ARES I FIRST STAGE DESIGN, DEVELOPMENT, TEST, AND EVALUATION

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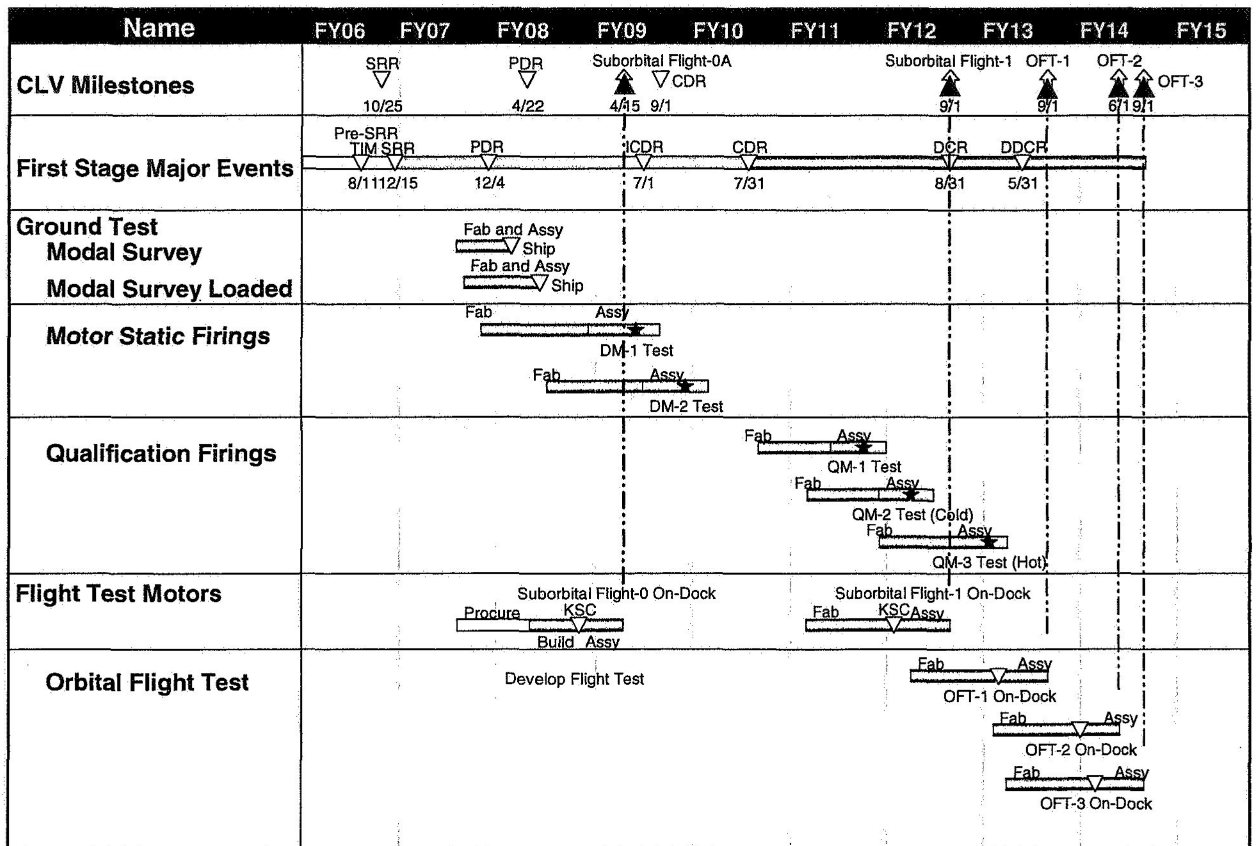
ABSTRACT

The Ares I Crew Launch Vehicle (CLV) is an integral part of NASA's exploration architecture that will provide crew and cargo access to the International Space Station as well as low earth orbit support for lunar missions. Currently in the system definition phase, the CLV is planned to replace the Space Shuttle for crew transport in the post 2010 time frame. It is comprised of a solid rocket booster (SRB) first stage derived from the current Space Shuttle SRB, a liquid oxygen/hydrogen fueled second stage utilizing a derivative of the Apollo upper stage engine for propulsion, and a Crew Exploration Vehicle (CEV) composed of command and service modules. This paper deals with current design, development, test, and evaluation planning for the CLV first stage SRB. Described are the current overall point-of-departure design and booster subsystems, systems engineering approach, and milestone schedule requirements.

