SPACE SHUTTLE

Solid Rocket Motors
Morton Thiokol Inc

Block II SRM Conceptual Design Studies Final Report

Preliminary Development and Verification Plan
Volume I, Book 2

(NASA-CR-179054) BLOCK 2 SRM CONCEPTUAL DESIGN STUDIES. VOLUME 1, BOOK 2: PRELIMINARY DEVELOPMENT AND VERIFICATION PLAN Final Report (Morton Thiokol) 88 p CSCL 21H G3/20

N87-21036

Unclas 43356

19 December 1986

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Publications No. 87354

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Space Booster Programs
Morton Thiokol, Inc.

Block II SRM Conceptual Design Studies Final Report

Preliminary Development and Verification Plan
Volume I, Book 2

19 December 1986

Prepared for

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Marshall Flight Center, Alabama 35812

Contract No. NAS8-37296

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1.0 Introduction

This document describes activities that will be conducted in support of the development and verification of the Block II Solid Rocket Motor. "Development" includes design, fabrication, processing, and testing activities in which the results are fed back into the project. "Verification" includes analytical and test activities which demonstrate SRM component/subassembly/ assembly capability to preform its intended function.

Morton Thiokol, Inc. has proposed new and different ideas within the constraints of the Block II SRM Study groundrules which consider performance, cost, and schedule while striving for assured system reliability. The early maturation of reliability in proposed designs will be accelerated and endowed with confidence through the results of an aggressive verification program.

The Development and Verification Plan (D&V Plan) defines the logic to be used to demonstrate that the conceived design for the Block II solid rocket motor (SRM) reliably meets all requirements for safety, design and performance. From the logic grows the analyses and tests necessary to verify achievement of the goals of various phases of the program. The depth of verification involvement is strongly influenced by the amount and quality of experience which backs the integrity of the proposed design. The plan draws heavily on experience gained during the development and verification of four previous SRM designs in order to save time and minimize losses due to redundant efforts. Following the structure of previous SRM D&V work, the plan defines objectives to:

(1) certify that the design achieves the requirements,

(2) certify that the hardware can be built to design specifications,

(3) perform acceptance testing and check-out to ensure that deliverable hardware is manufactured to the certified design,

(4) where possible, verify before flight that the SRM, when integrated with the other Shuttle elements, meets design and performance requirements,

(5) verify by flight and post-flight analysis and inspection that the SRM satisfies operational requirements.

The plan also introduces the management organization responsible for formulating and implementing the verification program. It identifies the controls which will monitor and track the verification program.

Integral with the design and certification of the SRM are other pieces of equipment used in transportation, handling and testing which influence the reliability and maintainability of the SRM configuration. The certification of this equipment is also discussed in this plan.

2.0 Block II Management

The Space Division of Morton Thiokol, Inc. provides dedicated resources to direct and control the activities needed to develop and verify the Block II SRM. The Vice President and General Manager of the Space Division, Mr. E. G. Dorsey, reports directly to the Aerospace Group President and has six functional groups reporting to him as shown in Figure 1. The six functional groups in the Space Division line organization are Safety, Quality Assurance, Operations, Engineering, Finance and Administration, and SRM Program Management. These line organizations are 100 percent dedicated to the SRM project.

Support groups assist the Block II SRM project through the direction of the Program Management Office. They are organized in accordance with a "team" concept, in which teams composed of members from the Space Division and the Support Services Division of Morton Thiokol, Inc. are assigned to specific tasks.

Changes due to implementation of new Block II ideas will affect most areas of the design to some degree. These changes will prompt the alteration of various facets of the Space Division's operations including facilities, tooling, and procedures. Effective use of existing resources is in the best ultimate interest of all concerned since it saves time and expense, and it fosters reliability through use of all established concepts and previously certified equipment. All established facilities, tooling, support equipment, manpower, policies, specifications, concepts and approaches for manufacturing and control which have been previously proven in the SRM project (plans, planning documents, and processing techniques) will be retained intact where possible; refurbishment concepts and Space Division facilities will require minimal changes.

An overview of the projected verification program master schedule is shown as Figure 2. Decisions based on test results will be charted to meet milestones of the master schedule. Figure 3 depicts a general view of the verification activities: over time, across components, in testing, in analysis, motor level, etc.

Morton Thiokol will maintain close working relationships with Marshall Space Flight Center (MSFC), other NASA centers, the NASA overview teams and interfacing Space Transportation System contractors. The company will provide complete performance data visibility during verification testing to promote identification and resolution of problems. Primary working interfaces and communication will be coordinated through the Space Programs office. The Space Programs Office serves as an on-site extension of the NASA Project Office and will provide for direct, single channel flow of information between NASA and the Space Division.

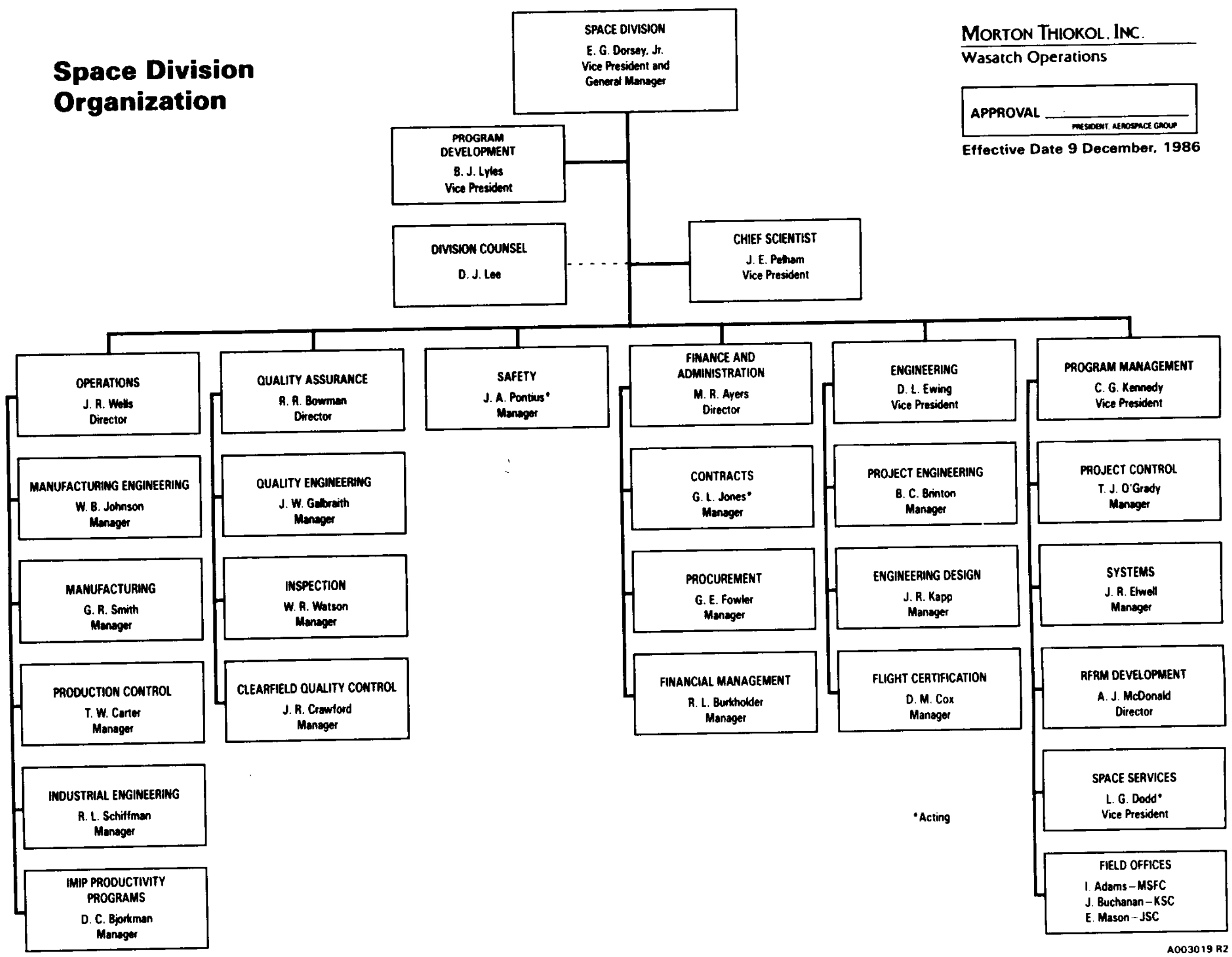

Figure 1. Space Division Organization

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FIGURE 2

BLOCK II D & V PROGRAM SCHEDULE

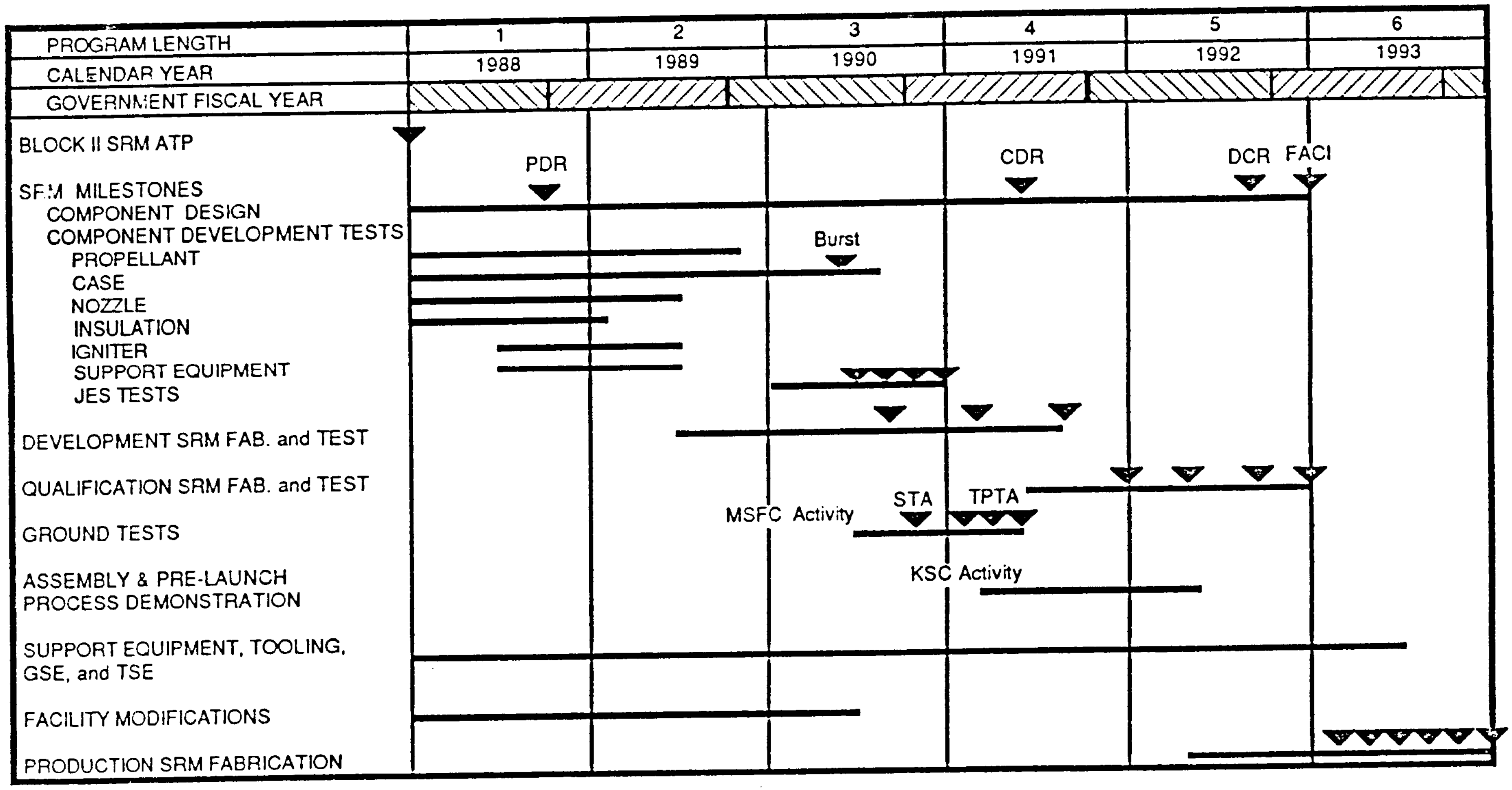


FIGURE 3: BLOCK II VERIFICATION

Areas	Materials	Analysis	Testing	Acceptance
Nozzle	Develop & Characterize	Struct. & Thermal	Structural, Hydroburst, Static test	Component and motor quality is ensured through raw material control, dimensional inspections, etc.
Insulation	Characterize	Thermal	Subscale Erosion/Ablation, Bonding, JES, Static test	Component and motor quality is ensured through raw material control, dimensional inspections, etc.
Case	Develop & Characterize MAR-T250	Struct.	Development: Processes, Welding, Forging, Sectioning, Hydroproof, Hydrotest, JES and JAD. Qualification: ATA, STA, TPTA	Hydroproof, vendor control
Propellant	Characterize	--	Physical, Mechanical, Burn rates, Pressure sensitivity, Bonding, Static test: at $40^{o}F$, ambient, and $90^{o}F$	Materials, Inprocess burn rates and total solids
Motor	--	Ballistc & Gas Dynamic	Modal survey, <u>Static Testing:</u> Demonstration motors 1-3 at ambient Qualification motors: Q_1 & Q_3 - ambient Q_2 - $40^{o}F$, Q_4 - $90^{o}F$	--

3.0 Project Engineering and Flight Certification

Morton Thiokol, Inc. will compile all of the Block II requirements into a Design Requirements Document (DRD) to serve as a convenient, comprehensive source book. Allocation of requirements to the system, sub-system and component levels will be documented in the Design Requirements Document. This in-house document will be maintained in concert with the Contract End Item (CEI) specification and all sub-tier documents. The System Requirements Section of the Space Division is responsible for preparation and maintenance of these documents throughout the development phase of the program.

The DRD is an autonomous working document which retains the CEI specification numbering system for reference and provides the designers with a single source of design requirements, constraints, interfaces, and test verification requirements. The DRD serves as a data base of requirements for design, design review, change evaluation, tradeoff study evaluation, technical performance measurement, test planning, and test specification development.

Standard system analysis procedures will be used to assure proper allocation and integration of requirements at the component level, to track and incorporate trade study results, and to communicate design information throughout engineering to ensure a coordinated engineering effort. System analysis also provides a tracking system for assuring verification of compliance to: the CEI specification, Morton Thiokol, Inc. imposed requirements, and FMEA and Hazards Analysis recommendations.

3.1 Design Integration Department

Design integration during the program will require a concentrated effort to disseminate, coordinate, and integrate all design requirements and changes to the appropriate Morton Thiokol design departments. A proven and disciplined process involving responsible personnel and controlled documentation will be used to accomplish this effort. The prime concern in SRM design integration is configuration definition, evaluation, and control through the media of the DRD, drawings, specifications, and bills of material. Collectively, these documents comprise all of the information required for procurement of materials and components, manufacture of parts, performance of subassembly operations, inspections, qualification testing, final assembly, and sell-off.

The allocation of individual hardware requirements in the DRD will be organized to the component, subsystem, and system levels which will serve as a check to eliminate duplication of work and insure that all requirements are incorporated. The DRD

will be a repository of hardware design requirements from which drawings and specifications will be generated and to which all design definition and control documentation will be traceable.

Hardware design requirements will be translated into designs by means of part, subassembly, and final assembly drawings. The interfacing and integration aspects of these hardware drawings will be further controlled by a master layout drawing and drawing tree, which provides total configuration definition. Bills of Material will be prepared directly from released drawings to identify and control the acquisition of hardware and raw materials.

Additional control of SRM hardware will be provided by specifications and test procedures. Basic information and data for these specifications are extracted from the requirements section of the DRD. As drawing requirements and CEI specifications dictate the need, additional company standards and specifications will be prepared to describe requirements for materials, parts, and processes. Impetus for preparation and refinement of specification documents will come as detailed design data are provided by the maturation of component, subsystem, or system designs.

As the design process continues, in-house design reviews will be conducted at the component, subsystem, and system levels to verify that DRDs are incorporated. These design reviews are supported by representatives of the Program Office, Design Engineering, Safety, Manufacturing, Quality Assurance, Reliability, and Management. The drawings and specifications will be reviewed for aspects of technical and functional completeness, producibility, reliability, safety, maintainability, quality assurance, and cost effectiveness. Reviews will identify and close-out additional requirements to be incorporated or design changes to be made to the DRD, drawings, and specifications. Formal design review boards will be complemented with NASA participation; the Preliminary Design Review (PDR) will achieve incremental approval of preliminary designs and Part I CEI Specifications, and the Critical Design Review (CDR) will provide approval to release detail drawings and Part II CEI Specifications. Some long lead-time items will require NASA approval in advance of PDR or CDR. Review results will be documented to ensure implementation of the technical decisions.

An area of great importance in design integration is formal design control. Morton Thiokol has an efficient configuration control system that includes strict change control policies and procedures carried out through a change control board. All drawings and specifications approved by NASA at either incremental or final design reviews will be constituted a design standard or "baseline". These baselines become customer controlled and are changed only with NASA concurrence through the change control board. Configuration management is established and maintained throughout the project lifespan.

Integration activities will prepare and update documents which control demonstration motors, qualification motors, test assemblies, and flight motor subassembly, assembly, and instrumentation drawings. An additional task will be to prepare flight test reports.

3.2 Interface Control Documents

Morton Thiokol, Inc. will conduct activities for SRM/SRB (motor/booster) support. Interface requirements are identified, evaluated, and allocated to specific hardware items as approved by MSFC and the Shuttle Processing Contractor. The Interface Control Documentation (ICD) program is administered by the SRM Project Office. Detail drawings and documentation are prepared and controlled as directed by the project engineer. Design drawings and specifications for the SRM, support equipment (SE), and tooling are reviewed and evaluated against the ICD baseline to assure compliance with all requirements. Detail activities of the interface control program are:

1. Provide internal centralized interface control management.
2. Provide representatives to all NASA, Rockwell International, and SPC coordination interface meetings when SRM related ICDs are on the agenda.
3. Provide data, schedules, and status reports on SRM related ICD effort as required by NASA.
4. Initiate SRM drawing revisions due to ICD changes.
5. Participate in Technical Interchange meetings to resolve technical problems affecting interfaces with the SRM.
6. Review and make recommendations for input to each of the following NASA documents.
   a. ICD Index and Status Report.
   b. NASA Baseline Activity Index and Status Report.
   c. ICD Cross Reference Index.
7. Review and respond to Interface Revision Notices affecting SRM related ICDs.
8. Resolve all Interface Revision Notice discrepancies related to ICD controlled areas affecting the SRM.
9. Prepare ICD drawing departure authorizations.
10. Prepare and maintain ICD compliance report.

3.3 Reliability

The SRM reliability program will be defined in the Reliability Program Plan.

