluminum Alloy"

Typical Weld Strength [5]

2014-T6 Sheet, .125 thick, MIG Butt Welds, 4043 Filler

	F_{tu}	F_{ty}	Elong.
As welded properties at Room Temp.	42.1 KSI	35.5 KSI	1.7% in 2 in.

NOTE: These weld strengths tend to support those in the preceding tabulation. It should be noted that Douglas specification DPS 14052, Section 8.2.7, calls out a minimum ultimate tensile strength of 38.5 KSI for preproduction fusion butt welds in aluminum Saturn assemblies.

Typical strength of fillet welds similar to those on the Common Bulkhead to LOX Tank Aft Dome lap joint are presented in the following tabulations. The strength of fillet welds is a function of the shear strength of the filler alloy.

Shear Strength vs Fillet Weld Size [6]
4043 Filler Alloy

	Shear Strength-KSI per lineal in. of weld Fillet Weld Size-inches					
Loading Direction	.125	.250	.375	.500	.625	.750
Longitudinal	1.5	3.0	4.0	5.5	7.0	8.5
Transverse	2.0	3.5	5.5	7.5	9.0	11.0

These values were determined from tests of fillet welds in aluminum lap joints. The strength of 4043 aluminum filler alloy, calculated from those tests are shown in the data which follows:

Typical Strength of 4043 Aluminum Alloy Filler

Property	Strength - KSI
Longitudinal Shear	16
Transverse Shear	21

It should be noted that Douglas specification DPS14053, section 8.4.8, calls out a minimum ultimate tensile strength of 10 KSI for preproduction fusion fillet welds in aluminum Saturn assemblies.

[5] NASA-CR-74992, Development of Welding Techniques & Filler Metals for High Strength Aluminum Alloys

[6] From The Welding Handbook, American Welding Society & Welding Kaiser Aluminum, Kaiser Aluminum & Chem. Sales Co.

1.3.2 Forward Skirt

The material design allowables for each structural element of the S-IVB-503 Forward Skirt are shown in the following tabulations. All allowables shown are "A" values. In the case of extruded shapes, the allowables were selected after crippling factors were calculated for each segment of a structural shape.

Following each group of material design allowables is a list of part numbers, including part name, to which the allowables are applicable.

<u>7075-T6 Clad Sheet, .012-.039</u>

	75°F	285°F	375°F
F_{tu} KSI (L)	70	53	37
F_{ty} KSI (L)	61	46	34
E 10^6 psi	10.3	9.3	8.6

These material design allowables are applicable to the following elements:

1A39264-105	Intercostal
-11	Skin
-131	Doubler
-15	Skin
-269	Intercostal
-279	Intercostal
-3	Skin
-305	Intercostal
-306	Intercostal
-353	Intercostal
-355	Intercostal
-357	Intercostal
-358	Intercostal
-367	Intercostal
-372	Intercostal
-375	Intercostal
-5	Skin
-655	Skin
-633	Skin
-53	Intercostal
-55	Intercostal
-57	Intercostal
-621	Web
-629	Skin
-707	Cap

1.3.2 Continued

1A39264-721	Doubler
-723	Doubler
-731	Skin
-735	Skin
-737	Skin
-771	Intercostal
-805	Intercostal
-807	Intercostal
-819	Intercostal
-829	Intercostal
-841	Intercostal
-783	Doubler
-803	Skin
-9	Skin
-87	Skin

7075-T6 Clad Sheet, .040-.062

	75°F	285°F	375°F
F_{tu} KSI (L)	72	54	38
F_{ty} KSI (L)	63	48	35
E 10^6 psi	10.3	9.3	8.6

These material design allowables are applicable to the following elements:

1A39264-101	Rib
-109	Angle
-110	Angle
-119	Skin
-121	Skin
-135	Skin
-137	Angle
-138	Angle
-153	Frame
-154	Frame
-155	Intercostal
-159	Clip
-165	Skin
-167	Skin
-169	Skin
-179	Skin
-181	Clip
-187	Intercostal
-189	Intercostal
-193	Intercostal

1.3.2 Continued

1A39264-211	Intercostal
-215	Skin
-229	Skin
-255	Skin
-257	Skin
-261	Frame
-265	Frame
-271	Clip
-289	Intercostal
-287	Angle
-297	Frame
-313	Clip
-314	Clip
-373	Intercostal
-623	Clip
-624	Clip
-631	Clip
-632	Clip
-633	Rib
-635	Rib
-641	Doubler
-634	Doubler
-649	Retainer
-71	Rib
-72	Rib
-73	Rib
-745	Intercostal
-773	Clip
-809	Clip
-81	Clip
-79	Clip
-80	Clip
-83	Clip
-799	Support
-801	Angle
-835	Angle
-827	Doubler
-831	Doubler
-835	Angle
-853	Filler
-99	Skin
1B37372-501	Skin