INTRODUCTION

To return to the moon by the end of the next decade, NASA is developing a Crew Launch Vehicle first stage, which draws heavily on the impressive success of the Space Shuttle program SRB. To meet the challenge, the Ares first stage NASA team has structured integrated teams covering all major subsystems and system engineering tasks. NASA Marshall Space Flight Center is responsible for the overall launch vehicle along with management of the first stage effort. As prime contractor for the first stage, ATK is responsible for system engineering, subsystem design, development and qualification. Following the System Requirements Review (SRR) in December 2006 and Preliminary Design Review (PDR) in December 2007, the first full-scale static firing of the five-segment booster and the first suborbital flight test will occur in 2009. Motor qualification will be complete no later than 2013, with the first manned flight no later than 2014 (Figure 1). The design is built around maximizing the use of heritage hardware from the Space Shuttle vehicle adapted to the inline Ares first stage. The motor is adapted from the reusable solid rocket motor (RSRM) used on the Shuttle and uses the same motor case segments and propellant with a larger nozzle. Full-scale static testing of a similar five-segment motor has already been accomplished. The Range Safety System (RSS) will be the same as the SRB system adapted to the necessary changes in the Ares hardware. The aft section, including the aft skirt and thrust vector control (TVC) system, are unchanged from the Shuttle SRB. As a result of the inline vehicle architecture, new forward structure hardware is being developed. Because of obsolescence and vehicle architecture changes, the avionics system will be new. The deceleration system will be redesigned to decelerate the five-segment motor such that water impact energy is the same as for the current four-segment RSRM. The major subsystems and the system approach are discussed in this paper.



Note: SRR = System Requirements Review, PDR = Preliminary Design Review, ICDR = Interim Design Certification Review, OFT = Orbital Flight Test, CDR = Critical Design Review, DCR = Design Certification Review, DDCR = Delta Design Certification Review, KSC = Kennedy Space Center, QM = Qualification Motor, TIM = Technical Interchange Meeting, DM = Development Motor

Figure 1. Ares First Stage Development Plan

FIRST STAGE CONCEPTUAL DESIGN

The Ares first stage design is a logical adaptation of the proven RSRM used on the current Space Shuttle vehicle. The stage is recoverable and the majority of its components are reusable. Many of the heritage RSRM components, processes, and methodologies have been applied to the CLV first stage. This approach permits the development and implementation of a very robust launch vehicle configuration in a timely manner. The stage consists of five major forward structural components necessary to mate with the upper stage, house the stage recovery systems, package the booster avionics, and attach to the propulsion system. The stage also provides the vehicle guidance authority via the TVC system during first stage ascent. The TVC system is contained in the aft skirt, which also supports the entire vehicle on the launch platform.

The major forward structures are the frustum, aeroshell, forward skirt extension (FSE), main parachute support structure (MPSS), and forward skirt (Figure 2). The frustum is the primary interface to the upper stage and transitions from the 146 in.-diameter of the first stage to the 216 in.-diameter of the upper stage. The frustum also provides protection for the J-2X engine bell and the aeroshell. The aeroshell is part of the recovery system and is mounted to the top of the FSE. Its primary purpose is to house the pilot and

