Block II SRM Conceptual Design Studies Final Report

Appendix A—CEI Specification CPW1-1900
Appendix B—Composite Motor Case
Volume I, Book 1

(NASA-CR-179049) BLOCK 2 SRM CONCEPTUAL DESIGN STUDIES. VOLUME 1, BOOK 1: APPENDIX A: CEI SPECIFICATION CPW1-1900, APPENDIX B: COMPOSITE MOTOR CASE Final Report (Morton Thiokol) 171 p CSCL 21H G3/20

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19 December 1986

MORTON THIOKOL, INC.

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Publications No. 87354

SPACE SHUTTLE

Solid Rocket Motors
Morton Thiokol, Inc

Block II SRM Conceptual Design Studies Final Report

Appendix A—CEI Specification CPW1-1900
Appendix B—Composite Motor Case
Volume I, Book 1

19 December 1986

Prepared for

National Aeronautics and Space Administration
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Contract No. NAS8-37296

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Specification No. CPW1-1900

PRIME EQUIPMENT CONTRACT END ITEM
DETAIL SPECIFICATION
PART I OF TWO PARTS

PERFORMANCE, DESIGN, AND VERIFICATION REQUIREMENTS
SPACE SHUTTLE SOLID ROCKET MOTOR BLOCK II
CPW1-1900
FOR
SPACE SHUTTLE SOLID ROCKET MOTOR PROJECT

25 November 1986

PRELIMINARY PER NAS8-37296

PREPARED FOR:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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APPROVED BY:

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Systems Management

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Program Management

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Release (ECS SS600)

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Date

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1.0 SCOPE

1.1 General. This part of this specification establishes the requirements for performance, design and verification of one type of equipment identified as the Space Shuttle Block II Solid Rocket Motor CPW1-1900. This Contract End Item (CEI) is used to provide the propulsion for the Solid Rocket Boosters (SRB) of the Space Transportation System (STS) for the Eastern Test Range (ETR) and Western Test Range (WTR). This CEI requires interfacing with the SRB.

2.0 APPLICABLE DOCUMENTS

The following documents, of the exact issue shown, form a part of this specification to the extent specified herein. Current issue is shown for some documents in place of specific date and issue when the document is under CCB control. Reference to all applicable documents in Sections 3, 4, and 5 will be by the basic number.

2.1 Specifications.

Military

MIL-D-1000, March 1, 1985

Drawings, Engineering and Associated Lists

Applicable Paragraphs: 3.3.1.3, 3.3.1.3.1, 3.3.1.3.2, 3.3.1.3.4, 3.3.1.3.6

MIL-B-5087B(2), August, 31, 1970

Bonding, Electrical, and Lightning Protection for Aerospace Systems

Applicable Paragraphs: 3.2.1.6, 3.3.5.2

MIL-W-6858C, October 20, 1964
Interim Amendment 1 (USAF), June 1965

Welding, Resistance, Aluminum, Magnesium, Non-Hardening Steels or Alloys, Nickel Alloys, Heat--Resisting Alloys, and Titanium Alloys, Spot and Seam

Applicable Paragraphs: 3.3.6.6

MIL-I-6866B(2), January 30, 1969

Inspection, Penetrant Method of

Applicable Paragraphs: 4.1.1.1.3

MIL-I-6870C, March 27, 1973

Inspection Program Requirements, Nondestructive Testing for Aircraft and Missile Materials and Parts

Applicable Paragraphs: 4.1.1.1.3

MIL-S-7742B, Amendment 1, March 15, 1973

Screw Threads, Standard, Optimum Selected Series, General Specification for

Applicable Paragraphs: 3.3.6.9

MIL-B-7883B, February 20, 1968

Brazing of Steels, Copper, Copper Alloys, Nickel Alloys, Aluminum and Aluminum Alloys

Applicable Paragraphs: 3.3.6.7

MIL-S-8879A, Notice 2, March 15, 1973

Screw Threads, Controlled Radius Root with Increased Minor Diameter, General Specification for

Applicable Paragraphs: 3.3.6.9

MIL-N-8922, 28 January 1972

Nut, Self-locking, Steel, 220 KSI FTU, 450° F

Applicable Paragraphs: 3.3.6.10

MIL-N-25027E, Amendment 3, 21 October 1985

Nut, Self-locking, 250° F, 450° F, 800° F

Applicable Paragraphs: 3.3.6.10

MIL-I-26860B, April 25, 1974

Indicator, Humidity, Plug, Color Change

Applicable Paragraphs: 5.2.2

National Aeronautics and Space Administration

JSC 07636C, August 1, 1984; Change Notice 11, October 17, 1984

Lightning Protection Criteria Document

Applicable Paragraphs: 3.3.5.2, 3.3.5.5

JSC 07700, Vol. X, Revision D, Appendix 10.10, September 30, 1983 through Change No. 83, May 5, 1986

Space Shuttle Flight and Ground System Specification, Level II Program Definition and Requirements

Applicable Paragraphs: 3.2.7.1

JSC 07700, Vol. XII, Revision B, February 18, 1983

Space Shuttle Program Integrated Logistics Requirements

Applicable Paragraphs: 3.4, 3.4.2

JSC 08060 (D), January 20, 1983

Space Shuttle System Pyrotechnic Specification

Applicable Paragraphs: 3.2.1.4.12, 3.2.1.4.12.1, 3.2.1.5.1, 3.3.6.10, 4.1, 5.3

JSC 08800A, November 1974

JSC Supplement to NHB 5300.4(3A), "Requirements for Soldered Electrical Connections"
Applicable Paragraphs: 3.2.1.6, 3.3.5.3

JSC 09084, October 1974

Coordinate Systems for the Space Shuttle Program

Applicable Paragraphs: 3.3.10

JSC 20007, November 16, 1984

Space Shuttle Lightning Protection Verification Document

Applicable Paragraphs: 3.3.5.5

JSC-SL-E-0001, June 4, 1973

Electromagnetic Compatibility Requirement, Systems for the Space Shuttle Program

Applicable Paragraphs: 3.2.1.6, 3.3.5.1

JSC-SL-E-0002A, September 16, 1974 through Change No. 12, March 10, 1986

Specifications, Electromagnetic Interference Characteristics, Requirements for Equipment for the Space Shuttle Program

Applicable Paragraphs: 3.2.1.6, 3.3.5.1

JSC-SE-R-0006A, April 2, 1973

Materials and Processes, NASA JSC Requirements for

Applicable Paragraphs: 3.2.9.2, 10.1

JSC-SE-S-0073B, February 1975

Space Shuttle Fluid Procurement and Use Control

Applicable Paragraphs: 3.3.9

JSC-SN-C-0005, March 1974

Specification Contamination Control Requirements for the Space Shuttle Program

Applicable Paragraphs: 3.3.9

MSFC-SPEC-250(1), February 28, 1963

Protective Finishes for Space Vehicles, Structures and Associated Flight Equipment
Applicable Paragraphs: 3.3.8.2

MSFC-SPEC-445, May 1965

Adhesive Bonding, Process Inspection, Requirements for

Applicable Paragraphs: 3.3.6.8, 10.1

MSFC-SPEC-504A, November 1977

Welding, Aluminum, Aluminum Alloys

Applicable Paragraphs: 3.3.6.6, 4.1.1.1.3

MSFC-SPEC-522A, November 18, 1977

Design Criteria for Controlling Stress Corrosion Cracking

Applicable Paragraphs: 3.3.8.2

Morton Thiokol, Inc.

CPW1-3300 (Current Issue)

Performance, Design and Verification Requirements, Space Shuttle Solid Rocket Motor Lightweight CPW1-3300 for Space Shuttle High Performance Solid Rocket Motor Project Operational Flight

Applicable Paragraphs: 4.2.1

ECW3-3404 (Current Issue)

Engineering Critical Component Specification Part I of Two Parts; Performance, Design and Verification Requirements for Space Shuttle Systems Tunnel

Applicable Paragraphs: 3.2.1.10

2.2 Standards.

Military

MIL-STD-100A, October 1, 1967
Engineering Drawing Practices

Applicable Paragraphs: 3.3.1.3, 3.3.1.3.6

MIL-STD-105D, Change 2, March 20, 1964

Sampling Procedures and Tables for Inspection by Attributes

Applicable Paragraphs: 4.1.1.1.4

MIL-STD-129F (1), May 20, 1974

Marking for Shipment and Storage

Applicable Paragraphs: 3.3.12, 5.2.6

MIL-STD-130F (1), July 2, 1984

Identification and Marking of U.S. Military Property

Applicable Paragraphs: 3.3.12

MIL-STD-143B, November 12, 1969

Standards and Specifications, Order of Precedence for the Selection of

Applicable Paragraphs: 3.3.1

MIL-STD-280A, July 7, 1969

Definitions of Item Levels, Item Exchangeability, Models, and Related Terms

Applicable Paragraphs: 3.3.11

MIL-STD-414, Change 1, May 8, 1968

Sampling Procedures and Tables for Inspection by Variables for Percent Defective

Applicable Paragraphs: 4.1.1.1.4

MIL-STD-453, Change 1, September 4, 1963

Inspection, Radiographic

Applicable Paragraphs: 4.1.1.1.3

MIL-STD-454D, August 31, 1973

Standard General Requirements for Electronic Equipment

Applicable Paragraphs: 3.3.8.1

MIL-STD-462, Notice 1, August 1, 1968, Notice 2, May 1, 1970

Measurement of Electromagnetic Interference Characteristics

Applicable Paragraphs: 3.2.1.6, 3.3.5.1

MIL-STD-463, June 9, 1966

Definitions and System of Units, Electromagnetic Interference Technology

Applicable Paragraphs: 3.3.5.1

MIL-STD-681B, February 6, 1967

Identification Coding and Application of Hookup and Lead Wire

Applicable Paragraphs: 3.3.12

MIL-STD-794D, Notice 2, December 18, 1975

Parts and Equipment, Procedures for Packaging and Packing of

Applicable Paragraphs: 5.2

MIL-STD-810C, March 10, 1975

Environmental Test Methods

Applicable Paragraphs: 3.3.8.1

MIL-STD-1246A, August 18, 1967

Product Cleanliness Levels and Contamination Control Program

Applicable Paragraphs: 5.2.4

MIL-STD-1472B, December 31, 1974

Human Engineering Design Criteria for Military Systems, Equipment, and Facilities

Applicable Paragraphs: 3.3.14

National Aeronautics and Space Administration

MSFC-STD-136, June 11, 1971

Parts Mounting Design Categories for Soldered Printed Wiring Board Assemblies

Applicable Paragraphs: 3.3.5.4

MSFC-STD-154A, December 15, 1965

Printed Wiring Boards, (Copper Clad) Design, Documentation and Fabrication of

Applicable Paragraphs: 3.3.5.4

MSFC-STD-349A, October 29, 1965
Amendment 1, July 16, 1968

Electrical and Electronic Reference Designations

Applicable Paragraphs: 3.2.1.6

JSCM 8080, Change 6, 7, and 8, December 1, 1977 (as changed by Approved Deviation DAR SRM0005 and standard 133B requirements are not applicable)

Manned Spacecraft Criteria and Standards

Applicable Paragraphs: 3.2.1.6.1.1, 3.2.1.6.1.2, 3.3.2.1, 5.3, 10.1

2.3 Handbooks.

Military

MIL-HDBK-5B, September 1, 1971

Metallic Materials and Elements for Aerospace Vehicle Structures

Applicable Paragraphs: 3.3.6.2

MIL-HDBK-17A, January 19, 1971

Plastics for Flight Vehicles

Applicable Paragraphs: 3.3.6.2

MIL-HDBK-23A(1), December 30, 1968

Structural Sandwich Composites

Applicable Paragraphs: 3.3.6.2

National Aeronautics and Space Administration

NHB 1440.4A, July 19, 1968

Specifications and Standards for NASA Engineering Data Micro Reproduction System

Applicable Paragraphs: 3.3.1.3.3

NHB 5300.4(1D-2), October 1979

Safety, Reliability, Maintainability and Quality Provisions for the Space Shuttle Program

Applicable Paragraphs: 3.2.3, 3.2.6, 4.1.1.1

NHB 5300.4(3A), May 1968

Requirements for Soldered Electrical Connectors

Applicable Paragraphs: 3.2.1.6, 3.3.5.3

NHB 5300.4(3G), April 1985

Requirements for Interconneting Cables, Harnesses, and Wiring

Applicable Paragraphs: 3.3.5.6

NHB 5300.4(3H), May 1984

Requirements for Crimping and Wire Wrap

Applicable Paragraphs: 3.2.1.6

NHB 6000.1C, July 1976

Requirements for Packaging, Handling, and Transportation for Aeronautical and Space Systems, Equipment and Associated Components

Applicable Paragraphs: 5.2, 5.2.5, 10.1

NHB 8060.1A, February 1974

Flammability, Odor and Offgassing Requirements and Test Procedures for Materials in Environments That Support Combustion

Applicable Paragraphs: 3.3.8.3

MSFC-HDBK-505A, January 1981

Structural Strength Program Requirements

2.4 Publications.

Military

AMCR 385-100, August 1, 1985

Army Material Command Regulation Safety Manual

Applicable Paragraphs: 3.2.6.4

DOD 4145.26M, March 1986

DOD Contractor's Safety Manual for Ammunition, Explosives, and Related Dangerous Materials

Applicable Paragraphs: 3.2.6.4

AFM 71-4, August 9, 1971

Packaging and Handling of Dangerous Materials for Transportation by Military Aircraft

Applicable Paragraphs: 5.3

National Aeronautics and Space Administration

MMI 1700.17, June 4, 1982

MSFC Procedure for Acquiring Permits to Ship Rocket Motors Containing Class B Explosives in a Propulsive State Or With Igniters Installed

Applicable Paragraphs: 5.2

CM-017-016-2H, (Current Issue)

Interface Control Documentation Contractual Index and Status Report, Space Shuttle Projects

Applicable Paragraphs: 3.1.4

ICD-2-00001, (Current Issue)

Shuttle Vehicle Mold Lines and Protuberances

Applicable Paragraphs: 3.6.2, Figure 4

ICD-2-0A001, (Current Issue)

Shuttle System/Launch Platform Stacking and VAB Servicing

Applicable Paragraphs: 3.1.3.1, 3.6.2

ICD-2-0A002, (Current Issue)

Space Shuttle Launch Pad and Platform

Applicable Paragraphs: 3.1.3.1, 3.6.2

ICD-2-4A001, (Current Issue)

Solid Rocket Booster Receiving and Processing Station

Applicable Paragraphs: 3.1.3.1, 3.6.2

ICD-2-4A002, (Current Issue)

Solid Rocket Booster Retrieval Station

Applicable Paragraphs: 3.1.3.1, 3.2.1.4.10, 3.2.1.4.12.2, 3.6.2

ICD 3-44001, (Current issue)

Solid Rocket Motor to Forward Skirt

Applicable Paragraphs: 3.2.1.3, 3.2.7.2, 3.6.2, Figure 4

ICD 3-44003, (Current Issue)

Solid Rocket Motor to Aft Skirt and Thrust Vector Control Actuator

Applicable Paragraphs: 3.2.1.3, 3.2.1.4.1, 3.2.1.4.4, 3.2.1.4.8, 3.2.1.4.9, 3.2.1.4.12, 3.2.1.4.12.3, 3.2.7.2, 3.6.2, Figure 4

ICD 3-44004, (Current Issue)

Solid Rocket Motor to ET Attach Ring

Applicable Paragraphs: 3.2.1.3, 3.2.7.2, 3.6.2, Figure 4

ICD 3-44005, (Current Issue)

Solid Rocket Motor to Solid Rocket Booster Electrical and Instrumentation Subsystem

Applicable Paragraphs: 3.2.1.4.4, 3.2.1.4.12.1, 3.2.1.4.12.4, 3.2.1.5, 3.2.1.5.2, 3.2.1.6, 3.2.1.6.1.2, 3.2.1.6.1.3, 3.2.1.6.2, 3.2.1.6.2.1, 3.2.1.6.2.2, 3.3.5.1, 3.3.5.5, 3.6.2

ICD 3-44008, (Current Issue)

Systems Tunnel to SRB Systems

Applicable Paragraphs: 3.2.1.3, 3.2.1.6, 3.2.1.10.2, 3.2.1.11, 3.2.7.2, 3.6.2

SE-019-019-2H(B), May 19, 1978

Shuttle Master Verification Plan, Vol. IV, Solid Rocket Booster Verification Plan

Applicable Paragraphs: 4.1

SE-019-043-2H, May 20, 1975
SCN 01, September 24, 1982

Natural Environments for the Space Shuttle Solid Rocket Motor Booster

Applicable Paragraphs: 3.2.7.1

SE-019-049-2H(A), December 17, 1976
SCN 13, February 2, 1977
SCN 14, March 9, 1977
SCN 15, May 25, 1977
SCN 16, June 3, 1977
SCN 17, July 12, 1977
SCN 18, August 10, 1977
SCN 20, October 20, 1977
SCN 21, October 20, 1977
SCN 22, October 20, 1977
SCN 23, October 27, 1977
SCN 24, October 27, 1977
SCN 25, January 9, 1978
SCN 26, March 15, 1978
SCN 27, April 3, 1978
SCN 28, May 15, 1978
SCN 29, June 22, 1978
SCN 30, August 14, 1978
SCN 31, October 10, 1979
SCN 32, April 9, 1979
SCN 33, July 12, 1979
SCN 34, April 10, 1980
SCN 35, August 12, 1980
SCN 36, September 26, 1980
SCN 37, March 26, 1981
SCN 38, July 15, 1981
SCN 39, May 26, 1982
SCN 40, July 2, 1982
SCN 41, July 23, 1982
SCN 42, October 15, 1982
SCN 43, January 17, 1983
SCN 44, January 7, 1983
SCN 47, February 6, 1984

Vibration, Acoustic and Shock Design and Test Criteria

Applicable Paragraphs: 3.2.7.2, 4.1

SE-019-053-2H(E), January 1986

SRB Re-entry Thermal Environment Data Book

Applicable Paragraphs: 3.2.7.2

SE-019-057-2H(B), November 16, 1978
SCN 033, February 23, 1979
SCN 034, March 1, 1979
SCN 036, April 12, 1979
SCN 037, June 11, 1979
SCN 039, August 27, 1979
SCN 042, January 11, 1980
SCN 043, March 7, 1980
SCN 046, August 8, 1980
SCN 047, September 25, 1980
SCN 049, January 8, 1982
SCN 060, August 9, 1984
SCN 062, May 1, 1985

Space Shuttle SRB Design Loads, Book 1

Applicable Paragraphs: 3.2.7.2

SE-019-057-2H(F), September 17, 1976
SCN 014, November 30, 1976
SCN 017, February 22, 1977
SCN 019, June 13, 1977
SCN 020, July 25, 1977
SCN 022, November 10, 1977
SCN 023, November 29, 1977
SCN 025, March 27, 1978
SCN 026, April 11, 1978
SCN 027, May 1, 1978
SCN 029, September 21, 1978
SCN 030, October 25, 1978
SCN 031, January 22, 1979
SCN 032, February 23, 1979
SCN 035, April 9, 1979
SCN 038, June 18, 1979
SCN 040, September 28, 1979
SCN 041, January 11, 1980
SCN 044, April 25, 1980
SCN 045, June 25, 1980
SCN 048, January 8, 1982
SCN 050, May 26, 1982
SCN 051, June 14, 1982
SCN 052, August 24, 1982
SCN 053, November 19, 1982

SCN 054, February 6, 1984
SCN 055, February 6, 1984
SCN 057, April 12, 1984
SCN 058, June 7, 1984
SCN 059, June 21, 1984
SCN 061, August 23, 1984
SCN 063, May 1, 1985
SCN 064, November 1, 1985
SCN 065, April 9, 1986

Space Shuttle SRB Design Loads, Book 2

Applicable Paragraphs: 3.2.7.2, 10.1

SE-019-058-2H(A), March 23, 1977

SRB Contamination Control Plan (Paragraphs 7.1.3 and 7.1.4 only)

Applicable Paragraphs: 3.3.9

SE-019-067-2H, December 16, 1975
SCN 001, January 10, 1977
SCN 002, June 26, 1981
SCN 004, January 14, 1977
SCN 010, April 26, 1977

SRB Component Environmental Test Requirements and Methods

Applicable Paragraphs: 3.2.7.2

SE-019-094-2H(A), March 1978 (as modified by S/A No. 237)
SCN 001, March 1983

Material Selection List and Use Instructions SRM/SRB

Applicable Paragraphs: 3.3.1.1

MM8040.12(A), July 2, 1976

Standard Contractor Configuration Management Requirements MSFC

Applicable Paragraphs: 3.1.4

American Society of Mechanical Engineers

ASME Code Section VIII, 1974

ASME Boiler and Pressure Vessel Code

Applicable Paragraphs: 4.1

American Society for Testing and Materials

ASTM E 399-74

Plane Strain Fracture Toughness of Metallic Materials

Applicable Paragraphs: 3.3.6.2

Other Agencies

CFR 49, Parts 100-177, December 1, 1980

Code of Federal Regulations - Transportation

Applicable Paragraphs: 5.3

Rockwell International, Space Division

SD73-SH-0181-3A, September 1978
Change No. 1, March 12, 1979
Change No. 2, May 8, 1979
Change No. 3, September 26, 1980
Change No. 4, October 20, 1980

Space Shuttle Aerodynamics Heating Data Book, Shuttle Vehicle Booster-Ascent, Volume III

Applicable Paragraphs: 3.2.7.2

SD74-SH-0144D, December 1977
Change No. 1, September 22, 1978
Change No. 2, May 12, 1978
Change No. 3, March 28, 1980
Change No. 4, April 23, 1982
Change No. 5, October 29, 1982

Space Shuttle Program Thermal Interface Design Data Book

Applicable Paragraphs: 3.2.7.2

Project Plans

TWR-10184A, January 10, 1975 (CD)

Fracture Control Plan

Applicable Paragraphs: 3.3.6.2

TWR-10192C, December 1976 (CD)

Material Selection and Control Plan for Space Shuttle SRM Project

Applicable Paragraphs: 3.2.9.2, 3.3.1.1, 3.3.8.3

TBD

Fracture Control Plan for Space Shuttle Block II SRM

Applicable Paragraphs: 3.3.6.2

TBD

Fracture Control Plan for the Space Shuttle Block II SRM

Applicable Paragraphs: 3.3.6.2

Documents

DPD 400A, September 11, 1975

Information Requirements Document

Applicable Paragraphs: 3.1.4, 3.3.1.3.5, 3.3.1.3.6, 4.4.3, 5.2.3

TWR-10195, (Current Issue)

GFE/GFP Requirements for the Space Shuttle Solid Rocket Motor

Applicable Paragraphs: 3.1.6

TBD

Block II SRM Motor Internal Insulation Design and Evaluation Requirements

Applicable Paragraphs: 3.3.6.1.3

2.5 Drawings.

National Aeronautics and Space Administration

MSFC-DWG-10A00516, September 23, 1977

SRM Alignment Criteria

Applicable Paragraphs: 3.2.5.1

MSFC-DWG-11A00950H, March 22, 1984

Paint Pattern-SRB

Applicable Paragraph: 3.1.3.1

MSFC-DWG-85M03936A-3, March 1973

EEE Parts Selection and Application Guidelines for the Space Shuttle External Tank and Solid Rocket Booster

Applicable Paragraphs: 3.2.1.6, 3.3.1.2.1

MSFC-DWG-10509308, EO-1 (January 1967), June 1960

Welding Carbon Low Alloy Stainless Steel

Applicable Paragraphs: 3.3.6.6

3.0 REQUIREMENTS

3.1 Definition. The Contract End Item (CEI) is defined in terms of its function, major components, missions and operational concepts.

3.1.1 General Description. The SRM CEI is used as a major subsystem of a solid rocket booster for the Shuttle Vehicle. The Shuttle Vehicle Booster will consist of two Solid Rocket Boosters (SRBs), each of which will utilize one CPW1-1900 SRM. The two SRMs will operate in parallel with the Space Shuttle Main Engines and will provide impulse and enable thrust vector control to propel and control the Space Shuttle Vehicle from liftoff to SRB staging. The SRM will consist of a lined, insulated, segmented metal rocket motor case loaded with solid propellant; an ignition system complete with electromechanical safe and arm device (S&A), initiators, and igniter assembly; moveable nozzle; exit cone with a linear shaped charge for severance and a nozzle plug; instrumentation; and integration hardware including electrical brackets, systems tunnel, grounding provisions, stiffener rings, and attachment provisions to the forward and aft SRB skirts and the SRB/ET attach ring.

3.1.2 Missions. Flight hardware and ground systems requirements will be based on providing SRMs for operational flights.

3.1.3 Operational Concepts. The SRM design requirements have been based on the following operational concepts:

3.1.3.1 Assembly Operations Concept. The SRM will be delivered to the launch site in motor segments and subassemblies which are as large as practical. The S&A device with initiators installed will be shipped to the launch site as an assembly separate from the SRM. Preassembly and checkout will have been accomplished at Morton Thiokol's production facility to the maximum extent feasible. To comply with the assembly operations concept, the SRM will meet those interface requirements of ICD 2-0A001, ICD 2-0A002, and ICD 2-4A001 which affect SRM interface with the Receiving Station, the Vehicle Assembly Building (ETR only), the Mobile Launcher Platform (MLP) (ETR only), and the Launch Pad. The SRM forward rocket motor segment, center rocket motor segments, aft rocket motor segment, nozzle extension, and integration hardware will be inspected and stored vertically or horizontally either outdoors (with protection as required) or indoors; or further assembled vertically in the Vehicle Assembly Building (VAB) (ETR) or on the Launch Pad (WTR). The aft booster assembly, forward booster assembly, and center segments will be stacked on the MLP (ETR) or Launch Pad (WTR). Stacking of the assemblies and segments will include installation of the pin retainer assembly following satisfactory leak checks of all case joints to verify proper assembly. The joint paint pattern shall meet the requirements of MSFC-DWG-11A00950 (ETR) or ICD 2-4A002 (WTR). The S&A device will be installed on the SRM and then the seal between the S&A device and the igniter will be leak checked. System verification checks will be accomplished through the Launch Processing System (LPS) at various points.

3.1.3.2 Launch Pad Operations Concept. The SRM will be verified ready for launch in the VAB prior to pad rollout (ETR) or on the launch pad (WTR). Final system readiness checks will be conducted on the launch pad.

3.1.3.3 Booster Operations Concept. During the boost phase of flight, the two SRMs will operate in parallel with the Space Shuttle Main Engines (SSME). The SRB will provide impulse and thrust vector control while functioning in parallel with the SSME from lift-off to SRB separation.

3.1.3.4 Recovery Concepts. Upon separation from the external tank (ET), the SRBs will initially decelerate by inherent aerodynamic drag forces. An active deceleration system will be provided by each SRB to reduce the velocity before water entry. A portion of the nozzle exit cone of each nozzle will be separated to reduce the impact loads imparted to the nozzle assembly, actuators, and case. The SRB will be dewatered with the SRB dewatering system and then towed back to the dock to begin refurbishment.

3.1.3.4.1 Refurbishment Concepts. The SRM will be cleansed and disassembled into the following components: (a) casting segments, (b) S&A device, (c) nozzle exit cone extension, and (d) stiffener rings. The remaining portion of the nozzle exit cone extension will be removed from the nozzle forward assembly at the field joint. The igniter and nozzle shall be capable of removal to allow inspection of the igniter to case and the nozzle to case seals. The joint areas will be protected during the transportation and refurbishment operations. All other SRM components will be prepared for shipment and shipped to the factory where they will be refurbished and remanufactured for reuse.

3.1.4 Organizational and Management Relationships. The Systems Requirements Section is responsible for the preparation and maintenance of Part I of this specification. The Systems Management Manager of the SRM Project/Program office is responsible for the control of this specification. This specification is prepared in accordance with the requirements of NAS8-37296, the Information Requirements Document (IRD), and MM8040.12, Standard Contractor Configuration Management Requirements, MSFC Programs, and will be controlled to the level shown in the specification tree referenced in Paragraph 3.1.5. All changes to this specification will be processed in accordance with the requirements of MM8040.12. In the event of conflict between requirements referenced and the content of this specification, the order of precedence will be as follows:

1) This document.

2) All other applicable specifications and standards.

3) MSFC SE-prefix document loads take precedence over derived Interface Control Document identified loads.

The current status of Interface Control Documents (ICDs) may be determined from CM-017-016-2H.

3.1.5 Systems Engineering Requirements. The relationship of the Space Shuttle Contract End Item (CEI) Specification to other Shuttle Program and Space Shuttle Project Systems Engineering documentation is presented in the Integrated Logistics Support Plan. The components covered by this specification appear on the specification tree.

3.1.6 Government Furnished Property List. The Government Furnished Equipment (GFE) is identified in TWR-10195, GFE/GFP Requirements for the Space Shuttle Solid Rocket Motor.

3.1.7 Critical Components. This paragraph is not applicable to this specification.

3.2 Characteristics. The SRM shall burn continuously as the propulsive element in each of two SRBs in parallel with the Space Shuttle Main Engines to provide impulse to propel the flight vehicle and enable thrust vector control from ignition to SRB staging. The thrust and impulse characteristics of each SRM are specified relative to the nozzle centerline.

3.2.1 Performance. The SRM shall function from sea level to 200,000 feet over a motor propellant mean bulk temperature (PMBT) (see 6.1.1) range of +40 to +90° F during and after the motor has been exposed to the thermal environments of 3.2.7. SRM performance requirements shall be based on a PMBT of +60° F. The specified performance limits and tolerances shall apply to the qualification configuration and to all deliverable flight SRMs.

3.2.1.1 General Performance. The propulsion system shall conform to the following performance characteristics.

3.2.1.1.1 Ignition Characteristics. The following ignition characteristics shall be applicable to an SRM over a PMBT range of +40 to +90° F during the ignition transient.

3.2.1.1.1.1 Ignition Interval. The ignition interval shall be between 170 and 340 milliseconds after ignition command to the initiators in the S&A device up to a point at which the head-end chamber pressure has built up to 563.5 psia.

3.2.1.1.1.2 Pressure Rise Rate. The maximum rate of pressure buildup shall be 109 psi for any 10 millisecond interval.

3.2.1.1.2 Motor Characteristics. The SRM shall meet the following performance characteristics.

3.2.1.1.2.1 Nominal Thrust-Time Curve. The nominal (see 6.1.1) vacuum thrust-time data for the SRM is tabulated in Table I. Also tabulated are upper and lower bounds about the nominal curve that represent the population range expected to encompass the nominal thrust-time trace using all appropriate SRM flight motors when corrected to the target burn rate at a PMBT of 60° F.

3.2.1.1.2.2 Performance Tolerances and Limits. The nominal value, tolerance, and limits for selected performance parameters are tabulated in Table II for individual flight motors. The delivered performance values for each individual motor when corrected to a 60° F PMBT shall not exceed the limits specified for any performance parameter in Table II. The PMBT used in the performance calculation for each motor will be based on air temperature measurements taken at the launch pad. Maximum matched pair performance difference values for applicable parameters are also tabulated in Table II for matched pairs of motors. The difference for each parameter for a matched pair shall be determined by dividing the absolute value of the difference by the arithmetic mean value of the pair. These values expressed in terms of percent for each matched pair shall not exceed the maximum differences specified in Table II. The differentials for matched pairs are applicable throughout the PMBT range of 40 to 90° F assuming a maximum PMBT difference of 1.4° F between motors of a flight set. The maximum PMBT difference is based on calculations using prelaunch meteorological data taken at the launch pad and is not verified by motor case temperature measurements.

3.2.1.1.2.3 Thrust Differential. With a maximum PMBT difference of 1.4° F between the two SRMs on a Shuttle Vehicle, the differential thrust between the two SRMs shall not be greater than the values given in Table III at any time during the periods shown. These differentials are applicable over PMBT range of 40 to 90° F.

3.2.1.2 Pressure Seals. The design and performance of the pressure seals used in the SRM shall be in accordance with the following requirements.

a. Redundant, verifiable seals shall be provided for each pressure vessel leak path except for the flex bearing.

b. Sealing shall accommodate case rounding, axial elongation, clevis/tang relative motion, nozzle rotation, and any other structural deflections which may occur. This shall apply for the actual as-built dimensions of each joint (all components) at mating. Sealing shall not require, but shall accommodate, pressure assistance.

c. Seals shall provide zero leakage (no evidence of blowby or erosion) under worst case flight environment.

d. Seals shall be capable of operating within a temperature range resulting from all natural and induced environments specified in paragraph 3.2.7 and all manufacturing processes.

e. No single undetectable failure mode shall result in the loss of joint sealing capability.

f. All leak paths shall remain sealed at both primary and secondary seals at all times, i.e., from the final leak test through the entire ignition pressure transient and the motor burn without evidence of blow-by or erosion.

g. The verification process must not degrade the performance or integrity of the system.

h. O-ring seal design shall be consistent with the following parameters:

	Min(%) Squeeze	Max(%) Squeeze	Gland Fill(%)	Surface Finish (Microinches) Top	Bottom	Sides
Bore seals	10(1)	35	$\leq$ 90	32	32	63
Face seals	10(1)	35	$\leq$ 95	32	32	63

(1) Minimum squeeze shall be 10%, including effects of temperature, compression set, and pressure effects.