The role of Reliability in the development and verification process begins with the generation of a preliminary Failure Modes Effects Analysis (FMEA). All aspects of the SRM will be carefully analyzed to assure that all potential failure modes are identified. The preliminary FMEA receives input from NASA, engineering, Q.A., operations, trade studies, etc.

Additional tests and analyses may be required as a result of FMEA analysis. In response to testing identified in the preliminary FMEA, input will be made to the proper test and analysis plan to assure that each critical failure mode is addressed. This allows analysis and/or testing to be planned into the program for closeout of failure modes and causes.

As a result of the PDR, the FMEA will be updated to reflect Review Item Discrepancy actions, updated requirements, updated design concepts, and new D&V Plan requirements. Continuing FMEA review cycles (both in-house and with NASA) assure that historical and new failure modes will be analyzed until they can be controlled or eliminated, thus achieving closure.

Prior to CDR, the Critical Item List will be developed as a follow-up to the FMEA. It will identify criticality, retention rationale, and failure history. The FMEA and Critical Item List will be reviewed and updated for formal design reviews.

3.4 System Safety

The primary function of System Safety is to use engineering and management principles, criteria, and techniques to optimize safety within the constraints of operational effectiveness, time and cost throughout all phases of the system life cycle. In the development and verification of the Block II SRM, System Safety will review the design and the planning to ensure the safety of personnel, product, and facilities.

For Preliminary Design Review (PRD), System Safety will generate a Concerns List and Matrix on specific areas of the design. As the certification process continues after PDR a Subsystem Hazard Analysis will be developed on each subsystem which, after Critical Design Review (CDR), will be used in the development of a System Hazard Analysis. An Operational Site Hazard Analysis and a Ground Support Hazard Analysis will also be provided during the same time frame. With this complete effort, System Safety will be providing analyses on the SRM, associated equipment, and facilities which may impact the SRM.

The System Safety Concerns Lists and Matrices will be generated from preliminary designs provided to System Safety.

Concerns lists and matrices are to be generated to identify parts, procedures, processes, or materials which are believed to be vital to safety. Concerns matrices document hazards/effects, failure cause, and required action and closure methods. The hazard/effects column lists the condition which is a pre-requisite to a mishap. The failure causes column identifies those conditions which if allowed to exist can cause a hazard. Required action and closure methods column lists design, process, material, and procedure controls which when followed will control hazards. The verification phase and verification methods are also designated. The required action and closure methods assist in cross checking and/or requiring tests, analysis, inspection, etc. in order to qualify the design, processes, procedures, material, etc.

Following PDR the Subsystem Hazard Analysis (SSHA) will consider each subsystem or component and identify hazards associated with operating or failure modes. The SSHA will determine how operation or failure of components affects the overall safety of the system. Hazard identification of the SRM is based upon review of the design requirements documents, system and subsystem specifications, design drawings, design/stress analyses, test reports, trade studies, and the Failure Mode and Effects Analysis prepared by the Morton Thiokol Reliability Section.

The Subsystem Hazard Analysis will identify necessary actions, using the System Safety Order of Precedence to determine how to eliminate or reduce the risk of identified hazards. Overall, the SSHA will identify components and equipment, including software, whose performance, degradation, functional failure, or inadvertent functioning could result in a hazard or whose design does not satisfy contractual safety requirements. Actions to control identified hazards will be implemented through appropriate documents such as: Common Planning Index (CPI), Operational Maintenance Document (OMD), Operations and Maintenance Requirements and Specification Document (OMRSD), launch commit criteria, etc. and will be updated as additional test data become available.

The SRM System Hazard Analysis (SHA) will be used to determine the safety problem areas of the total system design including potential safety critical human errors. It will identify hazards and assess the risk of the total system design, subsystem interfaces and software. The SHA examines all subsystem interfaces for:

a. Compliance with safety criteria called out in the applicable system/subsystem requirements documents.

b. Possible combinations of independent or dependent failures that can cause hazards to the system or personnel. (Failure of controls and safety devices should be considered.)

c. Possibility for normal operations of systems and subsystems to degrade the safety of the system.

d. Design changes to systems, subsystems, or interfaces, logic, and software that can create new hazards to equipment and personnel. Information for SHA hazards identification will be obtained from review of the SSHA and the documents, studies, drawings, etc.

The SHA will be accomplished in much the same way as the subsystem hazard analysis. It will examine the effects of component operation and failure on the system and will determine how system operation and failure modes can effect the safety of the system and its subsystems. The SHA will begin after the CDR milestone and will be updated until the design is complete. (Design changes will be evaluated to determine their effects on the safety of the system and its subsystems.) This analysis will contain recommended actions to eliminate or reduce the risk of identified hazards. Actions to control hazards identified in the SHA as well as the SSHA will be implemented through appropriate documents such as CPI, OMD, OMRSD, etc.

Operation and Support Hazard Analyses (O&SHA) will be provided for operational sites and for ground support equipment. These analyses will be performed primarily to identify and evaluate hazards associated with environment, personnel, procedures, and equipment involved throughout the operation of the system.

The O&SHA effort will start after PDR and will provide inputs to the design prior to system test and operation. The O&SHA will be effectively used as a continuing closed-loop interactive process, whereby, proposed changes, additions, and formulations of functional activities are evaluated for safety considerations, prior to their adoption.

Timely application of the O&SHA will provide some guidance for design. Recommended actions to control identified hazards will be implemented through such appropriate documents such as CPI, OMD, OMRSD, launch commit criteria, etc. Therefore, care will be exercised in assuring that the analyses results are disseminated to proper groups for effective accomplishment of the O&SHA objectives.

3.5 Mass Properties

Morton Thiokol will maintain a mass properties control system to insure compliance with NASA imposed mass properties limits and to ensure that adverse trends in mass properties characteristics are determined and controlled early.

Design control is accomplished through use of an SRM Mass Properties Design Criteria and Control Document requiring responsible design organizations to design components within a specified weight and center of gravity envelope. Updates are prepared as needed. Morton Thiokol engineers trained in weight control and SRM design influence component design so that weight will be within the established envelope. Mass properties calculations are performed as drawings become available and appropriate corrective action taken if required. All drawings, engineering change orders, and specifications are reviewed and approved, as required, by the mass properties engineer before design release. Verification of compliance with mass property requirements is determined by weight measurement of manufactured items.

Mass property compliance is initially verified by analysis. Computer programs are used to determine volumes, moments, and moments of inertia. Computer generated SRM mass properties data as a function of burning time will be developed by using (1) geometrically defined grain configurations during motor operation, (2) chamber temperature, (3) insulation exposure time, (4) material properties, and (5) location in the motor. Weight, three-axis center of gravity and three-axis moment of inertia data are produced for reports directly from output sheets.

Quarterly Mass Property Status and Computer Tape Reports will be prepared during the program to provide up-to-date SRM mass property data. Mass Property History Logs will also be prepared for each development and qualification test motor. The mass property data reported in the History Log will include the total inert weight (CEI control weight), propellant weight, and center of gravity.

Mass properties requirements derived from SRM contractual requirements will be incorporated into procurement documents. Subcontractors supplying parts, components, or assemblies with specified maximum weight requirements will submit a weighing system calibration plan and verify compliance by mass measurements.

The computerized mass properties accounting system will record information necessary for determination of SRM mass properties data. Data for the various end items will be stored so that when part changes occur, new end item data can be substituted efficiently. Coordination with field personnel will ensure information availability. Close working relationships and coordination with NASA mass properties personnel will be established and maintained.

Mass properties requirements specified in Contract End Item Specification, component specifications, and drawings will be verified as describedin STW7-2684.

3.6 Material Control

The logic, responsibilities, and required actions involved in the materials selection and control program for the SRM will be presented in the Materials Selection and Control Plan. It will be used in the selection and control of materials used by Morton Thiokol in the fabrication and testing of in-house manufactured SRM components. The processes used by Morton Thiokol in the Manufacture of all SRM components will be discussed in detail in the manufacturing plans.

All materials, both metallic and nonmetallic, used in the design of solid rocket motor hardware will be identified and documented by the Material Accountability, Tracking and Control data system. This system is designed to provide complete and accurate material usage information, tracking, and retrieval capability for the Space Shuttle System.

4.0 Block II SRM Development and Verification

4.1 Development

The development program described in this plan presents the design, fabrication/processing, and testing effort associated with the Conceptual Design Package for the Block II SRM.

Data from qualification testing, from joint simulation tests, and from other development tests will support design development as well as verify that each component, sub-assembly, and end item will fully satisfy the requirements for its' intended use. Verification of the Block II SRM will be ultimately accomplished by static testing three development and four qualification motors.

The development approach followed in the Block II SRM program is based upon an asbestos-free design and goals to enhance reliability, increase performance, and reduce costs. Baseline requirements for performance, design, and verification are taken from (Specification No. CPW1-1900).

The lessons learned in bringing the previous SRMs to production and flight will be weighed in the recommendations for implementing Block II SRM concepts. This background will also be useful in identifying important changes in the design or verification approach for the Block II motor.

The Block II SRM concept for critical pressure seals will have to equal or improve upon the re-design presently underway for the Shuttle SRM. All Criticality 1, 1R, 2, and 2R pressure seals will be fully redundant and verifiable, and will not require pressure actuation to perform the sealing function. To ensure reliability, the verification plan will demonstrate the behavior of the seal under all operating conditions. The verification process will take advantage of the analysis techniques, simulation methods, and test demonstrations being used in the Shuttle SRM requalification effort, as well as the information learned from previous SRM designs.

Increased payload capability for the Space Shuttle has been a frequent objective of the studies of previous and development efforts; the SRM project has contributed to system performance growth with implementation of the lightweight case, high performance motor, and filament-wound motor. The impact of performance enhancements on other elements of the Shuttle system will be carefully coordinated with NASA and the integrating contractor. Additional performance may be gained with an alteration of the existing SRM combined with a heads-up flight mode. As the Block II SRM concepts mature the capability to accommodate performance growth will be evaluated.

4.2 Verification

The verification program is to provide confidence that the Block II SRM and support equipment (SE) meet all specification requirements. The verification program will permit certification of components, subsystems, and the system as well as the associated SE through test and/or analysis. The general flow of verification activities is illustrated in Figure 4. The principles of verification operate over three time phases: development, certification and acceptance. Acceptance verification activities also include pre- and post-flight work. Table I describes each discipline.

TABLE I: D&V DISCIPLINE DESCRIPTIONS

Discipline	D&V Plan Section	Description
Development	4.2.1	Design development activities & feedback
Certification	4.2.2	Formal certification that the hardware meets design requirements
Acceptance	4.2.3	Manufacturing acceptance policy and procedures (quality conformance) which ensure that deliverable SRM hardware is manufactured to the certified design
Pre-flight Check	4.2.4	Pre-flight check-out to confirm that the SRM, when integrated with other Shuttle elements, meets design and performance requirements
Post-flight Check	4.2.5	Verification by post-flight analysis and inspection that the SRM satisfies operational requirements

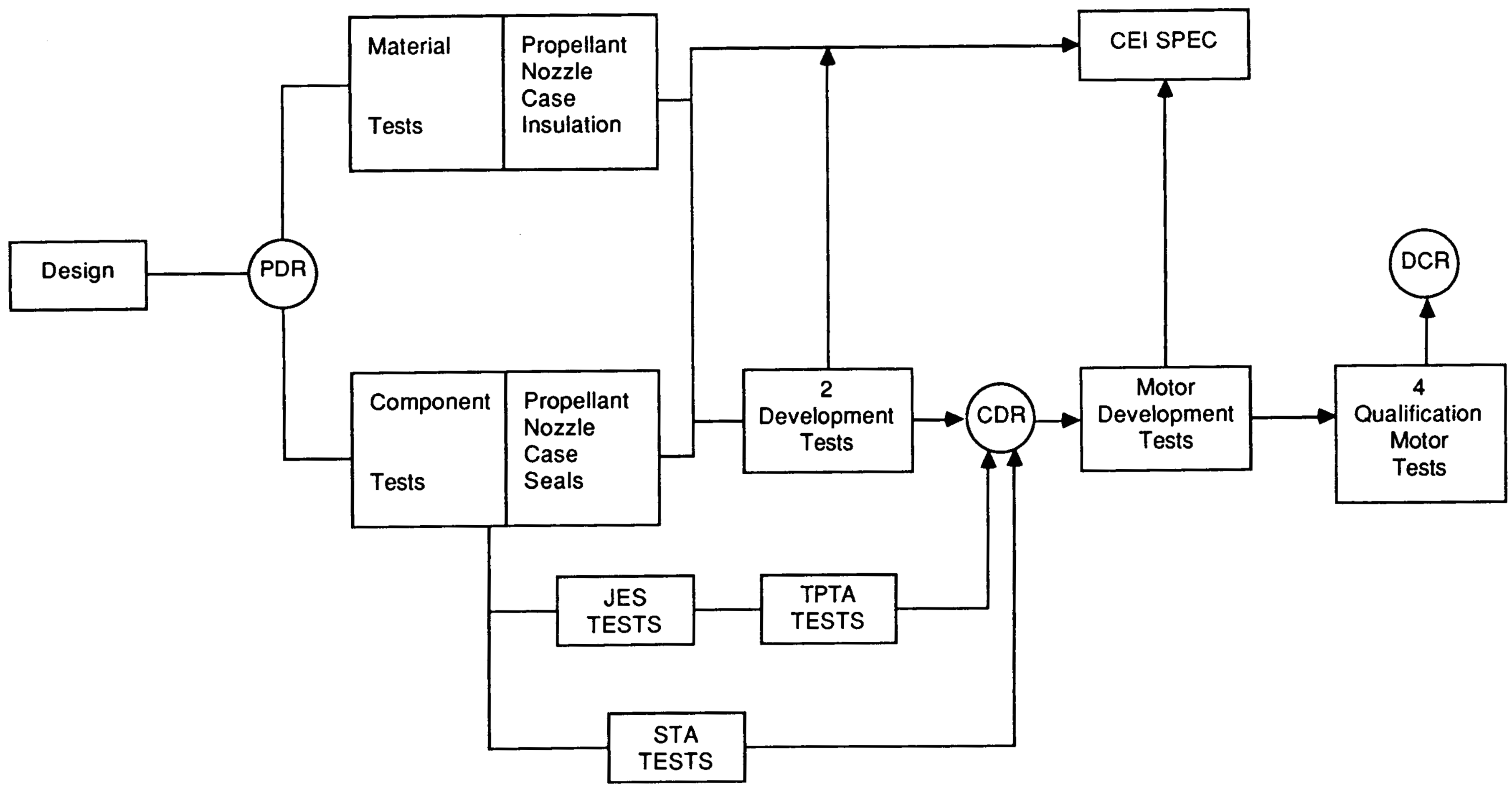
4.2.1 Verification during Design Development

During the development phase of the Block II program all candidate designs and procedures are to be examined for satisfactory verification of integrity. In general, certification may be accomplished by any means capable of resolving the questions at hand. Justifications may be founded in common sense, established by analysis methods, or built through lengthy and expensive testing. The most trustworthy rationale is built from testing and analysis.

The preferred method of certification is accomplished by testing and is done when a reasonable need exists to merit the expenditure of time and money. Testing will be required to identify unknowns with respect to material properties, testing procedures, new environments, or where existing data cannot be traced to accepted sources. Verification by testing is required when candidate designs and procedures have not been conclusively assessed by analysis and/or similarity. Where necessary to test, test plans include comprehensive reporting of the test results,

FIGURE 4

BLOCK II SRM PRELIMINARY D & V PLAN LOGIC



test configuration, and other pertinent data. All testing is conducted under strict control of environments and procedures to verify conformance to requirements.

Design analysis techniques may be utilized for validation of complicated concepts. Design techniques are indispensable in difficult situations which might be due to: testing limitations, environmental complications, excessive cost, or the need to extrapolate data beyond testing abilities. Verification by analysis may consist of accepted analytical techniques or considerations of similarity. Analysis work will be documented in the development program and will confirm the achievement of design margins while accounting for the effects of combinations of tolerances within the given operating extremes.

4.2.2 Certification of Design

"Certification" (qualification) is the one-time process of verifying that hardware meets all design requirements when manufactured by approved processes. Certification is conducted following design solidification for every part number and may be completed early, during development testing, when intent to certify is declared. Methods of inspection, testing and analysis will be used to certify hardware and support equipment. Traditional mature ("off-the-shelf") hardware may be certified by comparison when used in environments which are not more severe than the analogous qualification environment. Recertification becomes necessary (1) when manufacturing sources change or become idle longer than permissible, (2) when environments are found to be more severe, or (3) when design changes affect form, fit, function or reliability. Certification of service life will be accomplished by similarity, except for sealing materials whose service lives will be established by testing.

All certification procedures will be performed in a professional fashion: (1) manufacturing will control the identification and flow of hardware, (2) comprehensive documentation of manufacturing, testing, and data reduction will permit reassembly of every significant detail of the items history, (3) management policies and procedures applicable to quality functions, data transmittal, failure reporting, etc. will be followed, (4) internal audits will be conducted, and the customer will be notified of test results in the traditional fashion. Verification of the ability to manipulate the SRM with the facilities and support equipment also will be demonstrated as part of certification. A Certificate of Qualification (with backup data/analysis and rationale) will be transmitted to NASA for approval of all new designs: case and seals, nozzle, igniter, propellant, insulation and liner.

4.2.3 Acceptance

Day-to-day acceptance of hardware will be accomplished through requirements, plans, and procedures written to traditional standards of high quality. Acceptance requirements for material and components will be contained in the individual component and material specifications and drawings. Plans for acceptance at the component, sub-system and assembly levels will guide the formation of the Manufacturing Plan. Procedures such as shop travelers and operations sheets will spring from the manufacturing plans to map the course of quality control.

Acceptance is to be performed on each component, subassembly, and assembly to verify that the hardware meets the design and performance requirements. Component acceptance verifies that the materials, construction, workmanship, dimensions, configurations, and where possible, performance comply with the applicable specifications and drawings. Sub-assembly tests and/or inspections will be conducted to perform acceptance prior to assembly into the SRM. Acceptance on the assembled SRM will be controlled by the "Operations and Maintenance Requirements and Specification Document" which identifies the items to be tested, the test constraints, the requirements, the documents imposing requirements, and inspection details.

Items procured through vendors will be verified through accomplishment of the proceedings of the Source Inspection Plan, and completion of Vendor Inspections and Morton Thiokol, Inc. Receiving Inspections.

4.2.4 Pre-Flight Checkout

Pre-flight checkout includes all post-delivery activities which verify the readiness of the SRM. This effort culminates with the completion of pre-launch activities on the launch pad, and includes SRM integration and space shuttle vehicle system testing. This work begins upon receipt of the motor segments at the receiving station in the Rotation, Processing, and Storage Facility (RP&SF) and ends in the Recovery Facility. The following paragraphs describe the facility integration and verification.