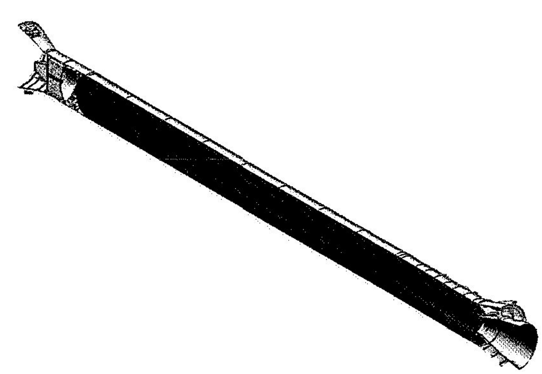


Figure 2. Ares First Stage

drogue parachute packs. The frustum and aeroshell are not reusable. The FSE and MPSS are integral components designed to accommodate the three main parachute packs and to react loads induced by the drogue parachute and aeroshell jettison. The forward skirt provides mounting provisions for the booster avionics, access to the propulsion system safe and arm (S&A) device, and load carrying capability for the main parachutes. The FSE and forward skirt are reusable components.

At the heart of the stage architecture is a solid propulsion system derived from the highly reliable, four-segment RSRM. This propulsion system, referred to as RSRMV with the V representing five segments instead of the four segments utilized on RSRM, has been adapted to Ares by: 1) incorporating an additional casting segment, 2) configuring the propellant grain for optimal Ares performance, and 3) modifying the RSRM nozzle assembly to accommodate the increased mass flow rate. The RSRMV is capable of producing nearly 3.7 million pounds of vacuum thrust and, when combined with the J-2X upper stage, can lift in excess of 58,000 lbs to low earth orbit. The RSRMV maintains the same level of reusability as the current RSRM.

Several major design activities are underway to mature the Ares first stage design. Minimizing stage mass is a driving requirement. The forward structures mentioned previously are all aluminum components. Because significant weight savings may be realized by utilizing composite materials, composite forward structures designs are being assessed against vehicle weight allocations, stiffness requirements, robustness, cost, and other factors.

Another major design study being conducted is high altitude deceleration (HAD). The first stage apogee after separation from the upper stage is significantly higher than the current RSRM. The resulting reentry conditions are at extremely high mach numbers and produce large dynamic pressures and severe heating environments. Several approaches are being evaluated that would maximize the stage's reentry drag to slow the vehicle down while simultaneously distributing the thermal loads more evenly over the vehicle. Options such as fins, ballutes, and drogues have been considered. The most promising option is inducing pitch into the stage immediately after separation such that the stage tumbles end-over-end. This would be accomplished by firing small solid rocket motors attached to the frustum.

Five-segment Motor Design

The five-segment motor design was derived from the RSRM to retain the robust, human-rated features of the world's most reliable solid rocket motor. The RSRM was designed with healthy factors of safety that are verified after every flight through rigorous inspections and hardware dissection. It is this heritage of hardware, along with systemic design and inspection processes, that have been carried forward to ensure the long-term success of the Ares first stage.