Where additional standards are required, consensus seal industry standards shall be used for sizing seals and seal glands, determining tolerances and establishing required surface finishes.

3.2.1.2.1 Field Joints, Nozzle to Case Joints and Nozzle Internal Seals.

a. Failure of the primary seal shall not result in failure of the secondary seal(s).

b. Both the primary and redundant seals shall provide independent sealing capability without evidence of blow-by or erosion.

c. A minimum of two seals for each leak path shall be verifiable after all ground environments which could affect seal performance have been experienced.

d. Bore seals must be verifiable in the proper sealing direction.

e. Each seal shall maintain a sealing margin of 100% (based on seal/metal tracking velocities) without pressure assistance, including the effects of manufacturing tolerances, permanent joint deformations, natural and induced environment, and changes in geometry during motor burn.

3.2.1.2.2 Flex Bearing Sealing. The flex bearing shall maintain a positive gas seal between its internal components.

3.2.1.3 Case. The case shall function as an integral part of the combustion chamber in accordance with the following requirements:

a. When performing as part of the combustion chamber, the case shall be capable of containing the internal MEOP.

b. The structural integrity of the pressurized portion of the case segments shall be demonstrated and verified prior to each use. Verification shall include a proof pressure test. In local areas where proof pressure tests are inadequate to reach the required stress level, inspection and fracture mechanics analysis shall be used to verify structural integrity.

c. The case shall contain risers for attaching the ET/SRB aft attach ring as defined in ICD 3-44004. The risers shall be part of the pressurized section of the case and shall not degrade the integrity of the case.

d. The case shall meet the SRB forward and aft skirt interfaces as defined in ICD 3-44001 and ICD 3-44003.

e. The case shall have SRB systems tunnel components and electrical grounding straps bonded to it as specified in Paragraph 3.2.1.6.b and ICD 3-44008.

f. The case segment mating joints shall incorporate provisions to insure proper segment orientation and alignment to facilitate joining, stacking, disassembly, and refurbishment for reuse.

g. The case segment mating joints shall not permit entry of external moisture when exposed to the natural environment of paragraph 3.2.7.

h. The forward and aft segments of the case shall have ports for the installation of the ignition system and the nozzle assembly respectively.

i. The case cylindrical segments shall be designed using biaxial improvement in the analysis.

j. The case segments shall be designed using motor internal pressure drop from head end to aft end during motor operation in the analysis.

k. The case joints shall not experience chemical dissolution, loss of strength or paint degradation when protected in accordance with paragraph 3.2.1.8.

3.2.1.4 Nozzle Assembly.

3.2.1.4.1 Vectoring. The nozzle assembly shall be movable and be capable of omniaxial vectoring to a minimum of 8 degrees (may be reduced up to 0.5 degree for alignment error) from the nozzle null position at all aft end stagnation chamber pressures above 75 psig. Vectoring in the retract direction shall be limited to -8 degrees (retract) at 75 psig aft end stagnation chamber pressure and decreased linearly to -3.5 degrees at 0 psig. Minimum nozzle gimbal rate and angular acceleration capability shall meet the requirements of ICD 3-44003.

3.2.1.4.1.1 Actuator Stall Force. The nozzle assembly shall be capable of withstanding the loads induced by an actuator stall force of 103,424 pounds in the plane of the actuator.

3.2.1.4.2 Geometric Thrust Vector. The geometric thrust vector shall not deviate from the limits illustrated in Figure 1 and stated below:

a. Maximum radial displacement of the nozzle centerline relative to the SRM centerline shall not exceed 0.25 inch.

b. Maximum angular displacement of the nozzle centerline relative to the SRM centerline shall not exceed 0.50°.

3.2.1.4.3 Dynamic Thrust Vector. The dynamic thrust vector during firing from MEOP to 35 psia, shall not deviate from the limits illustrated in Figure 2, and stated below:

a. Misalignment of the dynamic thrust vector with respect to the nozzle centerline, between null and 8°, shall not deviate more than one degree.

b. The radial offset between the dynamic thrust vector and nozzle centerline at the movable nozzle throat plane shall not exceed 1.13 inches.

3.2.1.4.4 Exit Cone Severance. The nozzle assembly design shall provide a capability to jettison a portion of the exit cone assembly upon receipt of an electrical signal initiated from the SRB via a double shielded electrical cable. Provision for severing the aft exit cone shall be in accordance with ICD 3-44003 and ICD 3-44005.

3.2.1.4.5 Nozzle Alignment. The nozzle alignment verification shall be possible prior to, or during assembly of the SRM.

3.2.1.4.6 Flex Bearing Protection. The nozzle assembly shall incorporate a nozzle snubbing device suitable for preventing flex bearing damage resulting from water impact. This device shall limit the flex bearing axial travel to approximately one inch when the nozzle is in the null position and shall not adversely affect the nozzle assembly deflection capability.

3.2.1.4.7 Environmental Protection.

a. The nozzle assembly shall contain a covering and/or plug to protect the SRM from the environments specified in 3.2.7.1 during storage after assembly.

b. The nozzle assembly shall contain a covering and/or plug to protect the SRM from the environments specified in 3.2.7.2 in the event of an on-pad SSME shutdown prior to SRB ignition. The covering and/or plug shall withstand an overpressure of 1.0 pounds per square inch. The covering and/or plug shall be capable of being expelled without damaging any part of the shuttle system or adversely affecting the SRM performance.

3.2.1.4.8 TVC Actuator Attach Points. The nozzle assembly shall have attach points for the government furnished TVC actuators and shall be compatible with the requirements defined in ICD 3-44003.

3.2.1.4.9 Nozzle Assembly/Aft Segment Interface. The nozzle assembly without the exit cone assembly, shall be capable of being inserted into an assembled SRB aft skirt as defined in ICD 3-44003.

3.2.1.4.10 Nozzle Assembly/Dewatering System Interface. The nozzle assembly shall be compatible with the SRB dewatering system in accordance with ICD 2-4A002.

3.2.1.4.11 Flex Bearing.

3.2.1.4.11.1 Total Deflection. The flex bearing shall be capable of providing a total deflection of 85° during each flight duty cycle.

3.2.1.4.11.2 Bearing Torque Limits. The flex bearing torque at 5° vector angle (using linear regression analysis of acceptance test sine wave event at 2 degrees and 7 degrees vector angles) shall not exceed the limitations shown in Figure 3.

3.2.1.4.12 Aft Exit Cone Severance Ordnance Ring. The aft exit cone severance ordnance ring shall sever a portion of the nozzle exit cone. Severance shall be accomplished by using a detonator cartridge, and a Linear Shaped Charge (LSC) as defined in ICD 3-44003. The LSC and its Electroexplosive Detonator shall meet the requirements of JSC 08060. Initiation of the LSC shall not damage the SRB aft thermal shield to the extent that it cannot perform its intended function.

3.2.1.4.12.1 Detonator. The aft exit cone severance ordnance ring shall use one government furnished detonator cartridge as defined in ICD 3-44005. The detonator cartridge includes an initiator as a piece part and will comply with the performance characteristics defined in JSC 08060.

3.2.1.4.12.2 Post Firing Hazards and Obstructions. Subsequent to the ordnance ring firing and the severance of the aft exit cone, the exit cone plane shall be free from any protrusions which are hazardous to personnel or which prevent insertion of a recovery/retrieval plug as referenced in ICD 2-4A002.

3.2.1.4.12.3 Mounting Provisions for Ordnance Ring Blast Shield and Aft Thermal Shield. The ordnance ring shall be designed to mount on the aft exit cone assembly, aft of the compliance ring. The thermal shield blast protector (blast shield) shall be designed to be mounted between the ordnance ring and the aft thermal shield in accordance with the requirements referenced in ICD 3-44003.

3.2.1.4.12.4 Ordnance Cables and Brackets. The aft exit cone severance ordnance cable and brackets shall be installed in accordance with the requirements referenced in ICD 3-44005.

3.2.1.5 Ignition System. The SRM shall use a head-end mounted ignition system comprised of two initiators, an electro-mechanical safe and arm (S&A) device, and an igniter. The ignition system design shall meet the requirements specified in ICD 3-44005, Paragraph 3.2.1.6 and the following:

a. The ignition system shall preclude hot gas leakage during and subsequent to motor ignition.

b. The igniter and the S&A shall be separable from each other.

3.2.1.5.1 S&A Device. With the S&A device in the "arm" position, a pyrotechnic charge contained in the barrier-booster assembly shall be ignited when either one or both of the initiators are fired. Firing of the initiators shall be initiated upon receipt of electrical power from the Pyro Initiator Controller (PIC) in the SRB. Gases generated by the ignited booster charge shall be vented axially into the igniter initiator chamber to provide the energy flow required to achieve igniter initiation. The design of the S&A device shall have the capability to meet the following requirements:

a. Enable and inhibit ignition.

b. Perform its intended function when either or both of the initiators are fired with the S&A device in the armed position.

c. Prevent ignition when the S&A device is in the safe position and either or both of the initiators fire.

d. Provide change of position from safe-to-arm and arm-to-safe through simplex command and control circuits and simplex actuation devices.

e. Provide simplex remote position indication in both the safed and armed positions.

f. Provide direct visual position indication in both the safed and armed positions.

g. Permit manual safing.

h. Prevent manual arming.

i. Provide a 90° (minimum) out-of-line mechanical barrier.

j. Provide a mechanical safety pin that prevents rotation of the barrier while it is in place and moves the S&A device into the safe position from the full arm or any intermediate position when manually installed.

k. A "safe-arm" talk back switch shall be provided. This switch shall be located on the barrier booster end of the S&A device motor drive shaft.

l. Shall use two initiators (government furnished equipment) and shall comply with the requirements of JSC 08060.

m. Prior to S&A shipment, each initiator shall be installed in the S&A and 100 percent leak checked following installation.

n. Shall allow installation in only one position (rotational orientation).

o. Shall allow each initiator to be lockwired in place.

p. Provide for the installation of two initiators into the barrier-booster.

3.2.1.5.2 Igniter Design. The igniter design shall be in accordance with the ignition system requirements specified in Paragraph 3.2.1.5. The igniter design shall provide ports to accommodate the instrumentation as specified in ICD 3-44005 and provide ease of service, access, and replacement. The igniter hardware and materials shall not form any debris which is capable of damaging any other component from the beginning of ignition interval to the end of action time. The igniter shall be capable of being installed in only one predetermined rotational position onto the forward end of the SRM forward segment. Installation shall be accomplished from the outside of the SRM forward segment.

3.2.1.6 Electrical and Instrumentation. The electrical and instrumentation system is comprised of electrical components that are attached to the SRM and shall comply with the following requirements:

a. The electrical power, instrumentation and electrical control interfaces shall meet the requirements specified in ICD 3-44005.

b. The SRM shall provide the necessary mounting for installing the systems tunnel as defined in ICD 3-44008.

c. The electrical and electronic equipment shall meet the requirements of JSC-SL-E-0002 and MIL-STD-462. Specific tests which are to be performed will be approved by MSFC.

d. In addition to the tests conducted per JSC-SL-E-0002, the susceptibility characteristics of critical input circuitry shall be determined by tests or analyses.

e. The design shall meet the electromagnetic compatibility requirements of JSC-SL-E-0001, JSC-SL-E-0002, MIL-B-5087, and MIL-STD-462.

f. The structural and electrical parts shall meet the electrical bonding requirements of MIL-B-5087.

g. Criticality 1 and 2 electrical, electronic, and electromechanical (EEE) parts shall be selected and controlled in accordance with MSFC-DWG-85M03936 "EEE Parts Selection and Application Guidelines for the Space Shuttle External Tank and Solid Rocket Motor Booster".

h. Electrical and electronic reference designations shall be in accordance with MSFC-STD-349.

i. Electrical solder joints, where required, shall be in accordance with NHB 5300.4(3A) as supplemented by JSC 08800.

j. Crimping and wire wrap requirements shall be in accordance with NHB 5300.4(3H).

3.2.1.6.1 S&A Electrical Characteristics.

3.2.1.6.1.1 Electrical Circuits. The following JSCM 8080 Manned Spacecraft Design Criteria and Standards shall apply to the design of the electrical circuits: 4B, 12A, 13, 18, 19, 20A, 28, 31, 32, 36, 37, 69, 77, 80, 81, 85, 95, 98, 99, 100, 109, 112, 115, 116, 119, 121, 125, 128, and 148.

3.2.1.6.1.2 Electrical Connector. The electrical connector for the arming and monitor circuits shall be of the Bendix "Aquacon" series and shall be in accordance with ICD 3-44005. The "Safe-Arm" talkback switch shall utilize Bendix connector NAJ-OH-8-35P as defined in ICD 3-44005. The type of connector mounting to the S&A shall be optional. JSCM 8080 Standards 63 and 101 shall apply.

3.2.1.6.1.3 Power Supply. The S&A device shall meet all performance requirements of this specification using a power supply furnished for S&A device operation which has the following characteristics as defined by ICD 3-44005:

a. Steady state voltage limits of 24 to 32 vdc

b. Transient voltage limits of 20 to 36.7 vdc

c. Recovery to steady state limits within 200 milliseconds

3.2.1.6.1.4 Safe and Arming Time/Voltage. The S&A device shall "arm" or "safe" within one second at 24 plus 1 minus 0 vdc. The S&A shall cycle with the specified voltages at an atmospheric pressure of from 630 to 770 millimeters of mercury.

3.2.1.6.1.5 Current Requirements. The current required in the motor circuit for actuation shall not exceed 3 amperes at 32 vdc.

3.2.1.6.1.6 Electrical Bonding Resistance. The electrical resistance between A&M and the B-B portions of the S&A device and between the S&A device and the igniter shall be less than 2.5 milliohms at initial assembly.

3.2.1.6.2 Instrumentation. Operational flight measurements shall be as defined in ICD 3-44005. The instrumentation shall be capable of launch readiness checkout after ground system connection on the launch pad. Sensors to control heating shall be as defined in ICD 3-44005.

3.2.1.6.2.1 Operational Flight Instrumentation. The Operational Flight Instrumentation (OFI) shall monitor the chamber pressure of the SRMs over the range from 0 to 1000 psia. The chamber pressure measurement shall be accurate to plus or minus 15 psi. The instrumentation shall operate at a steady state input voltage level of from 22 to 32 vdc which has transient levels of from 20 to 36.7 vdc for periods of up to 200 milliseconds. The instrumentation shall provide a signal from 0 to 5 vdc with a response of 50 Hz. The operational pressure transducers (OPTs) shall be capable of withstanding a 5000 psi maximum assembly test pressure without leakage when leakage is defined as a visual indication of test fluid. After being subjected to a 5000 psi maximum assembly test pressure, the OPTs shall not be required to function. To provide the required redundancy, three operational pressure transducers (OPTs) shall be used to monitor the SRM chamber pressure. The OPT pressure seals shall meet the requirements of 3.2.1.2. For protection of the redundant components, the OPTs shall be mounted to provide the physical separation and orientation consistent with the accomplishment of their function as defined in ICD 3-44005.

3.2.1.6.2.2 Cable Mounting Brackets. Cable mounting brackets for sensor leads, power supply cables, operational flight instrumentation and nozzle LSC double shielded cables shall be installed as required. Conductive bonding material is not required. Brackets shall preclude the abrading of attached cable harnesses as defined in ICD 3-44005.

3.2.1.6.2.3 Ground Environmental Instrumentation. The Ground Evironmental Instrumentation (GEI) shall monitor the temperature of the SRBs while on the ground at the pad. It is not required to function during flight. These instruments will be monitored on the ground through cables with liftoff breakaway connectors.

3.2.1.7 Propellants. The SRM and igniter propellants shall be developed, characterized, and qualified composite propellant formulations that are capable of being bonded to the applicable chamber via appropriate insulation, liner, and other inert materials.

3.2.1.8 Insulation. Insulation shall be designed to ensure that the mechanical properties of the case are not degraded by flight and/or subsequent thermal soak for worst case PMBT over a range of 40 to 90° F.

3.2.1.8.1 Igniter Insulation. The igniter insulation shall provide thermal protection for the main igniter chamber and adapter metal parts to ensure that SRM operation does not degrade their functional integrity or make them unsuitable for refurbishment. The insulation shall ensure a maximum adapter to insulation and igniter chamber to insulation interface temperature of 300° F during action time and a maximum temperature of 400° F during thermal soak conditions following web burnout.

3.2.1.9 Reuseability. Reuseability goals are listed in Table IV. Reusability requirements shall not result in degradation of SRM hardware below the design safety factor.

3.2.1.10 Systems Tunnel. The systems tunnel shall provide flight environment protection to the SRB cabling and LSC, and shall be designed and shall perform according to ECW3-3404.

3.2.1.10.1 Systems Tunnel Design. The systems tunnel shall be designed to attach to the case, accommodate the GFE LSC, provide for the Operational Flight Instrumentation (OFI) and as a goal, provide for at least 30 percent of the volume of OFI for the Development Flight Instrumentation (DFI).

3.2.1.10.2 Thermal Protection. When exposed to the thermal environments of 3.2.7.2, the tunnel shall maintain cable and LSC temperature at or below that specified in ICD 3-44008.

3.2.1.10.3 Venting/Sealing. Tunnel must be designed to the extent necessary to prevent rain and hot gas entry into the tunnel. Tunnel venting will be used if necessary to relieve internal pressure loading.

3.2.1.10.4 Structural Integrity. The structural integrity of the systems tunnel shall withstand the induced environments identified in 3.2.7.2.

3.2.1.10.5 Grounding. The cable tunnel shall provide a low resistance path which is electrically continuous both axially and circumferentially. Bonding across joints and interfaces shall be 2.5 milliohms or less. The tunnel shall be grounded to the motor case every five feet or less to provide a path for lightning current from the tunnel to the motor case.

3.2.2 Physical.

3.2.2.1 Design Envelope. Design geometry shall conform to the dimensions shown in Figure 4 and meet the interface requirements referenced in Paragraph 3.6.2.

3.2.2.2 Mass Properties.

3.2.2.2.1 Control Weight (Inert). The inert weight (see 6.1.1), excluding GFE items installed by others, shall not exceed TBD.

3.2.2.2.2 Propellant Weight. The total loaded propellant weight (see 6.1.1) shall be a minimum of TBD.

3.2.2.2.3 Center of Gravity. The center of gravity shall be within the envelope defined below.

Condition	Longitudinal Axis (x)	Vertical Axis (Z)	Lateral Axis (Y)
Inert (See 6.1.1)	TBD	-0.2 to +0.2	TBD
Loaded	TBD	-0.3 to +0.3	TBD

3.2.2.2.4 Accuracy Requirements. The weight and CG accuracy requirements for each measurement shall be within 0.2 percent and 1.0 inch respectively for the reduced mass property.

3.2.3 Reliability. The reliability program shall comply with the requirements established in NHB 5300.4(1D-2). The design shall minimize the probability of failure in a cost effective manner taking into consideration the potential failure modes identified and defined by Failure Modes Effects Analyses. However, cost shall not be considered as a criteria in selecting between two or more design solutions with differing reliability potential. Reliability will take precedence over cost effectiveness.

3.2.3.1 Primary Structure, Thermal Protection, Pressure Vessels. The primary structure, thermal protection, and pressure vessel subsystems shall be designed to preclude failure by use of adequate design safety factors, relief provisions, fracture control, or safe life and/or fail safe characteristics.

3.2.3.2 Flight Vehicle Subsystem Functional. The redundancy requirements for subsystems (except primary structure, thermal protection, and pressure vessels) shall be established on an individual subsystem basis, but shall not be less than fail safe. This fail safe requirement does not apply to the premature firing failure mode of pyrotechnic devices and functional systems, except associated avionics (electrical and instrumentation).

3.2.3.3 Isolation of Subsystem Anomalies. Isolation of anomalies of time-critical functions shall be provided such that a faulty subsystem element can be deactivated either automatically or manually without disrupting its own or other subsystems. During ground operations, capability to fault isolate to the Line Replaceable Unit (LRU) (or group of units) without disconnections or use of carry-on equipment, shall be provided.

3.2.4 Maintainability. Any maintenance and/or replacement functions required during or after stacking shall be capable of being accomplished within the 160 hour Shuttle turnaround requirement. The times required to remove/replace Line Replaceable Units (LRUs) shall be identified and verified. Interface connections and maintenance operations are to be performed with standard tools wherever possible. Subsystem elements, e.g. electrical, ignition and nozzle assemblies, shall be capable of checkout and servicing while installed. Components that require hoisting or lifting devices for installation shall be self-aligning. Accessability of all LRUs for maintenance functions shall be a design consideration.

3.2.5 Operational Availability.

3.2.5.1 Assembly/Disassembly of Segments. The SRM shall be capable of assembly/disassembly in both the vertical and horizontal position. The SRM shall be capable of vertical assembly in a manner to meet the alignment criteria of MSFC-DWG-10A00516 without a requirement for optical equipment.

3.2.5.2 Assembly and Checkout Schedule. Assembly and checkout of the SRMs (2) shall be compatible with the space shuttle turnaround schedule and shall be accomplished within the time allotted for buildup and checkout of the SRB. Each critical path of redundant subsystems shall be capable of verification of operational status during ground operations.

3.2.5.3 Hold, Launch, and Recycle Requirements. The SRM shall be capable of supporting a Shuttle launch within a twenty-four hour notification-for-launch period and maintaining a launch standby status for 24 hours. The SRM shall also be capable of being launched from a standby status within 120 minutes.

3.2.5.4 Solid Rocket Booster to External Tank Buildup and Mating. The SRM assembly and verification on the mobile launcher (ETR) or launch pad (WTR) shall be required prior to mating to the external tank.

3.2.5.5 Retargeting. The SRM shall be capable of meeting the Space Shuttle retargeting to a dissimilar mission requirement within 16 hours and this requirement shall not preclude the capability to retarget within two hours.

3.2.5.6 Useful Life. Both new and refurbished SRMs components and subassemblies shall be capable of meeting the performance requirements of this document after a maximum storage period of five years in uncontrolled humidity, within a temperature range of +32° F to +95° F, and/or exposure to uncontrolled humidity and to ambient temperatures and times during transportation and handling as specified below:

a. Transportation to ETR 1/ 2/

(1) Up to 3 hour exposure: minimum temperature -7° F, maximum temperature 102° F.

(2) 24 hour exposure: average daily minimum temperature 5° F, average daily maximum temperature 89° F.

(3) 9 days exposure: average daily minimum temperature 16° F, average daily maximum temperature 85° F.

b. Transportation to WTR 1/ 2/

(1) Up to 3 hour exposure: minimum temperature 3° F, maximum temperature 113° F.

(2) 24 hour exposure: average daily minimum temperature 11° F, average daily maximum temperature 98° F.

(3) 9 day exposure: average daily minimum temperature 20° F, average daily maximum temperature 93° F.

The five year useful life begins following SRM component acceptance by NASA.

1/ Logarithmic interpolation shall be used for determination of requirements for exposure times which are between 3 and 24 hour or between 24 hour and 9 days.

2/ Interior temperature shall be measured and recorded during transportation in each shipping container for each shipment.

3.2.5.7 Recovery and Refurbishment. The SRM and its subsystems shall be capable of reuse following recovery and retrieval after submersion in sea water for up to seven days (168 hours) in accordance with the reusability goals in Table IV.

3.2.6 Safety. The Safety Program shall comply with NHB 5300.4 (1D-2) and the following safety requirements:

3.2.6.1 Flight Safety. The SRM and its subsystems shall eliminate hazards by appropriate design features, or prevent hazards through the use of safety factors and safety devices, or counter hazardous conditions by special procedures.

3.2.6.2 Ground Safety. The SRM shall preclude and/or counteract failures or hazards that would jeopardize personnel safety or damage/degrade the SRM during manufacturing, handling, transportation, turnaround, maintenance and refurbishment operations.

3.2.6.3 Personnel Safety. Provisions for personnel safety shall be in accordance with the following:

a. Safety Devices. Known hazards which cannot be eliminated through design selection shall be reduced to an acceptable level through the use of appropriate safety devices as part of the system, subsystem, or equipment.

b. Warning Devices. Where it is not possible to preclude the existence or occurrence of a known hazard, devices shall be employed for the timely detection of the condition and the generation of an adequate warning signal. Warning signals and their application shall be designed to minimize the probability of wrong signals or of improper personnel reaction to the signal.

3.2.6.4 Explosive and/or Ordnance Safety. The propellants for the SRM and the igniter shall meet the requirements of hazard classification 1.3 as defined in the Army Material Command Regulation Safety Manual AMCR 385-100, or DoD Contractor's Safety Manual for Ammunition, Explosives, and Related Dangerous Materials, DoD 4145.26. The SRM segments and ignition system less initiators shall have a DOT explosive classification of Class B.

3.2.6.5 Debris Prevention. The SRM shall be designed to preclude the shedding of debris (see 6.1.1) from the elements during prelaunch and flight operations that would jeopardize the flight crew and/or mission success.

3.2.7 Environment.

3.2.7.1 Natural Environment. The SRM shall withstand the natural environments defined in JSC 07700, Volume X, Appendix 10.10, and the air and sea temperature environments and salinity of SE-019-043-2H.

3.2.7.2 Induced Environment. The SRM shall withstand the induced environmental conditions as defined in the following documents:

Thermal
Base Heating - SD73-SH-0181-3
Launch and Ascent - SD73-SH-0181-3
Re-entry - SE-019-053-2H
Interface - SD74-SH-0144, ICD 3-44003

Loads
Vibration, Acoustic and Shock - SE-019-049-2H and SE-019-067-2H. In case of conflict, SE-019-049-2H shall take precedence over SE-019-067-2H.
Prelaunch through Separation - SE-019-057-2H, Book 1 as changed by SA42-280-86
Post Separation through Recovery - SE-019-057-2H, Book 2 (interpolated for a vertical velocity of 85 feet per second) ICDs 3-44001, 3-44003, 3-44004, 3-44008

Dynamic Aeroelasticity
External panels shall be free of panel flutter at 1.5 times the local dynamic pressure at the appropriate temperature and mach number for all flight regimes.

Transportation Loads
During transportation, the flight structure shall not be subjected to loads more severe than the structural capabilities if the SRM and of its components which have been designed to meet the flight load requirements.

3.2.8 Transportability/Transportation. The SRM and its component parts, when protected in accordance with the Preparation for Delivery requirements of Section 5, shall be capable of being handled and transported by rail or other suitable means to and from fabrication, test, operational launch, recovery/retrieval, and refurbishment sites. The SRM and its components shall be compatible with the handling, packaging, and transportation systems to the extent that:

a. The size and weight of the SRM and its components does not exceed the limitations of handling, packaging, and transportation systems. The shipping envelope limitations for routine rail transportation shall be as shown in Figure 5.

b. No loads are induced in the SRM and its components during transportation and handling which will produce stresses, internal loads, or deflections in excess of the structural capability of the SRM and its components which have been designed to the requirements of 3.2.7 and 3.3.6.1 through 3.3.6.5.

c. The SRM and its components are adequately protected, by passive means, against natural environments during transportation and handling.

3.2.9 Storage.

3.2.9.1 Post Acceptance Requirements. The performance capability of the SRM or of any of the separate deliverable end items which comprise the SRM after accceptance by NASA shall not be adversely affected by a maximum storage period of five years within a temperature range of +32 to +95^{o} F. The assembled SRM shall be capable of being stored in the vertical position for up to 180 days launch pad stay time and capable of holding on the launch pad for 14 days without GSE support. The assembled SRM shall meet all requirements specified herein, provided the propellant operational mean bulk temperature is within the limits of +40 to +90^{o} F. Prior to final assembly, the SRM segments and subsystems shall be capable of being stored in either a horizontal or vertical position in either their shipping containers or with protective end closures and covers.

3.2.9.2 Storage/Age Control. Storage monitoring of the SRM and its subsystems shall require only electrical grounding and visual inspection. Natural rubber items, propellant and liner contained in safety critical components, except for electrical connectors, accessories and the nozzle flex bearing, shall be age controlled in accordance with the requirements of JSC-SE-R-0006 (as changed by approved deviation RDW0001R2, see 10.1) as defined in the Material Selection and Control Plan, TWR-10192.

3.3 Design and Construction Standards.

3.3.1 Selection of Specifications and Standards. All materials, parts and processes shall be defined by specifications and standards selected in accordance with MIL-STD-143, except that NASA documents referenced in this specification shall take precedence. Rationale for the selection of contractor specifications and standards over existing higher order or precedence standards and specifications shall be compiled and maintained for historical record and shall be made available to the procuring activity upon request. This rationale shall include an identification of each higher order or precedence specification or standard examined and state why each was unacceptable. For purposes of this order or precedence, commercial materials, parts and processes shall be considered equivalent to contractor standards.

3.3.1.1 Selection of Materials, Parts, and Processes. All SRM materials, parts, and processes shall be selected in accordance with the requirements of TWR-10192 and shall be defined by specifications and standards suitable for the intended purpose and approved by Morton Thiokol material and engineering personnel prior to their incorporation into the SRM design. The SRM material selection list and use instructions requirements shall be in accordance with SE-019-094-2H as defined in TWR-10192 except that in lieu of MSFC Material Usage Agreement Form 551, the Morton Thiokol Material Usage Agreement Form TC 4658 shall be used. NASA approved authority and responsibilities for SRM materials, parts, and engineering processes shall be as specified in TWR-10192.

3.3.1.2 Parts Selection.

3.3.1.2.1 EEE Parts. EEE parts shall be selected in accordance with MSFC-DWG-85M03936. When EEE parts listed therein will not satisfy design requirements, selection of parts shall consider previously qualified parts and selection shall minimize the number of styles and generic types.

3.3.1.2.2 Standard and Commercial Parts. MS, AN, or MIL-STD parts shall be used whenever suitable for the intended purpose. If no suitable MS, AN, or MIL-STD parts are applicable or available, commercial parts may be used provided they conform to the requirements of this specification and do not affect the qualification status of the end item hardware.

3.3.1.2.3 Instrumentation Selection. Commonality of sensors and measurement range standardization with other Shuttle system elements shall be implemented where practical.

3.3.1.3 Drawing Standards. Drawings and associated lists shall be prepared in accordance with requirements of MIL-STD-100, MIL-D-1000, Form 2 for Categories B, C, E, F, H, I, and J; MIL-D-1000, Form 2 or Form 3 for Categories A, D, and G; and the following subparagraphs. Drawings and associated lists shall be identified by the contractor's code identification and number. Deviations from these requirements are permissible, and encouraged if cost effective, with the prior approval of MSFC.

3.3.1.3.1 Flight/Non-Flight Critical Items. Drawings and associated lists shall be prepared in accordance with the requirements of Category E, Form 2 of MIL-D-1000.

3.3.1.3.2 Deliverable Non-Flight Items. Drawings for deliverable non-flight items shall be prepared in accordance with requirements of applicable Categories C, E, F, G, or H, Form 2 of MIL-D-1000.

3.3.1.3.3 Legibility. Drawings and reprints shall be of sufficient clarity such that every line, number, letter, and character data is clearly legible and readable. Microfilming shall be in accordance with NHB 1440.4 for Type 1, Class I microfilm.

3.3.1.3.4 Drawing Quality. The drawings shall be in accordance with the quality assurance requirements of MIL-D-1000.

3.3.1.3.5 Delivery Requirements. The delivery requirements for drawings shall be as specified in the Information Requirements Document DPD 400.

3.3.1.3.6 Drafting Practices. Drawings shall be prepared using the drawing practices requirements of MIL-STD-100, specified in MIL-D-1000, with the conditions and exceptions, delineated in DPD 400.

3.3.1.4 Units. The requirement for use of the international system of units has been waived.

3.3.1.5 Traceability. Traceability shall be provided by assigning a traceability identification to each SRM part and material and providing a means of correlating each to its historical records, and conversely, the records must be traceable to each part and material throughout the life of each component.

3.3.2 General.

3.3.2.1 NASA/JSC Standards. The SRM shall comply with the applicable standards listed in JSCM 8080. JSCM 8080 Standards requirements shall not be applicable to off-the-shelf hardware. JSCM 8080 Standard 88 shall be applicable to SRM wire splicing. JSCM 8080 Standard 107, "Separate Stock for Spaceflight Parts and Material", requirements as changed by DAR SRM 0005 (see 10.1) shall be applicable. JSCM Standard 133B requirements for harness, wire, and connector testing are not applicable.

3.3.3 Aeronautical. This paragraph is not applicable to this specification.

3.3.4 Civil. This paragraph is not applicable to this specification.

3.3.5 Electrical. Electrical and electronic equipment shall meet the following requirements:

3.3.5.1 Electromagnetic Interference. The SRM shall be designed and tested in accordance with the requirements of JSC-SL-E-0001, JSC-SL-E-0002, MIL-STD-462 and ICD 3-44005. Definitions and system of units shall comply with MIL-STD-463.