The SRM segments, nozzle extension and integration hardware shall be inspected at the Receiving Station. Following inspection, they are placed in storage or mated with Solid Rocket Booster (SRB) components to the level of assembly identified as booster sub-assemblies. A considerable amount of testing will be accomplished at this level. Sub-system tests will be preformed on the nozzle exit cone assembly, aft segment to nozzle, integrated aft skirt assembly to the aft motor segment interface, TVC actuator installation and checkout in addition to development flight instrumentation and/or operational flight instrumentation checkout.

RP&SF integration will include the vertical assembly of the SRB aft booster sub-assembly, the SRM center and forward segments and the SRB forward skirt assembly on the Mobile Launch Platform, and the integration of the SRBs, external tank and orbiter. Verification of conformance to applicable requirements and of the functionality of plans and procedures for test and checkout will be accomplished.

The effort will also include leak tests of the mated motor segment joints (accomplished with Morton Thiokol, Inc. representation), electrical alignment check of the SRB and nozzle assembly, and then the physical mating of the SRB to the external tank and orbiter.

After the subassembly tests have been completed, system tests will be accomplished at the Space Shuttle Vehicle level. Thorough systems tests will be completed before flight and after transport of the Space Shuttle Vehicle to the launch pad. All system testing will be accomplished by the Shuttle Processing Contractor supported by Morton Thiokol, Inc. personnel. Morton Thiokol, Inc. will: (1) provide SRM test requirements, (2) analyze data, and (3) provide anomaly resolution.

4.2.5 Post Flight Analysis

Flight performance will be examined for conformance to design requirements and data will be analyzed to characterize the flight environment. Required performance of the ignition, boost, separation, retrieval, refurbishment, and turn-around functions will be compared with flight data. Parameters such as thrust imbalance, base heating, structural integrity, refurbishability and reuseability will be evaluated with the aid of flight and post-flight data. Morton Thiokol, Inc. will support this effort through review, analysis and documentation as directed by NASA.

4.2.6 Ground Turnaround Operations Reverification

Ground turn-around operations reverification will be supported by Morton Thiokol, Inc. in the following circumstances:

(1) Active and passive Functional Paths (FP) will be reverified if:

a. Anomaly occurred in the FP during the last flight,

b. FP is needed on next flight and was not used on the last flight,

c. FP was disturbed since the last flight due to main tenance, servicing, or modification activities,

d. FP was not used since exposure to a hostile flight environment and has not been shown to be insensitive to such environment by analysis or experience. (This criterion is applicable to vertical flight turnaround only. During initial turn-around, all FPs will be reverified. The number of FPs to be reverified will be reduced with time based on early experience.),

e. The FP is needed on the next flight and the down-time was excessive.

(2) All active redundant FPs and all energized passively redundant FPs will be reverified if necessary to insure that vehicle is safe to launch or safe for takeoff (even if reverified previously per Item 1 above). This reverification will include items identified in the Critical Items List.

(3) Line Replacement Units removed from the vehicle for field maintenance must be reverified prior to reinstallation in the vehicle. Functional verification of the affected paths within the line replaceable units will suffice when the repair involves replacement of plug-in modules only. Repair involving more than module replacement (i.e: soldering, potting) will necessitate complete acceptance testing of the line replaceable unit, including environmental acceptance testing when applicable.

4.3 SRM Analysis and Integration

Under the Block II analysis and integration effort Morton Thiokol, Inc. will perform the functions of systems analysis, design analysis, and design integration. These functions collectively generate a totally integrated SRM system conforming to the SSV system specification requirements. The design requirements will be integrated with the support equipment and tooling requirements to insure systems compatibility. This design and analysis effort will be expanded in detail during the flight test program to insure that all individual and interacting system design parameters are fully identified and evaluated, and that compatible final design solutions are established. These trade studies also will include SRM design improvements and cost reduction techniques for possible incorporation during flight testing.

The efforts conducted at the SRM system level are those that are not amenable to be performed at the component or subsystem level, but which require a partial or total systems level design definition for accomplishment. The analyses, however, will verify compatibility of all SRM components with system requirements. The specific endeavors to be accomplished will be controlled and time phased to provide the required feedback for component and sub-system design and analysis as the need arises.

Morton Thiokol, Inc. will perform a comprehensive SRM system requirements analysis that defines the proposed flight system. This analysis will be expanded to define and control the detailed functional and design requirements applicable to development, qualification, ground test, flight test, and operational motors. The results of the analysis, requirements for SRM flight hardware, will be documented in the Design Requirements Document (DRD). The SRM requirements analysis will provide integrated systems engineering documentation. Morton Thiokol, Inc. will coordinate with NASA to insure that all requirement changes are acceptable for the SRB and Space Shuttle Vehicle systems. Complete data packages will be provided to NASA at the PDR and CDR for review and approval and changes resulting from these meetings will be incorporated. Data for SRM or component designs will be supplied as required for incremental PDRs and CDRs.

4.4 Nozzle

The Block II nozzle is an aft pivoted flexible bearing design. It is partially submerged to minimize erosive conditions in the aft end of the motor and to fit within envelope dimensional limitations. The flexible bearing provides eight degrees of omni-axial deflection capability. The design has been optimized to provide high performance, minimum weight and low cost.

The forward nozzle assembly consists of the flex bearing, nose cap support, throat support, five ablative and insulative liners, and a sacrificial flex bearing. The structural parts interface with the fixed housing and the exit cone assembly. Inlet and forward exit cone contours are formed by the sacrificial flex bearing, nose cap, nose inlet, throat inlet, throat and forward exit cone surfaces.

Snubbing devices, positioned on the aft end of the throat support steel structure, permit vectoring of the nozzle but will bottom out on the bearing aft end ring at water impact to limit forward motion of the nozzle which will preclude damage to the flexible bearing and the motor aft closure. Lightning bypass cables are provided between the exit cone assembly and the fixed housing as conductive paths from the exhaust plume to the skirt and case interfaces.

The exit cone assembly consists of a D6AC steel structural adapter, carbon cloth ablative liners, a support structure of filament wound graphite epoxy, an aluminum compliance ring, and actuator brackets for attachment of the actuation system. The structural shell, compliance ring, and actuator brackets form a structure that adequately withstands and distributes flight and water impact loads. The shell structure also contains provisions for attachment to the forward nozzle section during final SRB assembly and for attachment of the Linear Shaped Charge (LSC) hold-down brackets.

An exit cone cutoff device (linear shaped charge) is attached to the cone aft of the compliance ring to sever the aft portion of the cone prior to splashdown to reduce water impact loads on the system. A blast shield over the LSC is provided to prevent damage to the SRB heat shield. The LSC initiation signal is provided through triple shielded cabling running from the initiator to the field joint. Connectors at the field joint permit attachment to additional cabling on the forward exit cone assembly and aft dome that leads to the system tunnel.

PAN based carbon cloth phenolic will be used for the manufacture of the ablative liners in the nozzle.

The flexible bearing provides an omni-directional TVC capability for the SRM. The bearing consists of a flexible core that is contained between two steel end rings and is thermally protected by an inner stretch boot of silicone rubber and an outer sacrificial flex bearing. The flexible core is a laminated structure consisting of 10 spherical steel shims and 11 rubber pads. End rings and shims absorb the applied loads, while allowing relative motion to occur between the structural members. The nozzle steel parts and bearing end rings have a protective coating of Rust-Oleum®. The bearing shim ends are not painted but are protected by an ozone barrier coating.

A nozzle plug (internal shield) will be provided in the forward exit cone section to protect the SRM propellant from radiant and/or convective heating during the Flight Readiness Firing tests (orbiter main engine tests) or potential launch pad aborts.

The shield is made of molded foam and is bonded and sealed to the forward cone liner with a flexible, low strength adhesive/ sealant material. The shield is designed to withstand orbiter main engine ignition and buildup over-pressures on the pad and to buckle and eject at approximately 50 psi upon SRM ignition.

Verification will include detailed aero, thermal, structural and functional analyses, material characterizations, pressure tests (proof & burst), Nozzle Joint Environmental Simulation tests, and static firings (demonstration and qualification motors). The nozzle design will be continually updated and refined, its functional performance and structural integrity will be maintained to insure that all system requirements are satisfied. Final certification of the nozzle assembly will be conducted during the qualification motor static tests and analyses.

4.4.1 Ablatives

Testing of ablatives will generate physical, mechanical, thermal, fabrication and processing data for the Block II solid rocket motor (SRM) ablative materials. Mechanical and thermal characterization data will be generated at Southern Research Institute. The fabrication and processing studies will be performed at Morton Thiokol. The general test philosophy for this program is to use the same specimen designs, hardware, machines and test procedures for each material. Each type of mechanical test specimen will be run at the same constant stress rate or crosshead speed. In all tests, temperature gradients in the gage sections will be minimized by using a uniform heating rate.

Six ablative materials have been chosen for this program and are being divided into two groups: low density and standard density materials. There are four standard density ablative materials and two low density ablative materials. Raw material data and fabricated panel data for each material will be given in panel certification sheets.

Physical Characterization Testing

Physical properties will be determined for the cured and uncured materials of both low and high density. These tests include resin content, residual volatiles, volatile content and resin flow.

Mechanical Characterization Testing

The mechanical test matrix for the six ablative materials is given in Table II. Each material will receive a level of mechanical characterization based on its specific end use and on existing data. Therefore, most of the materials have different mechanical test matrices.

The tests consist of evaluations in the two principle material directions: with-ply (WP) and across-ply (AP). The across-ply direction is obvious while the with-ply direction will be explained briefly. These materials will be constructed with the warp and fill directions of each fabric layer rotated at 90 degrees so that a balanced layup will result. Thus, the two fiber directions are considered equal and each is designated as the with-ply direction. The test matrix for each material consists of three test types: tension, compression, and shear.

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Table II. Mechanical Test Matrix

	TEST TEMP (°F)	ULT. COMP. MODULUS STRAIN POISSON		ULT. TENS. MODULUS STRAIN POISSON		ULT. SHEAR STRENGTH		SHEAR MODULUS		TEST TEMP (°F)	ULT. COMP. MODULUS STRAIN POISSON ±45° OFF-AXIS	ULT. SHEAR MODULUS STRENGTH DIRECT SHEAR INTERLAMINAR
		WP	AP	WP	AP	WP	AP	WP	TDRSN			
PAN CARBON PHENOLIC												
Fiberite - MX4961	RT	2	2	2	2	2	2	2	2	RT	3	3
Cont. T-300, 3K	1000	2	3	-	-	3	3	3	-	100	3	3
Union Carbide	2500	3	3	3	3	3	3	3	-	300	3	3
	5000	3	-	3	-	3	3	3	-	500	3	3
USP - FM5879	RT	2	2	2	2	2	2	2	2	RT	3	3
Cont. CCA-4, 3K	1000	2	3	-	-	2	2	3	-	100	3	3
Hitco	2500	2	3	3	3	2	2	3	-	300	3	3
	5000	3	-	3	-	3	3	3	-	500	3	3
Fiberite - K411	RT	2	2	2	2	2	2	2	2	RT	-	-
Staple PAN, SWB-8	1000	2	3	-	-	2	2	3	-	100	-	-
Stackpole	2500	2	3	3	2	2	2	3	-	300	-	-
	5000	3	-	3	-	3	3	3	-	500	-	-
USP - FM5834A	RT	2	2	2	2	2	2	2	2	RT	3	3
Staple PAN, PCSA	1000	3	3	-	-	3	3	3	-	100	3	3
Polycarbon	2500	3	3	3	2	2	2	3	-	300	3	3
	5000	3	-	3	-	3	3	3	-	500	3	3
LT WT PAN CARBON PHENOLIC												
Fiberite - MX134LD	RT	2	2	2	2	2	2	2	2	RT	3	3
Cont. T-300, 3K, PW	1000	3	3	-	-	3	3	3	-	100	3	3
Union Carbide	2500	3	3	3	3	3	3	3	-	300	3	3
	5000	3	-	3	-	3	3	3	-	500	3	3
USP - FM5908	RT	2	2	2	2	2	2	2	2	RT	-	-
Cont. PAN, 6K, Leno	1000	3	3	-	-	3	3	3	-	100	-	-
Hitco	2500	2	3	3	3	2	2	3	-	300	-	-
	5000	3	-	3	-	3	3	3	-	500	-	-

Duplicate data will be obtained for all test conditions. Test temperatures will range from room temperature (RT) to 5000°F. Elevated temperature tests will be conducted in an argon atmosphere.

Bulk Density

Bulk density values for as-received and char specimen blanks for each material will be calculated from direct measurements of weights and dimensions.

Tensile Testing

Two types of tensile specimens will be utilized for property determinations: one for the with-ply evaluations and the other for the across-ply evaluations. Tensile strength, modulus, strain and Poisson's ratio data will be obtained from these tests.

With-ply tensile specimens will be tested from RT to 5000°F. The tensile evaluations will be performed in a gas-bearing tensile facility. Specimens will be loaded to failure at the designated stress rate of 10 ksi/min (68.9 MPa/min).

Specimens will be tested for across-ply tensile from RT to 5000°F. The across-ply tensile evaluations will again be performed in a gas-bearing tensile facility.

Axial strain will be measured over a 1.00 inch (2.54 cm) gage length. Poisson's ratio will be measured at room temperature with two axial and two lateral strain gages wired in series.

Two types of compressive specimens will be tested: one for the with-ply and across-ply evaluations and another for the off-axis +/- 45° ply evaluations. Compressive strength, modulus, strain and Poisson's ratio data will be obtained from these tests.

With-ply compressive specimens will be tested from RT to 5000°F The compressive properties - initial modulus, strength, strain, stress-strain response and Poisson's ratio - will be measured in a gas-bearing, compressive facility.

Compressive specimens will be used for the RT to 5000°F across-ply compressive evaluations. The compressive properties - initial modulus, strength, stress-strain response and Poisson's ratio - will be measured in a gas-bearing compressive facility.

Compressive specimens will be used for the RT to 5000°F off-axis 45° ply compressive evaluations. The compressive properties - initial modulus, strength, strain, stress-strain response and Poisson's ratio - will be measured in the gas-bearing compressive facility.

The load deformation response will be transformed into the stress-strain response by simple scale factors.

Shear Tests

Five types of shear specimens will be tested. One will be used exclusively to obtain RT to 5000°F with-ply interlaminar shear strength using a double-notched specimen. The second will be used to obtain the pure across-ply shear strength, G13, using a Rumanian shear specimen. The third, fourth and fifth types of shear specimens will be used to measure shear moduli. A with-ply torsional (Pagano) shear specimen will be used to determine shear strengths G_{12} and G_{13} ($G_{12} = G_{21}$ and $G_{13} = G_{23}$ for a warp-fill, balanced material) at RT.[12] A direct shear specimen will also be used to determine G_{13} along with the with-ply interlaminar shear strength. Direct shear specimens will be tested at RT to 500°F. Plate shear specimens will be tested at RT for with-ply shear modulus (G_{12}) evaluations.

Thermal Characterization Testing

The thermal property test matrix is shown in Table III. There are six SRM materials to be evaluated: four standard density ablative materials and two low density ablative materials. Each material will be supplied by Morton-Thiokol in the form of plates approximately 15 inch x 15 inch x 1.5 inch thick and blocks approximately 8.5 inch x 8.5 inch x 4 inch thick. X-rays will be taken to determine density variations and locations of delaminations so that specimen cutting plans can be developed. After a preliminary machining the plates and blocks will be subjected to an ultrasonic inspection to locate any material irregularities not detected by the X-rays.

The blocks and plates will then be measured for bulk density. The densities of individual specimens will also be taken. For material that has to be tested at an elevated temperature, bulk material will be heated slowly to the required test temperature in an inert atmosphere (charred slowly). The char density will then be determined. This charred material will then be final machined to the desired specimen configuration.

Testing for thermal properties will include determinations of specific heat (heat capacity), thermal conductivity and thermal expansion. Thermal conductivity will utilize the comparative rod apparatus and radial inflow equipment. Determinations of thermal expansion will use the method of quartz dilatometry for temperatures up to 1800°F and the method of graphite dilatometry for temperatures above 1800°F and up to 5000°F.

Table III. Thermal Test Matrix

	Thermal Conductivity WP	Thermal Conductivity AP	Coef. Thermal Expansion WP	Coef. Thermal Expansion AP	Specific Heat	Temp (°F)
PAN CARBON PHENOLIC						
Fiberite - MX4961	2	2	3	3	3	RT
Cont. T-300, 3K	3	3	↓	↓	↓	2500
Union Carbide	3	3	↓	↓		5000
USP - FM5879	2	2	2	2	3	RT
Cont. CCA-4, 3K	3	3	↓	↓	↓	2500
Hitco	3	3	↓	↓		5000
Fiberite - K411	2	2	2	2	2	RT
Staple PAN, SWB-8	2	2	↓	↓	↓	2500
Stackpole	2	2	↓	↓		5000
USP - FM5834A	2	2	3	3	2	RT
Staple PAN, PCSA	3	3	↓	↓	↓	2500
Polycarbon	3	3	↓	↓		5000
LT WT PAN CARON PHENOLIC						
Fiberite - MX134LD	2	2	2	2	2	RT
Cont. T-300, 3K, PW	3	3	↓	↓	↓	2500
Union Carbide	3	3	↓	↓		5000
USP - FM5908	2	2	2	2	3	RT
Cont. PAN, 6K, Leno	2	2	↓	↓	↓	2500
Hitco	3	3	↓	↓		5000

Fabrication and Processing Studies

A fabrication and processing development plan has been developed to evaluate the PAN based carbon-phenolic materials being considered for use as ablative liners on the SRM Block II nozzle. The following outline describes the four phases of the fabrication and processing plan:

I. Evaluate the four standard density PAN materials selected for consideration; two each from Fiberite and U. S. Polymeric. Each material will be characterized by Rheometrics Dynamic Spectrometer (RDS) and Differential Scanning Calorimeter (DSC) for thermal response behavior. Small test rings will be fabricated to test the PAN materials for the properties of Table IV by the methods of STW5-2845.

TABLE IV: PAN MATERIAL TESTING

CURED MAT'L TESTS	SAMPLE SIZE	TEST SETS/RING
—		
	0.5" x 0.5" x 1.0"	3
Density, gm/cc	0.3" x 0.3" x 0.6"	3
Compressive Strength	0.3" x 0.3" x 0.6"	3
Tensile Strength	0.5" x 0.5" x 1.0"	1
Resin Content	0.5" x 0.5" x 1.0"	1
Residual Volatiles		

UNCURED MAT'L TESTS	SAMPLE SIZE	NUMBER OF TESTS
—		
	5 plies,	3-isotherms each, 8 hours
RDS	0.5" x 0.4" ea.	per test
		5-7 cure simulations, 20-24 hours per test
	20 mg	10 per material type
DSC		(H,Cp, Onset)
		1 hour per test
	3 plies, 4" x 4"	5 per material type
Volatile Content		

II. Evaluate the two low density PAN materials selected for consideration; one each from Fiberite and U. S. Polymeric. The two low density materials will be characterized by the same methods as in Phase I.