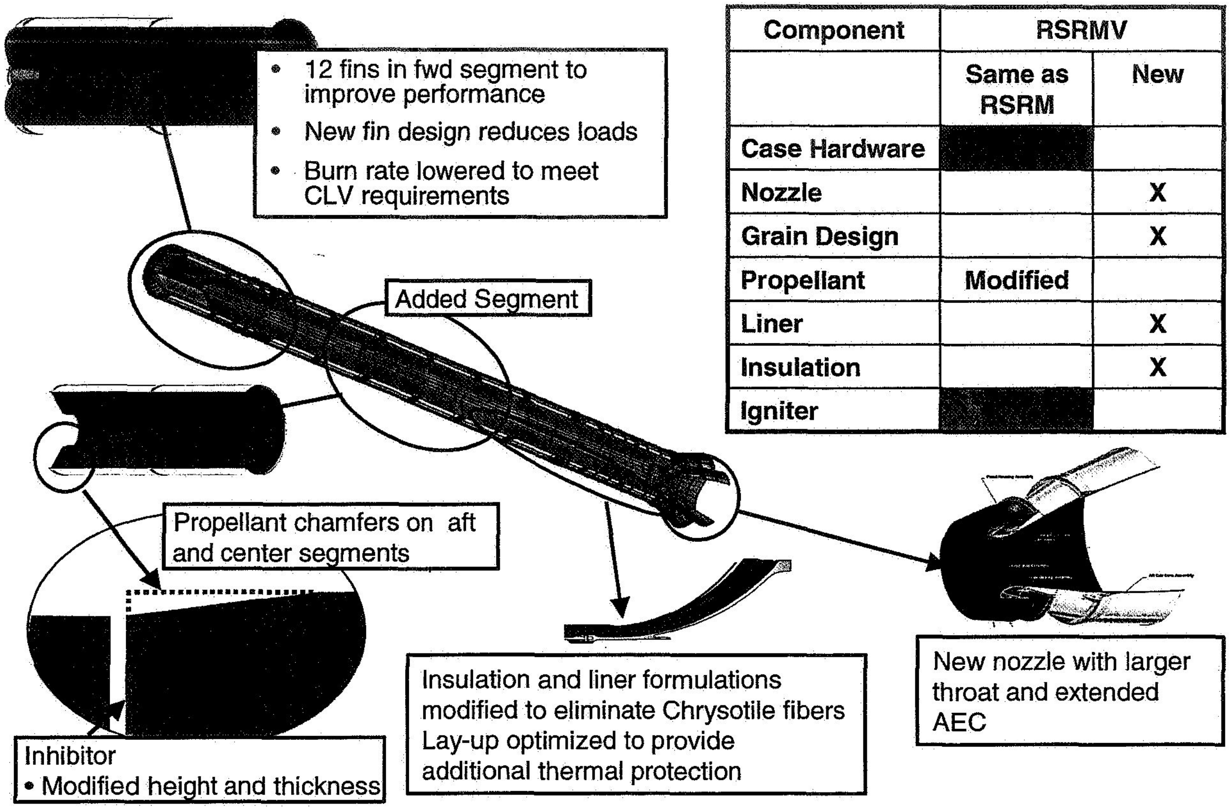
The proof of concept for the five-segment motor was a full-scale static test of a five-segment engineering test motor (ETM) that pushed design limits for burn rate, nozzle geometry, insulation exposure, and margins of safety. Wherever possible, the RSRMV was configured as closely as possible to RSRM within the parameters bench-marked by the ETM (see Table 1).

Table 1. RSRM, ETM and RSRMV Design Comparison

	RSRM	ETM-3	RSRMV
Motor			
Overall Length (in.)	1,513.49	1,868.25	1,868.25
Case Diameter (in.)	146.08	146.08	146.08
Nozzle			
Throat Diameter (in.)	53.86	56.11	56.86
Exit Diameter (in.)	149.64	152.75	152.75
Expansion Ratio	7.72	7.41	7.22
TVC Vector Clearance at Throat (deg)	11.64	11.64	5.22
Ballistics			
Total Propellant Weight	1,105,925	1,366,306	1,373,518
Maximum Thrust	3,326,311	3,689,934	3,550,820

Meeting performance demands and improving margins of safety beyond those of the already robust RSRM provided the basis for several key adaptations from RSRM. Tailorability of the solid rocket motor readily facilitated the needs of the CLV. Key design features transitioned directly from RSRM and those modified are summarized in Figure 3.

Twelve fins in the propellant grain were utilized in the forward segment to achieve high initial thrust and then transition to reduced thrust levels during maximum dynamic pressure for



Component	RSRMV	
	Same as RSRM	New
Case Hardware		
Nozzle		X
Grain Design		X
Propellant	Modified	
Liner		X
Insulation		X
Igniter		

Figure 3. RSRMV Design Summary

the vehicle. The transition from fin to center perforated propellant grain in the forward segment was tapered to maximize structural margins of safety, which now exceed those of RSRM. Thrust characteristics resulting from the modified grain and updated nozzle design are shown in Figure 4.