3.3.5.2 Electrical Bonding. Structural and electrical parts shall meet the bonding requirements of MIL-B-5087 in all areas, except in the area of lightning protection where the requirements of JSC 07636 shall apply.

3.3.5.3 Soldering. Soldering of all electrical connections shall comply with the requirements of NHB 5300.4(3A) as supplemented by JSC 08800.

3.3.5.4 Circuit Boards. Soldered printed wire board assemblies shall be designed in accordance with MSFC-STD-154 and parts shall be mounted in accordance with MSFC-STD-136.

3.3.5.5 Static Electricity and Lightning Protection. Static electricity and lightning protection shall comply with the requirements of JSC 07636, JSC 20007, and ICD 3-44005.

3.3.5.6 Harnesses and Cables. Harnesses and cables shall comply with the requirements of NHB 5300.4(3G).

3.3.6 Mechanical.

3.3.6.1 Design Safety Factors.

3.3.6.1.1 General Safety Factors.

Before SRB separation

Yield factor of safety = 1.10

Ultimate factor of safety = 1.40

After SRB separation before water impact

Yield factor of safety = 1.10

Ultimate factor of safety = 1.25

During water impact

Stiffener rings = 1.00*

Yield factor of safety = 1.10*

Ultimate factor of safety = 1.25*

* This is a design goal only for water impact loads. Analyses will be conducted on the effects of water impact loads for the following water entry conditions:

a. Nominal vertical velocity of 85 fps.

b. Horizontal velocity of 0 to 45 fps.

c. Impact angle -5 to +5 degrees.

3.3.6.1.2 Safety Factors for Pressures.

Before SRB separation

Yield pressure = 1.20 x limit pressure (6.1.1)

Ultimate pressure = 1.40 x limit pressure

After SRB separation before water impact

Yield pressure = 1.10 x limit pressure

Ultimate pressure = 1.25 x limit pressure

During water impact

Yield pressure	= 1.10* x limit pressure
Ultimate pressure	= 1.25* x limit pressure
Buckling pressure	= 1.00*

* This is a design goal only for water impact loads. Analyses will be conducted on the effects of water impact loads for the following water entry conditions:

a. Nominal vertical velocity of 85 fps.

b. Horizontal velocity of 0 to 45 fps.

c. Impact angle -5 to +5 degrees.

Results of these analyses will be evaluated and the calculated factors of safety will be the basis of attrition rate determinations.

3.3.6.1.3 Internal Insulation. The SRM internal insulation system consisting of case side wall thermal insulation, stress relief flaps, and propellant grain inhibitors shall utilize the SRM component design configurations (Ref. TWR- TBD) as baseline. Safety factors are determined based on a comparison of material affected depth against minimum design thickness. Post-test and post-flight verification of insulation compliance with design safety factor requirements shall be based on a comparison of material affected depth against minimum design thickness.

3.3.6.1.3.1 Case Insulation. The case insulation shall have a minimum safety factor of 1.5 assuming normal, motor operation and 1.2 assuming loss of a castable inhibitor.

3.3.6.1.3.2 Metal Part Joint - Insulation. Case insulation adjacent to metal part field joints and extending over factory joints shall have a minimum safety factor of 2.0.

3.3.6.1.3.3 Multiple Insulation Materials. Case insulation in sandwich constructionn regions (aft dome and center segment aft end) shall have a minimum safety factor of 1.5 (performance ratio TBD).

3.3.6.1.3.4 Inhibitors. The aft facing, castable, propellant grain inhibitors shall have a minimum safety factor of 1.25. The forward facing, propellant grain inhibitors shall have a minimum safety factor of 1.5.

3.3.6.1.3.5 Insulation Performance. Insulation performance shall be calculated using actual pre- and post-motor operation insulation thickness measurements. Compliance with safety factor requirements shall be calculated using minimum insulation design thickness.

3.3.6.1.4 Insulation/Liner Bond. The safety factor for the physical properties of the insulation/liner bond shall be 2.0 minimum during the life of the SRM. The bond safety factor shall be based on the bond strength of the bond line. The procedure for determining bond line strength shall be submitted to MSFC for approval.

3.3.6.1.5 Propellant and Propellant/Liner Bond. The safety factor for propellant and propellant/liner bond shall be 2.0 minimum during storage and launch with the exceptions that the propellant safety factor during horizontal storage shall be: 1.4 in the forward segment transition region, 1.8 in the forward segment flap and 1.7 in the center segment flap. The safety factor requirements are for a minimum PMBT of +52° F for the five year life.

3.3.6.1.6 Nozzle Safety Factors. The minimum design safety factors for the nozzle assembly primary ablative materials shall be as listed below for the worst nozzle environment over a PMBT range of +40 to +90° F.

a. All components except flex bearing thermal protector

    1. Erosion: 2.0 times maximum predicted local final erosion depth.

    2. Char: 1.25 times maximum predicted local final (end of action time) char thickness.

b. Flex bearing thermal protector: (material affected depth) 1.5 times the maximum predicted final material affected depth.

    3. Thermal Protection: 1.0 on the insulation.

3.3.6.2 Allowable Mechanical Properties. Fracture control requirements and applications shall be as specified in TWR-10184, SRM fracture control plan, supplement 2 fracture control plan for Space Shuttle Ignition System, TBD, fracture control plan for Space Shuttle Block II SRM motor case, and TBD fracture control plan for the Space Shuttle Block II SRM nozzle. Fracture mechanics properties of materials shall be determined in accordance with ASTM E 399. Values for other allowable mechanical properties of structures and joints in their design environments; i.e., subjected to single stresses or combined stresses, shall be in compliance with MSFC sources and/or MIL-HDBK-5, MIL-HDBK-17, MIL-HDBK-23, or supplier guaranteed and approved properties. Where values for mechanical properties of new materials, or properties of existing materials in a new environment are not available, they shall be determined by analytical or test methods approved by MSFC. Generally, a larger safety factor shall be incorporated into data supported by a small number of samples as opposed to that data supported by a large number of samples. Where tests are required, they shall be of sufficient number to establish values for the mechanical properties on a statistical basis. The effects of temperature, thermal cycling and gradients, and detrimental environments shall be accounted for in defining allowable mechanical properties.

3.3.6.3 Ultimate Combined Loads. The external, thermally induced, and internal pressure loads should be combined in a rational manner according to the equation given below to determine the design loads. Any other loads induced in the structure, e.g., during manufacturing, shall be combined. No load conditions which exceed manned flight loads shall be considered. In no case shall the ratio of the allowable load to the combined limit loads be less than the designated Safety Factor (SF).

(K1) L(external) + (K1) L(Thermal) + (K2) L(Pressure) = Ultimate Combined Load

K1, K2 = SF of 1.4 for boost conditions when the term is additive to produce the ultimate combined load.

K1, K2 = Calculated after SRB separation based upon conditions prior to separation. Calculated values shall be the basis for attrition rate determination.

K1, K2 = 1.0 when the term is subtractive to produce the ultimate combined load.

L(External) = Mechanically external applied loads, e.g., inertial loads, aerodynamic pressure

L(Thermal) = Thermally induced loads

L(Pressure) = Maximum expected operating pressure (MEOP) where additive to produce the ultimate combined load.

L(Pressure) = Minimum expected operating pressure when subtractive to produce the ultimate combined load.

This equation is applicable to either tension or compression loads. All structural components that are subject to compressive inplane stresses, including loads resulting from temperature changes, shall be investigated for buckling failure. The evaluation of buckling strength shall consider the combined action of primary and secondary stresses and their effects on (1) general instability, (2) local or panel instability, (3) crippling, and (4) creep. Design loads for buckling shall be ultimate loads. Loads tending to alleviate buckling shall not be increased by the ultimate factor of safety. Destabilizing limit loads shall be increased by the ultimate factor of safety although stabilizing loads shall not.

3.3.6.4 Proof Pressure Factors. Fracture mechanics analyses shall be performed to establish the proof pressure factors required to determine the maximum possible flaw size for verification of service life with respect to the cyclic and sustained load history. The proof factor to be used shall be determined by fracture mechanics analyses using typical K sub IC values.

3.3.6.4.1 Proof Factor Determination. The proof factor shall be determined for a proof test to be conducted prior to each mission and is intended to show a potential of four additional missions. All cyclic and sustained loads shall be considered in determining the proof factor. A minimum proof factor of 1.05 is established as a lower bound.

3.3.6.5 Life Factors. Structures and components shall both be designed to demonstrate the following requirements as applicable:

a. Low Cycle Fatigue (<10,000 cycles) - 4 times the cycles to be expected in the number of uses.

b. High Cycle Fatigue (>10,000 cycles) - 10 times the cycles to be expected in the number of uses.

c. Fracture Mechanics - The crack growth to be expected in one service life (the number of uses).

3.3.6.6 Welding. Welding of steels, including stainless steels, shall be in accordance with MSFC-DWG-10509308. Resistance welds shall comply with the requirements of MIL-W-6858. Weldments of aluminum shall comply with the requirements of MSFC-SPEC-504.

3.3.6.7 Brazing. Brazing shall comply with the requirements of MIL-B-7883.

3.3.6.8 Adhesive Bonding. Adhesive bonding shall meet the requirements of MSFC-SPEC-445 (as changed by approved deviation RDW0043R1, see 10.1).

3.3.6.9 Screw Threads. Screw threads for threaded fasteners used on Shuttle System hardware shall be of unified thread form in accordance with MIL-S-7742 or MIL-S-8879, as applicable;

a. Material strength levels up to, but not including, 160 KSI may be threaded per MIL-S-7742 or MIL-S-8879. Rolled threads are preferred.

b. Material strength levels 160 KSI and above shall be threaded per MIL-S-8879. External threads shall be rolled after heat treatment.

Threads shall be class 3 for initial use and may be class 2 for reuse except that class 2 is acceptable for refurbished pyrotechnic devices.

3.3.6.10 Locking Threaded Parts. All threaded fasteners except nozzle leak test port plugs and internal nozzle bolted joints shall be positively locked. Lock method requirements for ignition system components shall be as specified in JSC 08060. Locking methods for other components shall be in accordance with MIL-N-8922 and MIL-N-25027. Self-locking devices shall be used one time only except for self-locking nuts as specified in MIL-N-25027 which are allowed up to 15 reuses.

3.3.7 Nuclear. This paragraph is not applicable to this specification.

3.3.8 Materials. As a design goal, the SRM design shall not include the use of age sensitive materials. When the use of age sensitive materials cannot be avoided, the replacement of such materials may be scheduled during the storage period (see 3.2.9). Materials will be selected with characteristics that will not present hazards to personnel or flight hardware in their intented use or environment. The SRM shall not use asbestos-filled insulation materials.

3.3.8.1 Moisture, Fungus Resistance, and Oxidation Resistance. Materials which are non-nutrient to the fungi defined in MIL-STD-810, Method 508, should be used. When fungus nutrient materials must be used, they should be hermetically sealed or treated to prevent fungus growth for a period of five years. Materials not meeting this requirement shall be identified as a limited life component and the contractor shall identify any action required such as inspection, maintenance, or replacement periods. Fungus treatment shall not adversely affect unit performance or service life. Materials so treated should be protected from moisture or other environments that would be sufficient to leach out the protective agent. When cork is used for external thermal protection, the cork shall be coated with a water resistant protective coating but fungus treatment of the cork shall not be required. Fungus inert materials are listed in MIL-STD-454 (Requirements No. 4). Materials which are sensitive to oxidation shall be treated with a protective coating. All TPS material and installation design shall minimize absorption and entrapment of liquids or gases which would degrade thermal or physical performance or present a fire hazard (wicking), and shall not require draining, drying or any dedicatd purge system from refurbishment through launch.

3.3.8.2 Corrosion of Metal Parts.

a. Corrosion Protection - Inasmuch as practical, corrosion resistant metals shall be used. Dissimilar metals shall not be used in combination unless galvanic corrosion is prevented by means of protective coatings, sealants, or insulation. Consideration shall be given to weight, thermal emissivity, and electrical bonding requirements. All exposed metal surfaces shall be treated to resist corrosion. The use of dissimilar metals, finishes, and coatings shall meet the requirements of MSFC-SPEC-250.

b. Stress Corrosion - The criteria for material selection in the design to prevent stress corrosion failure of fabricated components shall be in accordance with MSFC-SPEC-522.

3.3.8.3 Flammability, Odor and Off-Gassing. Flammability, odor, and off-gassing properties of materials to be used in environments that support combustion shall be in accordance with NHB 8060.1 as defined in TWR-10192.

3.3.9 Contamination Control. Contamination shall be controlled to assure system safety, performance, and reliability. Control shall be implemented by a coordinated program in accordance with JSC-SN-C-0005 from design concept through procurement, fabrication, assembly, test, storage, delivery, operations, and maintenance. Paragraphs 7.1.3 and 7.1.4 of SE-019-058-2H shall be applicable to contamination control. Selection of system design shall include consideration of materials compatibility, corrosion resistance, and sensitivity to contamination. Fluid systems design shall include self-cleaning (filtering) protection compatible with component sensitivity. Specific cleanliness levels in accordance with JSC-SN-C-0005 shall be established for material surfaces, fluid systems, and functional items, as required for effective control of contamination. Fluids identified in JSC-SES-0073 and required for manufacture, test, cleanliness evaluation, and operation shall meet the purity, cleanliness, and analysis requirements of JSC-SE-S-0073.

3.3.9.1 Cross Contamination. The SRM shall not cause detrimental cross contamination (see 6.1.1) of other Space Shuttle elements during the flight mission through SRM action time.

3.3.10 Coordinate Systems. Coordinate system standards shall be compatible with those defined in JSC 09084, Coordinate Systems for the Space Shuttle System.

3.3.11 Interchangeability and Replaceability. Components and subsystems shall be capable of application to either the "right" or "left" hand SRM. To meet the thrust differential performance requirements of 3.2.1.1.2.3 between the two SRMs on a Shuttle vehicle, these two SRMs shall consist of performance matched pairs of SRMs. With the exception mentioned above, the definitions of item levels item exchangeability, models and related items, shall be in accordance with MIL-STD-280.

3.3.12 Identification and Marking. The SRM component identification and marking shall be in accordance with MIL-STD-130, except that the "design activity code", "manufacturer's trade mark", and "licensor code identification" need not be combined with the part number when marking parts and assemblies. Electrical wiring shall be identified in accordance with MIL-STD-681. Packaging marking requirements shall conform to the requirements of MIL-STD-129. Cosmetic requirements for the SRM shall be restricted to appropriate markings or decals as necessary. Priority consideration shall be given to weight and thermal performance.

3.3.13 Workmanship. The SRM shall be fabricated, processed, and installed using standards of workmanship which are consistent with the performance, reliability, and reuse requirements. All hardware shall conform with the requirements for form, fit, and function defined by design drawings and related specifications. The hardware and software shall be free of defects which would result in hazardous or unsafe conditions or which could result in failure or materially reduce the usability and reusability of the SRM for its intended purpose.

3.3.14 Human Performance/Human Engineering. MIL-STD-1472 shall be used as a guide for human engineering design criteria.

3.4 Logistics. The logistics program shall comply with the intent of JSC 07700, Volume XII.

3.4.1 Maintenance. The maintenance concept shall be to "remove and replace" to the functional line replaceable unit (LRU) level, at the organizational level, and on an unscheduled basis as determined from malfunctions. The SRM shall be designed so that the maintenance can be accomplished in a manner which will provide support of operational time constraints, prevent deterioration of inherent design levels of reliability and operating safety, and accomplish this support and protection at minimum practical costs.

3.4.2 Supply. Supply support functions shall comply with the intent of JSC 07700, Volume XII.

3.4.3 Facilities and Facility Equipment. The SRM shall be designed to minimize the need for new logistics facilities. Existing facilities and facility equipment must be used for the storage of spares and maintenance functions to the maximum possible extent.

3.4.4 Spare Parts. Spare parts shall be standardized and off-the-shelf wherever possible and selected for simplicity and ease of maintenance.

3.5 Personnel and Training. The design shall consider tasks to be accomplished by operating, test and maintenance personnel. Considerations should include safety, accessibility, critical tasks, complexity and necessity for training.

3.6 Interface Requirements. The SRM shall meet the interface requirements of the following interfaces:

3.6.1 Interprogram. This paragraph is not applicable to this specification.

3.6.2 Intraprogram.

a. ICD 2-00001 Shuttle Vehicle Mold Lines and Protuberances

b. ICD 2-0A001 Shuttle System/Launch Platform Stacking and VAB Servicing

c. ICD 2-0A002 Space Shuttle Launch Pad and Platform

d. ICD 2-4A001 Solid Rocket Booster Receiving and Processing Station

e. ICD 2-4A002 Solid Rocket Booster Retrieval Station

f. ICD 3-44001 SRM to Forward Skirt

g. ICD 3-44003 SRM to Aft Skirt and Thrust Vector Control Actuator

h. ICD 3-44004 Solid Rocket Motor to ET Attach Ring

i. ICD 3-44005 Solid Rocket Motor to Solid Rocket Booster Electrical and Instrumentation Subsystem

j. ICD 3-44008 Systems Tunnel to SRB Systems

3.6.3 Intraproject. This paragraph is not applicable to this specification.

4.0 VERIFICATION

4.1 General. Verification shall be accomplished in accordance with Table V, Verification Cross Reference Index.

a. Pyrotechnics Verification. Verification of pyrotechnics shall comply with JSC 08060.

b. SRM Component and Subsystem Verifications. Component subsystem and end item verification shall be in accordance with the SRB Verification Plan, SE-019-019-2H.

c. Environmental. All secondary mounted components required to operate during flight shall be certified as complying with SE-019-049-2H by test and analysis.

4.1.1 Responsibility for Verification. Unless otherwise specified in the contract or order, the Morton Thiokol Corporation, Space Division, shall be responsible for the performance of all verification requirements as specified herein.

Except as otherwise specified, Morton Thiokol may utilize its own facilities or any commercial laboratory acceptable to the Government. The Government reserves the right to perform any of the verifications specified herein and to witness and verify the results of all verifications accomplished.

4.1.1.1 Quality Assurance. The Quality Assurance Program shall comply with the requirements established in NHB 5300.4(1D-2).

4.1.1.1.1 Quality Assurance Activities. Quality assurance activities shall ensure that the design approach permit and facilitate productivity, repeatability, inspectability, refurbishability/maintainability, and that related quality considerations are well defined.

4.1.1.1.2 Quality Design Criteria. Quality design criteria shall be developed and utilized in the design approach as follows:

a. Identification of critical hardware characteristics necessary for procurement or fabrication.

b. Identification of tolerances or limits.

c. Assurance that characteristics which influence quality are within inspection "state-of-the-art" capabilities.

d. Quality controls at interfaces are defined.

e. Critical or special process controls are defined.

4.1.1.1.3 Quality Inspection Requirement.

a. Nondestructive inspection requirements for materials and parts shall be in accordance with MIL-I-6870. Prior to performance of penetrant inspection of all metallic surfaces which have been previously machined or mechanically cleaned, the surfaces shall be etched to remove all smeared metal that could mask defects; however, 7000 series aluminum parts shall be etched only during parts fabrication.

b. Radiographic inspection of welds in steels shall comply with the requirements of MIL-STD-453 for thin material and ASME Boiler and Pressure Code, Section VIII, Paragraph UW51 for thick materials. Weldments of aluminum shall be inspected per MSFC-SPEC-504. Dye penetrant inspection of steel and aluminum weldments shall comply with the requirements of MIL-I-6866 and prior to penetrant inspection of a weldment surface which has been previously machined or mechanically cleaned, the surface shall be etched to remove all smeared metal that could mask defects.

4.1.1.1.4 Quality Sampling Requirements. Sampling requirements shall be in accordance with MIL-STD-105 and MIL-STD-414.

4.1.2 Verification Method Selection. Verification methods shall include similarity, analysis, inspection, demonstration and test. The selection of the verification method shall be based upon achievement of verification requirements by a reliable method. Testing shall be planned at the highest level of assembly yielding credible data. Use of existing test facilities requiring minimum modification shall be considered. The earliest program event practical shall be used for verification. The method selection given in the verification cross reference index (see 4.3) has been determined by such factors as the available knowledge of the design requirements and is based upon design maturity, criticality categories, complexity, and risk. The following techniques of verification as listed above shall be utilized:

a. Similarity. Similarity may be used if (1) it can be shown that the article is similar or identical in design and manufacturing process to another article that has been previously qualified to similar criteria, and (2) analysis of dissimilarities either in design, manufacturing, process or verification criteria, substantiates that the article will perform its intended function within the specified envelope. Similarity shall pertain to characteristics such as material, configuration, and functional element or assembly, and may be applied selectively for applicable environments.

b. Analysis. Verification by analysis may be used in lieu of testing whenever it can be shown by MSFC approved analytical techniques that the article will meet the applicable technical requirements. Analyses shall be performed as required on logic circuits, and sub-assemblies, etc. to assure that the design will meet the specified requirements.

c. Inspection. Verification by inspection shall be used whenever it can be shown that inspection techniques are adequate to assure that the article will meet the applicable technical requirements. Inspection shall be used to verify the construction features, compliance with drawings, workmanship and physical condition of the article.

d. Demonstration. Demonstration shall be used when actual conduct/operation can verify attainment of requirements such as service and access, maintainability, transportability, and human engineering features.

e. Test. When inspections and analyses are inadequate to verify specified requirements, tests shall be performed as necessary for verification. In addition, tests shall be performed if the testing will increase the level of confidence in the system verification.

4.1.3 Relationships to Management Reviews.

4.1.3.1 Preliminary Design Review (PDR). The development and verification program shall have been started prior to PDR to provide design data to support the preliminary design. Candidate materials, designs, and procedures shall be verified by analysis and/or similarity and by standard laboratory testing.

4.1.3.2 Critical Design Review (CDR). At the time of the CDR, the development verification program shall provide data to be used to obtain approval of the detailed SRM design and performance requirements as depicted by drawings and specifications.

4.1.3.3 Configuration Inspection (CI). At the time of SRM CI, the certification phase and the acceptance phase of the verification program shall have been accomplished to the extent that all SRM design, performance, and acceptance requirements identified in this specification have been verified.

4.1.3.4 Flight Readiness Review. The verification of the prelaunch checkout requirements as specified in 4.2.5 shall have been accomplished by the time of the flight readiness review for each vehicle to be used in the Flight Program.

4.1.4 Test/Equipment Failures. When a failure occurs, failure analysis shall be accomplished to the extent required to identify the cause of the failure before the hardware is removed, altered, or the test continued. Additional tests may be conducted when their purpose is to resolve the cause of the failure. Failure analysis shall also determine if degradation or failure has occurred elsewhere in the system as a result of the failure. Tests may continue on subsystems not affected by the failure. Test failures shall be reported and documented with the results of the failure analyses.

4.1.5 Verification for Unplanned Equipment Uses. The SRM shall be used only for the requirements specified in Section 3. There shall be no verification for unplanned uses.

4.2 Phased Verification Requirements.

4.2.1 Development. The development phase of the verification program, not accomplished during development per CPW1-3300, shall be primarily concerned with those verification activities which will provide the engineering data base necessary to support design development. The data required will also be used to support other phases of the verification program. NASA participation in development activities shall be at its discretion. The development phase of the verification program shall provide data from the verification methods specified in 4.1.2 to determine the following:

a. Adequacy and optimization of design margins.

b. Significant failure modes and effects.

c. The effects of combinations of tolerances and drift on performance.

d. The effects of combinations and sequences of environments and stress levels.

e. Safety parameters and functions.

f. Overstress conditions where additional confidence or design margin data are required to verify safe operating conditions.

g. Electromagnetic Compatibility (EMC) susceptibility levels.

h. Compatibility of physical, functional, and operational interfaces.

i. Heat transfer effects on operational systems.

4.2.1.1 Similarity. See Table V for requirements to be verified by similarity. An engineering evaluation shall be documented to show that the design differences between the items being developed and a previously developed item have no significant adverse effects as applied to the SRM; that the previously developed similar item was qualified to equal or higher environmental stress levels and time durations than required for the item being developed; and that the item being developed was fabricated and qualified by the same manufacturer as the similar item using the same processes, material, and quality control.

4.2.1.2 Analysis. See Table V for requirements to be verified by analysis. An engineering analysis shall be performed using reasonable analytical techniques to verify that materials, components, or assemblies can meet or exceed the environmental requirements. The analytical techniques shall include system engineering analysis, statistics, qualitative analysis, analog modeling, and computer simulation. The analysis shall be documented to provide sufficient data to perform an independent verification based on the results of the analysis. An analysis report shall document the analysis results, the conclusions reached, and establish that the respective component or subsystem meets the design requirements. Analysis verification reports shall be available.

4.2.1.3 Inspection. See Table V for requirements to be verified by inspection. Inspection shall be used to verify all physical characteristics that can be independently verified. Inspection shall be the preferred method of verification when this method can demonstrate compliance with requirements. Inspection requirements shall be satisfied by quality assurance with approved engineering techniques.

4.2.1.4 Demonstration. See Table V for requirements to be verified by demonstration. Demonstration shall be used to verify requirements whenever the physical performance of operations involving the article will assure that the article meets the applicable technical requirements.

4.2.1.5 Test. See Table V for requirements to be verified by test. Development testing shall meet the following:

a. Development tests that are to be used for verification shall be conducted on hardware or materials that have characteristics similar to flight hardware. The tests shall be flexible enough to permit freedom to provide assurance (by test results or the analyses of test data) that hardware materials meet the environmental stress levels, durations, and performance requirements. The tests shall be conducted in accordance with the test plans and procedures approved and controlled by Morton Thiokol.

b. A development test plan shall be prepared for the development phase of the verification plan.

c. Qualification requirements will be satisfied during development testing on some components when the intent to qualify by development test is declared. These development tests will meet the requirements of qualification testing.

4.2.2 Certification. The SRM shall be certified to conform to the design performance, physical characteristics, environmental, and operating life requirements specified herein. Certification shall be achieved by qualification tests, engineering analysis, similarity, inspection, and demonstration. Certification shall be conducted at the highest level of assembly that is practical to verify that the SRM meets or exceeds design performance requirements. Certification of Qualification (COQ), MSFC Form 511, will be prepared to document certification activities of each SRM item requiring certification. COQs will be forwarded to the MSFC Reliability and Quality Assurance Office (R&QA) for approval and file retention.

4.2.2.1 Similarity. Certification by similarity must be documented with Similarity Analysis Report depicting an engineering evaluation of design and usage comparison of the SRM flight item and the similar item. Qualification test results of the similar item should be included in the Similarity Analysis Report. See Table V for requirements to be certified by similarity.

4.2.2.2 Analysis. An Engineering Analysis Report must be prepared to document the analytical technique and results used to certify a SRM item. See Table V for requirements to be certified by analysis.

4.2.2.3 Inspection. See Table V for requirements to be verified by inspection.

4.2.2.4 Demonstration. See Table V for requirements to be verified by demonstration.

4.2.2.5 Test. Qualification tests will be performed on flight configured items to formally certify the design performance and some environmental requirements. Qualification tests will be conducted under strict control of test item configuration, environmental conditions, and test procedures. Qualification Test Reports shall be prepared to document test results. See Table V for requirements to be verified by test.

4.2.3 Acceptance. Acceptance inspection, tests, and analyses or combination thereof, will be performed on flight production items and qualification test items to assure that these items are manufactured and assembled to drawing and specification requirements. Acceptance activities shall be performed at the component, subsystem, and end item level to assure that these items are acceptable for the next higher assembly.

4.2.3.1 Similarity. This paragraph is not applicable to this specification.

4.2.3.2 Analysis. See Table V for requirements to be verified by analysis. Analysis shall be used for acceptance whenever it can be determined that (a) rigorous and accurate analysis is possible, (b) analysis is more cost-effective than test, and (c) acceptance by inspection is not adequate.

4.2.3.3 Inspection. See Table V for requirements to be verified by inspection. Inspection shall be used for acceptance verification of all physical requirements that can be independently verified.

4.2.3.4 Demonstration. See Table V for requirements to be verified by demonstration.

4.2.3.5 Test. See Table V for requirements to be verified by test. Acceptance tests shall be conducted to verify functional performance and satisfactory workmanship which cannot be verified through analysis or inspection techniques. The functional and/or environmental test levels shall not exceed normal operating limits.

4.2.4 Integrated Systems. Verification of the integrated systems requirements shall be accomplished during the preflight checkout phase as specified in 4.2.5.

4.2.5 Preflight Checkout. Preflight checkout shall include all post-delivery activities used to verify the readiness of the SRM for its intended use. Preflight checkout shall be used for verification only if other testing cannot satisfy test requirements.

4.2.5.1 Similarity. This paragraph is not applicable to this specification.

4.2.5.2 Analysis. See Table V for requirements to be verified by analysis. An engineering analysis meeting the requirements of 4.2.1.2 shall be used for preflight checkout.

4.2.5.3 Inspection. See Table V for requirements to be verified by inspection.

4.2.5.4 Demonstration. See Table V for requirements to be verified by demonstration.

4.2.5.5 Test. See Table V for requirements to be verified by test.

4.2.6 Flight. The flight operations phase of verification shall include:

a. Analysis of maintainability, reliability and safety functions to support trend evaluations.

b. Test of SRM performance under flight conditions to support design evaluation.

4.2.6.1 Morton Thiokol Responsibilities. Morton Thiokol shall support the flight/mission operations by providing the following:

a. Launch support and anomaly resolution.

b. Analysis of test data.

4.2.6.2 Flight Phase Requirements. This phase of the verification program shall provide data to determine the following:

a. Adequacy of the SRM design under actual operating conditions.

b. Adequacy of the refurbished equipment.

c. Adequacy of the safety functions.

4.2.7 Postflight. Postflight requirements shall be included as an integral part of the flight phase of verification (see 4.2.6).

4.3 Verification Cross Reference Index. Each Section 3 requirement shall be verified by the verification method and during the verification phase shown on Table V.

4.4 Test Support Requirements.

4.4.1 Facilities and Equipment. Personnel, procedures, and safety requirements shall be verified prior to equipment/ facilities use. Adequacy of the facility/equipment shall be verified by operational readiness inspections (ORI).

4.4.1.1 Morton Thiokol Facilities. Except for those facilities required at the launch site to refurbish the stiffener rings and to prepare other components for return to the factory, Morton Thiokol shall provide the total facilities effort required to design, develop, manufacture, refurbish, and test the SRM or portions thereof during development and certification. Included are all Government-furnished facilities, installation of fixed equipment, and miscellaneous facilities support activities. Special Test Equipment (STE), Transportation Support Equipment (TSE), and integrated logistics support and test support shall be supplied by Morton Thiokol.

4.4.1.2 Government Facilities - KSC and VAFB. The Government will provide the total facilities effort required to conduct complete SRM assembly, test, launch, flight, recovery, and partial refurbishment operations at the KSC and VAFB.

4.4.1.3 Launch Site Activation and Operations Plans. Morton Thiokol shall support development, planning, analyses, and integration of all activities related to launch site operations. Included shall be support of preliminary operational test and checkout planning and analyses to identify launch site and Ground Support Equipment (GSE) operational plans, verification plans, test specifications and requirements, test and checkout plans and timelines, and procedures planning for test and checkout, handling, transportation, and maintenance.

4.4.1.4 Common Support Equipment. Morton Thiokol shall recommend GSE and shall analyze specified and potential GSE requirements in the design of Support Equipment and Tooling (SE&T) for commonality and design/cost impact. Incorporation of unique GSE design/ operational requirements in SE&T shall be approved by the NASA Project Engineer.

4.4.1.5 Support Equipment Certification. All support equipment shall undergo certification tests as a part of the configuration inspection. Certification testing shall include interface, functional, and qualification proof load on each item of support equipment.

4.4.2 Articles. The articles defined herein are motors to support WTR and ETR flights.

4.4.3 Software. The requirements and criteria applicable to documentation necessary to assure demonstration of the functional and operational integrity of the SRM are defined in the Information Requirements Document, DPD 400.

4.4.4 Interfaces. Interface control shall be implemented through the interface requirements defined in Paragraph 3.6 of this specification.

5.0 PREPARATION FOR DELIVERY

5.1 General. The requirements specified herein shall govern the preparation for shipment and the transport of the SRM, its components, and support equipment to all contractor and Government facilities or test sites.

5.2 Packaging, Handling, and Transportation. Packaging, handling, and transportation for shuttle system elements shall be in general accordance with NHB 6000.1 (as changed by Approved Deviation RDW0497, see 10.1) and MMI 1700.17, or as amended by the following subparagraphs. Procedures for packaging and packing of parts and equipment shall be in accordance with MIL-STD-794. Drop testing of loaded segments in their shipping containers shall not be required.

5.2.1 Reusable Containers. Where analysis indicates desirability of using reusable containers, maximum practical utilization shall be made of standard off-the-shelf, low cost metal or plastic containers.