III. Evaluate co-wrap and co-cure behavior of forward and aft exit cone liners. Interface integrity will be evaluated with subscale rings. Three test rings for each material with a nominal size of 5" ID X 7" OD X 3" high will be used as the source of samples. Five tensile pull specimens will be machined from each ring and pulled to the breaking point. The interface will be visually and radiographically inspected before machining.

IV. Evaluation of recommended materials in full scale rings will be accomplished. Full scale rings will provide thermal profile data needed to establish cure cycle parameters as well as providing material to test for part quality and consistency. One ring of each configuration will be thermocoupled and cured based on RDS and DSC material characterization data. Cured rings will be NDT tested, sectioned, samples extracted, and tag-end tests made per STW5-2845C methods for density, compressive strength, tensile strength, etc. The other ring of each configuration will be thermocoupled and cured (modifications to cycle as seem necessary from the results of the first ring). Cured rings will be NDT tested, sectioned, etc. A minimum of 2 test articles per ring configuration will be tested.

A preliminary schedule for the fabrication and processing D and V plan for the ablative liner materials is given in Figure 5.

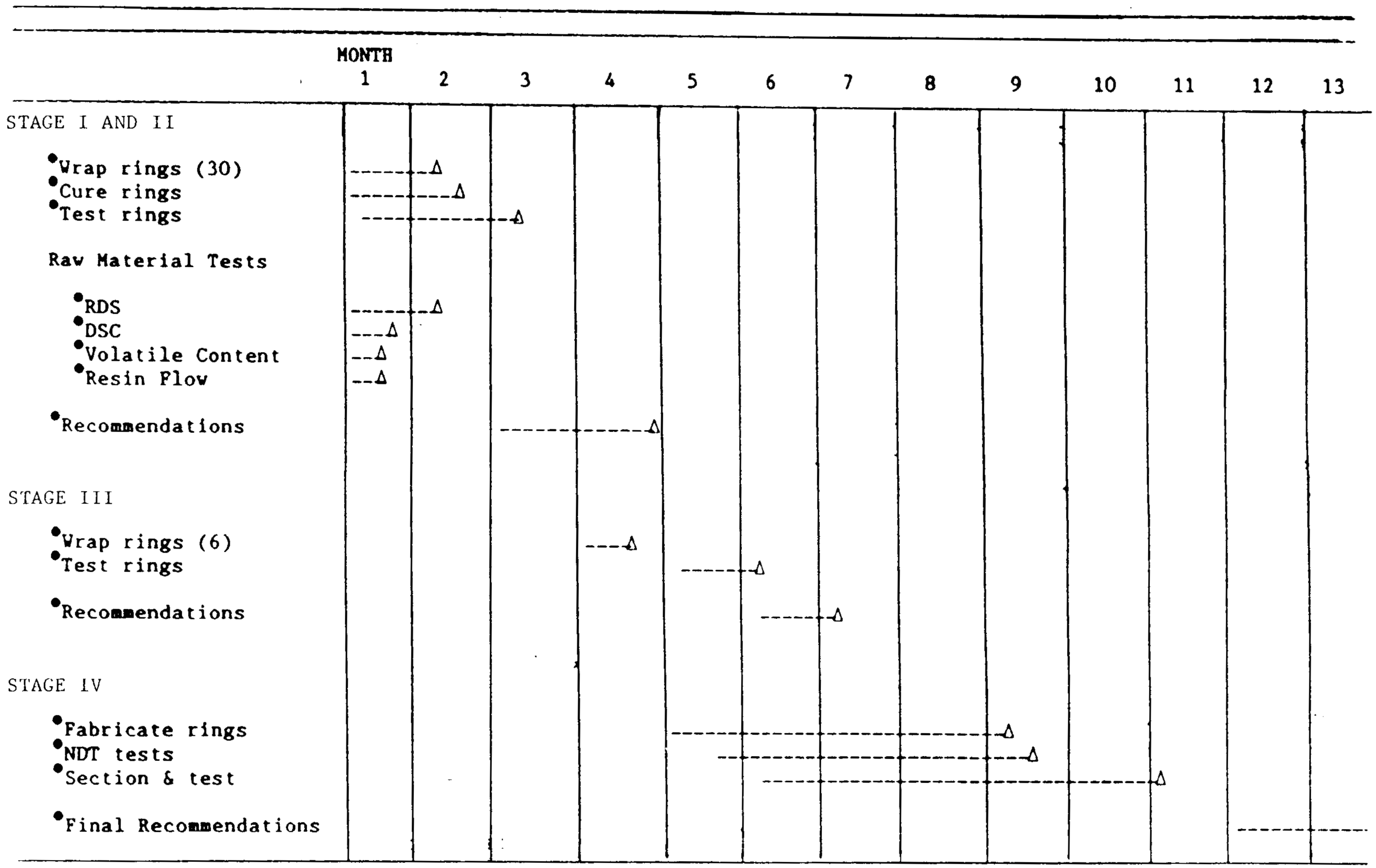

Figure 5 . Fabrication and Process Development Plan Schedule

4.4.2 Flex Bearing

The flexible bearing consists of a flexible core contained between two steel end rings and is thermally protected by a second sacrificial flex bearing. The flexible core is a laminated structure consisting of alternating steel shims and polyisoprene rubber pads. The thermal protection bearing consists of carbon cloth phenolic end rings and a core of laminated carbon cloth phenolic shims and polyisoprene rubber pads.

Because of reuse requirements the flexible bearing will require development testing of the materials and the bearing assembly. The current primary elastomer candidate, and the Block II SRM flexible configuration concept will be fully tested and characterized relative to elastomer strain, life cycle and torque characteristics, pivot point shift and deflection characteristics, and overall performance capability.

The candidate elastomer will be fabricated into a significant number of tensile, shear and torsional test coupons. These coupons will be tested and evaluated to establish the physical and performance properties and characteristics of the elastomer. Processes and fabrication sequences will be developed and demonstrated,and checkout of the fabrication tooling and fixtures and test fixtures will be accomplished. Three full scale prototype bearings will be designed analyzed fabricated and subjected to a comprehensive test sequence to obtain full performance characteristics, maximum load and life cycle capabilities, to determine the pivot point shift and axial deflection envelopes and to verify interfaces with the current actuation system. Results of these test and evaluation efforts will be fed not only into the final design of the flexible bearing and nozzle but into the design of the control systems for the current actuation system.

Materials Testing

All structures in the flexible bearing assembly will use either D6AC steel or carbon cloth phenolic which are both used in state of the art applications and need no further characterization at the material level and need only to be tested at the component level.

The DL-1514 polyisoprene elastomer will be tested for bulk modulus, rheometric properties, tensile properties, shear properties and peel adhesion as shown in Table V. In addition, a real time aging program to determine the effects of aging on the shear properties of the elastomer using QLS specimens will be initiated at the earliest possible time.

Component Testing

Three full scale prototype bearings of both the structural and thermal configurations will be fabricated and tested to obtain pivot point data, shim stresses, vectoring torque, stiffnesses, and other structural and performance data and structural margins of safety. The tests to be conducted are outlined in Table VI. These tests will also provide data on flex bearing/actuation system compatibility.

4.4.3 Structures

The graphite epoxy filament wound aft exit cone overwrap system proposed for the SRM Block II nozzle is similar to the ones used on D5 and C4 as well as that proposed on SICBM First Stage. The material characterization of these graphite/epoxy systems is sufficient to support the thermal/structural analysis of the exit cone. The extent of the development work that will be required is, therefore, restricted almost exclusively to fabrication and processing studies. The development and verification plan for the graphite epoxy overwrap process is outlined in Table VII:

TABLE V: ELASTOMER TEST MATRIX

	Description	Total Specimens Material* TR-3005		Total Specimens Material** DL-1514	
I.	Bulk Modulus, 3" x 3"x 5"	3		2	
II.	Rheometer Evaluation	3		2	
III.	Quadruple Lap Shear (QLS) Specimens				
A.	1"x 1"x 0.075" Thick Square Standard C-3 Specimen	84		84	
B.	4"x 4"x 0.3" Thick Square Specimen	60		60	
C.	8"x 8"x 0.3" Thick Square Specimen	60		60	
D.	3" I.D. x 9" O.D. X 0.3" Annual Specimen	60		60	
IV.	Tensile Specimens				
A.	Standard Dogbone Specimens	27		27	
B.	Disc Specimens				
1.	2" Diameter Solid Ring	18	(39 total)	18	(39 total)
2.	4" Diameter Solid Ring	3		3	
3.	6" Diameter Solid Ring	9		9	
4.	3" I.D. x 9" O.D. Annual Ring	9		9	
C.	Cone Specimen	30		30	
V.	Peel Tests - Standard Peel Test Specimen	12		12	

*Current Material - Testing Complete

**Primary Candidate Material

TABLE VI: FLEX BEARING TEST MATRIX

BEARING NO	TESTS TO BE CONDUCTED	OBJECTIVES
All	Actuation (Standard duty cycle)	Obtain data on torque, pivot point and vectoring stresses in components
All	Axial deflection (with thrust relief piston)	Determine compressive spring constant and component stress levels under simulated motor pressure levels
All	Axial deflection (Flat plate)	Determine compressive spring constant, component stress levels and self vectoring tendencies
1	Structural strength (to 1.4 times MEOP loads)	Verify structural margins of safety
2	Life Cycle (Multiple duty cycles)	Establish reusability of structural flex bearing
3	Tensile limit[1]	Measure tensile spring constant, assess structural limits and tensile fatigue characteristics

[1]This test is to be conducted with the structural bearing only. All other tests will utilize both structural and thermal bearings in tandem.

TABLE VII: OVERWRAP FAB. & PROCESS DEVELOPMENT

Overwrap and Cure Graphite Epoxy
- Use Various Winding Techniques
- Low Density Substrate
- Standard Density Substrate

Evaluate for Adhesive and Interface Characteristics
- Shear Ring Specimens
- Tensile Adhesion Specimens
- Determine Pot Life of Interface Adhesive

Evaluate Bond of External Insulation to Graphite Epoxy
- Tensile Adhesion Specimens
- Peel Specimens

The test matrix for the graphite epoxy overwrap fabrication and process study is included in Table VIII.

TABLE VIII: GRAPHITE-EPOXY-OVERWRAP PROCESS TEST MATRIX

	Temperature		
	Ambient	Max Low	Max High
Graphite Epoxy Overwrap to Liner Material			
Shear Ring Specimens (per adhesive)	10	10	10
Tensile Adhesive Specimens (per adhesive)	10	10	10
External Insulation to Graphite Epoxy			
Tensile Adhesion Specimens (per adhesive)	10	10	10
Peel Specimen (per adhesive)	10	10	10

4.4.4 Exit Cone Severance Device

The same linear shaped charge (LSC) which is used on the present SRM will be used on the Block II nozzle. This device is fully characterized and needs no further development.

4.4.5 Nozzle Plug/Shield

The foam nozzle plug is similar in design to the one used on the HPM SRM and will be characterized during the current SRM redesign activities.

4.5 Case Assembly and Seals

The Block II SRM case will be fabricated from MAR-T250 steel in a segmented configuration. Billets will be forged into case segments, the combination of which will make the four segments of an entire SRM motor case (as on the previous SRM design). The maraging steel will permit the case forgings to be welded into casting segment length pieces and heat treated without quenching. The assembled segments will have lengths identical to the previous SRMs. The segments will be joined by a Block II tang and clevis style field joints having a capture feature, and redundant gas seals. High strength MAR-T250 steel has been selected for the case development because of its strength (250,000 psi ultimate) and enhanced corrosion resistance. Fracture mechanics and environmental characteristics appear favorable and are to be thoroughly characterized in the course of development.

The joints will have detailed stress analysis performed with follow-up testing of the joint rotation in full scale testing. Joint Environmental Simulation (JES) tests followed by development motor, and qualification motor static firings will be conducted with the goal in mind of certification.

The objective of seal development is to develop a system to guarantee the absence of gas travel through joint interfaces. Candidate seals will be investigated during development. Sealing material physical properties will be fully characterized with respect to temperature, compression, anticipated chemical interaction, and time. Seal, bench and full size tests will be performed to verify all important aspects pertaining to the sealing function.

All seals will undergo testing for capability to maintain contact with receding metal surfaces while continuously exceeding a minimum fraction of their original compressive force. These tests will involve a minimum of five specimens at each condition of temperature and squeeze. Gap opening distance and rate will duplicate motor pressure rise rate for applicable joint locations. These tests will be performed with and without pressure which increases with gap opening distance.

New seals will be tested in an apparatus which focuses a hot gas jet against the seal. Duration and intensity of the exposure is controlled by one of two orifice sizes and an eight cubic inch reservoir which is filled with combustion gases originating from a five inch cylindrical perforate motor. Seals response to a hot gas pressure wave will also be characterized in a modification of the same test fixture in which soot blow-by or heat effects are noted.

Regular size seals will be tested in seventy pound motor configurations having full scale joint dimensions (aside from the radial measurements which will be much smaller).

Seals will be included in tests which characterize erosion rates. Nine tests will be run: three each at a minimum, nominal and maximum expected heat transfer coefficient.

Ten full scale vertical assembly tests will verify damage free containment of 50 psi cold gas by losing less than one psi drop in ten minutes and by visual inspection of the seal following test. A minimum of three combinations of flight hardware will be used.

Seals will be tested to determine extrusion characteristics under pressures up to MEOP.

All seals on flight hardware will be capable of being leak checked following assembly.

Flight certification will be verified by seven full scale SRM static tests. Three will be development motors and four will be a qualification motors. The motors will be processed, assembled and horizontally static fired for the full 120 second duration. Joint deflection will be measured by miniature transducers, pressure and temperature transducers will monitor conditions between the seals and barrier, and visual inspections will follow the tests.

Materials used as thermal barriers in the insulation will be demonstrated to maximize heat capacity, tortuosity and internal surface area to facilitate the rapid diffusion and transfer of kinetic and thermal energy from potential hot gas leaks to the barrier.

4.5.1 Case Description

The block II SRM case is fabricated from 18 percent nickel, titanium-strengthened, 250-grade maraging-steel in a segmented configuration. The segment concept consists of an aft segment with integral nozzle fixed housing, a stiffened aft cylindrical segment with ET attach provision, two cylindrical segments and a forward segment Block II tang and clevis joints allow field assembly while girth welds join the roll-formed cylinders into casting segments.

High strength (250 ksi) 18 percent nickel, titanium strengthened maraging steel (MAR-T250) was selected for the Block II case development because of its higher yield and ultimate strengths with the same fracture toughness as the D6AC low alloy steel that has been proven successful in the original Space Shuttle SRM cases. The maraging steel develops its full strength by a solution anneal and aging process which offers potential for improved consistency over quench and temper processes for low alloy steels.

The 146-inch diameter, 116-foot long case is made up from 12 forgings joined by girth welds into four casting segments and an aft closure which includes the nozzle stationary shell. These casting segments are joined with Block II tang and clevis joints at final assembly. The aft closure to aft casting segment joint is assembled prior to shipment from Wasatch. The other three field joints are assembled at the launch site.

The forward casting segment consists of two cylindrical segments and a 1.6:1 elliptical dome. Two cylindrical segments are required due to the limitations on the length of the present shear forming equipment. The dome will be forged and machined from a pancake billet and will include the forward stub skirt and the flange for the ignition system attachment. The aft closure will be assembled from two ring rolled forgings with a girth weld near the ring which reinforces the cone to sphere transition. The cone and reinforcement ring may be combined in one forging. This closure interfaces with the aft casting segment with a Block II clevis joint and interfaces with the aft end ring of the nozzle flex seal with a face-sealed, bolted joint. The cylindrical casting segments are fabricated by girth welding two cylindrical shear formed case segments, heat-treating the assembly and finish machining the tang and clevis details. The aft casting segment case will be fabricated by girth welding three shear formed cylinders that include rolled-in buildups for external tank and stiffening ring attachments. The ET attach stub rings will be machined from a thickened region of the cylinder, but the stiffness ring stubs may be welded to less thick buildups on the case.

The case wall thickness is sized to carry the pressure vessel loads after accounting for pressure drops along the length of the case, biaxial improvement, machining tolerance, and refurbishment material removal. For the MAR-T250 the ultimate strength criteria (with the 1.4 factor of safety) will govern the design size. The yield criteria with a factor of safety of 1.2 will be satisfied when the ultimate criteria is satisfied.

4.5.2 Case Requirements

The SRM case must provide structural capability for pad loads, motor operation (including all flight loads), water impact loads, and handling loads. Further requirements are associated with interfacing with the SRB and ET components.

Motor operation requires a factor of safety of 1.4 in the material strength through detailed design using a high strength steel. Case pressurization, SRB weight and design, ET attachment loads, and flight loads all require detailed investigation and design to ensure proper case performance during ascent of the Shuttle. Case recovery and recycle requirements are established by accounting for water penetration, cavity collapse, splashdown, salt water environment, refurbishment, and handling effects.

The production of a reliable, safe, high performance SRM necessitates a case with precise dimensions to allow consistent loading, fitting and interfacing. The requirement of 20 uses produces increased emphasis on cyclic and environmental flaw growth. Fracture mechanics is one of the design tools used to assure the reliable performance of the Shuttle SRM case in connection with reuse.

Important features of the case development approach are:

1. Early demonstration of case material process using existing tooling with a secure alternate material backup.

2. Case design evaluation through further trade studies, fabrication considerations, and detailed cost analyses. (Reliable, minimum cost alternatives that achieve performance enhancement will be selected).

3. Maximum utilization of redesign SRB methods and techniques for verification analyses and tests.

4. Full integration of test and analysis to provide method of verification across the full range of applied and induced loads and environments where testing is not always feasible or even possible.

Since the case requires the longest lead time of any SRM component, early design configuration establishment is necessary to initiate the required procurement actions. While major materials and tooling equipment are being produced, supporting activities are scheduled to obtain earliest practical identification of material characteristics and process demonstrations.

Many of the design features of the Block II baseline case design are logical extensions of the RSRM, HPM, & SRM. These three programs provide a large amount of test data and many analyses to apply to the verification of the Block II case assembly.

Since the Block II case uses a material that is new to the Shuttle program, the database must be assembled by literature study and testing to achieve the high standard essential for man-rated flight systems. The fabrication processes must be proven, and the detailed design and optimization must be completed. The resulting components must be verified through carefully integrated testing and analysis work in the development and qualification programs to certify that the component designs satisfy all essential requirements and meet the performance and reliability goals of the system.