Propellant for the RSRMV is a polybutadiene-acrylonitrile-acrylic acid polymer (PBAN) binder, epoxy curing agent, ammonium perchlorate (AP) oxidizer, and aluminum powder fuel. The AP is used in an unground and ground bimodal mixture.

Granular aluminum powder is used in the motor propellant. Small quantities of ferric oxide (Fe_2O_3) are added to tailor burn rate flexibility. The 86 percent solid RSRMV formulation is very similar to RSRM and ETM-3. Quantities of AP, aluminum, and Fe_2O_3 are shown in Table 2.

The majority of the nozzle components were retained with only the movable portion of the nozzle requiring modification. TVC clearances were maintained to ensure vehicle controllability for angles up to 4.5 degrees. The throat diameter was increased from 53.86 in. (RSRM) to 56.86 in. to provide the high levels of thrust needed at liftoff. Metallic throat, inlet, and forward exit cone housings were also increased in diameter to accommodate throat diameter increase and to provide for further increases in nozzle thermal performance factors, making the RSRMV nozzle the most robust nozzle ever designed for flight.

A new insulator material consisting of p-phenylene-2, 6-benzobisoxazole (PBO) fibers and nitrile butadiene rubber (NBR) was chosen to provide a 10 percent reduction in weight and maintain long-term supplier viability while still meeting demonstrated structural and thermal performance requirements. All other components, such as the safe and arm device, igniter, and case hardware were carried over directly from RSRM to preserve the demonstrated heritage and minimize development efforts.

Versatility was retained during the RSRMV design to allow for future growth options and adaptation to future vehicles. Total motor thrust can be increased to over four million pounds. With minimum reduction in thermal performance requirements for the throat, the diameter can be opened up to 58.86 in. Extra case margin allows