5.2.2 Monitoring Devices. MIL-I-26860 humidity indicators shall be installed in the container wall or flexible barrier wall of all Method II packages. Other instrumentation for monitoring or recording in-transit environments (e.g. shock, vibration, temperature, etc.) shall be utilized as required by specific component specifications.

5.2.3 Packaging Data. Packaging data shall be provided in accordance with DPD 400.

5.2.4 Packaging of Precision Clean Items. Items cleaned to precision cleanliness shall be protected in accordance with MIL-STD-1246 to assure maintenance of specified cleanliness levels.

5.2.5 Packaging of Hazardous Materials. All hazardous material packaging shall comply, as applicable, with NHB 6000.1.

5.2.6 Marking for Shipment. Interior and exterior containers shall be marked and labeled in accordance with MIL-STD-129, including precautionary markings necessary to ensure safe handling, transportation, and storage. For hazardous materials, markings shall also comply with the requirements of applicable freight tariffs, requirements of the Department of Transportation, Nuclear Regulatory Commission, and Code of Federal Regulations.

5.3 Packaging and Shipment of Pyrotechnics. The packaging and shipment of pyrotechnics shall conform to the provisions of the Space Shuttle Pyrotechnics Specification, JSC 08060. Pyrotechnic shipping containers shall be designed and constructed in accordance with JSC 08060 and in accordance with JSCM 8080, Standard 90, CFR 49, or AFM 71-4, depending on the mode of transportation.

6.0 NOTES

6.1 Supplemental Information. The following design terms and definitions shall be used in designing the SRM and complying with the Space Shuttle Vehicle requirements.

6.1.1 Design Terms and Definitions.

a. Char. Char is defined as a physical state produced during the thermal decomposition of insulation materials. The interface separating the char from the parent material is referred to as the char line. The method used to determine the depth of the char line in phenolic insulation materials involves the calculation of an effective char density. The char line is therefore defined as the location where the density of the parent or virgin material has changed such that the resulting char density is K greater than the totally charred material density as defined below for both carbon and silica materials.

Char density = K(Rho Sub V-Rho Sub R) + (Rho Sub R)

Where: Rho Sub V = Virgin density

Rho Sub R = Residue density

K = 0.27 for carbon cloth phenolic

= 0.02 for silica cloth phenolic

b. Ignition Interval. Ignition interval is defined as the time interval from ignition command to the initiators in the S&A device to a point at which the headend chamber pressure has built up to 563.5 psia.

c. Impulse.

(1) Action Time Total Impulse. Action time total impulse is defined as the integrated thrust along the nozzle centerline over the action time.

(2) Delivered Specific Impulse. The delivered specific impulse is defined as the total impulse along the nozzle centerline delivered during action time divided by the loaded propellant weight. Delivered specific impulse at plant site shall be extrapolated to specific impulse at vacuum conditions.

(3) Web Time Total Impulse. Web time total impulse is defined as the integrated thrust along the nozzle centerline over the web time.

d. Initial Sea Level Thrust. Initial sea level thrust is defined as the sea level thrust along the nozzle centerline at the beginning of action time and at standard sea level atmospheric conditions.

e. Limit Load. The maximum load the structural components will experience during the operational cycle, including assembly, launch pad integration, flight, re-entry, water impact and recovery operations.

f. Mass Fraction. The nominal propellant mass fraction Lambda p is determined by the following method:

Lambda p = (W Sub p)/((W Sub p) + (W Sub i))

Where: W Sub p = Loaded propellant weight

W Sub i = Nominal inert SRM weight

g. Maximum Head-End Chamber Pressure. The maximum headend chamber pressure is defined as the highest pressure achieved within the SRM chamber, as recorded at the head-end.

h. MEOP. MEOP is defined as the maximum expected operating pressure, including the maximum pressure resulting from ignition overshoot, which will be experienced under specification conditions.

i. Motor Centerline. Motor centerline is defined as that line connecting the centroid of the forward attach stub skirt for structural SRB/SRM interface and the centroid of the aft attach stub skirt for structural SRB/SRM interface.

j. Post Acceptance. Post acceptance time is the total time from acceptance of the item by the Government to its use. This includes not only periods of storage, but also the time during assembly at the launch site and subsequent preparation for launch.

k. Propellant Mean Bulk Temperature. Propellant mean bulk temperature (PMBT) is defined as the arithmetic average of the temperature of all parts of the propellant.

l. Safe Life. A design criterion under which failure will not occur because of undetected flaws or damage during the specified service life of the vehicle; also, the period of time for which the integrity of the structure can be ensured in the expected operating environments.

m. Time.

(1) Action Time. Action time is defined as that interval of time which begins at a point at which the head-end chamber pressure has built up to a value of 563.5 psia and ends at a point at which the head-end chamber pressure has decayed to a value of 22.1 psia.

(2) Tail-Off Time. Tail-off time is defined as the time interval between the end of web time and the end of action time. This time interval is shown graphically in Figure 6.

(3) Web Time. Web time is defined as that interval of time which begins at a point on the pressure time trace at which the head-end chamber pressure has built up to a value of 563.5 psia, and ends at a point determined by geometric construction, using the tangent-bisector method. (For this definition, the construction will consist of the following steps:)

(a) Extend the general shape of the pressure time curve prior to and immediately after the beginning of tailoff.

(b) Bisect the angle formed by these extensions.

(c) Extend this bisector to intersect the pressure time trace. The time that corresponds to this intersection point is the end of web time. This time interval is shown graphically in Figure 6.

n. Ultimate Factor of Safety. The factor by which the limit load is multiplied to obtain the ultimate load. The wall thickness used in the stress calculations for pressure vessels and for tension and shear critical structures will be the minimum thickness. Stress calculations for compression critical and stability critical structures will utilize the mean thickness or 1.05 times the minimum thickness, whichever is less.

o. Ultimate Load. The product of the limit load multiplied by the ultimate factor of safety.

p. Weight.

(1) Burnout Weight. Burnout weight is defined as the total weight at the instant of propellant burnout.

(2) Expendable Weight. Expendable weight is defined as the weight of those items that are expended from the SRM from the time beginning at SRM ignition to splashdown including propellant, insulation ablatives, liner ablatives, nozzle ablatives, igniter charge, igniter ablatives, and jettisoned nozzle components. The expendable weight is further broken down as follows:

(a) Weight Expended to Liftoff. That portion of the expendable weight expended during the time between SRM ignition and liftoff.

(b) Weight Expended During Action Time. That portion of the expendable weight expended during the time between liftoff and the instant when action time ends.

(c) Weight Expended to Separation. That portion of the expendable weight expended during the time between SRM ignition and the instant of SRM separation.

(d) Weight Expended During SRM Descent. That portion of the expendable weight expended during the time between the instant of SRM separation and the instant of SRM splashdown.

(3) Total Loaded Propellant Weight. The total loaded propellant weight is defined as all solid propellant weight in the rocket motor, including igniter system propellant.

(4) Inert Weight. Inert weight includes: motor case with assembly provisions, internal insulation, liner, inhibitor, seals, nozzle assembly, complete systems tunnel (excluding cabling), operational flight instrumentation and attach provisions, paint, ignition systems excluding propellant, external insulation, nozzle plug, SRM assembly provisions, SRB/SRM forward and aft skirt assembly provisions, and joint external insulation. Development flight instrumentation is excluded.

(5) Tare Weight. Tare weight is the weight of all items weighed with the component or assembly being weighed which are not part of the component or assembly which were not "zeroed out" on the weight measurement device prior to weighment.

(6) Total Preflight Weight. Total preflight weight is defined as the weight of the SRM on the launch pad immediately prior to ignition command.

(a) Preflight Requirements Weight. Preflight requirements weight is the weight of all expendables used in preparation for liftoff.

(b) Liftoff. Liftoff is defined as the instant when the instantaneous thrust-to-weight ratio (T/W) is 1.0. (Equivalent to 1.9 million pounds of thrust at vacuum conditions for each SRM).

q. Nominal. Nominal shall be the arithmetic average of appropriate static test and flight motor performance. All motor performance will be adjusted to a +60^{o} F PMBT and to a common target burn rate.

r. Smoothed Data. The 320 samples per second measured pressure data is curve fit by a 5th order spline function which is then used to determine the maximum pressure rise rate value over any 10 millisecond interval.

s. Multiple ply. Multiple insulation layup performed at Morton Thiokol, Inc.

t. Differential tailoff time. Differential tailoff time is defined as the time interval beginning at the first SRM web time and ending at the last SRM action time.

u. Allowable Load. The maximum load which the structure can withstand without rupture or collapse.

v. Proof Pressure. The pressure to which production pressure vessels are subjected to fulfill the acceptance requirements of the customer, in order to give evidence of satisfactory workmanship and material quality. Proof pressure is the product of maximum operating pressure, times the proof factor.

w. Margin of Safety. The ratio of allowable load to ultimate load minus one.

x. Cross Contamination. SRM plum impingement on other Space Shuttle elements.

y. Material Affected Depth. The depth of the internal insulation material which has been visibly heat affected (decomposed) during motor operation. Depth is referenced to the initial, prefire insulation surface, and is obtained by removing the insulation char down to visibly unaffected virgin rubber.

z. Verifiable. Capable of meeting verification (see 6.1.2.p) requirements.

aa. Redundancy. A redundant system is one which will sustain one failure of an assembly/component and still retain the capability of performing the intended function.

ab. Minimum. Smallest acceptable value.

ac. Debris. Debris is defined as "broken, scattered remains emanating from the exterior surface(s) of any element".

6.1.2 Space Shuttle Design Terms and Definitions.

a. Certification. Qualification tests, major ground tests, and other tests and analyses required to determine that the design of hardware from the component through the subsystem level meets requirements.

b. Critical Categories.

Category	Definition
1	Loss of life or vehicle
1R	Loss of redundant life-essential components
2	Loss of mission
2R	Loss of redundant mission-essential components
3	All others

c. Fail Operational/Flight Vehicle. Fail operational for the flight vehicle is defined as the ability to sustain a failure and retain full operational capability for safe mission continuation.

d. Fail Safe/Flight Vehicle. Fail safe for the flight vehicle is defined as the ability to sustain a failure and retain the capability to successfully terminate the mission.

e. Functional Path. A functional path is a serial set of one or more functional elements (e.g., LRUs) constrained by the following:

(1) It is either the only path capable of performing the given function, or it is the smallest set (shortest string) of serial elements for which identical or similar serial elements can be substantiated by automatic or manual control (onboard or via GSE) to perform the same function via a redundant path for fail safe or fail operational capability.

(2) The string may contain non-controllable redundancies within itself to assure a satisfactory mean time between failure for the string (e.g., redundant components within a LRU), but must not contain redundancies needed to provide failure operational or fail safe capabilities.

(3) Any point along a path which support several "downstream" paths must constitute the termination point of the "upstream" functional path and the starting point of the "downstream" functional paths.

f. Hazard. Hazard is defined as the presence of a potential risk situation caused by an unsafe act or condition.

g. Interchangeability. An item which (1) possesses such functional and physical characteristics as to be equivalent in performance, reliability and maintainability, to another item of similar or identical purpose and (2) is capable of being exchanged for the other item (a) without selection for fit or performance and (b) without alteration of the items themselves or of adjoining items, except for adjustments, is defined as being interchangeable.

h. Line Replaceable Unit (LRU). An item whose replacement constitutes the optimum organizational maintenance repair action for a higher indenture item.

i. Operational Status. The condition of a functional path with regard to its capability to perform its intended function.

j. Certification Tests. Those tests conducted as part of the certification program to demonstrate that design and performance requirements can be realized under specified conditions.

k. Replaceability. An item which, if equivalent in performance, reliability and maintainability to another item of similar or identical purpose, but which may differ physically from the original item in that the installation of the replacement item could require operations such as drilling, reaming, cutting, filing, shimming, etc., in addition to the normal application and methods of attachment, is defined as being replaceable.

l. Shuttle Vehicle Booster (SVB). The shuttle vehicle booster shall consist of two SRBs (see m.) which are a part of the flight vehicle.

m. Solid Rocket Booster (SRB). One complete SRM (see n.) plus structure, recovery, thrust vector control, attachment/separation and electrical and instrumentation subsystems.

n. Improved High Performance Solid Rocket Motor Lightweight (SRM). One lightweight segmented motor case; ignition system complete with electro-mechanical safe and arm device, initiators, and igniter; movable nozzle; liner; insulation; propellant; instrumentation and electrical brackets; and integration hardware.

o. Standby Status. "Standby Status" is defined as ready for launch except main propellant fill, crew ingress and final system verification.

p. Verification. The process of planning and implementing a program that determines that the shuttle system meets all design, performance, and safety requirements. The verification process includes the qualification, development testing, acceptance testing, preflight checkout and flight demonstration and analyses necessary to support the total verification program.

6.2 Alternate Source Qualification. This paragraph is not applicable to this specification.

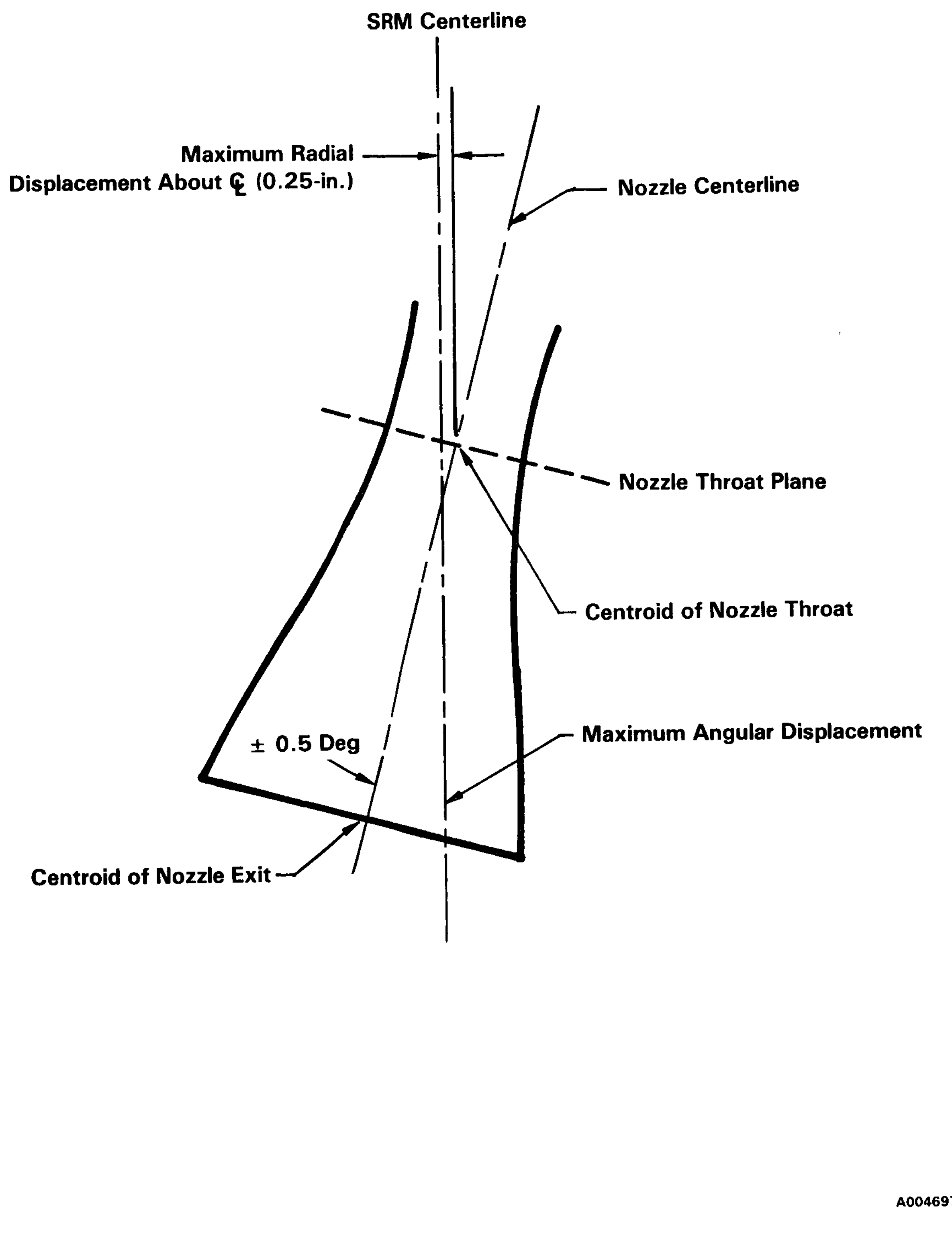
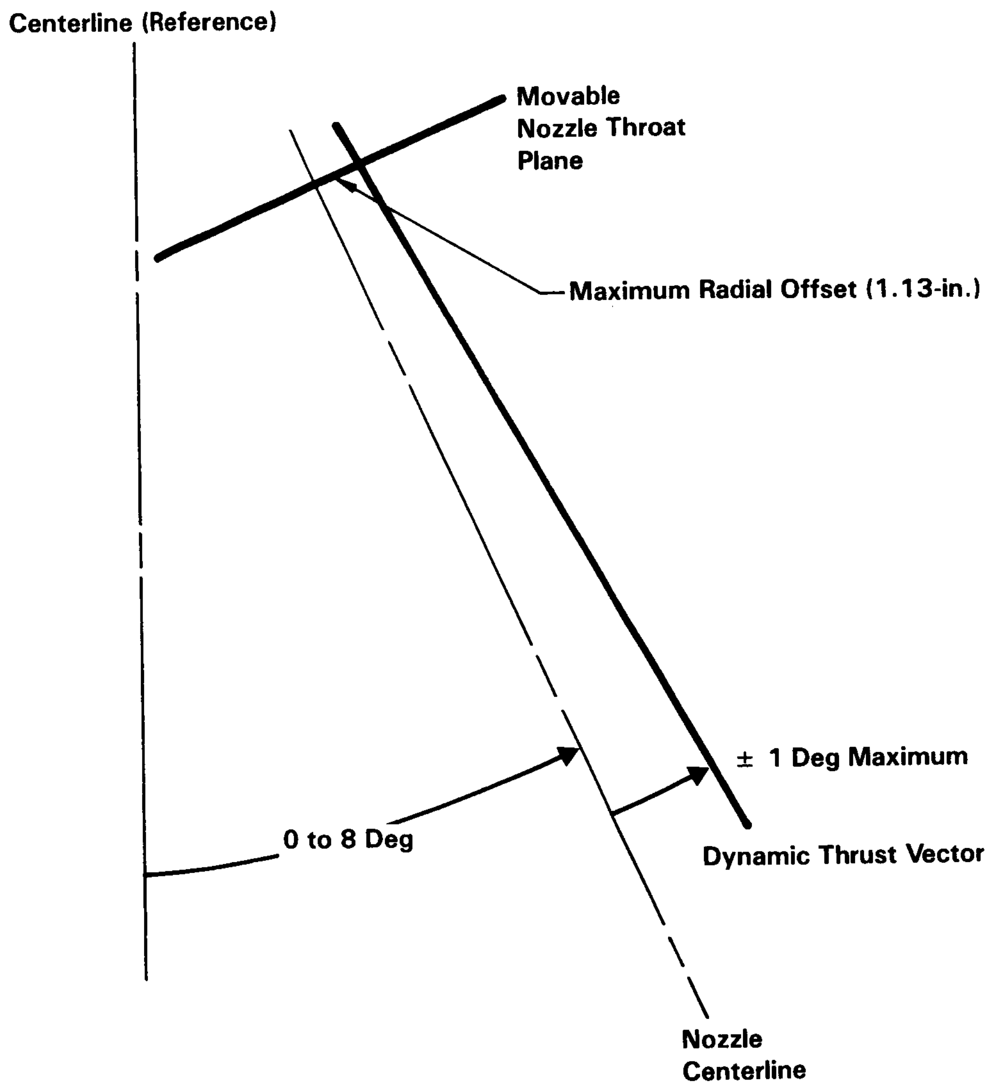


Figure 1. Geometric Thrust Vector



Note: Dynamic thrust vector requirement (nozzle in any deflected position up to ± 8 deg and at any pressure from MEOP to 35 psia)

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Figure 2. Dynamic Thrust Vector

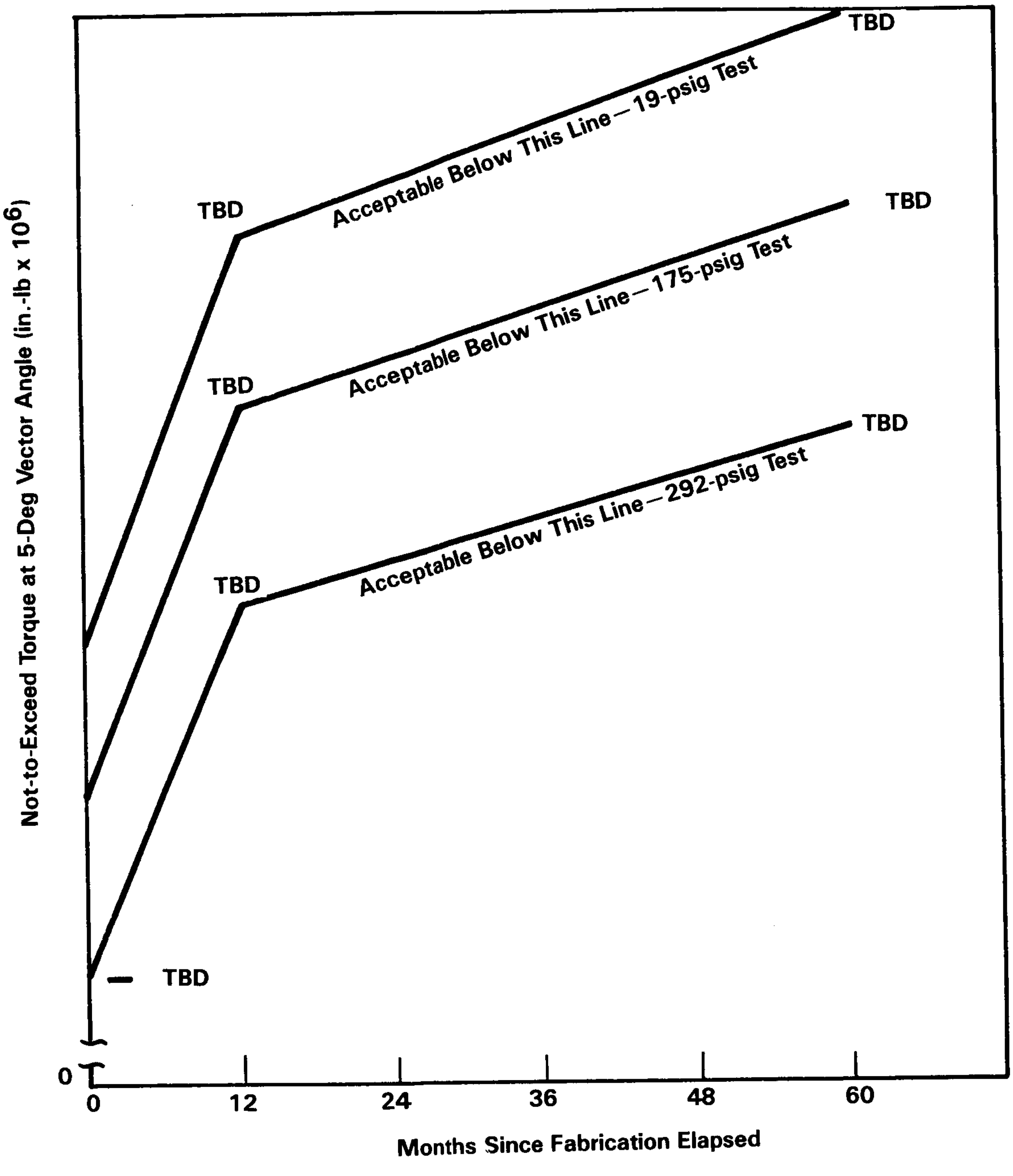
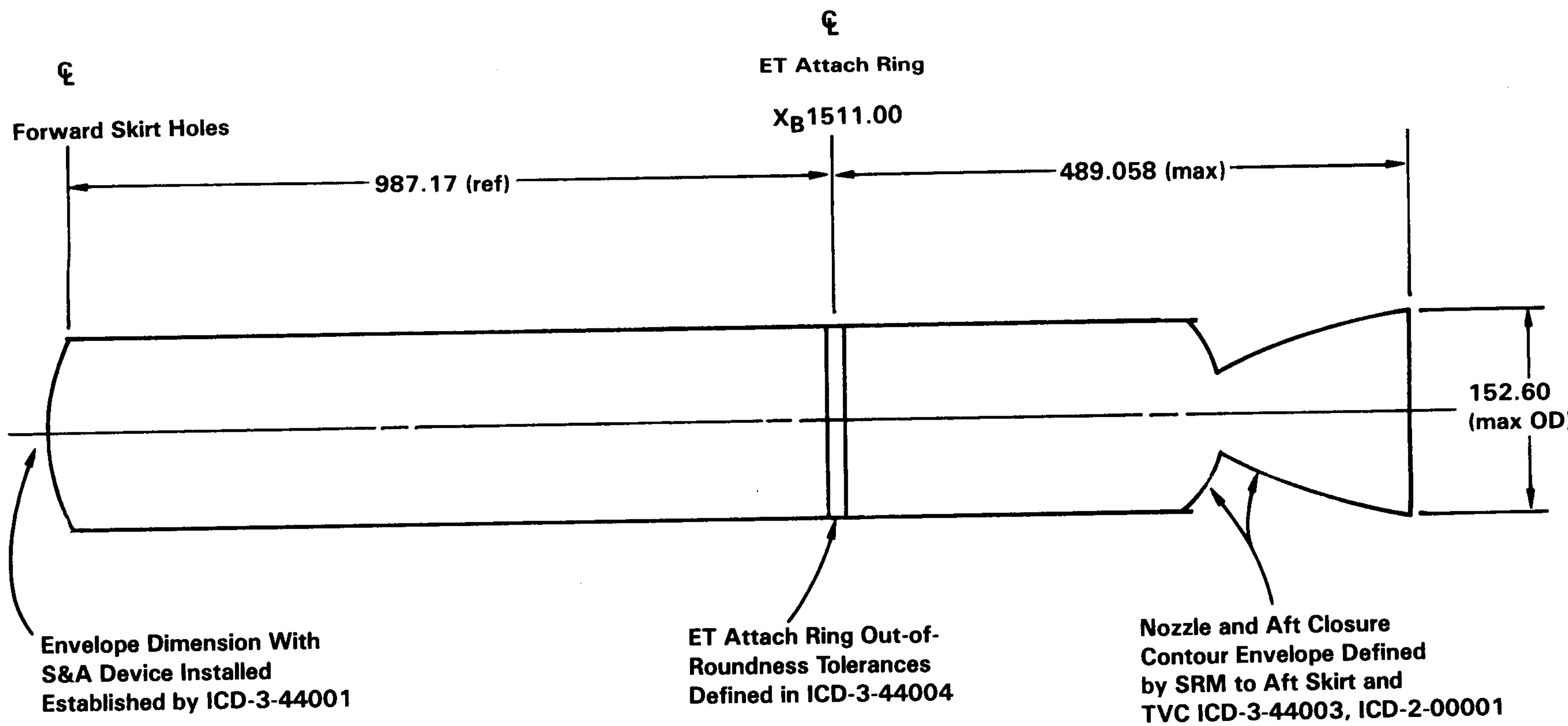


Figure 3. Bearing Torque With Aging



Note: The maximum length and outside diameter of the SRM and its components parts, when protected in accordance with the requirements of Section 5, shall not exceed the shipping envelope limitation for routine rail transportation, as shown in Figure 5.

Figure 4. Design Envelope

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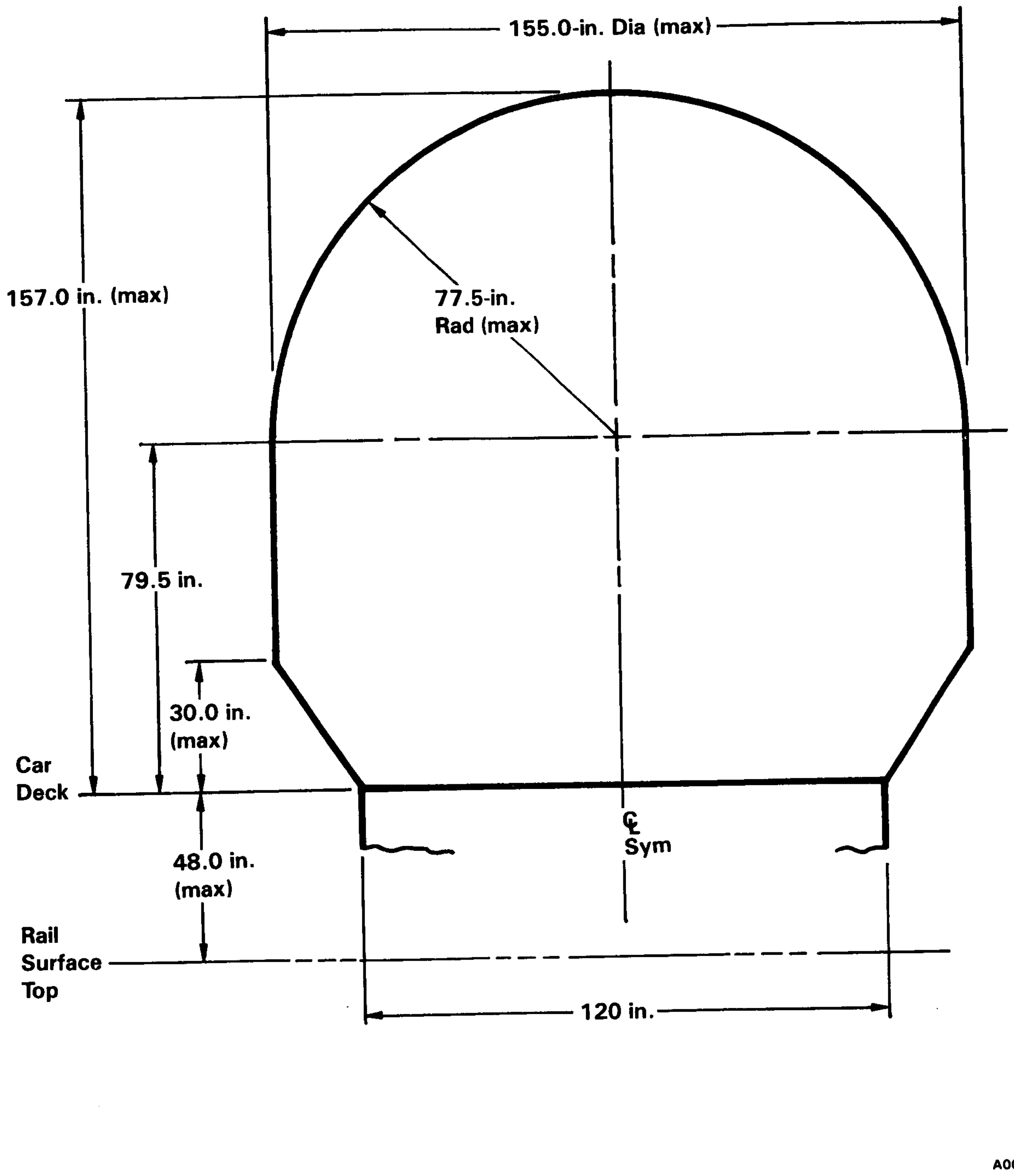