4.5.3 Case D&V Plans

4.5.3.1 Design Studies and Optimization

The fully detailed design of the Block II SRM case will be developed from the concept design presented in this document. Several concepts that have emerged during this study have not yet been fully developed. These will be included in trade studies during the initial design phase of the project. These concepts include:

(a) Integration of the kick ring, aft skirt attach, and case joint features into a single design feature. Under the study groundrules the interfaces referenced in the CPW1-1900 include providing an aft skirt for kick ring and skirt attach. Consequently, the baseline case design is restricted by the artificial differentiation of component design authority.

(b) During the welding development program. The feasibility of performing the weld prior to final cold, or hot and cold, ring forging will be studied. The advantages of working the weld material through the forging and shear forming processes are potential grain refinement and the elimination of the weld degradation factors for design.

(c) Circumferential case alignment may be accomplished by a combination of local boss buildup on the clevis leg with special tooling to round and align the segments for final assembly. This offers potential to eliminate the stress concentration effect of the three slots used in the present SRM to achieve the axial and circumferential alignment.

(d) Optimize the integration of the nozzle and aft closure designs to establish the minimum diameter for the sphere to cone shell transition. This study would involve dome contour (elliptical, toroidal, spherical), nozzle vectoring clearance, nozzle submergence, internal flow and insulation requirements, and case/closure joint location.

(e) Optimize the aft segment stiffener design to the splashdown loading conditions.

After establishing the final design, fully detailed analysis reports will be prepared for the PDR. These will be further supported by full scale component testing and analysis correlation before CDR.

4.5.3.2 Process Demonstration and Development

Since the baseline case design uses a relatively new material in large components, the metal working processes must be proven by demonstration with the working of 20,000 to 35,000 pound ingot material. Since the design requires welding of forgings, the weld technique selection and the weld process automation details must be worked out. These aspects of the case manufacturing must be proven in a pre-full scale development process demonstration program.

4.5.3.3 Material Characterization

Although the maraging steels have been used in large and small rocket motor cases for 20 years, the titanium strengthened grades are relatively new. They were formally introduced in 1981 at the Paris Air Show. The high reliability requirements for the Space Transportation System components will require additional material characterization testing on large ingot, shear formed material. It is anticipated that the specification for the SRM case material would control composition and inclusion content more strictly than the current specification for the material (MIS-36275). Consequently, the variability of properties can be expected to be quite small.

The characterization efforts will be directed toward establishing a database with adequate sample size to assure good estimates of "A-Basis" design allowables for strength, fracture toughness, and stress corrosion susceptibility. In addition to forged material testing, the weld material will be tested to establish design allowables and acceptance tolerances for non-destructive inspection. Additional substantiation of acceptable rework standards will be developed as required to allow economical fabrication of case components.

Much of the fundamental strength, stiffness and elongation data is available from material suppliers and is in the literature. Some of the fracture toughness, low cycle fatigue and flaw growth data must be developed for the specific SRM case material and process. Special attention will be focused on the weld material to assure adequate reliability of the welded case segments. By solution anneal and aging after welding, virtually all of the parent metal properties are reportedly recoverable. This will be verified in the test program.
The planned case material characterization schedule is presented in Figure 7.

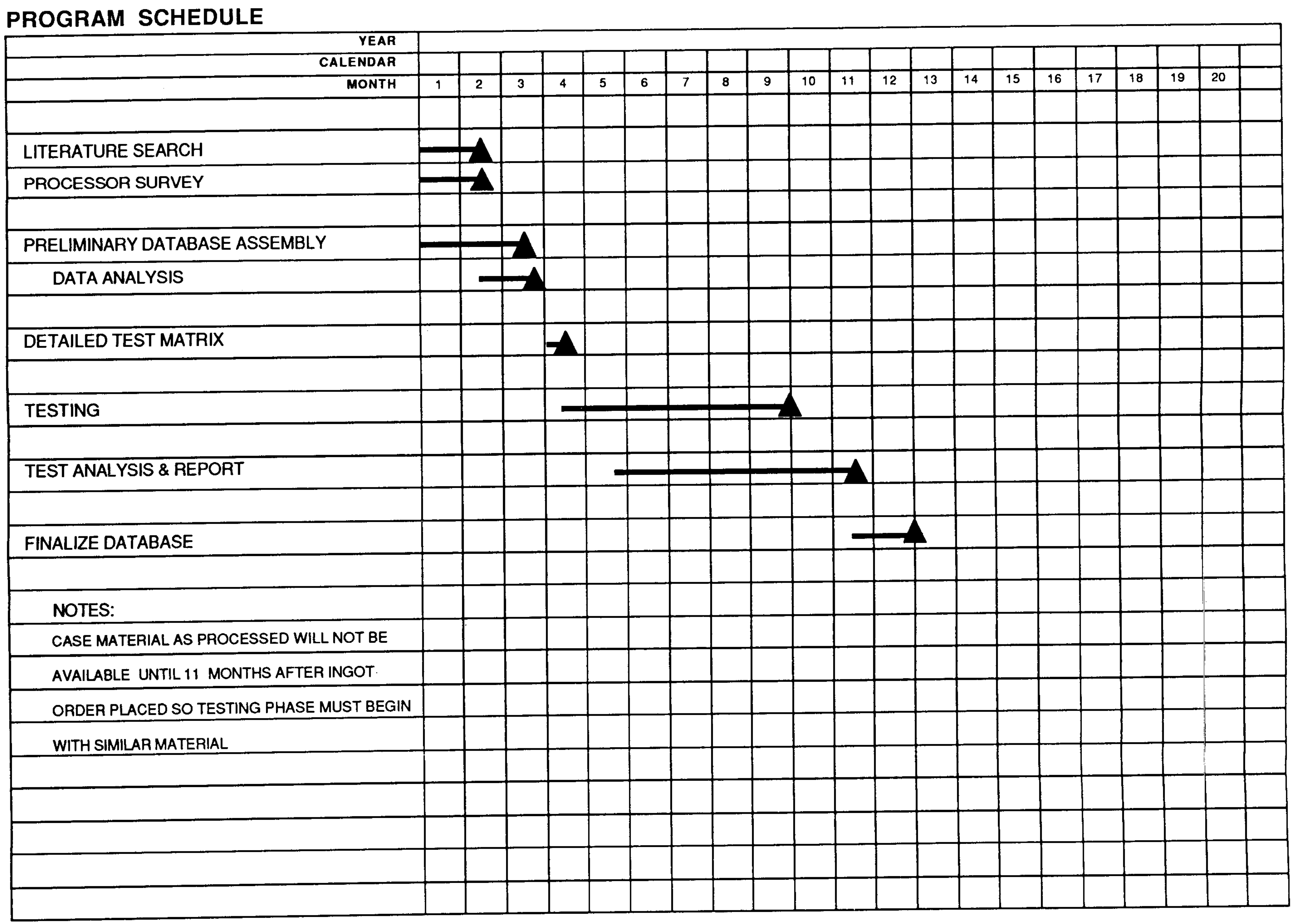

Figure 6 MATERIAL CHARACTERIZATION SCHEDULE

4.5.3.4 Case Assembly Verification

The Block II case assembly is considered to be a new design component even though the general design and fabrication techniques are proven concepts. Consequently, complete development and certification must be accomplished. The acceptance tests and criteria must be planned to assure all components will conform to the approved configuration.

Analysis will play a key role in the certification of the Block II case. Mathematical models based on state-of-the-art analytical procedures will provide the primary verification that the case and its components and subsystems meet all design and performance requirements. Analysis provides a method of verification across the full range of applied and induced loads and environments where testing is not always feasible or even possible.

Analytical model development will be closely integrated with major test activities to assure that the models accurately represent hardware behavior. This integration will be accomplished by developing analytical models of all major test articles. Pre-test analyses will be conducted to predict the test article response and to aid in the placement and ranging of test instrumentation. Following completion of each test, the test results and analytical predictions will be correlated with differences understood and resolved. This correlation of test and analysis results will provide proven analytical techniques and validated models allowing analytical verification of design adequacy with respect to loads and environments for situations in which it is not feasible to directly test.

4.5.3.4.1 Hydroburst

Both subscale and full scale hydroburst tests will be required to substantiate the biaxial improvement, flaw tolerance and material strength. To assure simulation of the cyclic loading associated with the refurbishment and reproofing of each case segment, a cyclic loading followed by burst testing of an abbreviated case consisting of forward, center, aft, and aft closure segments will be accomplished in the development program.

4.5.3.4.2 Structural Test

Flight load capability will be demonstrated as part of the "Structural Test Article" testing at MSFC to be scheduled as an essential part of the case qualification program.

4.5.3.4.3 Joint Environment Simulation and Transient Pressure Tests

The vertical launch environment effects on the Block II case joints will be evaluated with fully instrumented JES tests. These tests will provide verification data for seal gap changes and effectiveness of the Block II case sealing system (see Internal Insulation Section). These tests will be supplemented with Transient Pressure Test Articles which add the external loads to the full scale test components during the simulated ignition pressure transient.

4.5.3.4.4 Static Test

Case behavior during motor operation will be determined during three development motor static tests.

4.5.3.5 Acceptance Tests

Each new and refurbished case segment will be proof tested at a pressure in excess of MEOP to assure flaw detection that could compromise the successful completion of six additional mission cycles. The proof test factor has been calculated as 1.08 with the MAR-T250 material data.

Detailed raw material acceptance data requirements will be developed for the MAR-T250 material specification. The heat treatment process will be validated from excess material coupon testing from each case component.

4.5.3.6 Qualification Tests

With the development hydroburst test and structural test confirmed with advanced modeling and characterization, the case strength certification will be achieved. The joint response to transient pressure and repetitive loading will be defined over the range of operating conditions with the joint environmental simulation test which allows detailed deflection measurements for analytical correlation. Four full scale static tests will provide the final qualification of the motor components.

4.6 Propellant

DL-H396 propellant has been selected as the propellant for the Block II SRM. It offers potential for a significant performance gain in the "heads-up" mode. It is a modified Peacekeeper Stage I propellant.

DL-H396 propellant contains a R-45HT/HTPB polymer, aziridine bonding agent, IPDI (isocyanate curing agent), aluminum, and ammonium perchlorate. Iron oxide is used as a burn rate catalyst. The formulation, mechanical, and theoretical ballistic properties are presented in Table IX. The physical, mechanical, and ballistic properties of DL-H396 will meet or exceed the Block II SRM design requirements.

The SRM Block II propellant grain design (Figure 8) is essentially the same as the current SRM grain design. It consists of a forward segment with an 11-point star that transitions into a cylindrical perforated (CP) configuration in the cylindrical portion of the segment, two identically configured center segments that are tapered CP configurations, and an aft segment with a dual taper CP configuration. The aft face of the forward segment, both ends of the center segments, and the forward face of the aft segment are inhibited to achieve the required thrust-time profile.

4.6.1 Propellant Development and Tailoring

DL-H396 propellant will be designed, developed and qualified to meet all the requirements for the Block II SRM CEI specification, CPW1-1900. The propellant tailoring program will optimize processing properties, tailor burn rate, and characterize mechanical properties. Process optimization will consist of varying ground-to-unground oxidizer ratio to achieve the lowest end-of-mix viscosity, optimum rheology, pot-life and castability. Burn rate will be tailored with Fe_2O_3 catalyst. Mechanical properties will be characterized to define the curative-to-polymer ratio for maximum stress and strain at maximum stress.

The initial effort will encompass a grain analysis and grain stress analysis in conjunction with a propellant tailoring program. This will verify the compatibility of the propellant ballistic and physical properties and the SRM grain design. Repeatable ballistic and physical properties from mix-to-mix and motor-to-motor will be ensured through the use of raw material acceptance testing, propellant standardization procedures, and in-process inspection and acceptance testing. A theoretical combustion stability analysis will be conducted on the selected propellant and grain design. These data, coupled with the test data obtained from T-burner tests, will establish the overall SRM combustion stability. The T-burner (A tubular burner) is a test motor that either oscillates spontaneously or is made to oscillate through pulsing. Measurements of the logarithmic growth rate of the oscillations and/or the logarithmic decay rate for various propellant configurations yield data which provide a measure of the propellant stability characteristics.

TABLE IX: TYPICAL PROPELLANT DESIGN DATA

Formulation	Weight/Percent
R-45HT/HTPB Polymer	11.02
HX-752 Bonding Agent	0.15
Iron Oxide	0.2
Aluminum	19.00
Ammonium Perchlorate	68.92
IPDI Curing Agent	0.71

Mechanical Properties (JANNAF Uniaxial)	Temperature 77 Deg F
Initial Modulus (psi)	578
Strain at Max Stress (%)	45
Stress (psi)	142

Ballistic Properties (P_C = 715 psia, 60 deg F)	Chamber	Nozzle	Exit
Flame Temperature (deg K)	3522	3337	2327
Molecular Weight (lb/lb-mole)	29.29	29.54	30.53
Specific Heat Ratio	1.129	1.129	0.998
Blowing Coefficient (corrosivity index)	0.0935	0.0901	0.0809
Characteristic Velocity (fps)			5,173
Solid Density, Theoretical ($lb/in.^3$)			0.06508

Burn Rate Data at 1000 psia,	
60 Deg F	0.454 inch/sec
Burn Rate Exponent, n	0.38
Effective Nozzle Specific Heat Ratio	1.13
Vacuum Theoretical Specific Impulses	280.4 lb-sec/lb
Expansion Ratio	7.72:1
Absolute Viscosity of Chamber Gas	$1.63X10^{-7}$ lbF-sec/in-ft

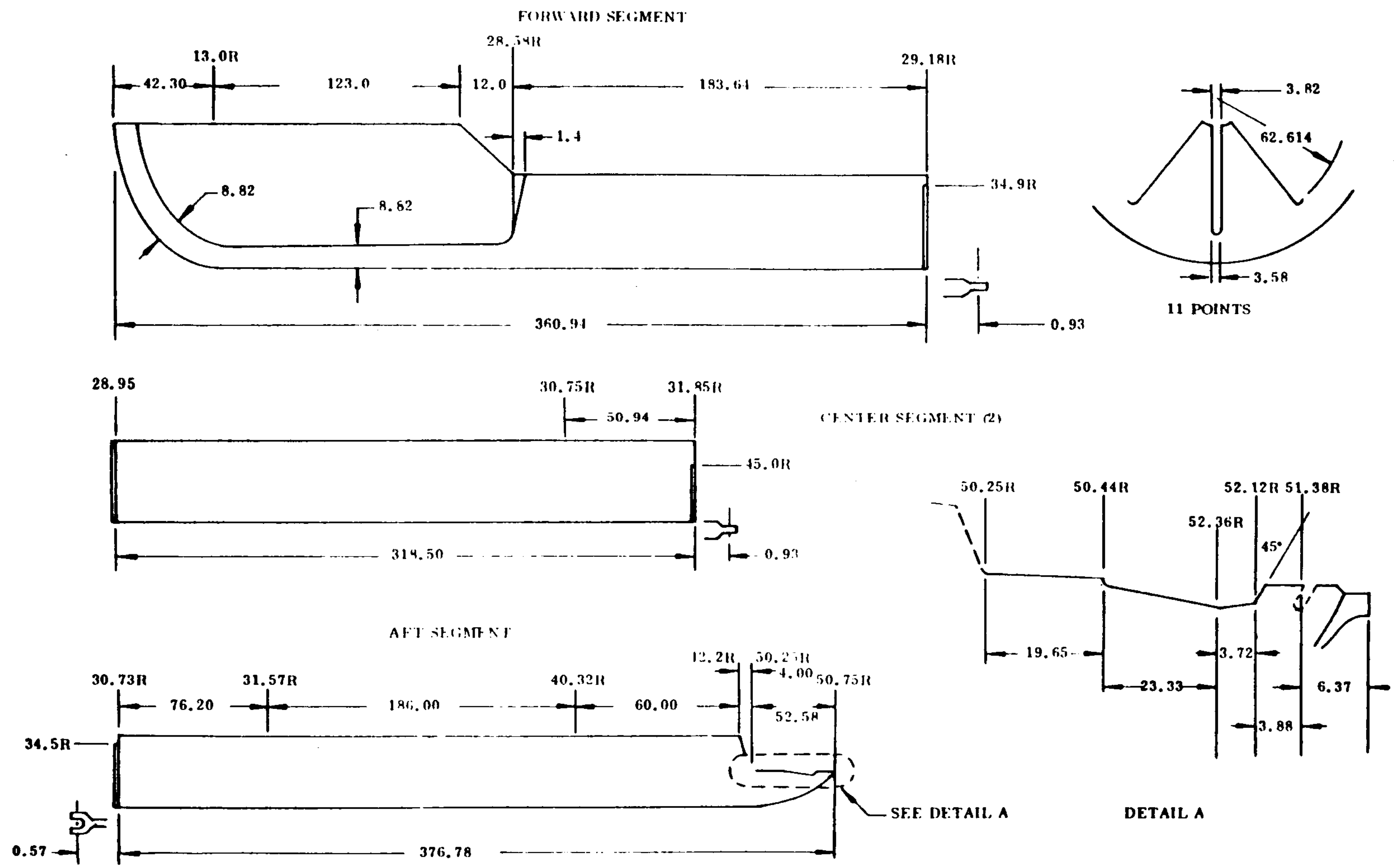

Figure 7 Propellant Grain Design

The SRM design that results from the analysis and testing will be formalized by the preparation of design drawings, propellant specifications, raw material specifications, and manufacturing plans. The propellant manufacturing plans will be the result of detailed processing studies, which will determine effects of casting delays, casting rates, mold release agents, cool-down times, cure rate, plus the effects of storage, vacuum conditions, and surface temperature.

Most of the tests and procedures used for the development and qualification of TP-H1148 propellant will be used when developing and qualifying DL-H396. Ballistic and physical properties of DL-H396 are expected to be similar to TP-H1148 except that DL-H396 is thought to have improved processing characteristics and better mechanical properties. Minor burn rate tailoring will be done to achieve the desired Block II SRM rate. The Block II SRM propellant testing will incorporate a thorough dynamic mechanical properties testing matrix. Table X shows all propellant testing currrently expected to be accomplished during development and qualification.

The propellant ballistic and physical properties are expected to be similar to those of other HTPB motor propellants. Changes in burning rate will be utilized to meet Block II SRM requirements. This will be accomplished by using a different oxidizer particle size distribution and/or modifying the burn rate catalyst content. Confirmation of these expectations will be accomplished by manufacturing five-gallon propellant mixes.

Five-inch CP motor test data and dogbone specimens from the five-gallon mixes will provide an early indication of the required percent ground oxidizer to achieve the desired burning rate and the polymer-to-curing agent ratio necessary for the required propellant mechanical properties. Three levels of percentage iron oxide (Fe_2O_3) will be used to establish the amount of Fe_2O_3 required to meet burn rate and the burning rate as a function of Fe_2O_3 relationship. Three levels of polymer-to-curing agent ratio (HTBP/IPDI) will be used to determine the propellant mechanical properties as a function of HTPB/IPDI ratio and establish the required HTPB/IPDI ratio. The propellant mechanical properties will be confirmed by testing the dogbone specimens. Testing for total-solids content will ensure correctness of raw material weights for each five-gallon mix of the basic formulation. Characterization of the burning rate behavior below 3,000 psi will be done with 5-inch CP motors, utilizing propellant formulation with the required amount of Fe_2O_3 as established in the preceding test procedures.