<u>7075-T6 Clad Sheet, .063-.187</u>

	75°F	285°F	370°F
F_{tu} KSI (L)	73	55	39

1.3.2 Continued

	75°F	285°F	375°F
F_{ty} KSI (L)	64	49	36
E 10^6 psi	10.3	9.3	8.6

These material design allowables are applicable to the following elements:

1A39264-113	Support
-139	Skin
-145	Fitting
-147	Fitting
-149	Fitting
-151	Fitting
-161	Frame
-163	Plate
-201	Frame
-203	Frame
-209	Frame
-217	Fitting
-219	Angle
-225	Angle
-221	Fitting
-227	Fitting
-223	Skin
-249	Channel
-259	Channel
-281	Strap
-291	Skin
-293	Channel
-299	Channel
-315	Strap
-317	Channel
-335	Channel
-337	Intercostal
-351	Frame
-381	Strap
-383	Frame
-384	Frame
-603	Splice
-627	Strap
-645	Plate
-653	Channel
-703	Spacer
-739	Skin
-75	Strap
-77	Skin
-789	Plate
-85	Support

1.3.2 Continued

1A39264-855	Doubler
-859	Door
-95	Splice
-1	Frame Segment
-501	Frame Segment
-503	Frame Segment
-505	Frame Segment
-507	Frame Segment
1A57757-1	Splice
1A58328-1	Frame Segment
1A65842-1	Splice
1A72749-3	Panel, Umbilical
1B44398-1	Fitting
1B44623-1	Fitting
-2	Fitting
1B53149-1	Fitting
-501	Fitting
1B44397-1	Fitting
-2	Fitting

<u>7075-T6 Extrusions, $\leq$.250</u>

	75°F	285°F	375°F
F_{tu} KSI (L)	78	59	41
F_{ty} KSI (L)	70	53	39
E 10^6 psi	10.3	9.3	8.6

These material design allowables are applicable to the following elements:

1A39264-111	Angle
-117	Stringer
-123	Cap
-125	Angle
-171	Cap
-173	Cap
-177	Clip
-183	Clip
-19	Stringer
-191	Clip
-197	Clip
-199	Clip
-205	Cap
-207	Cap
-21	Stringer
-213	Clip

1.3.2 Continued

1A39264-23	Stringer
-235	Stringer
-237	Stringer
-243	Stringer
-245	Stringer
-247	Stringer
-248	Stringer
-25	Stringer
-251	Angle
-253	Cap
-267	Angle
-275	Clip
-277	Cap
-29	Stringer
-301	Clip
-307	Cap
-308	Cap
-309	Cap
-31	Stringer
-311	Cap
-312	Cap
-319	Stringer
-321	Stringer
-329	Stringer
-33	Stringer
-331	Stringer
-341	Angle
-343	Cap
-345	Clip
-347	Clip
-349	Clip
-35	Stringer
-359	Cap
-360	Cap
-361	Cap
-362	Cap
-363	Angle
-364	Angle
-365	Cap
-37	Stringer
-39	Stringer
-377	Cap
-379	Cap
-380	Cap
-385	Angle
-386	Angle
-387	Angle
-389	Angle
-391	Angle

1.3.2 Continued

1A39264-397	Clip
-399	Angle
-637	Angle
-43	Stringer
-607	Stringer
-609	Stringer
-611	Stringer
-613	Stringer
-615	Stringer
-617	Stringer
-619	Stringer
-651	Stringer
-45	Angle
-59	Angle
-605	Stringer
-61	Angle
-62	Angle
-65	Angle
-625	Cap
-659	Cap
-661	Cap
-63	Angle
-67	Stiffener
-677	Angle
-68	Stiffener
-683	Stringer
-685	Stringer
-689	Stringer
-713	Stringer
-715	Stringer
-717	Stringer
-719	Stringer
-725	Stringer
-727	Stringer
-729	Stringer
-733	Stringer
-749	Stringer
-751	Stringer
-753	Stringer
-755	Stringer
-763	Stringer
-765	Stringer
-767	Stringer
-705	Angle
-741	Angle
-743	Stiffener
-747	Cap