Figure 5. Shipping Envelope Limitations

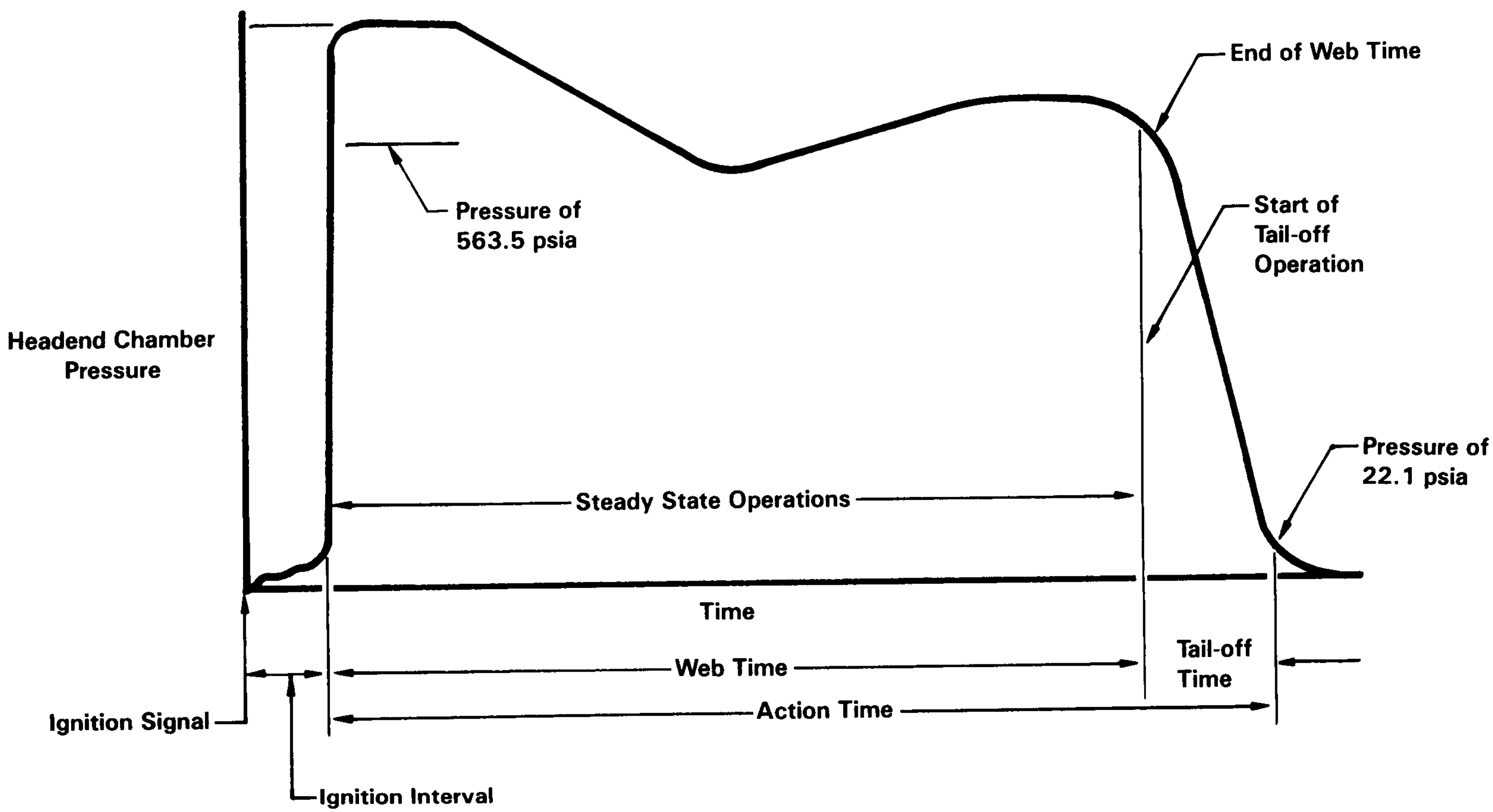

Figure 6. Performance Time Intervals

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TABLE I
SRM THRUST REQUIREMENTS
(KLB, 625 PSIA, 60 DEG F)

Time (sec)	Vacuum Thrust, K LBF Lower Bound	Nominal	Upper Bound
1.0	3380.5	3485.0	3589.6
2.0	3375.6	3480.0	3584.4
3.0	3379.5	3484.1	3588.6
4.0	3396.8	3501.9	3606.9
5.0	3438.5	3544.8	3651.2
6.0	3474.5	3582.0	3689.4
7.0	3488.5	3596.4	3704.3
8.0	3501.3	3609.6	3717.9
9.0	3513.9	3622.5	3731.2
10.0	3526.6	3635.7	3744.8
11.0	3536.3	3645.7	3755.0
12.0	3538.7	3648.1	3757.6
13.0	3537.1	3646.5	3755.9
14.0	3536.9	3646.3	3755.7
15.0	3639.4	3648.9	3758.4
16.0	3542.7	3652.3	3761.8
17.0	3546.7	3656.4	3766.1
18.0	3551.7	3661.5	3771.4
19.0	3552.7	3662.5	3772.4
20.0	3533.0	3642.3	3751.5
21.0	3470.6	3577.9	3685.3
22.0	3405.5	3510.8	3616.1
23.0	3345.3	3448.8	3552.2
24.0	3288.4	3390.1	3491.8
25.0	3237.9	3338.1	3438.2
26.0	3192.8	3291.5	3390.3
27.0	3150.6	3248.1	3345.5
28.0	3110.3	3206.4	3302.6
29.0	3071.0	3166.0	3261.0
30.0	3033.0	3126.8	3220.6
31.0	2996.1	3088.8	3181.5
32.0	2960.3	3051.8	3143.4
33.0	2924.5	3014.9	3105.4
34.0	2888.8	2978.1	3067.5
35.0	2855.7	2944.0	3032.3
36.0	2824.5	2911.9	2999.2

TABLE I (Continued)
SRM THRUST REQUIREMENTS
(KLB, 625 PSIA, 60 DEG F)

Time (sec)	Vacuum Thrust, K LBF Lower Bound	Nominal	Upper Bound
37.0	2793.6	2880.1	2966.5
38.0	2764.5	2850.0	2935.5
39.0	2738.5	2823.2	2907.9
40.0	2716.1	2800.1	2884.1
41.0	2696.4	2779.7	2863.1
42.0	2677.3	2760.1	2842.9
43.0	2659.9	2742.2	2824.5
44.0	2640.8	2722.5	2804.2
45.0	2620.4	2701.4	2782.5
46.0	2591.7	2671.8	2752.0
47.0	2562.6	2641.8	2721.1
48.0	2553.6	2632.6	2711.5
49.0	2557.9	2637.0	2716.1
50.0	2568.2	2647.6	2727.0
51.0	2581.6	2661.5	2741.3
52.0	2595.0	2675.2	2755.5
53.0	2607.5	2688.1	2768.8
54.0	2620.0	2701.0	2782.0
55.0	2633.1	2714.5	2795.9
56.0	2646.3	2728.1	2809.9
57.0	2658.2	2740.4	2822.6
58.0	2667.6	2750.1	2832.6
59.0	2677.7	2760.6	2843.4
60.0	2689.3	2772.4	2855.6
61.0	2698.3	2781.6	2865.2
62.0	2707.9	2791.7	2875.5
63.0	2716.0	2800.1	2884.0
64.0	2724.3	2808.6	2892.8
65.0	2732.9	2817.4	2902.0
66.0	2736.6	2821.3	2905.9
67.0	2740.9	2825.7	2910.5
68.0	2745.1	2830.0	2914.9
69.0	2748.6	2833.6	2918.6
70.0	2750.5	2835.6	2920.7
71.0	2747.1	2832.1	2917.1
72.0	2730.3	2814.7	2899.1
73.0	2696.3	2779.7	2863.1
74.0	2663.7	2746.1	2828.5

TABLE I (Continued)
SRM THRUST REQUIREMENTS
(KLB, 625 PSIA, 60 DEG F)

	Vacuum Thrust, K LBF		
Time (sec)	Lower Bound	Nominal	Upper Bound
75.0	2636.0	2717.6	2799.1
76.0	2602.6	2683.0	2763.5
77.0	2564.5	2643.8	2723.1
78.0	2529.1	2607.3	2685.5
79.0	2494.4	2571.5	2648.7
80.0	2443.9	2519.5	2595.1
81.0	2394.3	2468.3	2542.4
82.0	2370.1	2443.4	2516.7
83.0	2356.9	2429.8	2502.7
84.0	2338.3	2410.6	2482.9
85.0	2312.1	2383.6	2455.1
86.0	2277.6	2348.0	2418.4
87.0	2233.3	2302.3	2371.4
88.0	2195.2	2263.1	2331.0
89.0	2166.9	2233.9	2300.9
90.0	2136.6	2202.7	2268.8
91.0	2098.7	2163.6	2228.5
92.0	2059.7	2123.4	2187.1
93.0	2026.7	2089.4	2152.1
94.0	1994.5	2056.2	2117.9
95.0	1953.5	2103.9	2074.3
96.0	1906.1	1965.1	2024.0
97.0	1815.3	1923.6	1981.4
98.0	1709.8	1897.3	1954.2
99.0	1518.7	1872.1	1928.2
100.0	1238.1	1815.2	1909.6
101.0	957.5	1713.4	1895.0
102.0	742.7	1534.2	1871.1
103.0	582.2	1265.0	1815.3
104.0	458.1	988.4	1716.7
105.0	353.4	771.8	1547.7
106.0	271.8	608.1	1290.3
107.0	196.0	482.0	1017.5
108.0	136.1	372.1	799.2
109.0	90.5	293.1	634.3

TABLE I (Continued)
SRM THRUST REQUIREMENTS
(KLB, 625 PSIA, 60 DEG F)

	Vacuum Thrust, K LBF		
Time (sec)	Lower Bound	Nominal	Upper Bound
110.0	60.6	216.7	505.6
111.0	37.3	155.6	395.6
112.0	21.7	103.7	313.7
113.0		70.9	238.3
114.0		44.7	173.8
115.0		27.3	119.8
116.0			82.9
117.0			54.8
118.0			34.4
119.0			21.0

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Table II. Performance Tolerances and Limits

Parameter	Block II	Individual Motor Performance*			Matched Pair Performance, Maximum Difference (%)
		Nominal	Tolerances (%)	Limits	
Web Time (sec)	104.2	111.7	±5.0	106.1 - 117.2	2.0
Action Time (sec)	TBD	123.4	±6.5	115.4 - 131.4	3.0
Web Time Average Pressure (psia)	727.7	660.8	±5.3	625.8 - 695.8	2.0
Max Headend Pressure (psia)	1,025.5	918.4	±6.5	858.7 - 978.1	N/A
Max Sea Level Thrust (Mlbf)	3.442	3.06	±6.2	2.87 - 3.25	N/A
Web Time Average Vacuum Thrust (Mlbf)	2.851	2.59	±5.3	2.45 - 2.72	2.0
Vacuum Delivered Specific Impulse (lbf-sec/lbm)	268.2	267.1	±0.7	265.3 - 269.0	1.0
Web Time Vacuum Total Impulse (Mlbf-sec)	296.5	288.9	±1.0	286.1 - 291.8	1.4
Action Time Vacuum Total Impulse (Mlbf-sec)	TBD	296.3	±1.0	293.3 - 299.2	1.4

* Based on PMBT of 60°F

TABLE III

MAXIMUM SRM THRUST IMBALANCE FOR MATCHED PAIRS DURING IGNITION, STEADY STATE, AND TAILOFF

Maximum SRM Ignition Transient

Ignition Transient Time, sec.	Ignition Transient Thrust Imbalance, lbf
0	0
0.1	300,000
0.4	300,000
0.6	200,000
0.8	200,000
1.0	85,000

Maximum SRM Steady State Thrust Differential

Time	Maximum Thrust Imbalance, lbf 2/
1.0 second to end of steady state 1/	85,000

1/ End of steady state is defined as 4.5 seconds before earliest web time.

2/ Maximum thrust imbalance is defined as the maximum difference in average thrust of the left and right SRM's over any four-second time span contained within the steady state operation. Thrust imbalance increases linearly from 85,000 to 268,000 lbf during the time interval between the end of steady state and the beginning of tailoff.

TABLE III (Cont'd)

TAILOFF THRUST IMBALANCE

Differential Tailoff Time, % 3/	Maximum Vacuum Thrust Differential During Tailoff, lbf 4/
0	268,000
10	570,000
20	670,000
30	710,000
40	580,000
50	470,000
60	370,000
70	290,000
80	220,000
90	160,000
100	100,000

3/ Differential tailoff time is defined in Section 6.0

4/ Thrust imbalance impulse during the differential tailoff period must be $\leq$ 4,500,000 lbf-sec

TABLE IV

REUSABILITY GOALS

COMPONENT	NUMBER OF REUSES
1. Case cylindrical segments	19
2. Case forward segments	19
3. Case aft segments	19
4. Case aft closures	19
5. Case stiffener rings	19
6. Case clevis joint pins	19
7. Nozzle metal parts	19
8. Nozzle flex seal reinforcement shims and end mounting rings	19
9. Nozzle flex seal assy (elastomer material)	9
10. Nozzle boss attach bolts	19
11. S&A device	19
12. Igniter chamber	19
13. Igniter adapter	19
14. Chamber pressure transducers	19
15. Igniter port special bolts (for mounting chamber pressure monitoring OPTs)	5

TABLE V

	VERIFICATION CROSS REFERENCE INDEX	CPW1-1900 Dated: 25 November 1986 Page I-93

REQUIREMENTS FOR VERIFICATION

VERIFICATION METHOD:
1. Similarity
2. Analysis
3. Inspection
4. Demonstration
5. Test

N/A - Not Applicable

VERIFICATION PHASE:
A. Development
B. Certification
C. Acceptance
D. Preflight
E. Flight
F. Postflight

Section 3.0 Performance/ Design Requirement Reference	Verification Methods							Section 4.0 Verification Requirement Reference
	N/A	A	B	C	D	E	F	
3.1 Definition	X							
3.1.1 General Description	X							
3.1.2 Missions	X							
3.1.3 Operational Concepts	X							
3.1.3.1 Assembly Operations Concept	X							
3.1.3.2 Launch Pad Operations Concept	X							
3.1.3.3 Booster Operations Concept	X							
3.1.3.4 Recovery Concepts	X							
3.1.3.4.1 Refur-bishment Concepts	X							
3.1.4 Organizational and Management Relationships	X							

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	VERIFICATION CROSS REFERENCE INDEX	CPW1-1900 Dated: 25 November 1986 Page I-94

REQUIREMENTS FOR VERIFICATION

VERIFICATION METHOD:
1. Similarity
2. Analysis
3. Inspection
4. Demonstration
5. Test

N/A - Not Applicable

VERIFICATION PHASE:
A. Development
B. Certification
C. Acceptance
D. Preflight
E. Flight
F. Postflight

Section 3.0 Performance/ Design Requirement Reference	Verification Methods							Section 4.0 Verification Requirement Reference
	N/A	A	B	C	D	E	F	
3.1.5 Systems Engineering Requirements	X							
3.1.6 Government Furnished Property List	X							
3.1.7 Critical Components	X							
3.2 Characteristics	X							
3.2.1 Performance	X							
Altitude		2	2			5		4.2.1.2, 4.2.2.2, 4.2.6
Thermal		2/5	2/5			5		4.2.1.2, 4.2.1.5, 4.2.2.2, 4.2.2.5, 4.2.6
3.2.1.1 General Performance	X							
3.2.1.1.1 Ignition Characteristics		5	5			5		4.2.1.5, 4.2.2.5, 4.2.6
3.2.1.1.1.1 Ignition Interval		5	5					4.2.1.5, 4.2.2.5

TABLE V

	VERIFICATION CROSS REFERENCE INDEX	CPW1-1900 Dated: 25 November 1986 Page I-95

REQUIREMENTS FOR VERIFICATION

VERIFICATION METHOD:
1. Similarity
2. Analysis
3. Inspection
4. Demonstration
5. Test

N/A - Not Applicable

VERIFICATION PHASE:
A. Development
B. Certification
C. Acceptance
D. Preflight
E. Flight
F. Postflight

Section 3.0 Performance/ Design Requirement Reference	Verification Methods							Section 4.0 Verification Requirement Reference
	N/A	A	B	C	D	E	F	
3.2.1.1.1.2 Pressure Rise Rate		5	5					4.2.1.5, 4.2.2.5
3.2.1.1.2 Motor Characteristics	X							
3.2.1.1.2.1 Nominal Thrust-Time Curve		2/5	2/5			2/5		4.2.1.2, 4.2.1.5, 4.2.2.2, 4.2.2.5, 4.2.6
3.2.1.1.2.2 Performance Tolerances and Limits		2	2			2/5		4.2.1.2, 4.2.2.2, 4.2.6
3.2.1.1.2.3 Thrust Differential						2/5		4.2.6
3.2.1.2 Pressure Seals	X							
a. Redundant		3/5	3/5	5			3	4.2.1.3, 4.2.1.5, 4.2.2.3, 4.2.2.5, 4.2.3.5, 4.2.7
b. Deflections		2	2					4.2.1.2, 4.2.2.2
c. Zero leakage		2/5	2/5		5		3	4.2.1.2, 4.2.1.5, 4.2.2.2, 4.2.2.5, 4.2.5.5, 4.2.7

TABLE V

	VERIFICATION CROSS REFERENCE INDEX	CPW1-1900 Dated: 25 November 1986 Page I-96

REQUIREMENTS FOR VERIFICATION

VERIFICATION METHOD:
1. Similarity
2. Analysis
3. Inspection
4. Demonstration
5. Test

N/A - Not Applicable

VERIFICATION PHASE:
A. Development
B. Certification
C. Acceptance
D. Preflight
E. Flight
F. Postflight

Section 3.0 Performance/ Design Requirement Reference	Verification Methods							Section 4.0 Verification Requirement Reference
	N/A	A	B	C	D	E	F	
d. Temperature		2/5	2/5				3	4.2.1.2, 4.2.1.5, 4.2.2.2, 4.2.2.5, 4.2.7
e. Single failure		2	2					4.2.1.2, 4.2.2.2
f. Leak paths sealed		2/3	2/3				3	4.2.1.2, 4.2.1.3, 4.2.2.2, 4.2.2.3, 4.2.7
g. Verification		3	3					4.2.1.3, 4.2.2.3
h. Squeeze/finish		2/3	2/3	2/3				4.2.1.2, 4.2.1.3, 4.2.2.2, 4.2.2.3, 4.2.3.2, 4.2.3.3
3.2.1.2.1 Field Joints and Nozzle To Case Joints	X							
a. Failure		2	2					4.2.1.2, 4.2.2.2
b. Independent sealing		2/5	2/3				3	4.2.1.2, 4.2.1.5, 4.2.2.2, 4.2.2.3, 4.2.7
c. Two seals		3/5	3/5	3			3	4.2.1.3, 4.2.1.5, 4.2.2.3, 4.2.2.5, 4.2.3.3, 4.2.7

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VERIFICATION CROSS REFERENCE INDEX	CPW1-1900 Dated: 25 November 1986 Page I-97

REQUIREMENTS FOR VERIFICATION

VERIFICATION METHOD:
1. Similarity
2. Analysis
3. Inspection
4. Demonstration
5. Test

N/A - Not Applicable

VERIFICATION PHASE:
A. Development
B. Certification
C. Acceptance
D. Preflight
E. Flight
F. Postflight

Section 3.0 Performance/ Design Requirement Reference	Verification Methods							Section 4.0 Verification Requirement Reference
	N/A	A	B	C	D	E	F	
d. Bore seals		3/5	3/5	3			3	4.2.1.3, 4.2.1.5, 4.2.2.3, 4.2.2.5, 4.2.3.3, 4.2.7
e. Sealing margin		2/3	2/3					4.2.1.2, 4.2.1.3, 4.2.2.2, 4.2.2.3
3.2.1.2.2 Flex Bearing Sealing		3/5	3/5	3/5		5		4.2.1.3, 4.2.1.5, 4.2.2.3, 4.2.2.5, 4.2.3.3, 4.2.3.5, 4.2.6
3.2.1.3 Case	X							
a. MEOP		2/5	2/5	5		5		4.2.1.2, 4.2.1.5, 4.2.2.2, 4.2.2.5, 4.2.3.5, 4.2.6
b. Structural integrity		2/5	5	2/3/5		5		4.2.1.2, 4.2.1.5, 4.2.2.5, 4.2.3.2, 4.2.3.3, 4.2.3.5, 4.2.6
c. Case risers		2/3	2/3		3	5		4.2.1.2, 4.2.1.3, 4.2.2.2, 4.2.2.3, 4.2.5.3, 4.2.6
d. Interfaces		3	3		4			4.2.1.3, 4.2.2.3, 4.2.5.4
e. Bonding		3	3		3			4.2.1.3, 4.2.2.3, 4.2.5.3

TABLE V

	VERIFICATION CROSS REFERENCE INDEX	CPW1-1900 Dated: 25 November 1986 Page I-98

REQUIREMENTS FOR VERIFICATION

VERIFICATION METHOD:
1. Similarity
2. Analysis
3. Inspection
4. Demonstration
5. Test

N/A - Not Applicable

VERIFICATION PHASE:
A. Development
B. Certification
C. Acceptance
D. Preflight
E. Flight
F. Postflight

Section 3.0 Performance/ Design Requirement Reference	Verification Methods							Section 4.0 Verification Requirement Reference
	N/A	A	B	C	D	E	F	
f. Mating joints		3/4	3/4	3	4		4	4.2.1.3, 4.2.1.4, 4.2.2.3, 4.2.2.4, 4.2.3.3, 4.2.5.4, 4.2.7
g. No moisture		3	3					4.2.1.3, 4.2.2.3
h. Ports		3	3	3				4.2.1.3, 4.2.2.3, 4.2.3.3
i. Biaxial improvement		2	2	2				4.2.1.2, 4.2.2.2, 4.2.3.2
j. Pressure drop		2/5	2/5	2				4.2.1.2, 4.2.1.5, 4.2.2.2, 4.2.2.5, 4.2.3.2
k. Chemical dissolution		5	5					4.2.1.5, 4.2.2.5
3.2.1.4 Nozzle Assembly	X							
3.2.1.4.1 Vectoring		1/2/5	1/2/5					4.2.1.1. 4.2 1.2, 4.2.1.5, 4.2.2.1, 4.2.2.2, 4.2.2.5
3.2.1.4.1.1 Stall Force		2	2					4.2.1.2, 4.2.2.2

TABLE V

VERIFICATION CROSS REFERENCE INDEX	CPW1-1900 Dated: 25 November 1986 Page I-99

REQUIREMENTS FOR VERIFICATION

VERIFICATION METHOD:
1. Similarity
2. Analysis
3. Inspection
4. Demonstration
5. Test

N/A - Not Applicable

VERIFICATION PHASE:
A. Development
B. Certification
C. Acceptance
D. Preflight
E. Flight
F. Postflight

Section 3.0 Performance/ Design Requirement Reference	Verification Methods							Section 4.0 Verification Requirement Reference
	N/A	A	B	C	D	E	F	
3.2.1.4.2 Geometric Thrust Vector	X							
a. Radial		2/5	2/5					4.2.1.2, 4.2.1.5, 4.2.2.2, 4.2.2.5
b. Angular		2/5	2/5					4.2.1.2, 4.2.1.5, 4.2.2.2, 4.2.2.5
3.2.1.4.3 Dynamic Thrust Vector		2/5	2/5					4.2.1.2, 4.2.1.5, 4.2.2.2, 4.2.2.5
a. Misalignment of DTV		5	5					4.2.1.5, 4.2.2.5
b. Radial Offset		5	5					4.2.1.5, 4.2.2.5
3.2.1.4.4 Exit Cone Severance		3/5			3	5	3	4.2.1.3, 4.2.1.5, 4.2.5.3, 4.2.6, 4.2.7
3.2.1.4.5 Nozzle Alignment		3	3	3				4.2.1.3, 4.2.2.3, 4.2.3.3
3.2.1.4.6 Flex Bearing Protection		3	3			5	3	4.2.1.3, 4.2.2.3, 4.2.6, 4.2.7

TABLE V

REQUIREMENTS FOR VERIFICATION

VERIFICATION METHOD:
1. Similarity
2. Analysis
3. Inspection
4. Demonstration
5. Test

N/A - Not Applicable

VERIFICATION PHASE:
A. Development
B. Certification
C. Acceptance
D. Preflight
E. Flight
F. Postflight

Section 3.0 Performance/ Design Requirement Reference	Verification Methods							Section 4.0 Verification Requirement Reference
	N/A	A	B	C	D	E	F	
3.2.1.4.7 Environmental Protection	X							
a. Storage		2/3	2/3		3			4.2.1.2, 4.2.1.3, 4.2.2.2, 4.2.2.3, 4.2.5.3
b. Operational		2/3	2/3		3	5		4.2.1.2, 4.2.1.3, 4.2.2.2, 4.2.2.3, 4.2.5.3, 4.2.6
3.2.1.4.8 TVC Actuator Attach Points		3/4	3/4		4			4.2.1.3, 4.2.1.4, 4.2.2.3, 4.2.2.4, 4.2.5.4
3.2.1.4.9 Nozzle Assy/Aft Segment Interface			3		4			4.2.2.3, 4.2.5.4
3.2.1.4.10 Nozzle Assy/Dewatering System Interface		3	3				4	4.2.1.3, 4.2.2.3, 4.2.7
3.2.1.4.11 Flex Bearing	X							
3.2.1.4.11.1 Total Deflection		2/5	2/5			5		4.2.1.2, 4.2.1.5, 4.2.2.2, 4.2.2.5, 4.2.6

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	VERIFICATION CROSS REFERENCE INDEX	CPW1-1900 Dated: 25 November 1986 Page I-101

REQUIREMENTS FOR VERIFICATION

VERIFICATION METHOD:
1. Similarity
2. Analysis
3. Inspection
4. Demonstration
5. Test

N/A - Not Applicable

VERIFICATION PHASE:
A. Development
B. Certification
C. Acceptance
D. Preflight
E. Flight
F. Postflight

Section 3.0 Performance/ Design Requirement Reference	Verification Methods							Section 4.0 Verification Requirement Reference
	N/A	A	B	C	D	E	F	
3.2.1.4.11.2 Bearing Torque Limits		2/5	2/5	2/5				4.2.1.2, 4.2.1.5, 4.2.2.2, 4.2.2.5, 4.2.3.2, 4.2.3.5
3.2.1.4.12 Aft Exit Cone Severance Ordnance Ring		3/5			3	5		4.2.1.3, 4.2.1.5, 4.2.5.3, 4.2.6
3.2.1.4.12.1 Detonator		3			3			4.2.1.3, 4.2.5.3
3.2.1.4.12.2 Post Firing Hazards & Obstructions		3/4					4	4.2.1.3, 4.2.1.4, 4.2.7
3.2.1.4.12.3 Mounting Provisions for Ordnance Ring Blast Shield and Aft Thermal Shield		3			3			4.2.1.3, 4.2.5.3
3.2.1.4.12.4 Ordnance Cables and Brackets		3			3			4.2.1.3, 4.2.5.3
3.2.1.5 Ignition System		3	3			5		4.2.1.3, 4.2.2.3, 4.2.6
a. Preclude hot gas leakage		3/5	3/5			5		4.2.1.3, 4.2.1.5, 4.2.2.3, 4.2.2.5, 4.2.6

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REQUIREMENTS FOR VERIFICATION

VERIFICATION METHOD:
1. Similarity
2. Analysis
3. Inspection
4. Demonstration
5. Test

N/A - Not Applicable

VERIFICATION PHASE:
A. Development
B. Certification
C. Acceptance
D. Preflight
E. Flight
F. Postflight

Section 3.0 Performance/ Design Requirement Reference	Verification Methods							Section 4.0 Verification Requirement Reference
	N/A	A	B	C	D	E	F	
b. Igniter and S&A are separable		3/4	3/4		4		4	4.2.1.3, 4.2.1.4, 4.2.2.3, 4.2.2.4, 4.2.5.4, 4.2.7
3.2.1.5.1 S&A Device	X							
a. Enable and inhibit		5	5			5		4.2.1.5, 4.2.2.5, 4.2.6
b. Perform function		5	5			5		4.2.1.5, 4.2.2.5, 4.2.6
c. Prevent Ignition		5	5			5		4.2.1.5, 4.2.2.5, 4.2.6
d. Provide change of position		5	5	5	5	5		4.2.1.5, 4.2.2.5, 4.2.3.5, 4.2.5.5, 4.2.6
e. Provide simplex remote position		5	5	3/5	5			4.2.1.5, 4.2.2.5, 4.2.3.3, 4.2.3.5, 4.2.5.5
f. Provide visual position indication		3	3	3	3			4.2.1.3, 4.2.2.3, 4.2.3.3, 4.2.5.3
g. Permit manual safing		4	4	4	4			4.2.1.4, 4.2.2.4, 4.2.3.4, 4.2.5.4

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VERIFICATION CROSS REFERENCE INDEX	CPW1-1900 Dated: 25 November 1986 Page I-103

REQUIREMENTS FOR VERIFICATION

VERIFICATION METHOD:
1. Similarity
2. Analysis
3. Inspection
4. Demonstration
5. Test

N/A - Not Applicable

VERIFICATION PHASE:
A. Development
B. Certification
C. Acceptance
D. Preflight
E. Flight
F. Postflight

Section 3.0 Performance/ Design Requirement Reference	Verification Methods							Section 4.0 Verification Requirement Reference
	N/A	A	B	C	D	E	F	
h. Prevent manual arming		4	4	4	4			4.2.1.4, 4.2.2.4, 4.2.3.4, 4.2.5.4
i. Provide mechanical barrier		3	3	3				4.2.1.3, 4.2.2.3, 4.2.3.3
j. Provide a mechanical safety pin		4	4	4	4			4.2.1.4, 4.2.2.4, 4.2.3.4, 4.2.5.4
k. Provide a talk back switch		3	3	3				4.2.1.3, 4.2.2.3, 4.2.3.3
l. S&A with two initiators		3	3	3	3			4.2.1.3, 4.2.2.3, 4.2.3.3, 4.2.5.3
m. Leak Checked		5	5		5			4.2.1.5, 4.2.2.5, 4.2.5.5
n. Installation in only one position		4	4		4			4.2.1.4, 4.2.2.4, 4.2.5.4
o. Lockwire capability		3	3		4			4.2.1.3, 4.2.2.3, 4.2.5.4
p. Provide for two initiators		3	3	3	4			4.2.1.3, 4.2.2.3, 4.2.3.3, 4.2.5.4

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	VERIFICATION CROSS REFERENCE INDEX	CPW1-1900 Dated: 25 November 1986 Page I-104

REQUIREMENTS FOR VERIFICATION

VERIFICATION METHOD:
1. Similarity
2. Analysis
3. Inspection
4. Demonstration
5. Test

N/A - Not Applicable

VERIFICATION PHASE:
A. Development
B. Certification
C. Acceptance
D. Preflight
E. Flight
F. Postflight

Section 3.0 Performance/ Design Requirement Reference	Verification Methods							Section 4.0 Verification Requirement Reference
	N/A	A	B	C	D	E	F	
3.2.1.5.2. Igniter Design		3/5	3/5		3	5		4.2.1.3, 4.2.1.5, 4.2.2.3, 4.2.2.5, 4.2.5.3, 4.2.6
3.2.1.6 Electrical and Instrumentation		1/3	1/3		3			4.2.1.1, 4.2.1.3, 4.2.2.1, 4.2.2.3, 4.2.5.3
3.2.1.6.1 S&A Electrical Characteristics	X							
3.2.1.6.1.1 Electrical Circuits		3	3					4.2.1.3, 4.2.2.3
3.2.1.6.1.2 Electrical Connector		3	3		3			4.2.1.3, 4.2.2.3, 4.2.5.3
3.2.1.6.1.3 Power Supply		5	5	5	5	5		4.2.1.5, 4.2.2.5, 4.2.3.5, 4.2.5.5, 4.2.6
3.2.1.6.1.4 S&A Time/Voltage		5	5	5	5	5		4.2.1.5, 4.2.2.5, 4.2.3.5, 4.2.5.5, 4.2.6
3.2.1.6.1.5 Current Requirements		2/5	2/5	3				4.2.1.2, 4.2.1.5, 4.2.2.2, 4.2.2.5, 4.2.3.3

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VERIFICATION CROSS REFERENCE INDEX	CPW1-1900 Dated: 25 November 1986 Page I-105

REQUIREMENTS FOR VERIFICATION

VERIFICATION METHOD:
1. Similarity
2. Analysis
3. Inspection
4. Demonstration
5. Test

N/A - Not Applicable

VERIFICATION PHASE:
A. Development
B. Certification
C. Acceptance
D. Preflight
E. Flight
F. Postflight

Section 3.0 Performance/ Design Requirement Reference	Verification Methods							Section 4.0 Verification Requirement Reference
	N/A	A	B	C	D	E	F	
3.2.1.6.1.6 Electrical Bonding Resistance		5	5	5				4.2.1.5, 4.2.2.5, 5.2.3.5
3.2.1.6.2 Instrumentation					4			4.2.5.4
3.2.1.6.2.1 Operational Flight Instrumentation		1/5	1/5		3	5		4.2.1.1, 4.2.1.5, 4.2.2.1, 4.2.2.5, 4.2.5.3, 4.2.6
3.2.1.6.2.2 Cable Mounting Brackets		3	3		3			4.2.1.3, 4.2.2.3, 4.2.5.3
3.2.1.6.2.3 Ground Environmental Instrumentation		2/4	2/4		3			4.2.1.2, 4.2.1.4, 4.2.2.2, 4.2.2.4, 4.2.5.3
3.2.1.7 Propellants		5	5					4.2.1.5, 4.2.2.5
3.2.1.8 Insulation		2/5	2/5			5	3	4.2.1.2, 4.2.1.5, 4.2.2.2, 4.2.2.5, 4.2.5.3, 4.2.6, 4.2.7
3.2.1.8.1 Igniter Insulation		2/5	2/5			5		4.2.1.2, 4.2.1.5, 4.2.2.2, 4.2.2.5, 4.2.6

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REQUIREMENTS FOR VERIFICATION

VERIFICATION METHOD:
1. Similarity
2. Analysis
3. Inspection
4. Demonstration
5. Test

N/A - Not Applicable

VERIFICATION PHASE:
A. Development
B. Certification
C. Acceptance
D. Preflight
E. Flight
F. Postflight