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Table X. Propellant Tests

PROPELLANT TESTS

	Propellant Tailoring	Propellant Standardization[1] (4 mixes)	Development Motors (4 motors)	Qualification Motors (3 motors)
Strands	No strands	Cast 6 per 600 gal mix. Test at least 3 per mix Total = 24 Test = 12	Cast 9 per mix Test at least 3 per mix Total 9 x 40 x 4 x 4 5,760 Test 3 x 40 x 4 x 4 = 1.920 Standardization Strands Total = 36 x 2 = 72 Test = 36	Cast 9 per mix Test at least 3 Total = 9 x 40 x 4 x 3 = 4.320 Test = 1.920 Standardization Strands Total 36 x 2 = 72 Test -23 x 2 =24
5-inch CPs	3-5 gal mixes at 3 different oxidizer grind ratios Total mixes = 9 per vendor 3-5 in. CPs per mix Total = 27 per vendor. Test all 27 Assume 2 AP vendors Total 5-in CPs = 54	Four 600 gal mixes with six 5-in CPs from each mix Total = 24 Test all 24 Four 5 gal mixes with three 5-in. CPs from each mix Total = 12 Test all 12	See Table 5-in CP Load and Test test schedule Standardization 5 in. CPs Total = (24+12)x 2 = 72 Test = 72	Standardization 5 in. CPs Total = (24+12) x 2 = 72 Test = 72

Table X. Propellant Tests (Cont)

	Propellant Tailoring	Propellant Standardization[1] (4 Mixes)	Development Motors (4 Motors)	Qualification Motors (3 Motors)
Physical Properties Stamped JANNAF in/min at 77 deg F	Three loaves per Test at least 6 dogbones per mix 6x9x2=108	Make 3 loaves per 600 gal mix Total = 12 Test at least 6 dogbones per mix Total = 24 Make 3 loaves per 5 gal mix Test at least 6 dogbones	One loaf per mix Test 1 of 3 loaves Total loaves 40x4x4 = 640 Total tested 1/3(640) = 213 3Six dobgones per test = 1,278 Standardization samples Total loaves=24x 2=48 Total dogbones = 4x2x2x6=96	One loaf per mix Total = 480 Test 4 per Pull 2 segment Total = 48 loaves Total dogbones = 288 Standardization samples Total loaves=12x2 =24 Total dogbones=8 x6 = 48
Chemical Properties Infrared and Total Solids	Three tests per mix Total = 3x9x2=54	One pint per 600 gal mix Total = 4 pints Three tests per One pint per 5 gal mix Total = 4 pints Three tests per pint	One quarter per mix Total=1x40x4x4=640 quarts Standardization Data Total=8 pintsx2 = 16	One quarter per mix Total=1x40x4x3= 480 quarts Standardization Data Total=8 quarts

Comments:
[1]Standardize for every 2 motors - throughout program - use 4 full scale mixes and four 5 gal subscale mixes. Total solids and burning rate data will be determined during the DDT&E period.

Assumptions:
1. Forty mixes per segment - mixes weigh lb each.
2. Pull 1 cup (quart) for chemical properties per mix.
3. Reserve loaves are available if additional data per segment becomes necessary.
4. Four full scale processing practice mixes will be made prior to the first standardization.
5. Flight motors will have the same process acceptance tests.

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Burning rate tests will be conducted to evaluate the propellant burning rate sensitivity to the direction of propellant flow into the motor during casting; i.e., perpendicular versus parallel to the motor center line. These tests will determine burning rate sensitivity to flow direction.

4.6.2 Propellant Qualification:

Propellant and propellant/liner/insulation bond compatibility qualification testing will be done to ensure that the mechanical properties have not been affected during the tailoring program. Propellant strain endurance and propellant/liner/insulation bond strengths will be evaluated. Five-inch CP burn rate data will be used to verify the propellant burn rate temperature sensitivity parameters, pi_k, $sigma_p$. Verification of acceptable ballistic performance for the propellant will be ascertained during the static testing of the full scale motors.

4.6.3 Raw Materials Acceptance:

Each lot of raw materials must pass acceptance testing before being used. The acceptance testing consists of the chemical and physical tests listed in Table XI.

Each type of raw material has a designated maximum storage time. Acceptance testing will be repeated if the storage time of a material lot is exceeded or would be exceeded prior to completing the processing operations for which the material was released.

In-process tests (Table XII) are used to confirm that the correct materials and respective weights have been used and to verify the formulation chosen from standardization and verification data are correct.

4.6.4 Standardization

The propellant standardization program will establish raw material acceptance testing, propellant standardization procedures, in-process inspections and acceptance testing. Tests and procedures will be established to ensure reproducibility of ballistics and physical properties from mix to mix and from motor to motor.

Propellant standardization establishes the propellant formulation for a single lot combination or evaluation of raw materials. Sufficient information will be available from tailoring to approximate the nominal formulation prior to the first standardization. Refinements are accomplished by the standardization procedure.

TABLE XI: PROPELLANT RAW MATERIAL ACCEPTANCE TESTS

HTPB Polymer

Visual Examination
Hydroxyl Value
Peroxide Content
Moisture Content
Viscosity
Specific Gravity
Iron Content
Anti-oxidant Content

Aluminum

Visual Examination
Free Active Aluminum
Volatile Matter
Particle Size Distribution
Iron

Ferric Oxide

Visual Examination
Volatile Loss (Moisture)
Calcination Loss
Iron
Specific Surface

HX-752 Bonding Agent

Visual Examination
Imine Equivalent
Moisture
Hydrolyzable Chloride
Infrared Identification

IPDI Curing Agent

Visual Examination
Isocyanate Content
Moisture
Specific Gravity
Viscosity
Iron
Hydrolyzable Chloride
IR Identification

Ammonium Perchlorate With Conditioner

Visual Examination
Total Moisture
External Moisture
Internal Moisture
Acid Insolubles
Hydrogen Ion (pH)
Chloride
Sulfated Ash
Bromate
Chlorate
Iron
Perchlorate
Phosphate
Particle Size Distribution
Photomicrographic Analysis

TABLE XII: PROPELLANT IN-PROCESS TESTS

(Oxidizer, Premix, and Propellant)

<u>Ground Oxidizer Analysis</u>

Particle Size Distribution - Ro-Tap
Moisture

<u>Premix Analysis</u>

Total Solids Content

<u>Uncured Propellant Analysis</u>

Total Solids Content
Al + Fe Content
AP Content
Strand Burn Rate

A minimum of four subscale standardization 5-gallon batches will be required for each standardization of raw material evaluation. The subscale batches shall be processed in a 5-gallon vertical mixer. The propellant from these batches will use the same procedures for the subsequent full-scale (600-gallon) verification batches.

The nominal percent of ammonium perchlorate (AP) and ferric oxide (Fe_2O_e) percentages shall be adjusted so that their sum totals 69.00 percent. Approximately 30 percent of the AP will be ground. Four of the standardization batches will have the following composition variations:

a. IPDI = nominal + 0.02 percent
Fe_2O_3 = nominal +0.05 percent

b. IPDI = nominal + 0.02 percent
Fe_2O_3 = nominal +0.05 percent

c. IPDI = nominal + 0.02 percent
Fe_2O_3 = nominal +0.05 percent

d. IPDI = nominal + 0.02 percent
Fe_2O_3 = nominal +0.05 percent

Reproducibility of propellant physical, chemical, and ballistic properties will be ensured by using procedures developed and verified in previous motor development and production programs. The propellant standardization procedure will be the same as the procedure used for the current SRM. Samples are taken from lots of the various ingredients to make several mixes at various oxidizer grind ratios and binder-to-curing agent ratios. Loaf samples and 5-inch CP batch check motors are taken from each mix. Test results obtained from these samples enable identification of the proper raw material ratios required to achieve the desired propellant physical properties and burn rate.

The slope for the propellant mechanical properties versus polymer-to-curing agent ratio is expected to be similar to other HTPB propellants. This slope will be determined for each standardization. Each lot standardization mix has a different percent IPDI, enabling the determination of the percentage that will provide the required mechanical properties. The limits placed on the percent IPDI for the standardization mixes are consistent with previous experience.

The allowable range of propellant formulation variation and the standardization matrix is narrow enough to assume linear relations with interactions, however, a sufficient number of full-scale mixes are required to eliminate the impact of mix-to-mix variation. Initially, the excess standardization mix propellant is destroyed. When full-scale segment casting is occurring, these standardization mixes will be judiciously placed in segments. They will be cast into those segments that will not influence the thrust differential during tailoff, such as the forward portion of the forward casting segment to be burned out prior to tailoff. The uncured strands will be tested during standardization to establish a 5-inch CP-to-strand burning rate relations. a proper uncured strand target burning rate is established and will be used for future production mixes.

The maximum stress and the strain at maximum stress versus percent IDPI curing agent will be established during standardization. The percent IPDI that will give the target mechanical properties will be determined from the raw material lot standardization tests. The propellant to be cast into the next two SRMs will be processed using that percent IPDI.

The nominal percent IPDI and Fe_2O_3 will be separately determined from historical propellant performance and laboratory data. Raw material lots from the same vendor will use the same process as the lots being standardized. The nominal percent Fe_2O_3 is selected to give a target 5-inch CP motor burning rate of 0.450 ips at 717 psi at 60 deg F.

The propellant from each subscale standardization batch shall be used as follows:

a. Six uncured strands are taken from 1-pint sample for burning rate determination.

b. Three 5-9nch CP motors will be cast.

c. Three loaf samples are cured for mechanical property determinations.

d. A 1-pint sample will be obtained for in-process testing.

The full size verification batch processing will utilize the same mix size, process, sample tests, and equipment to be used in the manufacture of production DL-H396 propellant. Verification batches will be subject to all the acceptance requirements and tests specified for DL-H-396 propellant. A minimum of four verification batches will be required for each standardization of a specific combination of raw material lots.

Test data from verification batches will be used for verification of ballistic and mechanical properties and for production propellant formulation adjustments if required.

The full-size verification batches are processed using the formulation established during subscale standardization. The formulation is selected to meet the burn rate and mechanical properties. When any batch does not produce propellant meeting the acceptance requirements for DL-H396 propellant, it will not be cast into a Block II SRM segment.

Full size verification batches are used as follows:

a. Six uncured strands were cast from a 1-pint sample for burn rate determination.

b. Six 5-inch CP test motors are cast.

c. Three loaf samples are taken for mechanical properties.

d. A 1-pint sample is taken for in-process testing.

e. The verification mix is cast into the SRM segment.

Testing during production consists of: in-process monitoring for batch acceptance (before casting), testing of cured 5-inch CPs and loaf samples for motor performance prediction, and mechanical properties verification.

In-process monitoring consists of measuring total solids level and liquid strand burn rate.

Before the batch can be accepted and cast, the measured strand rates must fall within specified limits of a target rate established during standardization. The total solids loading must fall within acceptable limits.

The 5-inch CP measured burning rates taken during fabrication will be used to predict accurately the motor performance parameters. Mechanical properties measured from the test specimens made from the cured loaf samples will be recorded and maintained to verify compliance with required properties. Cured strands will be prepared from the loaf samples and testing using acoustic emission burning rate measurement technique.

4.7 Propellant Liner

The selected liner system is a Thermax-filled hydroxyl-terminated polybutadiene polymer system designated UF-2155. This is the same liner used in Peacekeeper Stage I, PAM-D II, and Standard Missile Motor Production Programs. The formulation for the Block II SRM liner is given in Table XIII:

TABLE XIII: LINER FORMULATION

UF-2155 Liner Raw Material	Function	Weight %
R-45M/HTPB	Liquid Polymer	55.7
IPDI (Isoprene Diisocyanate)	Curing Agent	7.0
HX-868	Bonding Agent	3.4
Thermax (Carbon Black)	Filler	33.9
Cab-O-Sil	Thickener	Variable as needed

The liner material must be capable of surviving the motor environmental and handling requirements. In addition to these criteria, the liner must:

1. Be compatible with the selected propellant and motor insulation.

2. Be developed and have characterized process and application techniques.

3. Have demonstrated aging characteristics.

4. Be manufactaured from readily available, low cost raw materials.

5. The factor of safety (FS) for physical properties of the propellant/liner/insulation shall be 2.0 minimum during the life of the SRM. The bond FS shall be based on tensile and peel strengths of the bondline.

Since the propellant and liner are different from the current HPM, a material testing program will verify that the DL-H396 (propellant)/UF-2155 (liner)/V-45 (insulation) composite bond meets all the Block II SRM requirements.

DL-H396 propellant is similar to Peacekeeper Stage I propellant, which uses UF-2155 liner. Historical data from the Peacekeeper Stage I propellant/liner production program will be used to establish the nominal liner formulation and processing parameters for the Block II SRM.

UF-2155 liner standardization procedures and verification test established for the Peacekeeper Stage I Program will be used for Block II SRM liner.

4.7.1 Liner Raw Material

Acceptance inspection of liner raw materials and the liner itself will be conducted in accordance with proven procedures presently applied to these materials in the Peacekeeper Stage I Production Program. These procedures include:

1. Raw materials acceptance by both chemical and physical analyses.

2. Liner composition standardization for each lot of raw materials based on physical properties and bond strength.

3. Liner production batch acceptance based on verification of raw material and liner formulation standardization acceptance/certification and liner propellant bond strength.

The Block II SRM liner test program is designed to demonstrate the reliability of the propellant/liner/insulation bondline. The testing program will optimize and characterize the liner bondline mechanical and physical properties to establish a nominal formulation (see Table XIV). Subscale 5-gallon propellant mixes will be made and cast into loaf cartons to determine 90 degree peel strength, tensile adhesion, shear stress, and penetrometer hardness of the bondline. Test matrices will establish the optimum curing agent ratio, bonding agent level,

TABLE XIV. UF-2155 LINER OPTIMIZATION

I. Optimize Mechanical and Physical Properties of Bonding

Objectives to Accomplish	Test Methods
Establish optimum NCO/OH curing agent ratio: Vary from 1.1 to 1.6 Establish optimum HX-868 bonding agent level: 0, 1, 1.7 & 3.4 percent Establish optimum Thermax filler level: Vary from 20 to 40 parts Establish optimum Cab-O-Sil thickness level: Vary from 0.5 to 4.0 parts	90 degree peel, Tensile adhesion, Shear stress, Penetrometer, Hardness, Slumping and Shore A Hardness

II. Optimize Processing Variables and their Effect on Bonding

Objectives to Accomplish	Tests
Establish precure time and temperature Establish optimum thickness of precured liner Establish effect of relative humidity and temperature on precured liner Establish process time between liner precure and propellant casting Establish effect of liner preheat prior to propellant casting Establish effect of cast delay on bondline properties	90 degree peel, Tensile tests, Shear stress, Penetrometer and Hardness

III. Short-Term Accelerated Aging

Objective to Accomplish	Tests:
Ensure bondline capabilities are maintained during short-term accelerated aging 1-month, 2-months at 135 deg F.	90 degree peel, shear stress, tensile adhesion, penetrometer hardness.

viscosity, and hardness. Once the nominal UF-2155 liner formulation is established for Block II SRM, subscale and full-scale propellant mixes will be made to establish standardization and verification procedures for the UF-2155 liner.

4.7.2 Liner Standardization and Verification

Procedures established for optimizing the mechanical and physical properties of the Peacekeeper Stage I propellant liner will be used for the Block II SRM (Table XV). A propellant verification mix will be cased into loaf cartons containing a single lot of liner raw materials at various NCO/OH ratios at a nominal Cab-O-Sil level. The NCO/OH ratio yielding optimum bondline mechanical properties establishes the nominal formulation for a given lot of liner raw materials. The thicker level (Cab-O-Sil) is then varied using the standardized (nominal) liner formulation to obtain optimum processing. The thickness level providing optimum liner processing is then selected for the nominal liner formulation.

TABLE XV: OPTIMIZATION OF BONDING MECHANICAL PROPERTIES

A. Three NCO/OH ratios in 4- to 6-lb liner mixes, nominal Cab-O-Sil, nominal and two variations: 1.4, 1.5*, 1.6 NCO/OH

*nominal Cast with optimized propellant formulation

<u>Tests:</u>

<u>Mechanical Properties</u>	<u>Physical Properties</u>
90 Degree Peel	Viscosity
Tensile Adhesion	Slumping
Shear Stress	Shore A Hardness
Penetrometer Hardness	

B. Vary Cab-O-Sil level at nominal NCO/OH nominal plus two variations to test for viscosity, slumping and shore A hardness

During liner verification, full-scale liner mixes will be made in production to verify that propellant/liner/insulation bond strength and processibility meet Block II SRM requirements. The optimized DL-H396 propellant (verification mix formulation) will be used with the UF-2155 liner mix. Bond strength will be verified through determination of peel strength, tensile adhesion, shear stress, and penetrometer hardness. The processibility will be verified using full-scale sling lining equipment on a mock-up insulation cylinder. Liner coverage, thickness, hardness, and viscosity (lack of slumping) will be verified.

4.7.3 Propellant/Liner System Characterization

The propellant/liner/insulation system will be characterized to ensure the design requirements are met. Critical conditions for the bondline are shearing forces upon ignition and long-term stress at the bondline caused by thermally induced loads (temperature cycling) during storage. High rate pressurization testing is used to determine the shearing capabilities during ignition. Tensile adhesion tests are performed at high temperatures with a slow rate of application of loading simulate long-term bondline stress. A variety of temperatures and loading rates will be used to fully characterize the capabilities of the bond-line system.

Grain structural analysis will be completed, based on preliminary bondline property characterization, before specific test matrices are defined.

Bondline test matrices will be characterized in detail with a minimum of three replicates per test condition. Bondline testing will include:

* 90 degree peel strength

* Tensile adhesion from analog flop determinations and flapped conical tenshear

* Shear Stress, as determined from flapped lap shear and flapped conical tenshear.

* Penetrometer hardness.

* Long-term constant load with flapped conical tenshear.

An aging program will be established to ensure the integrity of the bondline is maintained for the service life of the Block II SRM. The system is aged over the temperature and humidity extremes experienced during storage to ensure design requirements continue to be met. A minimum of three temperatures and two humidities will be used to characterize bondline properties during storage.

A chemical analysis profile of the bondline components will be done to understand the bondline aging characteristics during storage. This will be done at various temperatures and humidities.