1.3.2 Continued

1A39264-759	Stringer
-769	Cap
-775	Cap
-821	Cap
-823	Cap
-825	Cap
-89	Cap
-777	Stringer
-779	Stringer
-781	Stringer
-811	Stringer
-817	Stringer
-837	Stringer
-839	Stringer
-851	Stringer
-793	Angle
-833	Angle
-91	Cap
-93	Angle
-97	Tee
1A58875-1	Frame Segment
1A74879-1	Splice
1A74880-1	Splice
-501	Splice
1B32058-1	Splice
1A69873-1	Stringer
1A58608-1	Angle Segment
-501	Angle Segment
1A58609-1	Angle Segment
-501	Angle Segment
1A67605-1	Splice

7075-T6 Clad Sheet, .188-.249

	75°F	285°F	375°F
F_{tu} KSI (L)	75	56	40
F_{ty} KSI (L)	65	49	36
E 10^6 psi	10.3	9.3	8.6

These material design allowables are applicable to the following elements:

1A88817-1	Plate
1A93571-1	Plate

1.3.2 Continued

7075-T651 Bar, ≤4.000

	75°F	285°F	375°F
F_{tu} KSI (L)	77	58	41
F_{ty} KSI (L)	66	50	37
E 10^6 psi	10.3	9.3	8.6

These material design allowables are applicable to the following elements:

1A88816-1	Fitting
1A92868-1	Fitting
-501	Fitting
1A93572-1	Fitting
1A93888-1	Fitting
-2	Fitting
1A86248-1	Support Assy.
-2	Support Assy.
1B38194-1	Fitting
-2	Fitting
-501	Fitting
1B44308-1	Fitting

6061-T6 Sheet and Plate, .010-2.000

	75°F	285°F	375°F
F_{tu} KSI (L)	42	34	29
F_{ty} KSI (L)	36	31	26
E 10^6 psi	9.9	9.5	9.1

These material design allowables are applicable to the following elements:

1A72749-5	Panel, Umbilical

2024-T351 Bar 3.001-4.000

	75°F	285°F	375°F
F_{tu} KSI (L)	62	53	48

1.3.2 Continued

	75°F	285°F	375°F
F_{ty} KSI (L)	40	36	32
E 10^6 psi	10.5	10.1	9.6

These material design allowables are applicable to the following elements:

1B34960-3 Fitting

<u>7075-T651 Plate, .250-.499</u>

	75°F	285°F	375°F
F_{tu} KSI (L)	76	57	40
F_{ty} KSI (L)	68	52	38
E 10^6 psi	10.3	9.3	8.6

These material design allowables are applicable to the following elements:

1B54210-1 Plate

1.4 IU-503

1.4.1 IU-503 Shell

The following listings include information concerning the minimum qualification and acceptance allowables for those critical elements of the IU-503 shell. In the case of the inner and outer skins and the honeycomb core, material and sandwich design allowables are presented as well. The minimum qualification and acceptance allowables were obtained from the specifications referenced by the drawings.

Mechanical Properties, Minimum [1]
5052 Aluminum Honeycomb Core

Property	Minimum Strength Density 3.1 pcf	4.3 pcf	8.1 pcf
Core flatwise compression	200 psi	350 psi	1000 psi
Core shear modulus	25000 psi	38000 psi	78000 psi
Sandwich shear strength	86 lb/in. width	150 lb/in. width	472 lb/in. width
Delamination of core	Shall withstand 12.5 lb of tension load		

These mechanical properties are minimum qualification and acceptance allowables for core of 5/8 inch thickness, similar to that used in the following elements: [2]

30Z13030	Core, 5052 Al Honeycomb, Density	8.1 pcf
30Z13031	" " " " "	3.1 "
30Z13035	" " " " "	4.3 "

Mechanical Properties, Minimum [3]
Adhesive - Metlbond 329

Property	Minimum Strength Average	Individual
1-Sandwich peel strength (a) Room Temp.	12.3 in-lb/in. width	

[1] Per MIL-C-7438, qualification and acceptance tests

[2] These values are representative of 5/8 inch thick core. The 30Z13030 and 30Z13031 core are .90 inch thick while the 30Z13035 core is .250 inch thick.