Section 3.0 Performance/ Design Requirement Reference	Verification Methods							Section 4.0 Verification Requirement Reference
	N/A	A	B	C	D	E	F	
3.2.1.9 Reusability								
Case Cylindrical segments Stiffener segments Attach segments Fwd and aft segments Stiffener rings Clevis joint pins		1/2/5	1/2/5	5		5	3	4.2.1.1, 4.2.1.2, 4.2.1.5, 4.2.2.1, 4.2.2.2, 4.2.2.5, 4.2.3.5, 4.2.6, 4.2.7
Nozzle Metal parts Boss attach bolts		1/2/5	1/2/5			5	3	4.2.1.1, 4.2.1.2, 4.2.1.5, 4.2.2.1, 4.2.2.2, 4.2.2.5, 4.2.6, 4.2.7
Flex Bearing Reinforcement shims and end Mounting rings Elastomer material		1/2/5	1/2/5	5		5	3	4.2.1.1, 4.2.1.2, 4.2.1.5, 4.2.2.1, 4.2.2.2, 4.2.2.5, 4.2.3.5, 4.2.6, 4.2.7
Igniter Chamber Adapter Igniter port Special bolts		1/2/5	1/2/5			5	3	4.2.1.1, 4.2.1.2, 4.2.1.5, 4.2.2.1, 4.2.2.2, 4.2.2.5, 4.2.6, 4.2.7

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REQUIREMENTS FOR VERIFICATION

VERIFICATION METHOD:	VERIFICATION PHASE:
1. Similarity	A. Development
2. Analysis	B. Certification
3. Inspection	C. Acceptance
4. Demonstration	D. Preflight
5. Test	E. Flight
	F. Postflight
N/A - Not Applicable	

Section 3.0 Performance/ Design Requirement Reference	Verification Methods							Section 4.0 Verification Requirement Reference
	N/A	A	B	C	D	E	F	
S&A		1/2/5	1/2/5	5		5	3	4.2.1.1, 4.2.1.2, 4.2.1.5, 4.2.2.1, 4.2.2.2, 4.2.2.5, 4.2.3.5, 4.2.6, 4.2.7
Transducers		1/2/5	1/2/5	5		5	3	4.2.1.1, 4.2.1.2, 4.2.1.5, 4.2.2.1, 4.2.2.2, 4.2.2.5, 4.2.3.5, 4.2.6, 4.2.7
3.2.1.10 Systems Tunnel		3	3					4.2.1.3, 4.2.2.3
3.2.1.10.1 Systems Tunnel Design					3			4.2.5.3
3.2.1.10.2 Thermal Protection						5		4.2.6
3.2.1.10.3 Venting/ Sealing					3		3	4.2.5.3, 4.2.7
3.2.1.10.4 Structural Integrity							3	4.2.7
3.2.1.10.5 Grounding					3			4.2.5.3

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REQUIREMENTS FOR VERIFICATION

VERIFICATION METHOD:
1. Similarity
2. Analysis
3. Inspection
4. Demonstration
5. Test

N/A - Not Applicable

VERIFICATION PHASE:
A. Development
B. Certification
C. Acceptance
D. Preflight
E. Flight
F. Postflight

Section 3.0 Performance/ Design Requirement Reference	Verification Methods							Section 4.0 Verification Requirement Reference
	N/A	A	B	C	D	E	F	
3.2.2 Physical	X							
3.2.2.1 Design Envelope		3	3	3	3			4.2.1.3, 4.2.2.3, 4.2.3.3, 4.2.5.3
3.2.2.2 Mass Properties	X							
3.2.2.2.1 Control Weight (Inert)		3	3	2/3				4.2.1.3, 4.2.2.3, 4.2.3.2, 4.2.3.3
3.2.2.2.2 Propellant Weight		3	3	2/3				4.2.1.3, 4.2.2.3, 4.2.3.2, 4.2.3.3
3.2.2.2.3 Center of Gravity								
Inert		2	2	2				4.2.1.2, 4.2.2.2, 4.2.3.2
Loaded								
Longitudinal		5	5	2				4.2.1.5, 4.2.2.5, 4.2.3.2
Vertical		2	2	2				4.2.1.2, 4.2.2.2, 4.2.3.2
3.2.2.2.4 Accuracy Requirements		3	3	3				4.2.1.3, 4.2.2.3, 4.2.3.3

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REQUIREMENTS FOR VERIFICATION

VERIFICATION METHOD:
1. Similarity
2. Analysis
3. Inspection
4. Demonstration
5. Test

N/A - Not Applicable

VERIFICATION PHASE:
A. Development
B. Certification
C. Acceptance
D. Preflight
E. Flight
F. Postflight

Section 3.0 Performance/ Design Requirement Reference	Verification Methods							Section 4.0 Verification Requirement Reference
	N/A	A	B	C	D	E	F	
3.2.3 Reliability		2/5	2/5			5		4.2.1.2, 4.2.1.5, 4.2.2.2, 4.2.2.5, 4.2.6
3.2.3.1 Primary Structure, Thermal Protection, Pressure Vessels		1/2/5	1/2/5			5		4.2.1.1, 4.2.1.2, 4.2.1.5, 4.2.2.1, 4.2.2.2, 4.2.2.5, 4.2.6
3.2.3.2 Flight Vehicle Subsystem Functional		2	2			5		4.2.1.2, 4.2.2.2, 4.2.6
3.2.3.3 Isolation of Subsystem Anomalies				4	4			4.2.3.4, 4.2.5.4
3.2.4 Maintainability		2	2		4			4.2.1.2, 4.2.2.2, 4.2.5.4
3.2.5 Operational Availability	X							
3.2.5.1 Assembly/ Disassembly of Segments		1/4	1/4		4		4	4.2.1.1, 4.2.1.4, 4.2.2.1, 4.2.2.4, 4.2.5.4, 4.2.7
3.2.5.2 Assembly and Checkout Schedule					4			4.2.5.4

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REQUIREMENTS FOR VERIFICATION

VERIFICATION METHOD:
1. Similarity
2. Analysis
3. Inspection
4. Demonstration
5. Test

N/A - Not Applicable

VERIFICATION PHASE:
A. Development
B. Certification
C. Acceptance
D. Preflight
E. Flight
F. Postflight

Section 3.0 Performance/ Design Requirement Reference	Verification Methods							Section 4.0 Verification Requirement Reference
	N/A	A	B	C	D	E	F	
3.2.5.3 Hold, Launch and Recycle Requirements					4			4.2.5.4
3.2.5.4 SRB to ET Buildup and Mating					3/4			4.2.5.3, 4.2.5.4
3.2.5.5 Retargeting	X							
3.2.5.6 Useful Life		1/2	1/2					4.2.1.1, 4.2.1.2, 4.2.2.1, 4.2.2.2
3.2.5.7 Recovery and Refurbishment		1	1	3			3/4	4.2.1.1, 4.2.2.1, 4.2.3.3, 4.2.7
3.2.6 Safety		2	2					4.2.1.2, 4.2.2.2
3.2.6.1 Flight Safety		2	2					4.2.1.2, 4.2.2.2
3.2.6.2 Ground Safety		2	2					4.2.1.2, 4.2.2.2
3.2.6.3 Personnel Safety		2	2					4.2.1.2, 4.2.2.2
3.2.6.4 Explosive and/or Ordnance Safety		5	5					4.2.1.5, 4.2.2.5
3.2.6.5 Debris Prevention		2	2					4.2.1.2, 4.2.2.2

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REQUIREMENTS FOR VERIFICATION

VERIFICATION METHOD:
1. Similarity
2. Analysis
3. Inspection
4. Demonstration
5. Test

N/A - Not Applicable

VERIFICATION PHASE:
A. Development
B. Certification
C. Acceptance
D. Preflight
E. Flight
F. Postflight

Section 3.0 Performance/ Design Requirement Reference	Verification Methods							Section 4.0 Verification Requirement Reference
	N/A	A	B	C	D	E	F	
3.2.7 Environment	X							
3.2.7.1 Natural Environment		2	2					4.2.1.2, 4.2.2.2
3.2.7.2 Induced Environment								
Thermal								
Base heating, launch/ascent, re-entry		2	2					4.2.1.2, 4.2.2.2
Interface		2/5	2/5					4.2.1.2, 4.2.1.5, 4.2.2.2, 4.2.2.5
Loads								
Structural		2	2					4.2.1.2, 4.2.2.2
Vibration, Acoustic, Shock		2/5	2/5					4.2.1.2, 4.2.1.5, 4.2.2.2, 4.2.2.5
3.2.8 Transportability/ Transportation		1/2	1/2		4		4	4.2.1.1, 4.2.1.2, 4.2.2.1, 4.2.2.2, 4.2.5.4, 4.2.7

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REQUIREMENTS FOR VERIFICATION

VERIFICATION METHOD:
1. Similarity
2. Analysis
3. Inspection
4. Demonstration
5. Test

N/A - Not Applicable

VERIFICATION PHASE:
A. Development
B. Certification
C. Acceptance
D. Preflight
E. Flight
F. Postflight

Section 3.0 Performance/ Design Requirement Reference	Verification Methods							Section 4.0 Verification Requirement Reference
	N/A	A	B	C	D	E	F	
3.2.9 Storage	X							
3.2.9.1 Post Acceptance Requirements		1	1	2				4.2.1.1, 4.2.2.1, 4.2.3.2
3.2.9.2 Storage/ Age Control		3	3		3			4.2.1.3, 4.2.2.3, 4.2.5.3
3.3 Design and Construction Standards	X							
3.3.1 Selection of Specifications and Standards		3	3					4.2.1.3, 4.2.2.3
3.3.1.1 Selection of Materials, Parts, and Processes		3	3					4.2.1.3, 4.2.2.3
3.3.1.2 Parts Selection	X							
3.3.1.2.1 EEE Parts		3	3					4.2.1.3, 4.2.2.3
3.3.1.2.2 Standard and Commercial Parts		3	3					4.2.1.3, 4.2.2.3

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REQUIREMENTS FOR VERIFICATION

VERIFICATION METHOD:
1. Similarity
2. Analysis
3. Inspection
4. Demonstration
5. Test

N/A - Not Applicable

VERIFICATION PHASE:
A. Development
B. Certification
C. Acceptance
D. Preflight
E. Flight
F. Postflight

Section 3.0 Performance/ Design Requirement Reference	Verification Methods							Section 4.0 Verification Requirement Reference
	N/A	A	B	C	D	E	F	
3.3.1.2.3 Instrumentation Selection		3	3					4.2.1.3, 4.2.2.3
3.3.1.3 - 3.3.1.3.6 Drawing Standards		3	3					4.2.1.3, 4.2.2.3
3.3.1.4 Units	X							
3.3.1.5 Traceability		3	3	3	3			4.2.1.3, 4.2.2.3, 4.2.3.3, 4.2.5.3
3.3.2 General	X							
3.3.2.1 NASA/JSC Standards		3	3					4.2.1.3, 4.2.2.3
3.3.3 Aeronautical	X							
3.3.4 Civil	X							
3.3.5 Electrical	X							
3.3.5.1 Electromagnetic Interference		1/3	1/3					4.2.1.1, 4.2.1.3, 4.2.2.1, 4.2.2.3
3.3.5.2 Electrical Bonding		3	3		3			4.2.1.3, 4.2.2.3, 4.2.5.3
3.3.5.3 Soldering		3	3					4.2.1.3, 4.2.2.3

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REQUIREMENTS FOR VERIFICATION

VERIFICATION METHOD:
1. Similarity
2. Analysis
3. Inspection
4. Demonstration
5. Test

N/A - Not Applicable

VERIFICATION PHASE:
A. Development
B. Certification
C. Acceptance
D. Preflight
E. Flight
F. Postflight

Section 3.0 Performance/ Design Requirement Reference	Verification Methods							Section 4.0 Verification Requirement Reference
	N/A	A	B	C	D	E	F	
3.3.5.4 Circuit Boards		3	3					4.2.1.3, 4.2.2.3
3.3.5.5 Static Electricity & Lightning Protection		2/5	2/5		3			4.2.1.2, 4.2.1.5, 4.2.2.2, 4.2.2.5, 4.2.5.3
3.3.5.6 Harnesses and Cables		3	3		3			4.2.1.3, 4.2.2.3, 4.2.5.3
3.3.6 Mechanical	X							
3.3.6.1 Design Safety Factors	X							
3.3.6.1.1 General Safety Factors		1/2	1/2					4.2.1.1, 4.2.1.2, 4.2.2.1, 4.2.2.2
3.3.6.1.2 Safety Factors For Pressures		1/2	1/2					4.2.1.1, 4.2.1.2, 4.2.2.1, 4.2.2.2
3.3.6.1.3 Internal Insulation	X							
3.3.6.1.3.1 Case Insulation		1/2 /3	1/2 /3				2/3	4.2.1.1, 4.2.1.2, 4.2.1.3, 4.2.2.1, 4.2.2.2, 4.2.2.3, 4.2.7

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REQUIREMENTS FOR VERIFICATION

VERIFICATION METHOD:
1. Similarity
2. Analysis
3. Inspection
4. Demonstration
5. Test

N/A - Not Applicable

VERIFICATION PHASE:
A. Development
B. Certification
C. Acceptance
D. Preflight
E. Flight
F. Postflight

Section 3.0 Performance/ Design Requirement Reference	Verification Methods							Section 4.0 Verification Requirement Reference
	N/A	A	B	C	D	E	F	
3.3.6.1.3.2 Joint Insulation		1/2/3	1/2/3				2/3	4.2.1.1, 4.2.1.2, 4.2.1.3, 4.2.2.1, 4.2.2.2, 4.2.2.3, 4.2.7
3.3.6.1.3.3 Materials		1/2/3	1/2/3				2/3	4.2.1.1, 4.2.1.2, 4.2.1.3, 4.2.2.1, 4.2.2.2, 4.2.2.3, 4.2.7
3.3.6.1.3.4 Inhibitors		2/3	2/3				2/3	4.2.1.2, 4.2.1.3, 4.2.2.2, 4.2.2.3, 4.2.7
3.3.6.1.3.5 Insulation Performance		2/3	2/3				2/3	4.2.1.2, 4.2.1.3, 4.2.2.2, 4.2.2.3, 4.2.7
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3.3.6.1.6 Nozzle Safety Factors		1/2	1/2				3	4.2.1.1, 4.2.1.2, 4.2.2.1, 4.2.2.2, 4.2.7

TABLE V

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REQUIREMENTS FOR VERIFICATION

VERIFICATION METHOD:
1. Similarity
2. Analysis
3. Inspection
4. Demonstration
5. Test

N/A - Not Applicable

VERIFICATION PHASE:
A. Development
B. Certification
C. Acceptance
D. Preflight
E. Flight
F. Postflight

Section 3.0 Performance/ Design Requirement Reference	Verification Methods N/A	A	B	C	D	E	F	Section 4.0 Verification Requirement Reference
3.3.6.2 Allowable Mechanical Properties		1/2	1/2					4.2.1.1, 4.2.1.2, 4.2.2.1, 4.2.2.2
3.3.6.3 Ultimate Combined Loads		1/2	1/2					4.2.1.1, 4.2.1.2, 4.2.2.1, 4.2.2.2
3.3.6.4 Proof Pressure Factors		1/2	1/2					4.2.1.1, 4.2.1.2, 4.2.2.1, 4.2.2.2
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3.3.7 Nuclear	X							

TABLE V

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REQUIREMENTS FOR VERIFICATION

VERIFICATION METHOD:
1. Similarity
2. Analysis
3. Inspection
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5. Test

N/A - Not Applicable

VERIFICATION PHASE:
A. Development
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F. Postflight

Section 3.0 Performance/ Design Requirement Reference	Verification Methods							Section 4.0 Verification Requirement Reference
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3.3.13 Workmanship		3	3					4.2.1.3, 4.2.2.3

TABLE V

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REQUIREMENTS FOR VERIFICATION

VERIFICATION METHOD:
1. Similarity
2. Analysis
3. Inspection
4. Demonstration
5. Test

N/A - Not Applicable

VERIFICATION PHASE:
A. Development
B. Certification
C. Acceptance
D. Preflight
E. Flight
F. Postflight

Section 3.0 Performance/ Design Requirement Reference	Verification Methods							Section 4.0 Verification Requirement Reference
	N/A	A	B	C	D	E	F	
3.3.14 Human Performance/Human Engineering		3	3					4.2.1.3, 4.2.2.3
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3.5 Personnel and Training		3	3					4.2.1.3, 4.2.2.3
3.6 Interface Requirements	X							
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3.6.2 Intraprogram		3	3		3/4			4.2.1.3, 4.2.2.3, 4.2.5.3, 4.2.5.4
3.6.3 Intraproject	X							

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APPENDIX B. COMPOSITE MOTOR CASE

B.1 INTRODUCTION

This section presents the design concepts for the Block II SRM case using high–performance, fiber-reinforced composite materials. Fiber-reinforced composite pressure vessels are significantly lighter than their all metal counterparts. This makes them particularly attractive for rocket motor case design because large payload improvements are possible. Trade studies were conducted with the following considerations: (1) meet the composite case design requirements per CPW1-3400 specification, (2) enhance reliability, (3) reduce cost, and (4) increase performance. The design concepts presented build upon the foundation established by the filament wound case (FWC) development program. Simplified design concepts have been developed to correct problems encountered with the FWC design, and take full advantage of "lessons learned."

B.2 SUMMARY AND CONCLUSIONS

This study has found that composite motor cases offer significant performance improvements over the HPM steel case design. Payload increases in excess of 10,000 lb can be achieved with segmented composite cases which are less complex and more reliable than the current FWC design.

Composite motor cases have two major disadvantages: (1) the high cost compared to steel and (2) the reliability has not been demonstrated in a flight program. Reuse and refurbishment are required to make composite cases cost competitive with steel cases. Initial studies indicate that reuse is technically feasible, but a significant development program is required to develop insulator removal techniques and to prove that a used case is structurally sound. Issues surrounding the composite case susceptibility to impact damage must be resolved. Microencapsulated indicators could resolve the issue of hidden impact damage.

The major findings of the Block II composite material trade study are summarized below:

1. Use of high-strength, high-modulus carbon fibers such as Amoco's T-40 could result in a 10,000 lb payload increase over the HPM segmented case design.

2. The current axial growth requirement drives the case design resulting in 25 percent increased membrane weight. A single shock absorber at the forward ET attach could allow an optimum pressure vessel design, resulting in substantial savings in inert weight.

3. A composite/steel hybrid design has many attractive features, but would also require a shock absorber at the forward ET attach to handle a 6-in. axial growth.

4. New simplified designs have the potential of solving FWC development problems while lowering cost and increasing reliability.

5. Prepreg materials could potentially solve delamination and quality problems associated with the wet-wind process used for FWC. The low variation of the prepreg materials increases the case reliability, and prepreg should be cost competitive when purchased in high volume.

6. Simple innovative joint concepts have been developed which eliminate rotation of the seal, eliminate eccentric loading, and are lighter and lower cost than the FWC joints.

7. A two-step insulation process could enhance the reliability of the insulation seal, but at a significant cost increase.

8. Reuse could reduce case acquisition costs by a factor of seven, but technology development and demonstration are required. (NASA/Langley coupon data indicate impact damage that is not visible can cause 30 percent reduction in case membrane strength. A full-scale test is planned in FY 87 to resolve FWC impact issues.)

9. Composite cases are inherently as reliable as metal cases, but the reliability has not been demonstrated in a flight test program.

The development of reliable, high-performance composite cases is possible. Composite case reliability can be quantified by calculating the probability of events leading to a failure. Structural tests, static firings, analysis, NDT, acceptance tests, and quality control are employed to enhance reliability. However, almost every failure of a new design is caused by an "unknown" factor, i.e., the forward joint failure of the first FWC test article (TFS1), and the compressive transition/joint failure of STA-2A. Thus, a new design may be 99.9

percent reliable in theory, and fail during the test because of an unknown factor. New designs are less reliable than existing designs, simply because they do not have **demonstrated** reliability. Static test programs which simulate worst-on-worst flight conditions are necessary to develop confidence, and a statistically significant database to demonstrate reliability.

In conclusion, all existing data indicate that a reusable, reliable composite case is technically achievable, but a comprehensive large development and demonstration program is required.

B.3 STUDY OBJECTIVES AND APPROACH

The primary objective of this study is to develop composite case designs with enhanced reliability; secondary objectives are to optimize cost per pound of payload to orbit and to improve performance. Specific objectives are to develop simplified design concepts which eliminate design deficiencies of the FWC (cut helicals for example), and to identify materials and processes which could resolve FWC laminate delamination problems.

The overall approach is to conduct material and design trade studies and identify those candidates which best meet the objectives. Because the FWC has strict axial growth and axial stiffness requirements, only high modulus carbon fiber material systems need to be considered. Lower cost materials such as S-2 glass and Kevlar can only be considered in hybrid carbon fiber applications. Classical Laminated Plate theory was extensively used to determine the optimum ply orientation needed to simultaneously meet strength, growth, and stiffness requirements. Finite element modeling techniques were used to evaluate joint seal rotation for selected design concepts.

The baseline case design requirements are presented in Table B-1. The axial growth requirement drives the case design and weight. The growth and stiffness requirements are almost exclusive: low helical wrap angles are required for high stiffness, and high helical wrap angles are needed for low axial growth. The result is a laminate which is not optimized for strength or stiffness; the axial growth requirement adds over 25 percent to the membrane weight.

Trade studies were conducted for designs with high axial growth in order to significantly increase performance. These design concepts would require development of a shock absorber at the forward ET attach point to preclude overloading the external tank and payloads.

Table B-1. Block II SRM Composite Case Design Requirements

Axial Growth*	0.72 in.
Radial Growth	0.66 in. (forward segment only)
Axial Stiffness	2.63×10^6 lb/in. (spring constant)
Pressure	1,004 psi (1,100 psi for heads-up)
Thrust	3.35×10^6 (3.7×10^6 lb for heads-up)
Joint Line Load	37,500 lb/in.
Compression Load	27,200 lb/in.
Factor of Safety	1.4
Reuse	Metal parts 19 reuses

*Current axial growth requirement is conservative relative to 0.91-inch projected +3 sigma value for the steel SRM.

B.3.1 DESIGN REQUIREMENTS

The Block II SRM composite case is designed to be compliant with CPW1-3400. Each composite segment design is optimized in three regions: the membrane region, the joint region, and the transition region between the membrane and the joint region. The membrane region is optimized to meet strength, axial growth, radial growth, and axial stiffness requirements listed in Table B-1. The joint region design is optimized to balance net tension, shear out, and bearing failure modes with the axial loading defined in Table B-1.

The seals connecting the composite case segments use the following design guidelines:

- O-rings must have 15 percent minimum squeeze when assembled and at least 10 percent squeeze when compression set is considered.
- O-rings must have at least 0.002-in. clearance to prohibit contact with both side walls.

- Seal must maintain contact with the gland even at twice the expected displacement or twice the expected displacement rate.
- Seals must meet requirements for a temperature range of 20° to 120°F.
- Seals must not be damaged during joint assembly.
- Seals must be verified after assembly by a leak check.
- Seal performance must not be jeopardized by the joint corrosion prevention system or the seal lubricant.

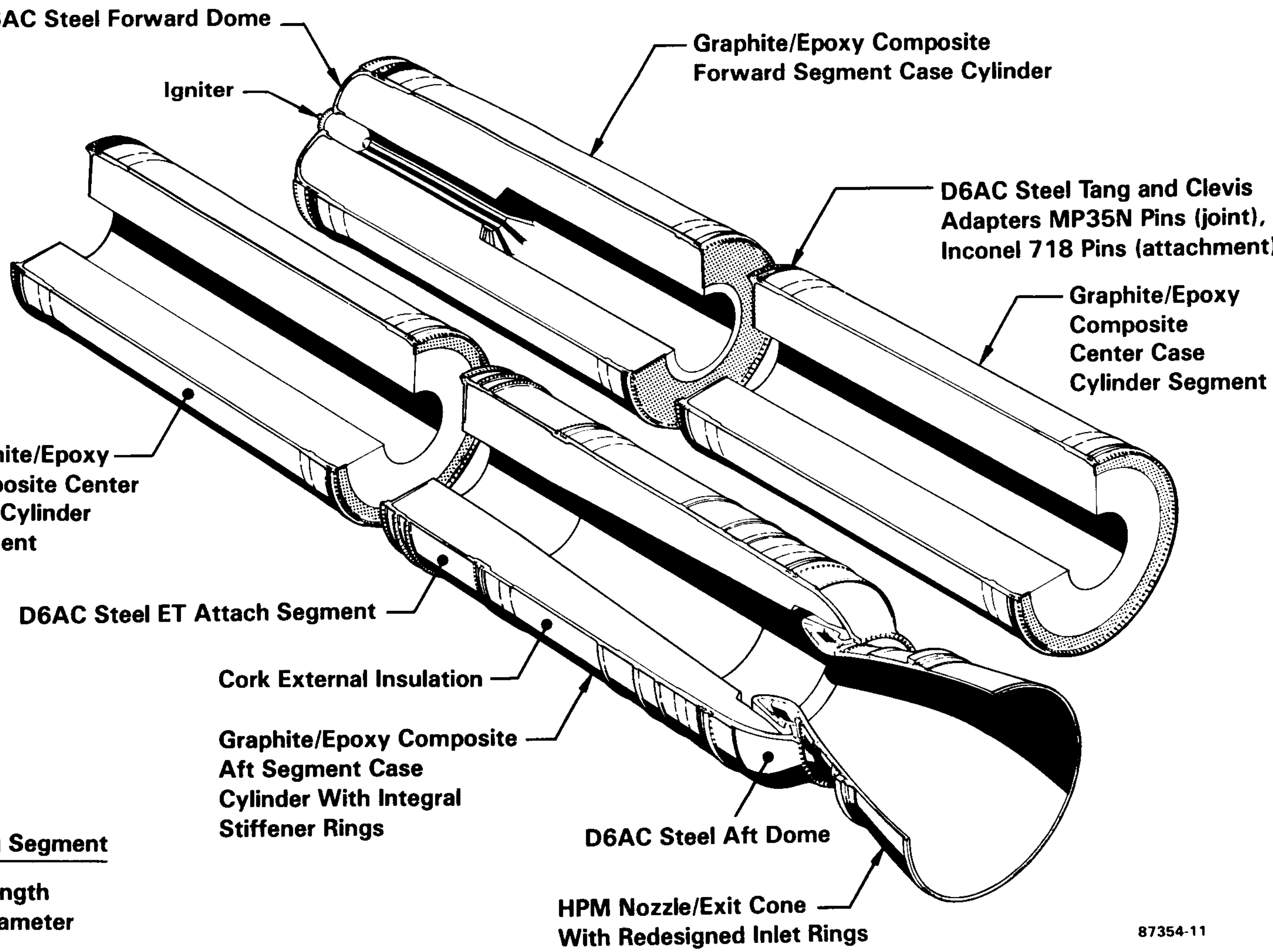
B.3.2 HEADS-UP MISSION DESIGN REQUIREMENTS

The concept of launching the Space Shuttle in an orbiter up position is being studied by NASA and Rockwell. The current launch mode has the orbiter on the underside of the external tank during ascent. The heads-up concept would decrease orbiter loads and increase the payload to orbit. The optimum SRM performance in this heads-up mode would require a 0.392 in./sec burn rate at 625 psia and 60°F (10 percent higher MEOP). Analysis predicts a 3,500-lb payload increase over the baseline case design (see Reference B-2). The motor cases for the Block II are evaluated for heads-up flight at 1,100 psig with a thrust of 3.7 x 10^6 lbf.

A detailed analysis was conducted to assess design changes required to upgrade the FWC for the 10 percent higher MEOP required for the heads-up mission. This study found that composite cases are readily adaptable to design changes, and simple addition of two hoop plies would allow the composite cases to maintain a 1.4 factor of safety. Results of this study, including an assessment of the metal part margins, are presented in References B-1 and B-2.

B.3.3 FWC DESIGN DESCRIPTION

When considering improved design concepts for Block II, experience with the Space Shuttle FWC-SRM provides a valuable baseline. As shown in Figure B-1, the 146-in.-diameter FWC-SRM consists of seven major structural components: two steel domes, a steel ET attach segment, and four graphite/epoxy composite segments. The composite segments are fabricated by wet filament winding Hercules AS-4



Each Casting Segment

- 26.6-ft Length
- 12.1-ft Diameter

Figure B-1. FWC-SRM Configuration

graphite fibers and HBRF-55A epoxy resin. In addition, the joint regions have AS-4 unidirectional broadgoods preimpregnated with 3501 epoxy resin. The composite segments are joined with pinned steel tang and clevis adapter rings (Figure B-2). Each composite segment is divided into three regions: the membrane region, the joint region, and the transition region between the membrane and joint regions. The membrane region laminate, designed to meet strength, axial growth, radial growth, and axial stiffness requirements (Table B-1), consists of $\pm$ 33.5-deg helical layers (1-in.-thick) interspersed with 90-deg hoop layers (0.32-in. thick). The joint region, designed for net tension and shear-out strength, consists of helical and hoop layers interspersed with 0-deg broadgood layers. In the transition region, three helical layers from the membrane are terminated (called "cut helicals"), and 48 0-deg broadgood layers are added for the joint.

The FWC joint design is shown in Figure B-2. A simple tang and clevis adapter configuration was selected for all FWC joints. The baseline FWC joint was designed to be compatible with the existing SRM steel components; thus, the interfaces with the SRM components are geometrically fixed. As a result, the joint must have a radial offset to allow for the thicker composite shell. Pin connections were chosen joints, and blind holes were used for all pinholes.

Throughout the FWC development program, many design and process problems were encountered, all of which were successfully resolved. However, several non-optimum design features remain which should be eliminated in a new Block II composite case design, such as:

a. During the evolution of the FWC design, three helical ply terminations (cut helicals) were required to simultaneously meet joint thickness and strength-plus-membrane axial growth requirements. These cut helicals are difficult to fabricate, difficult to analyze, and impose high discontinuity stresses. A delamination associated with the cut helicals ultimately led to the premature failure of the FWC structural test article STA-2. Cut helicals should be eliminated in the new case design.

b. The 0-deg broadgood reinforcements terminate in the transition region in such a manner as to impose high stress concentrations. The resulting low compression strength was a major contributor to the failure of STA-2. A new case design should taper the ply terminations to reduce the stress concentrations and increase compressive strength.

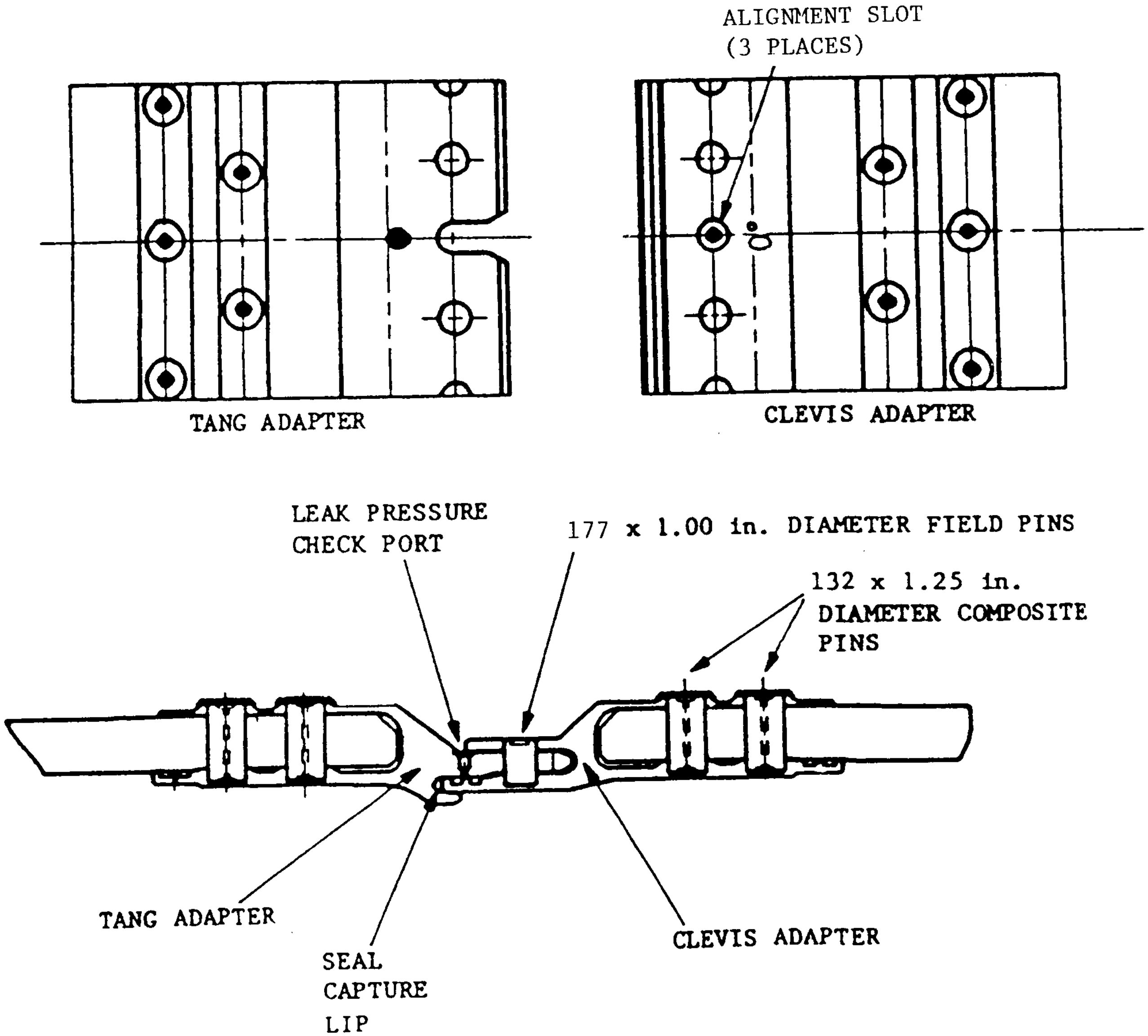


Figure B-2. Seal Capture Lip

c. The FWC was designed with an eccentrically loaded joint to meet interface requirements of existing metal hardware. The eccentric load results in non-optimum joint strength and imposes a three-dimensional stress state which is very difficult to analyze. The eccentric load path also causes the joint seal to rotate, resulting in a gap opening at the primary O-ring. A new case design should minimize load eccentricity and eliminate seal rotation.

d. The FWC development program was plagued with delaminations caused by the short out-life, wet-wind resin, poor resin content control, and other factors (Section B.7). A new Block II case should incorporate a new materials system to eliminate delaminations.

e. The existing FWC field joint seal design will not meet the requirements presented in Section B.3.1. The hardware design needs to be modified to reduce joint gap opening and increase O-ring squeeze.