4.7.4 Castable Inhibitor

The selected castable inhibitor is a modification of a titanium dioxide hydroxyl-terminated polybutadiene polymer system designated UF-2153. This is similar to the liner system currently used in HARM Production Program. The formulation is given in Table XVI:

TABLE XVI: CASTABLE INHIBITOR FORMULATION

Raw Material	Function	Weight %
R-45M/HTPB	Liquid Polymer	78
Dimethyl Diisocyanate (DDI)	Curative	
Methanol Amine	Cross-Linker	
Titanium Dioxide (TiO_2)	Filler	22
Cab-O-Sil	Thickness	

The inhibitor will provide thermal protection to the propellant grain and prevent its ignition and burning in the direction perpendicular to the inhibited surface. This inhibitor must also be chemically compatible with the liner and propellant.

Verification activities will cover processing, adhesion, aging and function of the inhibiter. Processing studies will check on (1) the effects of formulation variations on the inhibiter (ie: rheology, adhesion, tensile strength), (2) effect of cure time of the propellant during inhibiter casting, (3) pot life effects and (4) application studies (tooling use). Mechanical tests will characterize physical properties. Aging research will determine the effects of time and environment. Real time and accelerated aging will be conducted to confirm minimum storage life requirements. Sub-scale and full-scale (static) testing will ultimately determine the suitability of the castable inhibitor function.

4.8 Block II Insulation Design

4.8.1 Case Field Joint

The insulation configuration selected for the case field-joint region accommodates the capture-feature design and prevents internal motor gases from entering the joint.

The configuration utilizes a radial joint relief flap which performs two primary functions. First, this flap provides a method of accommodating manufacturing tolerances and propellant slump which ensures contact of the mating surfaces on assembly. This is accomplished by fabricating the free leg formed by the radial relief flap in the open or deflected position. Second, the flap provides a stress relief for joint movement due to thermal expansion/contraction of the propellant grain after assembly and pressurization deflections during motor operation.

The mating surfaces of the joint are bonded together upon assembly in the inboard portion of the insulation joint with the base region (adjacent to capture feature) released/unbonded to provide for the capability to destack.

This design will achieve qualification for Block II use by the verification activities of SRM redesign effort.

4.8.2 Nozzle/Case Insulation

A new insulation configuration is being proposed in the aft dome/fixed housing joint region. This is due to the replacement of the existing joint with a welded/forged aft dome/fixed housing.

4.8.3 Nozzle-to-Case Insulation Interface

The nozzle-to-aft dome insulation design is depicted in Figure 9. The design includes a flap for stress relaxation. The curing of the aft dome insulation will produce shrinkage of insulation which will result in the joint stress relief flap being open in its natural state. To counteract circumferential of gases in the stress relief flap a flow baffle is being proposed.

The aft-propellant grain also requires a feature for the relief of stresses. This is achieved by bonding a full-length flap to the aft-case propellant. The space inside the flap must be pressurizable at motor ignition for proper stress relief.

The function of both flaps and the circumferential flow-blocker will be verified in JES testing.

4.9 SRM Ground Test

Two major areas of ground tests have been identified to support the SRM project. They are integrated subsystem test program, and development and qualification test program.

The philosophy used in defining these major tests was to establish the minimum number of tests required to demonstrate the flight readiness of the SRM, as well as demonstrate the reuse of such SRM components as the case, nozzle bearing and metal parts, and ignition system components. The support equipment required to conduct these tests will be tool proofed to insure form, fit, and function prior to utilization. Tool proofing will include load testing, nondestructive test (radiographic or dye penetrant), dry fit, and in-bay functional checks prior to performing the test. In the case of the static test stand, tool proofing will include an in-bay calibration of side load.

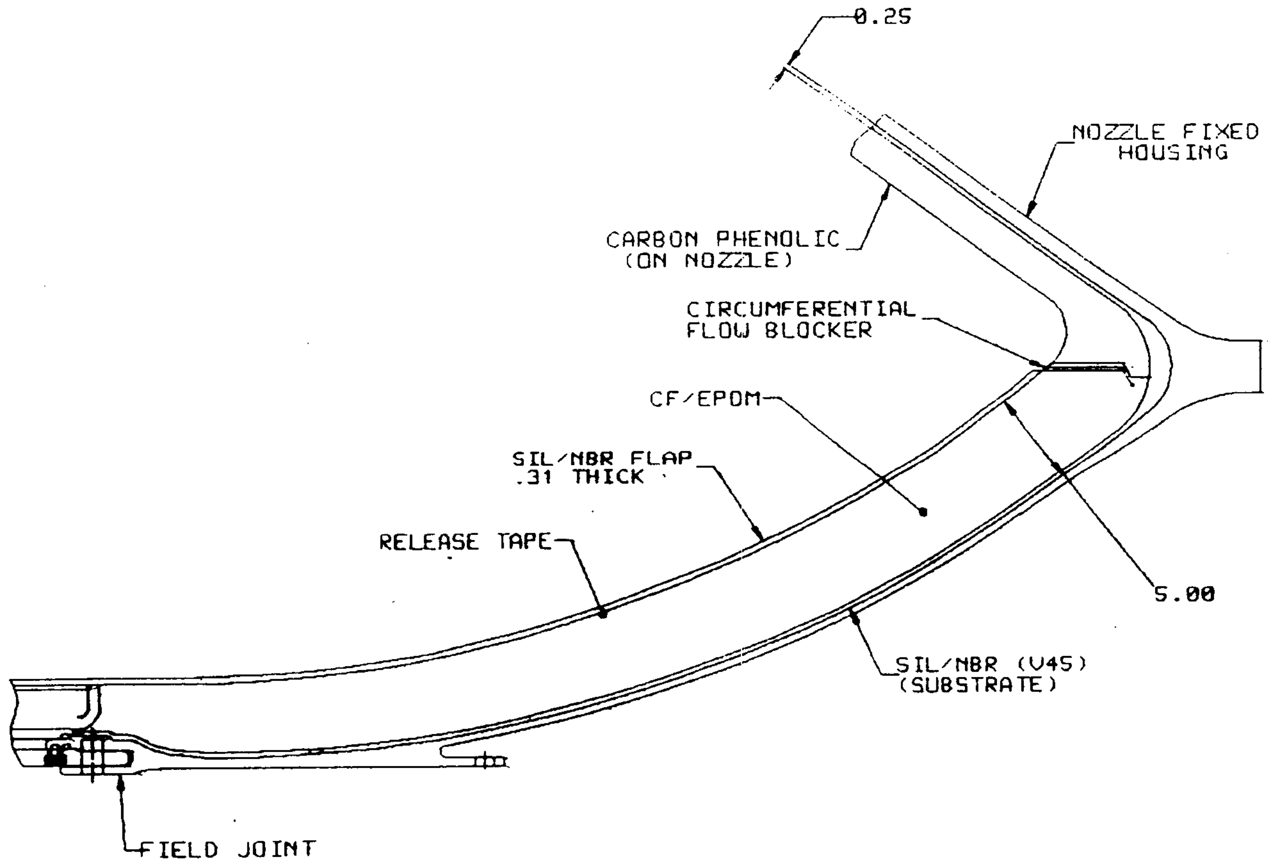

Figure 8 . Insulated Aft Dome

4.9.1 Integrated Subsystem Tests

4.9.1.1 Case Cycle and Hydroburst Test

Case cyclic and hydroburst tests will be conducted in the vertical position, with the nozzle end down, in an existing Morton Thiokol test bay. these tests will provide the data required to verify the fracture mechanics and crack growth analyses conducted during the case design effort and to demonstrate cyclic pressure load capability.

Coordination and planning activities related to these tests will be conducted.

An engineering drawing will be prepared to define the test configuration. The drawing will be used for the preparation of plans and shop travelers, which will include detail instructions and procedures for assembly and installation of the test hardware in the test bay.

An instrumentation drawing will be prepared to define the types, quantities, and location of instrumentation required to obtain the required data.

A detail test plan will be prepared. The plan will be reviewed and approved by NASA to insure compliance with overall program objectives. It will include test objectives, test item description, detail requirements, instrumentation data requirements, reports, and schedule.

The plan will include instrumentation discussed above plus instrumentation required to monitor pressurization of the case and system voltage and current requirements.

The test hardware will be installed in the test bay in accordance with the applicable drawings and procedures. The instrumentation will be installed and checked out and the test conducted in accordance with the requirements of the test plan.

The case will be pressurized sequentially to proof test pressure, MEOP pressure, and pressure to simulate water impact stress through 19 cycles (a cycle will consist of one proof followed by one MEOP pressurization and one water impact simulation). The case will then be pressurized by MEOP, 1.20 MEOP (proof pressure), 1.40 MEOP (ultimate pressure), and then burst. The pressurization rate up to 500 psi will be slow (approximately 1 psi/sec) to allow visual observation of the strain rates. The pressurization rate will increase to 5 psi/sec to proof pressure (1.20 MEOP), with a one-minute hold, and then to burst at the same rate.

Data will be reduced and analyzed. Morton Thiokol will submit quick-look data from the test within 24 hours after completion of the test. In addition, Morton Thiokol will make an interim test data submittal within 30 days. A final report will be submitted within 60 days after completion of the test.

4.9.1.2 Bearing/Actuator Compatibility Test

A bearing/actuator compatibility test will be conducted in the nozzle bearing test fixture.

This test will provide the data required to insure the operability of the SRB actuators prior to static test and to provide early identification and resolution of form, fit, and function problems. The data that will be obtained will include actuator performance parameters and nozzle bearing performance parameters.

The approach used for this test will be to utilize the bearing test fixture developed for bearing acceptance testing. The fixture will simulate nozzle center of gravity, mass, and torque and will duplicate interface points. A bearing from the development phase of the program or a bearing from a development motor test will be used for this test. The test will be scheduled to obtain early visibility of bearing/actuator interface problems to allow sufficient time for the problem resolution prior to system testing on development test motors.

Coordination and planning of activities related to equipment design, fabrication/procurement, installation, and checkout; bearing/actuator testing; data analysis and test reporting will be conducted.

An engineering drawing will be prepared to define the test configuration of the subsystem test. The drawing will be used for the preparation of plans and shop travelers, which will include detail instructions and procedures for assembly and installation of the test hardware in the test fixture.

An instrumentation drawing will be prepared to define the types, quantities, and locations of instrumentation required to obtain the required data.

A detailed test plan will be prepared and submitted to NASA to insure compliance with overall program objectives. It will include test objectives, test item description, detail requirements, instrumentation data requirements, reports, and schedules.

The plan will include the instrumentation discussed above plus instrumentation required to monitor actuator functions, system voltage and current requirements, and hydraulic system pressure requirements.

The test hardware will be installed in the bearing test fixture in accordance with the applicable drawings and procedures. The instrumentation will be installed and checked out and the test conducted in accordance with the requirements of the test plan.

The testing will include: demonstrating the operation of the SRB actuators and flexible bearing prior to subsequent operational tests; determining the transient response of the TVC system, evaluating the nozzle steady state accuracy, and determining the nozzle rate and acceleration under load prior to static testing Development Motor No. 1.

Data will be reduced and analyzed. Morton Thiokol will submit quick-look data from the test within 24 hours after completion of the test. In addition, Morton Thiokol will made an interim test data submittal within 30 days. A final report will be submitted within 60 days after completion of the test.

4.9.2 Development and Qualification Motor Tests

Three development and four qualification motors will be horizontally static tested in the large motor test bays (T-24 and T-93).

These tests will provide the data required to evaluate the Block II design. The data that will be obtained includes ballistic performance, ignition system performance, case structural integrity, nozzle structural integrity, internal insulation performance, thrust reproducibility, case, nozzle and igniter component reusability, TVC interface, dynamic thrust vector alignment, nozzle performance, and flight readiness.

The approach to be used to conduct these tests will utilize existing facilities and existing test methods. All activities will be scheduled to insure timely and successful completion of the effort.

Engineering assembly drawings will be prepared to define the test configuration of each motor. These drawings will be used to provide criteria for preparation of plans and shop travelers, which include detail instructions and procedures for assemblies and installing the motors in the test stand.

These assembly drawings will be prepared to define the quantities and location of instrumentation needed to obtain the required data. These drawings will define the instrumentation for measuring: (1) longitudinal and side thrusts; (2) motor, igniter and TVC pressures; (3) strains; (4) temperatures; (5) displacement to provide nozzle true position and dynamic thrust vector information; (6) accelerations; and (7) and other measurements.

The thrust vector control requirements will be demonstrated by a measurement of side thrust forces (forward and aft) and actual nozzle position relative to the motor/test stand centerline. During motor installation in the test bay, the motor will be positioned so that the yaw and pitch actuators were oriented 45 degrees to horizontal.

The bearing deflection will be measured during the bearing acceptance test in the bearing test fixture prior to static test. The actuator null bias due to measured bearing deflection will be combined with the estimated compliance of the aft closure at operating rocket chamber pressure to establish the actuator linkage center position.

In addition, 12 extensometers will be installed in groups of three to locate four points on the nozzle exit cone during a static firing. These four points then determined the location of the nozzle centerline. Additional extensometers will be located to monitor case movement and correct the nozzle centerline data. The extensometers will be mounted at known distances from the measurement point, either parallel or perpendicular to the motor, and a "zero" or null position will be recorded for all extensometers prior to the static test.

The dynamic thrust vector will be determined by data obtained from the three-component test stand. The expected accuracy of the dynamic thrust vector measurement will be determined by an error analysis.

Data from both the yaw thrust measurement and the extensometer will be analyzed. Since the measurements indicate an offset due to improper pretest nozzle-actuator tare, a correction factor will be determined and used.

A detail static test plan will be prepared for each test. This plan will be reviewed by NASA to insure compliance with overall program objectives. The plan will include test objectives, test item description, detailed requirements, instrumentation, photography, data requirements, reports, and schedule.

The plan will include the instrumentation discussed above plus instrumentation not installed on the motor to determine air sampling, atmospheric pollution data, tracer salt detection, system voltage, current requirements, and hydraulic system pressure requirements. Anticipated instrumentation is shown in Table XVII. Detailed instrumentation will be coordinated and finalized prior to motor testing. .

TABLE XVII: GROUND TEST INSTRUMENTATION

Static Test Motors	DM1	DM2	DM3	QM1	QM2	QM3	QM4	Data Rate/ Channel
Pressure Transducer								
Chamber	4	4	4	4	4	4	4	2,000
Igniter	1	1	1	1	1	1	1	2,000
Actuator (dP)	2	2	10	10	10	10	10	250
Hydraulic Supply	2	2	2	2	2	2	2	250
Aft Closure	--	4	4	--	--	--	--	250
APU	2	2	2	2	2	2	2	250
Thrust								
Longitudinal	2	2	2	2	2	2	2	2,000
Side, Fwd	2	2	2	2	2	2	2	250
Side, Aft	2	2	2	2	2	2	2	250
Thermocouple								
Nozzle	13	12	12	12	12	12	12	31.25
Case	13	13	13	13	13	13	13	31.25
Igniter	2	2	2	2	2	2	2	31.25
TVC	6	6	6	6	6	6	6	31.25
Skirt	--	--	8	8	8	8	8	31.25
Strain								
Nozzle	34	34	34	--	--	--	--	250
Case	60	52	52	26	26	26	26	250
TVC	14	14	14	14	14	14	14	250
Strain Sert	4	4	4	4	4	4	4	250
Accelerometers								
Igniter	3	3	3	3	3	3	3	FM 20 KHz
Nozzle	9	9	9	9	9	9	9	FM 20 KHz
Case	11	11	11	11	11	11	11	FM 20 KHz
Skirt	--	--	12	12	12	12	12	FM 20 KHz
Extensioneters								
Nozzle	16	16	16	16	16	16	16	250
Case	6	6	2	2	2	2	2	250
Calorimeter	2	2	2	--	--	--	--	32
Radiometer	7	31	31	7	7	7	7	32
Events	5	5	7	7	7	7	7	32
Current	2	2	8	8	8	8	8	32
Voltage	4	4	8	8	8	8	8	32
Accoustics								
Motor	6	6	6	2	2	2	2	FM 20 KHz
Far-field	--	13	13	--	--	--	--	FM 20 KHz
Overpressure	5	5	--	--	--	--	--	FM 20 KHz
Safety Interlocks	--	--	4	4	4	4	4	--
Shock Sensors	2	2	2	2	2	2	2	FM 20 KHz
FM Backups	5	5	5	5	5	5	5	FM 20 KHz
Exhaust Gas Sample	10	10	10	10	10	10	10	
Total Channels	268	288	313	214	216	216	216	
Digital	217	224	252	162	162	162	162	
FM	41	54	61	44	44	44	44	
Samples	10	10	10	10	10	10	10	

The test hardware will be installed in the test stand per the applicable drawings and procedures. Instrumentation will be installed and checked out and cameras set up in accordance with the requirements specified in he test plan. Eleven cameras will provide permanent coverage through high-speed and real-time coverage.

An automatic quench system will be installed for the purpose of quenching the motor immediately after static firing to maintain the nozzle and internal insulation in as-fired condition to prevent post-test insulation burning and charring.

On the day of the static test, a final checkout for the firing will be performed; all data channels will be checked for proper electrical calibration and proper data recording. The data from such parameters as TVC system response to the programmed duty cycle, nozzle actuation torque, and S&A device response will be recorded and converted into engineering units. These data will be carefully reviewed prior to proceeding. Once the dry run has been accepted, no changes to the data system, instrumentation, or electrical wiring - with exception of connecting ignition lines - will be allowed. Photographic coverage is considered a part of the total data package; therefore, a checkout of all photographic equipment will be included in the final dry run.

Following static test and quench of each motor, a post-test analysis of motor performance and hardware will be conducted.

As the motor is being disassembled, photographs will be taken of component condition prior to shipping the case to the refurbishment area; thus, a photographic record will be available for future use. Post-test operations will include a determination of insulation char depth, insulation erosion, and amount of virgin insulation material remaining, as well as segment and nozzle post-test weight and center of gravity, nozzle erosion, nozzle ablative material char, ignition component system condition, and the condition of the case.

All final static test data will be reduced using appropriate computer codes. Preliminary data may be hand reduced to provide a rapid quick-look at specific operating parameters. The quick-look data will also provide rapid assessment of any anomalies. Axial thrust data reduction will be based upon National Bureau of Standards (NBS) traceable calibration. All other data will be reduced from calibration derived from NBS traceable calibrated reference standards.

Data will be reduced and analyzed in time for an interim test data submittal within 60 days of the completion of the static test. The objective of these tests will be to certify the motor. Qualification will consist of confirmation of design functionality and, thus, certification of conformance to specification requirements.

5.0 Support Equipment and Tooling

Development of Support Equipment and Tooling (SE&T) includes trade studies, design work, fabrication, testing, checkout, qualification, assembly, and maintenance considerations. SE&T is defined as that equipment and tooling required to manufacture, refurbish, test, transport, handle, assemble, checkout, service, and disassemble the SRM and its component parts, including Transportation Support Equipment (TSE), Ground Support Equipment (GSE), Special Test Equipment (STE). Efforts in development of the SE&T include the design, fabrication, and delivery of equipment to support in-house and offsite SRM assembly and test operations. In addition, recovery tests include those effects associated with planning, generating requirements, and identifying additional SE&T to be acquired for future production needs. Design and test requirements for TSE, STE and GSE will be summarized in the "Consolidated Support Equipment Requirements" (CSER). The development and qualification of STE, TSE and GSE is described in this section.