[3] Per MIL-A-25463 and MIL-A-5090

2-Flatwise Tensile strength		
(a) Room temp	450 psi	400 psi
(b) 300°F	350 psi	315 psi
(c) -67°F	350 psi	315 psi
3-Flexural strength (total load)		
(a) room temp.	1750 lb.	1575 lb.
(b) 300°F	1500 lb.	1350 lb.
(c) -67°F	1750 lb.	1575 lb.
(d) after 192 hrs at 300°F	1200 lb.	1080 lb.
4-Creep deflection in flexure when loaded for 192 hrs. at:		
(a) room temp.	.025 in. max/1000 lb. load	
(b) 300°F	.050 in. max/1000 lb. load	
5-Tensile shear		
(a) room temp.	2250 psi	
(b) 10 min. at 300°F	2000 psi	
(c) 192 hr. at 300°F	2000 psi	
(d) 10 min at -67°F	2250 psi	
6-Fatigue strength		
(a) room temp.	750 psi at 106 cycles-600 psi at 10^7 cycles	
7-Creep-rupture		
(a) room temp. and 1600 psi	.015 in. max deformation after 192 hr.	
(b) 300°F and 800 psi	(Same as a)	
8-Tensile shear		
(a) room temp. after 30 days salt water spray	2100 psi	
(b) room temp after 30 days at 120°F, 95-100% relative humidity	2100 psi	

(c) room temp. after 7 days immersion in jet engine fuel JP-4 (MIL-J-5624), anti-icing fluid (MIL-F-5566), hydraulic oil (MIL-H-5606), standard test fluids (MIL-S-3136, type III) and 30 days immersion in tap water.	2100 psi

9. Pi-Tension

(a) room temp	950 psi
(b) 350°F	765 psi

The minimum mechanical properties numbered 1 through 9 are minimum qualification and acceptance allowables for the following adhesive:

30Z13032 Adhesive, core-to-metal

The minimum mechanical properties numbered 5 through 8 are minimum qualification and acceptance allowables for the following adhesive:

30Z13034 Adhesive, Metal-to-metal

Mechanical Properties, Minimum
Adhesive

Property	Stress, psi RT	300°F	350°F
Flexural stress	1480	940	
Compressive stress	1480	1290	
Shear stress	730	635	
Tensile stress	400	300	
Core beam shear stress			
(a) 8.1 pcf core density			160
(b) 3.1 pcf core density			100

These minimum mechanical properties are minimum qualification and acceptance allowables for the following adhesive:

30Z13042 Adhesive, Core-to-core

The material design allowables in this tabulation are "A" values in all cases:

7075-T6 Sheet, .015-.039

	RT	250°F
F_{tu} KSI (L)	76	62
F_{ty} KSI (L)	66	55
E 10^6 psi	10.3	9.5

These material design allowables are applicable to the following elements:

30Z13105-3	Skin, outer
-5	Skin, inner
30Z13106-3	Skin, outer
-5	Skin, inner
30Z13107-3	Skin, outer
-5	Skin, inner
30Z13008-5	Skin, outer
-7	Skin, inner
30Z13109-3	Face sheet
-5	" "

Sandwich Design Allowables
5052 Aluminum Honeycomb Core

	Longitudinal Shear		Transverse Shear		Compression	
Core Designation	Shear Strength	Shear Modulus	Shear Strength	Shear Modulus	Com. Strength	Com. Modulus
RT 8.1-3/16-.003P	529 psi	97,440 psi	312 psi	35,800 psi	1100 psi	175,000 psi
3.1-3/16-.001P	114 "	28,000 "	70 "	10,000	200 psi	49,000
4.3-1/4-.002P	265 "	48,800 "	150 "	18,000	360 psi	68,000

250°F 8.1-3/16-.003P	460 psi	77952 psi	271 psi	28,640 psi	869 psi	148750 psi
3.1-3/16-.001P	99 "	22400 "	61 "	8,000	158 "	41650
4.3-1/4-.002P	231 "	39000 "	131 "	14,400	284 "	57800

These sandwich design allowables are applicable to the following elements:

30Z13030	Core, 5052 Aluminum Honeycomb Density 8.1 pcf
30Z13031	Core, 5052 Aluminum Honeycomb Density 3.1 pcf
30Z13035	Core, 5052 Aluminum Honeycomb Density 4.3 pcf

The following materials:

30Z13033	Potting Compound
30Z13047	Adhesive, Metal-to-metal, Class II

are not referenced to any specification or test requirements by the Source Control Drawings. Both 30Z13033 and 30Z13047 materials are EPON 934, supplied by Shell Chemical Company. It is noted that 30Z13047 is equal to and completely interchangeable with 30Z13033.

1.5 CONCLUSIONS

The material design allowables used by the stage contractors in association with each of the identified critical elements, have been compared to those recommended by JSAT, which appear above. It was found that in most cases the allowables originally used were equivalent to or conservative as compared to those recommended. The non-conservative discrepancies were investigated as to their impact on margins of safety. There was no case in which the employment of the non-conservative value resulted in a negative or zero margin of safety. Thus it is concluded that the material and weldment design allowables used by the contractors for the identified critical elements, are satisfactory.