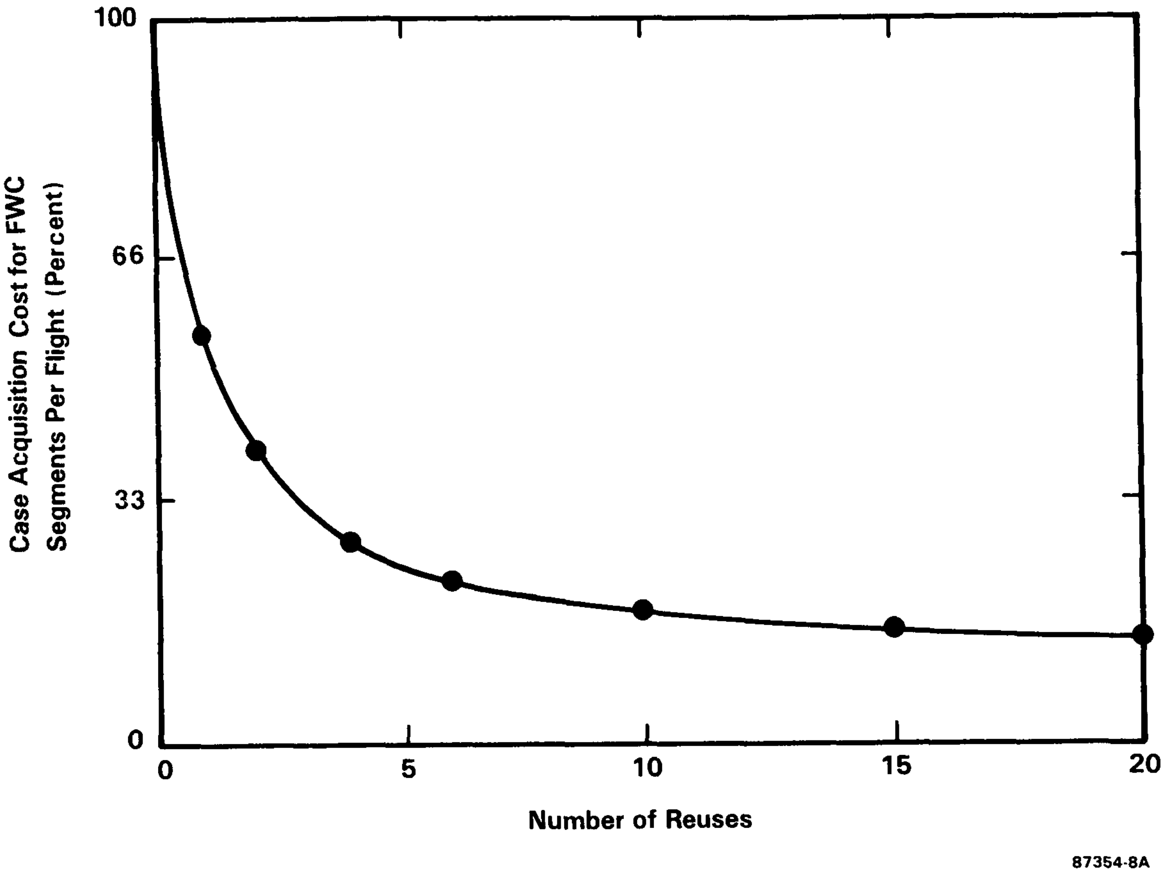
f. The FWC design incorporated O-ring seals between the metal adapter rings and composite case (Figure B-2). Manufacture of a defect-free seal surface on the composite case was very labor intensive and costly. This particular design feature did little to enhance the reliability of the case and should be eliminated.

B.3.4 COMPOSITE CASE REUSE

Development of case reuse capability is essential for the cost-effective use of composite case SRMs. Reuse as shown in Figure B-3 can reduce case acquisition costs by a factor of seven.

Initial studies indicate that case reuse is feasible. Subscale and full scale data show no case strength degradation over multiple pressure, temperature, and salt water exposure cycles. Adapter ring redrilling operation has shown the flexibility of ring reuse, and moderate success has been achieved in hydrolasing rubber from inside FWC segments with no composite damage.

The major concerns on composite case reuse center on critical damage detection and evaluation. NDT techniques are needed to detect internal, non-visible damage to the composite inflicted by impacts. Extensive work on low-velocity impacts (Ref. B-4) has shown extensive internal damage may occur with nonvisible external indications. Current methods rely on hydroproof tests and acoustic emission response to detect structural damage. Ultrasonic inspection techniques detect delamination and flaw growth. An NDT technique has yet to be demonstrated that can detect and assess visible and nonvisible damage. Once the damage issue is resolved, case reuse can be reliable and cost effective.



$$\text{*Cost/Flight} = \frac{\text{Acquisition Cost} + \text{Refurb Cost (N)}}{N+1}$$

Where N = Number of Reuses

Figure B-3. Case Acquisition Cost Versus Number of Reuses*

An extensive damage tolerance investigation program is planned for FWC in FY 1987. This program will include impact tests on subscale laminates, quarter-scale bottles, and a full-scale Damage Tolerance Test Article. This program should answer all open questions concerning the susceptibility of large composite motor cases to low-level impact damage.

Because nonvisible damage is a major concern, an outer coating will be needed to witness the impact event. Work is currently in progress at Southwest Research Institute on coatings with microcapsule indicators which burst and release a dye at a selected impact energy (Reference B-5). This type of coating could indicate the impact event location and energy level.

B.4 BLOCK II SRM COMPOSITE CASE DESIGN

The preferred Block II SRM composite case design is presented in Figure B-4. The design concept is built upon the foundation established by the FWC development program, and incorporates features which eliminate several design weaknesses. The 146-in.-diameter composite motor consists of seven major structural components: two steel domes, a steel ET attach segment, and four graphite/epoxy composite segments. The metal parts are fabricated from high-strength T250 steel. The composite segments are fabricated from T-40 carbon fibers preimpregnated with ERL 1908 epoxy resin. The design uses a simplified double-strap joint concept, and incorporates yokes to mate with the composite on the domes and ET attach segments. The current steel case weighs about 98,000 lb, while the existing FWC weighs about 70,000 lb. It is estimated that the Block II composite case would weigh 52,000 lb.

B.4.1 COMPOSITE CONFIGURATION AND LAYUP

The composite case design was divided into three regions for each segment in order to achieve the design requirements with a minimum weight configuration. The three regions are the joint region, the membrane region, and the transition region from the joint region to the membrane (Figure B-5). Each segment (forward, center, aft) was designed to its respective MEOP to gain further weight savings.

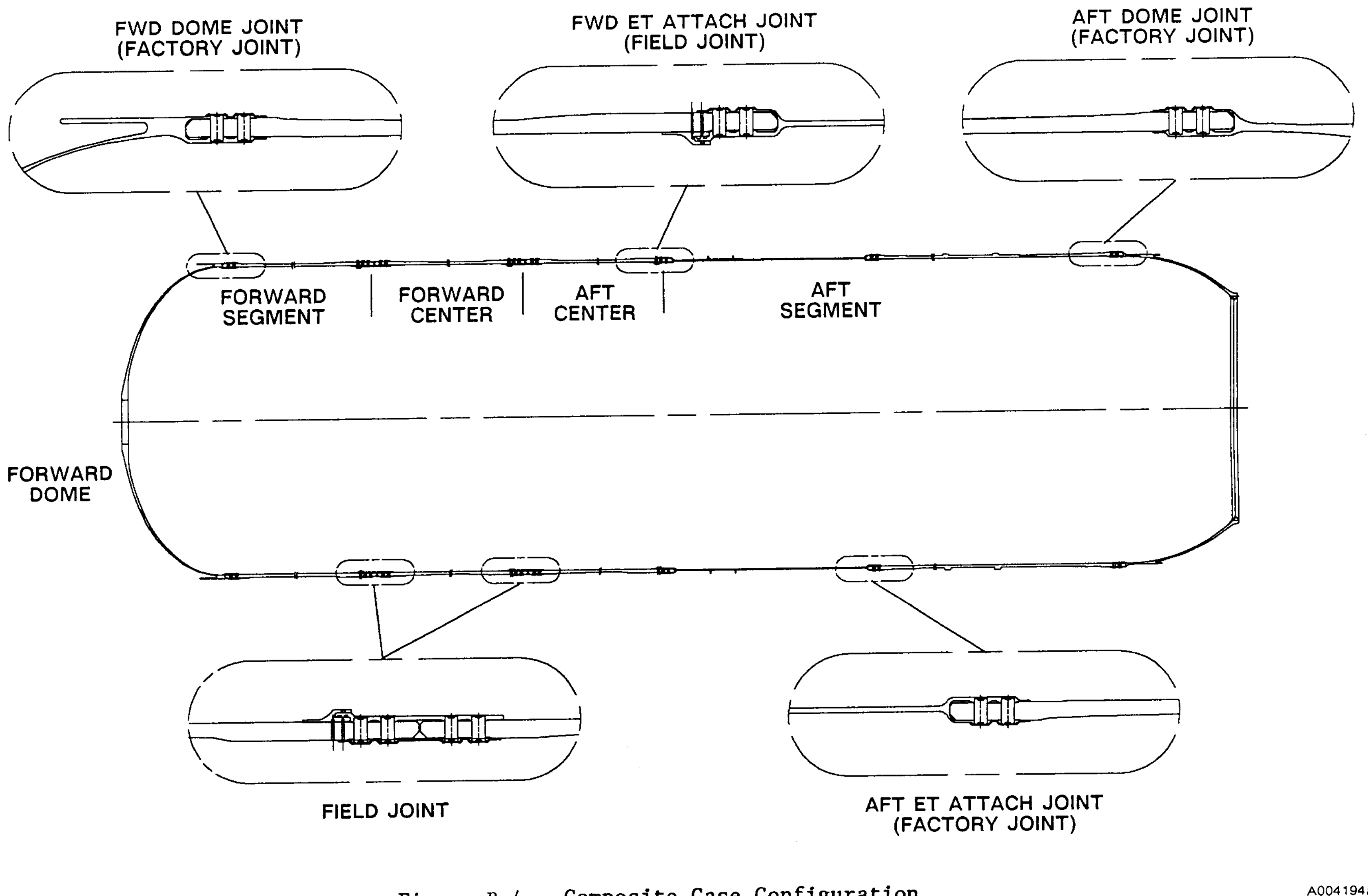
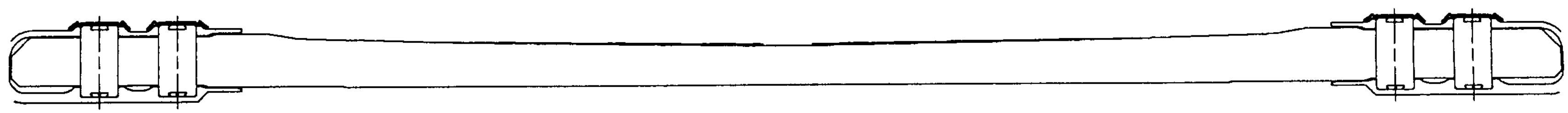


Figure B-4. Composite Case Configuration



THICKNESS (INCHES)	BASELINE FWC(AS-4)	BLOCK II(T-40)
JOINT		
0 DEG BROADGOODS	0.64	0.50
90 DEG HOOPS	0.28	0.216
33.5 DEG HELICALS	0.70	0.703
TRANSITION	48 PLIES ADDED IN STEPS 3 PLIES TERMINATED IN STEPS	38 PLIES ADDED IN STEPS
0 DEG BROADGOODS		0.00
33.5 DEG CUT HELICALS		0.415
90 DEG HOOPS	0.28	
33.5 HELICALS	0.70	0.703
MEMBRANE		
33.5 DEG CUT HELICALS	0.30	0.00
90 DEG HOOPS	0.32	0.216
33.5 DEG HELICALS	0.70	0.703
MOTOR WEIGHT(LBS)	69,000	52,000
DELTA PAYLOAD(LBS)	4600	12,000

*HEADS UP ±1100 PSIG

Figure B-5. **FWC Composite Segment Construction**

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The membrane design is optimized to meet the axial growth, axial stiffness, radial growth, and pressure strength requirements. The choice of T-40 fiber/1908 prepreg is based on trade studies presented in Section B.7. This material system results in a 30 percent reduction in case membrane weight, and eliminates delamination problems associated with the FWC wet-wind system. The optimum helical angle is ± 30 deg.

The joint laminate design is similar to the FWC design, except that the 0-deg reinforcements are uniformly dispersed to reduce stress concentrations. The FWC joint had a mixture of 3501 prepreg and HBRF-55A wet-wind resin systems. The Block II design uses a single-resin system throughout, reducing the delamination potential.

The joint design is optimized to carry the design loads without bearing, net tension, or shear-out failure.

The transition region is significantly improved over the FWC design. The cut helicals are eliminated, and the 0-deg ply terminations are tapered to reduce discontinuity stresses. the design also includes hoop plies dispersed through the laminate which results in a joint with zero rotation (Section B.4.2).

B.4.2 COMPOSITE JOINT AND SEAL DESIGN

Based on trade studies presented in Section B.6, a double steel strap concept (Figure B.6) is used as the joint on the segmented composite case. This joint consists of two steel straps, one located on the case inside diameter and the other on the outside diameter. A two-row pin pattern was selected for the composite-to-ring interfaces. The two rows are staggered with each row having 132 equally spaced pins. The joint sealing mechanism consists of three O-rings. Two are placed on the clevis end and one is located in the capture feature. The capture feature limits the movement of the clevis O-rings while the capture feature seal closes as a function of pressure. The double strap joint does not impose the stiff metal-to-metal interfaces associated with a typical tang clevis joint. With this joint flexibility plus high transition hoop stiffness, joint

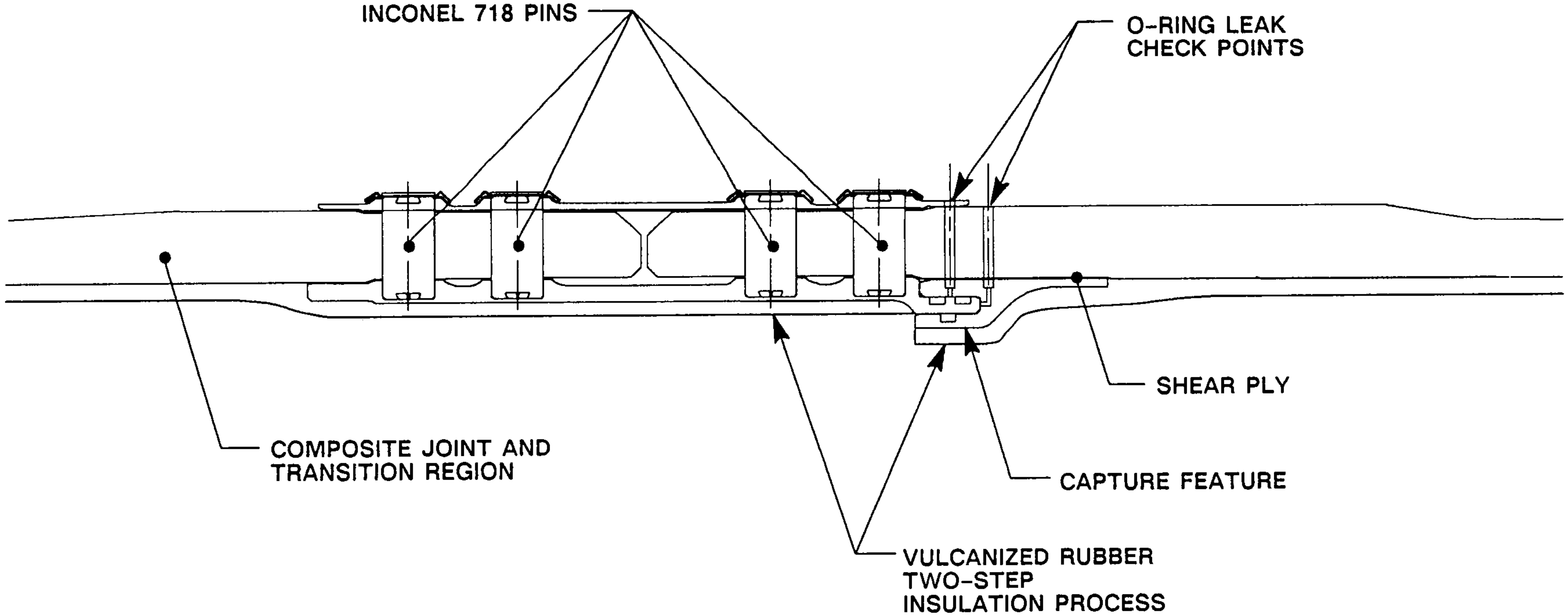

Figure B-6. Composite Case Field Joint

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rotation is eliminated. Development testing on a 92-in.-diameter segmented composite case (Figure B.7) showed zero joint rotation with a 36,830-lb/in. line load. A comparison between a typical FWC type tang and clevis joint and a double steep strap is presented in Section B.6.

The fundamental seal design is identical to that used for the redesigned SRM, and meets all requirements listed in Section B.3.1. There are two key differences, however: (1) the joint tends to close, not open, and (2) the seal is away from the primary load path which reduces the axial motion and seal distortion.

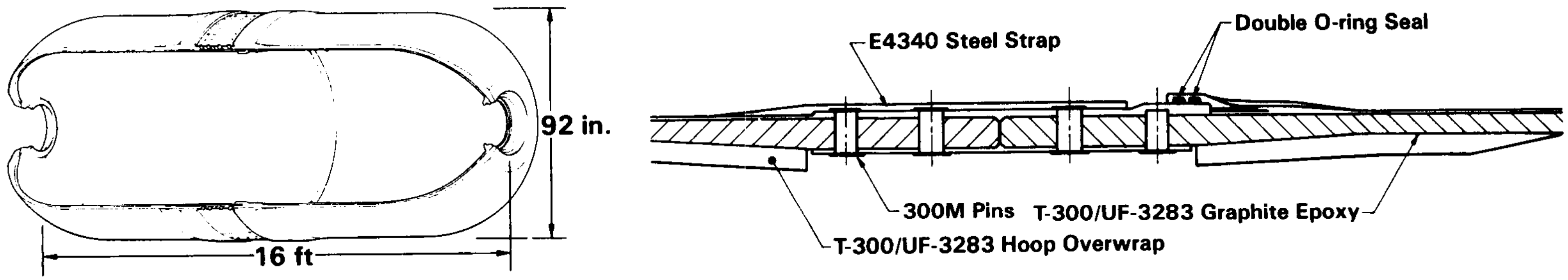
The baseline FWC design has O-rings between the metal adapter rings and composite case. This design is labor intensive, and does little to enhance the composite case seal reliability. A better concept, shown in Figure B.6, is to use a two-step insulation process. A thin bladder could be vulcanized to the case. The case would be hydroproofed, verifying the seal integrity. Next, a standard insulator would be vulcanized over the bladder. This concept would assure that insulation erosion during motor burn would not reveal an unknown leak path or "worm hole."

B.4.3 BLOCK II COMPOSITE CASE ANALYSIS RESULTS

A 2-D finite element model of the Block II composite redesign joint was constructed using ANSYS Revision 4.2. The modeling technique was the same as that used for the SRM capture feature analysis addressed in Reference B-6. The model consists of an axisymmetric composite tang with membrane, steel joint ring, capture feature, plane stress pins, and gap friction interfaces. The model is based on minimum geometry and uses geometric parameters so as to easily modify the joint, when necessary. Only half of the joint was modeled taking advantage of symmetry.

Figure B.8 shows the finite element grid and boundary conditions of the hybrid joint model. The model consists of axisymmetric 2-D isoparametric solid (stiff 42) elements, with the pins modeled with plane stress elements.

- Failure occurred in case membrane at 1,577 psi, demonstrating a joint line load of 36,830 pounds/inch



- Zero-rotation joint prediction confirmed by hoop strain measurements

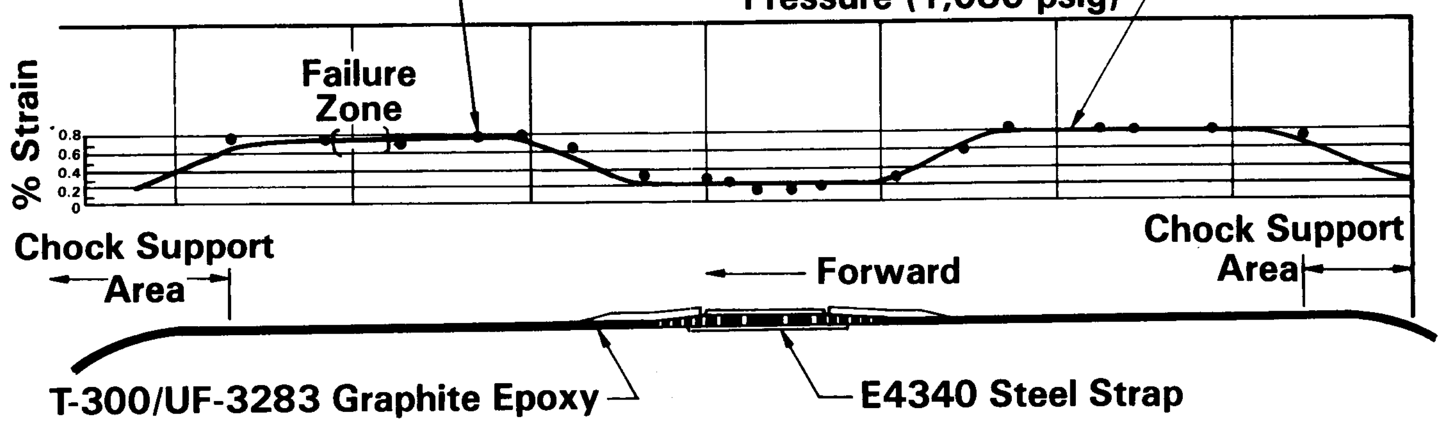


Figure B-7. Joint Concept FWC Feasibility Study

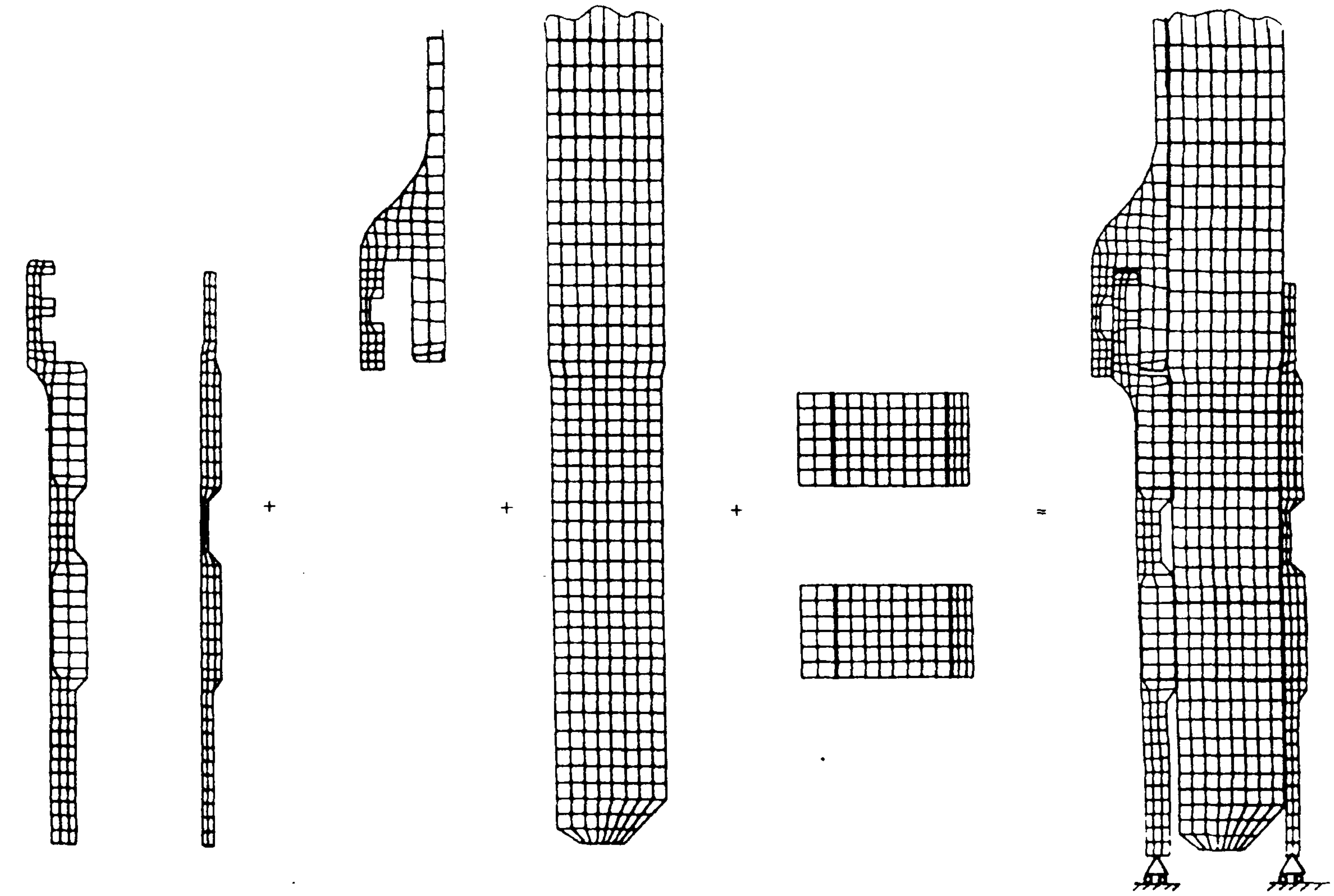


Figure B-8. Loading and Boundary Conditions

The addition of integrally wound hoop layers forward of the capture feature adds significant hoop stiffness to this joint. As a result, joint rotation is minimal and the sealing surface is allowed to close. As shown in Figure B.9, the radial displacement remains almost constant for approximately 20 in. from the lowermost point of the model. The maximum radial displacement is 0.766 in. at the outermost end of the membrane.

The maximum critical stresses of the steel rings and capture feature, along with their locations, are shown in Figure B.10. Note that the stresses within the capture feature and around the seal grooves are significantly lower than the maximum stresses. Table B-2 is a listing of key stresses, their allowables, and appropriate factors of safety.

B.4.4 BLOCK II COMPOSITE CASE DESIGN SUMMARY

The Block II composite case design has been configured to: (1) meet the design requirements per CPW1-3400, (2) enhance reliability, (3) reduce cost, and (4) increase performance. Compared to the HPM steel case design, the Block II composite case is almost 50 percent lighter. The Block II composite case uses "lessons learned" from the FWC development program:

a. Cut helical layers of FWC joint region, which led to the failure in compression of the first full-scale structural test article, are eliminated.

b. High-stress concentrations at joint reinforcement terminations are reduced by smoothing the transition region between the joint and the membrane.

c. Joint eccentricity and rotation are eliminated. This results in an optimum stress state in the pin joints and assures no opening of gap at O-ring seal.

d. A long out-of-life prepreg resin is used in order to prevent the delamination problems of FWC, which were caused by staging of the resin during the winding process and poor resin content control.

e. Double steel ring joint eliminates complex and expensive machining required for metal adapter rings.

f. A two-stage insulator design is employed to enhance the composite case seal reliability. O-rings between the metal adapter and composite case are eliminated.