The basic support equipment will be defined and design requirements established following a system engineering analysis. The support equipment Systems Requirements Analysis will be conducted in accordance with Morton Thiokol procedures and documentation and will be described in the Integrated Logistics Support Plan. This effort will determine the requirements for support equipment, test, technical data, training, maintenance, and spares to sustain the support equipment. The System Requirements Analysis will also determine the optimum combinations of Transportation Support Equipment (TSE), Special Test Equipment (STE) and Ground Support Equipment (GSE) needed to support the SRM program requirements. Through analysis and from design trade studies, equipment concepts will be developed and evaluated for design cost effectiveness.

One product of the System Requirements Analysis will be a specification for each item of support equipment. The specifications will provide the designer with comprehensive information on all design requirements for each item of support equipment. General design goals for SE which facilitate verification are listed in Table XVIII. Each design will be reviewed against the applicable specification.

A continuing System Requirements Analysis effort that influences SE will be performed to incorporate any SRM design changes into the affected support equipment specifications, to support PDRs and CDRs, to support integration and assembly operation, to insure that identified requirements are incorporated in the appropriate equipment specifications, and to review all support equipment design changes for compliance with design requirements.

TABLE XVIII: GENERAL DESIGN GOALS FOR SUPPORT EQUIPMENT

Economy

Maximum use of off-the shelf commercial equipment
Maximum use of commercial materials, specifications, and shop practices
Maximum use of state-of-the-art design techniques
Maximum use of government furnished equipment
Minimum development of unproven methods and concepts
Easy to fabricate
Easy to inspect
Easy to maintain
Realistic environmental design requirements
Reasonable tolerances, finishes, weld requirements, etc.

Reliability/Safety

Maximum SE/SRM electrical overload protection
Maximum economical use of corrosion resistant materials
Maximum required SE/SRM environmental protection
Avoid use of dissimilar material in combination
Adequate corrosion resistant coatings
Adequate identification tags and operating procedure decals
NASA approved structural and operational safety factors
Minimum effect of electrical interference from external or internal sources
Maximum possible elimination of electrostatic discharge

Versatility

Optimize for high operational use
Commonality of equipment for TC and vendor usage
Modular equipment
Easy to use
Self-supporting with minimum use of ancillary equipment
Easy to relocate with minimum facility modification
Multiple purpose use
Common electrical, hydraulic, pneumatic, and mechanical interfaces
Self-test capability

5.1 Transportation Support Equipment

Transportation Support Equipment (TSE) will be re-designed as necessary in accordance with the requirements of the Individual Identification Item specifications. It is anticipated that most TSE will be compatible for use with the Block II design with the exception of handling ring modifications, etc. The general design goals shown previously in Table XVIII will be used as guidelines during the development of the TSE designs.

The TSE will be used for transporting the structural test and dynamic test components to and from Marshall Space Flight Center (MSFC), and the manned orbital components to and from Kennedy Space Center (KSC) and Vandenberg Air Force Base; however, consideration will be given during the preliminary design phase to make the equipment compatible with the activities at KSC, MSFC and Vandenberg during follow-on programs. The TSE items, their functions, required quantities, and uses will be identified and described in the Consolidated Support Equipment Requirements (CSER) Document. Preparation/modification of support equipment will be in accordance with the SRM Master Schedule.

The development of TSE will begin with the preliminary design. Conceptual design layouts will be prepared to insure that each item meets the design requirements and is ready for the development of preliminary detail drawings. Requirements to meet form, fit, function, commonality, and low life-cycle costs will be mandatory. Care will be taken to use state-of-the-art parts and materials.

Major items of TSE will be subcontracted to a company or companies experienced in designing and manufacturing such items. The development of the design requirements and design definition will be accomplished by Morton Thiokol and will be transmitted to the subcontractors via procurement specifications and specification control drawings. Vendor control will be accomplished in accordance with Morton Thiokol's Procurement Plan, TWR-10194.

Design load factors will be commensurate with good design practice for transporting large heavy loads by rail and highway.

The design load factors for rail transportation are:

+/- 3g Longitudinal

+/- 1.5g Lateral

+/- 2g Vertical

All preliminary design or specification changes will be reviewed for accuracy and completeness and updated as necessary prior to completion of the Preliminary Design Review (PDR). Such a review will be accomplished for each end item.

Detail drawings will be prepared to Morton Thiokol format in accordance with Category E, Form 2, requirements of military specification MIL-D-1000. As stated previously, commercially available materials and equipment will be specified, when possible, to facilitate fabrication, reduce costs, and avoid schedule constraints.

Specification and source control drawings will be developed as required. Material, process, and component specifications will be prepared and maintained in accordance with SRM Configuration Management Plan, TWR-10150. Upon completion of the detail drawings, in-house and Critical Design Reviews (CDR) will be conducted. At the completion of CDR, all applicable TSE engineering documents will be updated and released for procurement and/or fabrication.

Newly proposed Transportation Support Equipment Testing requirements will include: (1) Interface demonstration tests, (2) Functional tests, (3) Static proof load tests, (4) Transportation dynamic tests, and (5) Electrical continuity tests. TSE modifications may not necessitate verification by all of the preceeding methods.

All tests will be monitored by Morton Thiokol Quality Assurance with Morton Thiokol Quality Assurance and/or Manufacturing personnel performing the tests. Testing will be in accordance with the test plans generated during the TSE design phase by TSE design personnel.

Development tests are not anticipated because commercially available components and materials and conventional design techniques will be employed.

Design compliance generally will be verified by analysis or similarity with like items of equipment. Such environmental testing as high/low temperature testing, temperature and humidity testing, transportation vibration testing, salt fog testing, sand and dust testing, and electromagnetic interference testing has been purposely eliminated. The reasons for this elimination includes:

1. The majority of the equipment will not be operated in an extreme environment.

2. The TSE will be designed and analyzed with sufficient margins of safety to alleviate any vibration problem.

3. Vibration data obtained from previous shipments (Ref Minuteman, Poseidon) precludes the need for dampening devices and vibration testing.

4. Protective coatings that will be used on the SRM have been extensively tested, and will provide protection against environments more severe than will be encountered during ground operations. Thus, testing the container against natural environment will not be necessary.

5. Standard coatings and finishes conforming to military and NASA requirements will be used in TSE designs.

6. Support equipment that will be electrical in nature will not be used in areas requiring Electromagnetic Interface Controls.

Acceptance test requirements will be identified in the applicable TSE specifications and will be included in the CSER. End item acceptance will be based on workmanship, drawings conformance, functional performance, static proof load, electrical continuity, and proof pressure tests. These tests will precede the First Article Configuration Inspection (FACI) and will be the only tests performed for follow-on acquisitions. The results of the acceptance and certification tests will be submitted as part of the FACI. This data will essentially provide the proof that the SE conforms to the specification and performance rquirements as witnesses by designated NASA personnel. No additional testing of STE, GSE and TSE is anticipated in support of FACI of existing designs.

Certification tests will be performed as a part of the configuration inspection. Applicable tests will be conducted on items of TSE as specified in the CSER. Periodic proof loading tests will be conducted on specific types of equipment; i.e. lifting and handling items.

Interface tests will be conducted to insure that form and fit requirements with the applicable SRM components are met.

Functional tests will be conducted to ensure that each item functions properly.

Static proof load tests of 1.5 x static design load will be conducted on the applicable segment transportation kit components and initial proof load tests of 2.0 x static design load will be performed on the miscellaneous hardware; i.e., lifting devices. These tests will be conducted utilizing load producing devices that simulate the required load distribution.

Results of fracture tests and analysis on handling ring assemblies/components have determined that periodic proof load testing of existing handling rings is not necessary (Ref. TWR-14165). Morton Thiokol initiated periodic NDT of these assemblies. Any modification, major discrepancy or new acquisition requires that an initial proof load be performed.

The segment shipping kit, including the associated tie down system and the transportation monitor set, have been subjected to a series of dynamic impact (railcar coupling) tests utilizing the GTM-5 forward segment to verify the structural/dynamic integrity of the transportation system. Horizontal accelerations have been characterized as a function of speed and coupling mechanisms. Limits have been established for horizontal acceleration during coupling. Acceleration is limited to a maximum of 3 g's and speeds less than 10 mph. Results of these tests, which have satisfied the design certification requirements, are summarized in the Final Test Report (Ref TWR-12343).

Additional tests (Ref TWR-13090) have verified the adequacy of handling ring bolt loads utilizing Straincert^R bolts for the lifting and transportation functions. All data from the coupling, over the road shipments and handling tests verified the integrity of the SRM transportation system.

Major modifications of the present system are not anticipated. Existing handling rings will be modified to accommodate the new joint interfaces, functional fit will be checked and the rings will be re-proof loaded to verify their structural integrity.

The loaded segment grounding strap and ESD provisions that will be included as part of the SRM segment shipping kits have been tested for electrical continuity and function. In, addition, the transport monitor set has also been functionally tested at temperatures ranging from -20^o to 120^{o}F and will be recalibrated every 6 months.

Verification of the SRM transportability has been accomplished by demonstration during previous SRM experience. Fully qualified TSE that has satisfactorily completed the acceptance and certification testing will be used to demonstrate (1) TSE-facility and TSE-SRM-facility interfaces, (2) functional performance, and (3) time and motion performance. SRM components and subsystems used in these demonstrations included the MSFC ground test motor and the KSC flight test motors. The results were satisfactory. The TSE-facility interface and will be reverified for any major change as required.

All TSE will receive an in-process and/or final inspection by Morton Thiokol Quality Control personnel. Purchased equipment will be inspected at the vendor's plant prior to acceptance by Morton Thiokol. For large contracts, Morton Thiokol will furnish inspectors at the vendor's plant. In-process engineering changes to facilitate manufacture, reduce costs, improve schedules, and improve designs will be coordinated through liaison engineers and processed in accordance with configuration management procedures. This procedure will insure that such details as cost, schedules, and traceability can be maintained within project objectives. Assurance that the equipment items meet the design requirements specified in the end item specification will be the responsibility of Morton Thiokol Engineering and Quality Assurance. Weld and material certifications, dimensional inspections, and other functions will be maintained by Quality Control. End item acceptance criteria will be based on workmanship, drawing conformance, and functional requirements.

5.2 Tooling

Tooling for the SRM project will be identified, designed, and acquired using the experience and systems developed in previous solid rocket motor development and production programs. Experienced Tool Design and Planning personnel will design tooling, handling equipment, and special test equipment to manufacture, inspect, and test SRMs and their components. Requirements for tooling are to be generated in parallel with the SRM design as part of Morton Thiokol Systems Engineering, which will provide producibility support and coordination through manufacturing, quality, and safety engineers.

Proof testing of lifting and handling equipment can be categorized as either initial proof testing or periodic proof testing. Items such as lifting beams, slings, spreader bars, etc., require an initial proof testing to twice the design load with periodic testing to a load 1.5 times the rated load annually. Support equipment such as stands, work platforms and other items not used for lifting or handling will be proof tested initially as specified on the engineering drawing to a load of 1.25 times the rated capacity unless waived by OSC. No periodic tests will be required.

Specific requirements for each item of tooling will be generated during the detailed formulation of the process sequence (Manufacturing Plan). A tool order specifying the design criteria and schedule then will be issued and will follow the established and demonstrated sequence. Tool designers will work within the identified criteria and requirements and will hold reviews with safety, quality, handling, and manufacturing engineers as the design progresses through the concept, layout, and finished drawing stages.

Compatibility of tooling with the SRM design will be assured through coordination and review with design engineers as part of the tool systems engineering approach. If the tool is built in-house a shop traveler will be generated and the part will be fabricated, inspected, and tool proofed at Morton Thiokol, Inc. Otherwise, fabrication of the part will be subcontracted to a selected vendor and inspections will be as specified by Morton Thiokol, Inc. Generally, tool proofing of these subcontracted tools will be accomplished in-house by Morton Thiokol. Inspection operations normally will be performed throughout the fabrication process. In each instance, this will be specified in the shop traveler or purchase requisition. All tooling will receive a final inspection to verify that all design requirements are met. A functional tool proof verification will be conducted to insure that the tool performs in accordance with the criteria established as a result of the planned manufacturing process.

Analysis of tool maintenance requirements is based on Morton Thiokol experience obtained on all programs, and on the tool concepts prepared specifically for the SRM. The condition of tooling will be monitored and when required, maintenance and/or repair will be initiated by manufacturing supervision through the tool planner. Such critical items as those that control configuration, for example will be inspected on a routine or "recycle" basis. Critical tools and their frequency of inspection will be identified based on an analysis of product design engineering requirement by quality engineers.

Component tooling furnished by subcontractors will be controlled by means of an approved procurement and property control system that will provide tool control and accountability. Accountability and control of subcontractor tooling will be accomplished by issue and control tool identification numbers. Subcontractors will be required to certify compliance on each item of tooling. Full compliance with ASPR and NASA requirements will be implemented and maintained.

A tool design and acquisition schedule will be prepared and maintained for all of the tools. The schedule and a discussion of tool requirements for Morton Thiokol and subcontractor tooling will be included the Manufacturing Plan for the Block II SRM Project.

5.3 Special Test Equipment and Ground Support Equipment

Special test equipment (STE) and ground support equipment (GSE) will be designed by Morton Thiokol in accordance with the requirements of the Individual Identification Item specifications. The preliminary design will include the following considerations.

1. Manufacturing and test tooling concepts and designs will be used to the maximum extent possible for STE and GSE. This concept will reduce design time, development time, and test requirements and will provide highly reliable equipment.

2. Components that require periodic maintenance will have spare components identified to permit line replacement to keep availability of equipment to a maximum.

3. Equipment will be designed for multipurpose use where feasible, thus reducing storage requirements, logistic efforts, time required to transfer equipment, and minimize additional items of equipment.

Safety requirements also will be of prime importance. A thorough analysis will be conducted for new and modified STE to insure that each design complies with the load factors specified in the CSER. In addition, adequate shielding, grounding, and explosion proofing will be provided for electrical equipment. Such electrostatic producing devices as transportation equipment and shrouds will be grounded, rotating machinery will be enclosed, and SRM segment enclosures will be adequate to prevent propellant contamination and/or ignition during normal transport, handling, and storage.

Preliminary design through detail design activities will be coincident with those outlined for the TSE. The STE and GSE items, their requirements, functions, required quantities, and uses will be described in the CSER, which will be maintained as the baseline document for identification of TSE, STE and GSE hardware. Included are the equipment functions, quantities, design, and schedule requirements. Preparation/modification of support equipment will be in accordance with the SRM master schedule. PDR's and CDR will be conducted on all new STE. Acceptance and certification of existing STE will be performed at the launch sites. Changes will be summarized in the applicable ICDs.

The test requirements for any new special test equipment and ground support equipment will be similar to those outlined for Transportation Support Equipment.

5.3.1 STE & GSE Acceptance Tests

Acceptance test requirements for new STE will be identified in the applicable STE specifications included in the CSER. End item acceptance will be based on workmanship, drawing conformance, functional performance, static proof load, electrical continuity, and proof pressure. All tests will be monitored by Quality Assurance and will be performed by Morton Thiokol Quality Assurance and/or Manufacturing personnel and/or vendors. These tests will precede the first article configuration inspection (FACI) and will be the only tests performed for follow-on STE and GSE acquisitions.

5.3.2 STE & GSE Certification Tests

Certification tests will be performed as a part of the FACI. Applicable tests will be conducted on each new item of STE and GSE as specified in the CSER.

Interface tests will be conducted on new and STE and GSE to insure that form and fit requirements with the applicable SRM component are met.

Functional tests will be conducted on new items of STE and GSE to insure that each item functions properly.

Static proof load tests and static proof pressure tests will be conducted as required to verify structural and mechanical requirements. The qualification proof test load requirements are:

Equipment Category	Proof Test Load
Handling	2.00 x static design load
Structural Support	1.50 x static design load
Pressure Systems	1.50 x static design load

Static proof load tests will be conducted with weights that duplicate the applicable SRM component load distribution. Upon completion of the tests, the STE and GSE will be inspected for part failure or deformation. In addition, electrical tests will be conducted on the applicable STE/GSE to verify electrical continuity and function.

5.3.3 STE & GSE Verification Tests

Verification tests will be conducted at the assembly and test sites using qualified STE and GSE to verify that the STE and GSE interfaces with the applicable facilities and SRM components, and that it functions within the specified time constraints. The verification tests include (1) STE and GSE facility and STE and GSE-SRM-facility interface tests, (2) functional tests, and (3) time and motion tests. Emphasis will be placed on the STE and GSE-facility interface tests and the SRM assembly and checkout time and motion tests. Verification that the STE, GSE and facilities are operationally ready will be the responsibility of Thiokol and the Shuttle Processing Contractor. Support equipment and facility operational procedures and SRM assembly procedures and timelines will be continuously updated along with the STE, GSE and facilities to insure that site activation can be maintained within the schedule with a minimum amount of effort. Changes to STE, GSE and facilities will be accomplished in the field with equipment modification kits. All changes will be documented and approved by NASA before implementation.

All permanently installed equipment will be interface tested with the applicable supporting facility. Clearances will be established and access to SRM components with such equipment as work stands and cranes will be checked for clearances and interfaces. Minimum hook heights will be established and access roads, and entrance way requirements will be verified.

All STE and GSE will be directly or indirectly functionally tested in its operating environment. As an example, checkout of the S&A device test kit would be a direct functional test, whereas determining the ease with which handling equipment or tiedown equipment can be installed or removed would be an indirect functional test. Each item of STE and GSE will be evaluated from a performance standpoint.

Fabrication

Special test equipment will be acquired in advance of the on dock delivery dates specified in the Master Schedule. The acceptance and qualification tests will be completed with ample time allotted for any equipment changes and verification necessary at the test site. Upon completion and Morton Thiokol and NASA CDR approval of the end item design, a data package will be prepared for review by the Make-or-Buy Committee. Based on the committee's decision and NASA's approval, STE and GSE will either be fabricated in-house or procured from qualified firms whose capabilities and manufacturing site locations are best suited for economical support of all program increments.

All STE and GSE will receive an in-process and/or final inspection by Morton Thiokol Quality Control personnel. Purchased equipment will be inspected at the vendor's plant prior to acceptance by Morton Thiokol. Morton Thiokol will furnish inspectors at the vendor's plant. In-process engineering changes to facilitate manufacture, reduce costs, improve schedules, and improve designs will be coordinated through liaison engineers and processed in accordance with the configuration management procedures. This will insure that costs, schedules, and traceability can be maintained within project objectives. Assurance that the equipment items meet the requirements as specified in the end item specification will be the responsibility of Engineering and Quality Assurance. Weld and material certifications and dimensional inspections will be conducted by Quality Control.