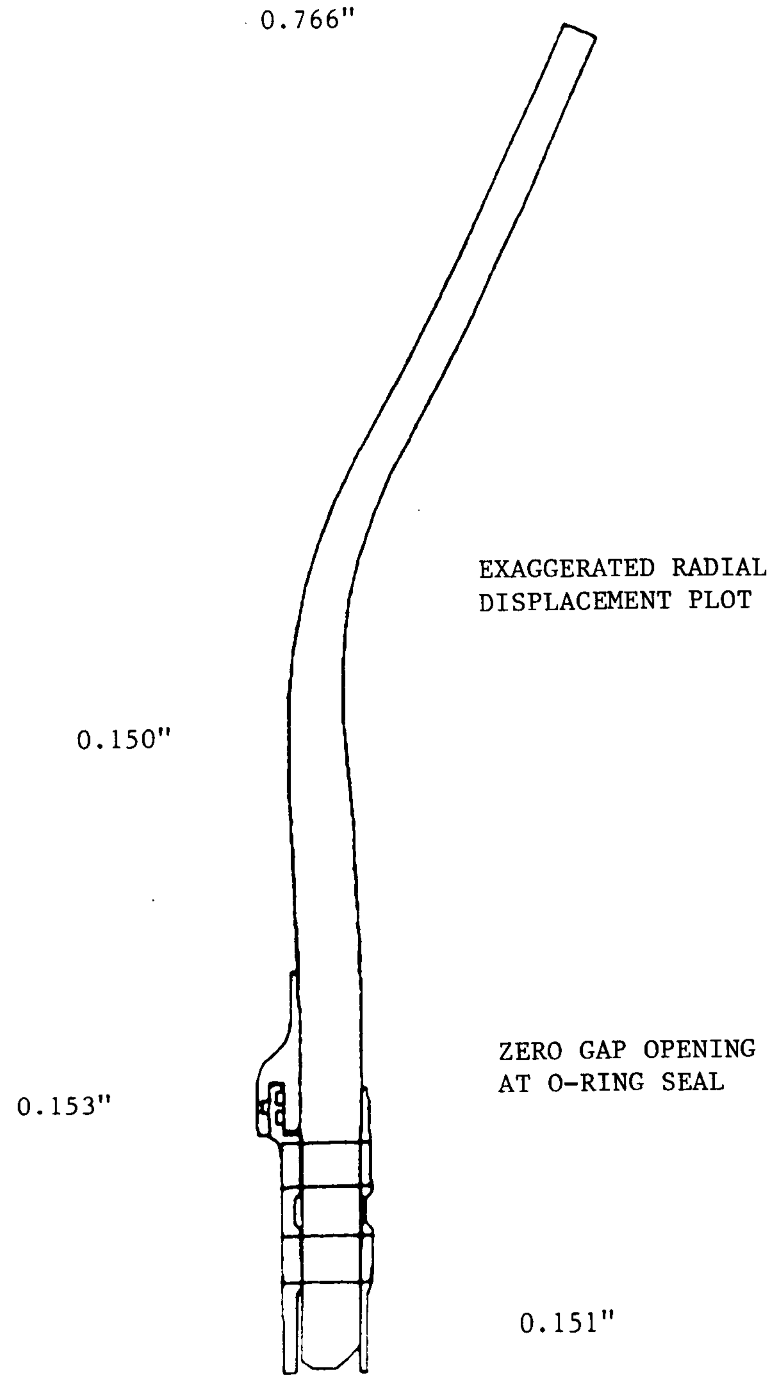


Figure B-9. Predicted Case Joint Radial Expansion

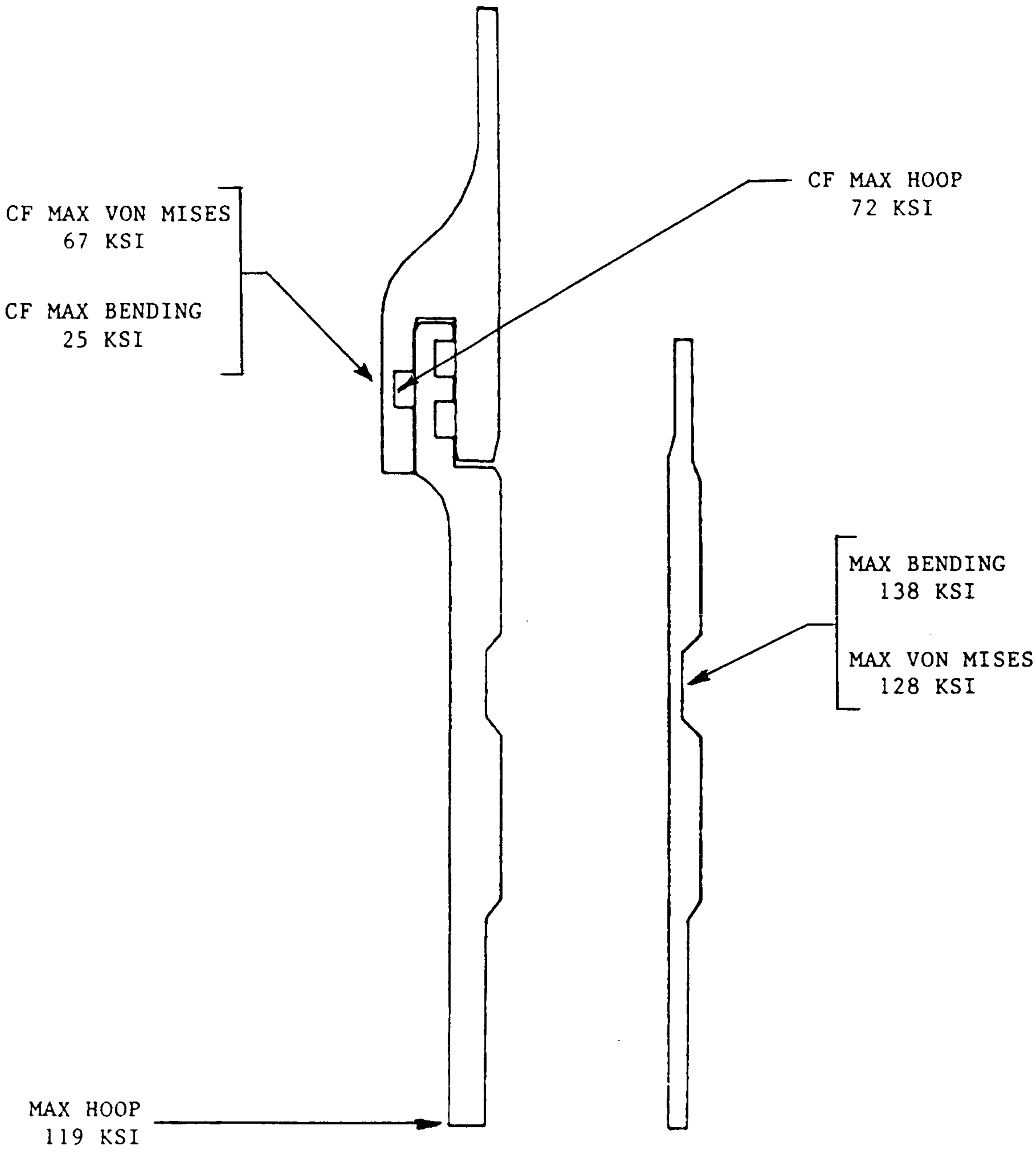


Figure B-10. Location of Maximum Critical Stresses in Metal Strap Components

Table B-2. Steel Rings and Capture Feature Critical Stress Data

STRESS	LOCATION	LIMIT KSI	ALLOWABLE (YIELD) KSI	F.S. (YIELD)	ALLOWABLE (ULTIMATE) KSI	F.S. (ULTIMATE)
BEARING	STEEL STRAP	109	357	3.28	386	3.54
AXIAL	STEEL STRAP	138	240	1.74	250	1.81
HOOP	STEEL STRAP	119	240	2.02	250	2.10
HOOP FIBER	COMPOSITE MEMBRANE	421	–	–	625	1.48

B.5 HYBRID METAL/COMPOSITE CASE

This section presents a design concept which uses a metal liner overwrapped with composite hoop plies. The metal liner is designed to serve as a gas barrier and carry the axial loads in the motor case. The hoop plies carry the hoop loads, and eliminate the O-ring seal joint rotation. The case would weigh about 63,000 lb. This concept has large (6-in.) axial growth, and would require modification of the forward ET attach point.

B.5.1 DESIGN DESCRIPTION

For a metal-lined composite motor case the joints are an integral part of the 0.225-in.-thick seamless T-250 steel forging (Figure B.11). The joints consist of a simple tang and clevis with pinned connections. The metal joint uses the three O-ring capture feature concept. The design would provide for an interference fit with the two clevis O-rings, which reduces the rotation of the clevis O-rings. All joint rotation is eliminated by a hoop-stiffened region close to the joint. This hoop overwrap region alters the shell deformation, thus eliminating bending in the joint. All bending is absorbed by the composite which results in a joint free from eccentric loads. With an equal load distribution through the joint, the propensity for joint rotation or opening is nonexistent. The metal shell is sized to transfer the axial loads. The 0.40-in.-thick T40/982 graphite epoxy hoop plies are sized to restrain the radial expansion and carry the hoop loads. The composite hoop sizing is determined by the allowable strain of the T-250 steel liner; hence, the composite is used primarily for its high stiffness characteristics.

Thermal strain differences between the composite and metal liner must be compensated for by either: (1) bonding the composite to the metal liner or (2) allowing the overwrap to slide relative to the liner. This would require an extensive analysis to fully understand the tractions caused by frictional and tangential sliding of the overwrap relative to the liner. A third concept considers the placement of a rubber shear ply between the composite and metal interfaces to compensate for the strain and expansion difference during both cure

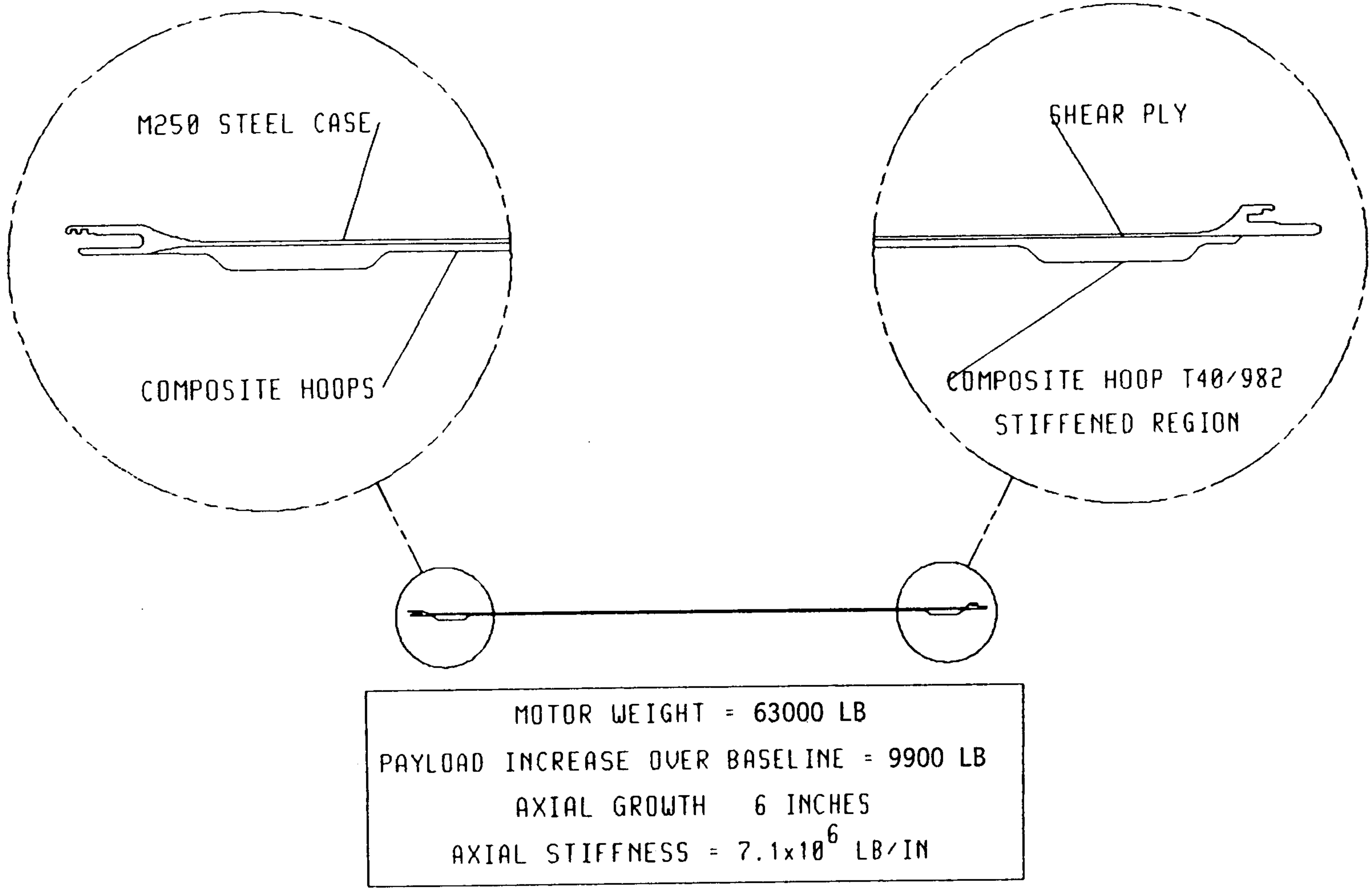


Figure B-11. Hybrid Metal/Composite Case and motor pressurization. this would also serve as a barrier to protect the case from galvanic corrosion. The use of T-250 steel would allow the design to include a welded factory joint for minimum weight.

B.5.2 HYBRID CASE STRUCTURAL ANALYSIS

The hybrid metal/composite case was analyzed with a TASS axisymmetric finite element model. The model was of sufficient fidelity to evaluate the stresses in the composite, rubber, and metal components. The case was analyzed in a closed vessel configuration with an internal pressure of 1,100 psig. The finite element model is shown in Figures B-12 and B-13.

The finite element analysis predicts maximum fiber stresses of 230 ksi in the case membrane region. Peak fiber stresses of 155 ksi are computed for the hoop-stiffened region. The allowable fiber stress for the 42-msi T-40 fiber is 625 ksi. The low fiber stress indicates the composite design is stiffness, not strength critical. The composite was sized to contain the radial expansion of the T-250 steel. The peak stresses in the metal case occur near the edge of the hoop-stiffened region. The 177 ksi stress is a result of the axial line loads plus the bending imposed due to the hoop stiffness variance in the region. Key stresses and locations are depicted on Figures B-12 and B-13.

B.5.3 AXIAL GROWTH AND STIFFNESS

The case specification limits the total motor axial growth to 0.72 in. under MEOP conditions. This axial growth requirement is imposed to limit the loads induced in the ET and orbiter. Total axial growth of the hybrid metal (composite) case is about 6 inches. This would require modification to the ET attach points to compensate for the increase in growth. A simple shock absorber at the forward ET attach would preclude overloading the ET and orbiter.

The case specification requires a minimum bending/axial stiffness of 2.63×10^6 lb/in. when expressed as an axial spring constant. This may also be expressed as average axial modulus times thickness ($E_z \cdot t$). The average axial

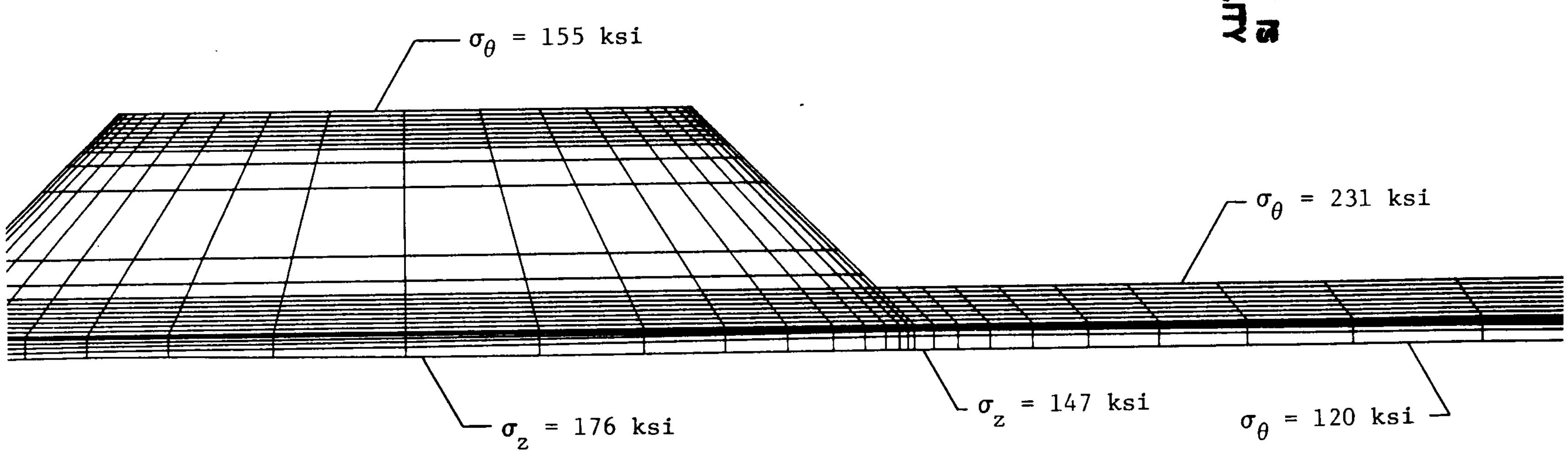


Figure B-12. TASS Finite Element Model Key Membrane Stresses

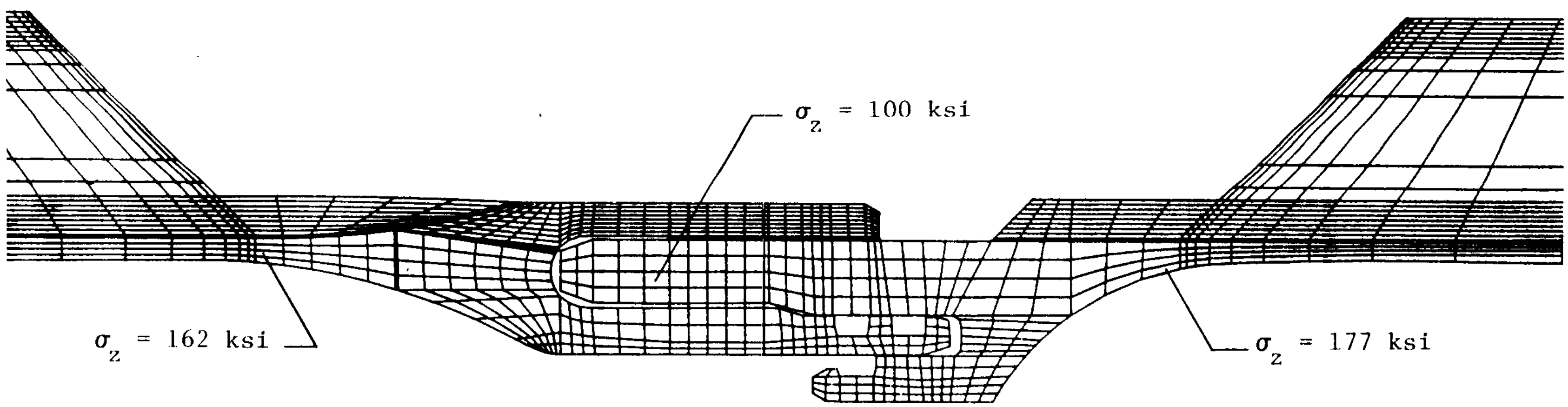


Figure B-13. TASS Finite Element Joint Model With Key Stresses modulus times thickness value of the FWC is 8.13 x 10^6 lb/in., while the axial modulus times thickness value of the hybrid case is 7.1 x 10^6 lb/inch. Further case optimization is required to show compliance to the case stiffness requirement.

B.5.4 HYBRID CASE REUSE

Reuse is essential for the cost-effective use of composite motor cases. Reuse of a composite case could reduce the acquisition costs by a factor of seven. Refurbishment of postfired filament wound cases has had limited success in the reuse of the composite shell, while rework of the metal hardware has been extremely successful.

With a metal liner, the current techniques of using a hydrolaser to remove the charred insulation could be incorporated. This would prepare the steel liner for new insulation. Postfired motor segments would go through extensive NDT evaluations; if the composite overwrap was suspect, the same hydrolaser cleaning technique could be employed to remove the existing composite and prepare the surface for new hoop plies.

B.6 JOINT TRADE STUDIES

Two joint concepts were evaluated for connecting the composite segments at the field joints. These concepts are compared in Figure B-14, and involve a simple steel strap design and a standard FWC type tang and clevis adapter design. These design concepts are discussed in detail as follows.

B.6.1 DOUBLE STEEL STRAP JOINT

A double steel strap concept is used as the baseline joint on the segmented composite case. This joint consists of two steel straps: one located on the case inside diameter and the other on the outside diameter. This concept was discussed in detail in Section B.4.2.

The joint sealing mechanism consists of three O-rings. Two are placed on the clevis end and one is located in the capture feature. The capture feature

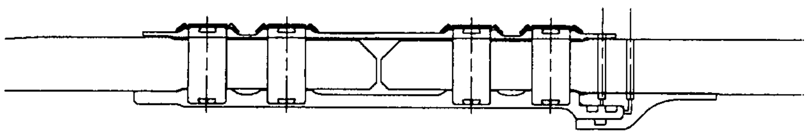
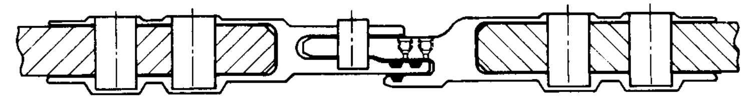
Baseline Design	FWC-Type Tang and Clevis Joint
	
• Lower weight • Less expensive (simple forgings) • 50/50 load split between rings possible due to symmetry to joint • Zero joint rotation • More adaptable to redesign • Handling adapters will eliminate damage potential to the steel rings during handling	• Higher weight (4,000 pounds per booster heavier than baseline) • More expensive (complex machining—FWC rings account for 20 percent of segment cost • Stiff metal-to-metal interface introduces rotation to joint • Limited modification flexibility—fixed clevis opening on the FWC made "cut helicals" necessary when joint was redesigned • No handling adapters required

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Figure B-14. Comparison Between Double Steel Strap and Standard FWC-Type Tang and Clevis Joint limits the movement of the clevis O-rings, while the capture feature seal closes as a function of pressure. The double strap joint does not impose the stiff metal-to-metal interfaces associated with a typical tang clevis joint. with this joint flexibility, joint rotation is eliminated. Development testing on a 92-in.-diameter segmented composite case showed zero joint rotation.

B.6.2 TANG AND CLEVIS JOINT

The tang and clevis joint on the baseline FWC is designed to be compatible with existing SRM components. This required a joint with a radial offset to attach to SRM domes, attach segments, and handling equipment. This radial offset causes an unequal load distribution through the joint and contributes to joint rotation. The eccentric loads and bending discontinuities imposed by the flexural differences between the composite case and joint result in joint rotation.

To eliminate this deleterious behavior, the Block II tang and clevis adapter rings (Figure B-15) are centered on the composite tang to create a line of action through the center of the joint. The addition of local hoop reinforcements in the joint areas has eliminated the rotation in the joint. The change in radial growth of the joint and basic case occurs outside of the joint area.

The Block II composite adapter rings consist of a capture feature tang that creates an interference fit when assembled with the clevis. This interference fit minimizes joint rotation on the clevis seals and the capture feature seal actually increases in compression as a function of chamber pressure and thrust. The metal-to-metal joint or field joint is connected by one-hundred seventy-seven 1-in.-diameter pins made of MP35N. Three alignment slots are used as guides for assembly.

B.7 MATERIALS AND PROCESS TRADE STUDY

The objective of this task was to select optimum materials and processes for high-quality laminate, high-performance large SRM cases. In considering the materials and processes for fabricating large motor cases, experience with the Space Shuttle SRM-FWC is valuable. To simultaneously meet the FWC strength, stiffness, and growth requirements, specific tensile strength is the design

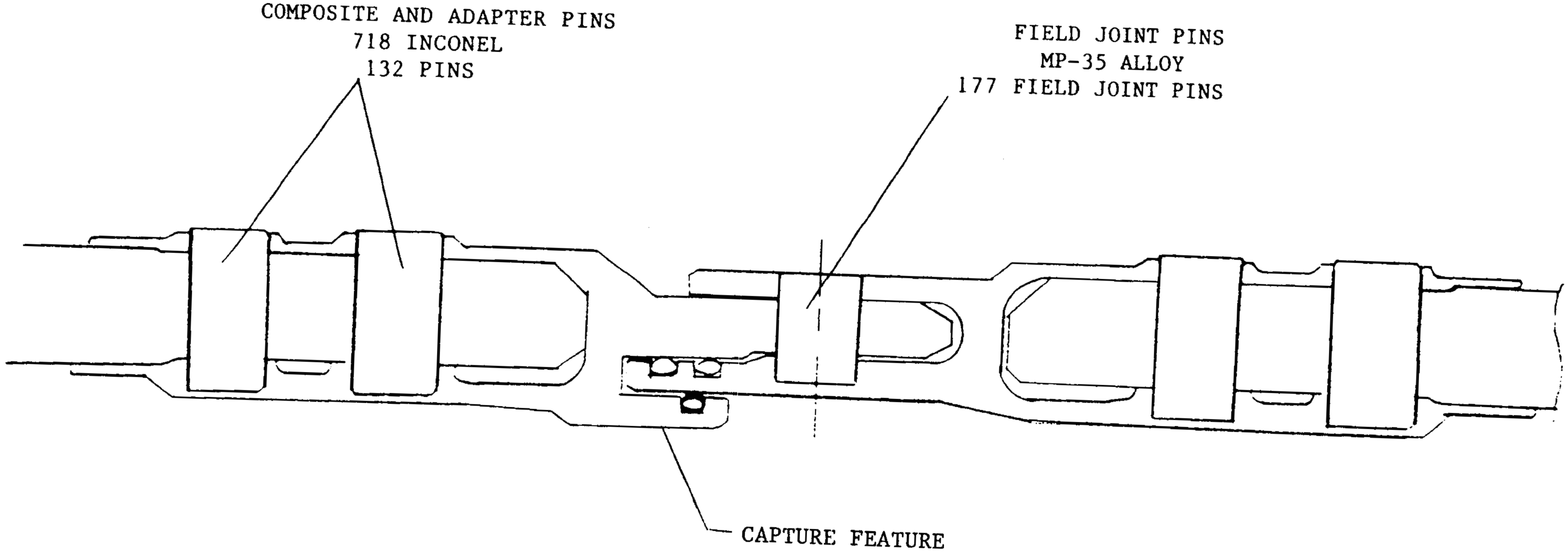

Figure B-15. SRM Block II Composite Case Tang and Clevis Joint driver for the hoop fiber and specific tensile modulus is the design driver for the helical fibers. Advanced carbon fibers such as Amoco T-40, Hitco Hitex 46-8, and Hercules IM7 offer significant improvements in both strength and modulus over the AS-4 fiber currently used. Hybrid fiber combination (Kevlar and S-2 glass hoops with graphite helicals) may offer performance/cost advantages not possible with the single material.

The high strength-to-weight ratios of Kevlar are attractive, but the low compressive and transverse strength of aramid fibers could not tolerate the handling, transportation, or Shuttle prelaunch compressive loads. The high radial case expansion of a booster fabricated with S-2 glass results in high stresses in the web region of the propellant. This stress level in the propellant may cause cracks to develop which severely affect motor performance. High-modulus graphite fibers are required to provide the strength and stiffness needed to meet the CPW1-3400 specifications.

B.7.1 TRADE STUDY WITH/WITHOUT AXIAL GROWTH REQUIREMENTS

Controlling axial growth, bending/axial stiffness, and radial growth in a rocket booster is extremely important to ensure proper performance of the Space Shuttle. Excessive axial elongation induces undue stress in the ET and orbiter. The bending/axial stiffness must be controlled to ensure dynamic stability, limit on-pad excursions, and prevent excessive loads from being imparted into the Shuttle's structural components. The radial growth in the star region of the forward propellant grain must be contained within an allowable limit to prevent the propellant from exceeding its strain capability.

The initial composite case concepts presented in Table B-3 incorporate axial growth and bending/axial stiffness as key parameters in the case design. Several hybrid case designs use a combination of fibers to maximize performance and minimize cost. Meeting the axial growth requirements severely limits the efficient use of composites. A 20 to 25 percent membrane weight penalty is required to achieve maximum upper 3-sigma growth of 0.72-inch. A series of case designs using the current bending/axial stiffness requirements and extending the axial growth to 3 in. is presented in Table B-4.

Table B-3. Composite Case Designs--Existing FWC Axial Growth and Stiffness Requirements at 1,100 psi MEOP

MATERIAL	FIBER MODULUS (MSI)	DESIGN STRENGTH (KSI)	WEIGHT (LBS)	PAYLOAD (LBS)	$\Delta\$ / \Delta PAYLOAD$ (3)
D6AC STEEL (1)	30	195	98000	BASE	--
AS-4 (FWC) (1)	34	440	71000	4600	BASE
AS-4	34	440	73000	8000 (2)	140
T-40	42	625	63000	10000 (2)	225
T-40 HOOPS/ T-500 HELICALS	42/ 34	625/ 440	70000	8600 (2)	215

(1) BASELINE SRM DESIGN @ 1004 PSI
(2) ASSUMES 3500 LB PAYLOAD INCREASE FROM HEADS UP CONFIGURATION
(3) REFLECTS MATERIAL COSTS ONLY, NEW DESIGNS USE PREPREG INSTEAD OF WET WIND

Table B-4. Composite Case Designs--Axial Stiffness and Strength Only,* 1,100 psi MEOP

*AXIAL GROWTH ABOUT 3 INCHES[1]

MATERIAL	FIBER MODULUS (MSI)	DESIGN STRENGTH (KSI)	WEIGHT (LBS)	PAYLOAD[3] (LBS)	Δ\$(FWC) / Δ PAYLOAD [4]
D6AC STEEL[2]	30	195	98000	BASE	---
AS-4	34	440	64000	9700	40
T-40	42	625	56500	11000	100
T-500 HELICALS T-40 HOOPS/	34/ 42	625/ 440	61000	10200	75
KEVLAR HOOPS/ T-40 HELICALS	18/ 42	380/ 625	60000	10400	65

(1) CONCEPT WOULD REQUIRE A "SHOCK ABSORBER" AT THE FWD ET ATTACH
(2) BASELINE DESIGN @ 1004 MEOP
(3) ASSUMES 3500 LB PAYLOAD INCREASE FOR HEADS UP CONFIGURATION
(4) REFLECTS MATERIAL COSTS ONLY, ASSUMES PREPREG MATERIAL

The tables show that high-strength, high-modulus carbon fibers (T-40) result in the greatest performance increase and the greatest material cost. The lowest material cost is the AS-4 wet-wind system currently used for FWC. As discussed in the following section, prepreg materials have been selected to eliminate laminate quality problems associated with the wet-wind process. It is anticipated that the new high-performance material systems will be cost competitive when purchased in large volume. Therefore, T-40 carbon fiber is selected as the material for the Block II case design.

B.7.2 COMPOSITE MATERIAL AVAILABILITY

The production of a composite case would require a large amount of graphite material. The production capacity of graphite fiber exceeds current demand. The cost of the high-strength, high-stiffness prepreg fiber is currently high. But, forecasts show that with high production rates, there will be a significant cost reduction. A summary of the candidate graphite fibers is listed below:

Material	Availability	Performance	Cost
T-40	Good	High	High
T500	Good	Moderate	Low
X-AS	Good	High variability	Low
IM-6	Good	High variability	High
Hitex 46-8B	Near production	High	High
AS-4	Excellent	Moderate	Low

B.7.3 WET WINDING VERSUS PREPREG

HBRF-55A epoxy resin is used for wet winding the hoop and helical layers of the FWC. The short gel time of the resin is not optimum for the current FWC winding process, which leads to high void content and delaminations. Most of these problems are related to the 20 to 30 days required for winding the 30-ft long, 1.3-in.-thick cylinders. The resin content variability is inherent in the current wet filament winding process. The HBRF-55A resin is not suitable for the prepreg broadgoods and unidirectional joint reinforcement tapes, and the use of the 3501 resin in these area necessitated a 350°F cure temperature. This cure temperature causes a considerable reduction in the resin elongation of the HBRF-55A which was designed for a 250°F cure, and complicates the thermal stresses. A further complication is the difference in Tg of the two resin systems. On cooldown, the 3501 resin (having a higher Tg) develops properties before the HBRF-55A, and the thermal stresses are relieved by deformation and/or delaminations in the composite layers containing the HBRF-55A. The short gel time of the HBRF-55A eliminates resin flow in the case during cure, and the mandrel expanding against the gelled composite is thought to introduce resin fractures which do not heal during cure. The potential effect on off-axis properties is important to the current design using the ±33-deg helicals.

Many of the drawbacks of the current FWC material system could be overcome through the use of a prepreg resin such as Fiberite 982 or Narmco 5245C, for both the case winding and the reinforcing broadgoods. Although this prepreg resin would solve the problems of short potlife, early gel, and resin content variation, the current belt compaction system may not be adequate. This would require the use of an in-process compaction, similar to the one used on the composite overwrap* which resulted in a laminate with less than 1 percent voids and a 64 percent fiber volume.

Many of the critical loads imposed on an SRM require high shear and compression strengths. The low void content (1 percent) of a prepreg composite delivers the high strengths necessary to withstand prelaunch, splashdown, and handling loads. Table B-5 presents a comparison of FWC and advanced Block II material technology.

Higher fiber design strengths are possible with prepreg fibers due to the low COV. Tests (Table B-6) with AS-4 HBRF-55A had a COV of 6.1 percent while that of T-40/ERL 1908 prepreg is 1.9 percent. A significantly higher design allowable is possible with a prepreg because the minus three-sigma design value is higher for systems with low statistical variations.

*T-40/998 material is used on the SRM redesign composite overwrap which is 1.9 in. thick, 9 in. wide, and 12 ft in diameter. The rib reverses the SRM joint rotation and causes the seal to close.

Table B-5. Comparison of FWC and Advanced Block II Material Technology

	FWC Technology	Block II Technology
Fiber	AS-4 34 msi modulus 440 ksi design strength	T-40 42 msi modulus 625 ksi design strength
Resin	HBRF-55A wet wound 3501-5A prepreg broadgoods	ERL 1908 prepreg
Resin content variability	± 10%	± 2%
Fiber volume	50-55%	60%
Void content	5%	1%
Compression/shear and hot/wet strength	Low	High
Delaminations	Severe	Minimal
Burst strength variation	6.1%	1.9%
Material cost	Low	Moderate*
Relative manufacturing cost	100%	80%
Cost of scrap, discrepancies and rejects	High	Low

*Material cost projected to be significantly lower when purchased in large quantity

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Table B-6. Fiber Strength Variation Study

AS-4/HBRF-55A Wet Wind (36-in.-dia.)	T-40/ERL 1908 Prepreg (18-in.-dia.)	T-40/ERL 1908 Prepreg (46-in.-dia.)
N = 18	N = 31	N = 2
X = 552 ksi	X = 730 ksi	667 ksi
COV = 6.1%	COV = 1.9%	668 ksi

Prepreg composites offer enhanced reliability and quality over wet winding. The cost of prepreg composite is currently high when compared to a wet-wind material system. The overall cost of the case may be about the same, because of lower fabrication and quality control concerns with a prepreg system.

The demonstrated reliability of a wet-wind system is evidenced on the C-4 program. Several C-4 wet-wind cases were rejected (failed) in a hydroproof acceptance test (First Stage, 1 of 46; Second Stage, 5 of 55; Third Stage, 8 of 50 burst below the minimum requirement). With a low-strength variation, the material is more predictable, hence, reliability increases.

Prepreg also offers reduced safety hazards in the filament winding area by reducing exposure to carcinogenic chemicals (MDA and NMA) and carbon fiber dust.

In summary, prepreg material costs are high, but significant price reductions are possible with high volumes. The overall case cost may be lower with prepreg. The cost issue is complex and a detailed cost benefit study must be conducted. The advantages of a prepreg system are summarized below:

- Lower manufacturing cost
- Higher performance
- Lower quality control costs
- Lower scrap/reject costs
- Higher reliability

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B-2. G. Z. Brinkerhoff, "Space Shuttle SRM Filament Wound Case Joint Analysis (Heads-up)," TWR-15388, 16 December 1985.

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B-5. "Detection and Inspection of Impact Damage to Composite Structural Components," SWRI Proposal 01-4158, Southwest Research Institute, 3 June 1986.

B-6 S. A. Klocksiem and M. J. Sandor, "A Two-Dimensional Finite Element Analysis of the SRM Steel Joint With Capture Feature," TWR-15908, 4 December 1986.