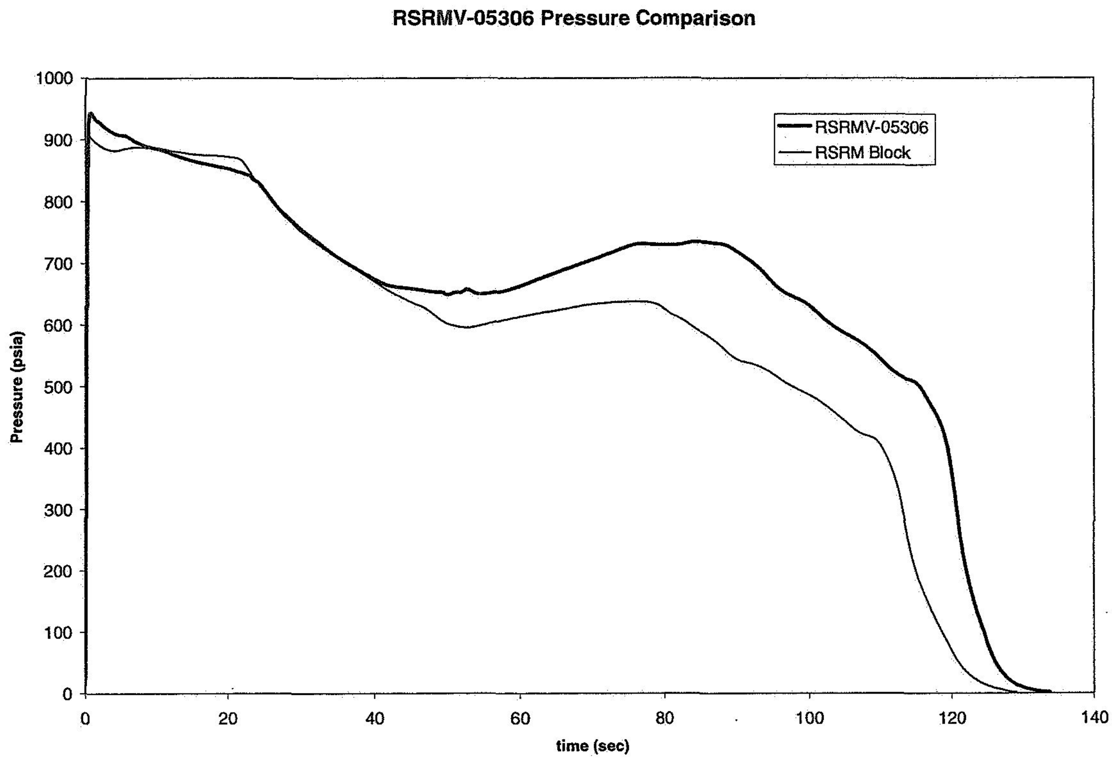


Figure 4. Thrust-time Trace for RSRM and RSRMV

Table 2. Propellant Formulation

Raw Material	Weight (%)	Function
AP	70 – Fe_2O_3*	Oxidizer
Aluminum Powder	16	Fuel
HB Polymer and Epoxy Resin	14	Binder curing liquid agent
Ferric Oxide (Fe_2O_3)	*	Burn rate catalyst

*Percentage of Fe_2O_3 is determined by burn rate tailorability required

maximum operating pressure to be increased to 990 psi, which can be readily achieved through burn-rate tailorability.

The robust nature of the RSRMV also provides opportunities for weight reduction after initial static tests. Insulator and exit liner thicknesses may be reduced if performance is within expected ranges. New low-temperature O-ring material may enable the elimination of joint heaters and associated cables and monitoring instrumentation. Slight increases in reusability risk could facilitate reductions in thermal protection system insulation offering further weight reduction opportunities. In total, the RSRMV design offers several thousand pounds of potential weight reduction to offset weight growth which is typical of a new program and ensures the CLV first stage meets its performance obligations to the vehicle.

<u>Forward Structures Assembly</u>

The forward structures assembly functions as the interface between the forward end of the RSRMV and the aft end of the upper stage. The assembly is comprised of several discrete structures including the forward skirt, MPSS, FSE, aeroshell, frustum, and separation joints. The baseline material for these structures is aluminum, with several alternate designs, materials, and manufacturing techniques under consideration. Each structure is shown in Figure 5.

The majority of the CLV first stage avionics components are housed in the internal volume of the forward skirt. As these avionics components are to be recovered and reused, the forward skirt is designed to preclude the intrusion of seawater into its internal cavity

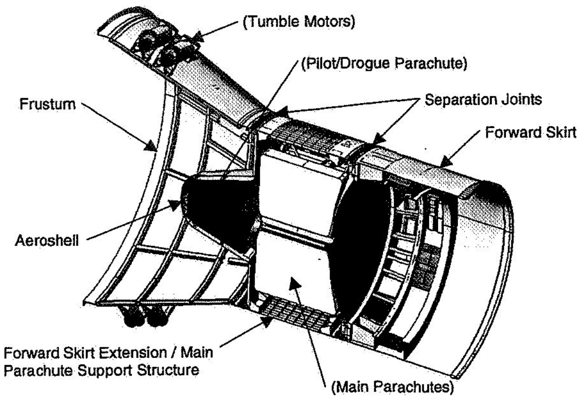


Figure 5. Forward Structures Assembly

during and after splashdown. In addition, the forward skirt must resist large axial, shear, and bending body loads during ascent. Finally, the forward skirt reacts the descent loads of the three main reentry parachutes through hard attach points located on the forward end of the skirt.

The MPSS is housed inside of, and works in conjunction with, the FSE. The three main parachutes, which are deployed during descent, are packed inside the FSE and are supported by the MPSS. The MPSS also deploys the main parachutes during descent. In addition, the MPSS provides a 3-D structural space frame that reacts the loads generated from the drogue chute deployment. Like the forward skirt, the FSE is also designed to resist the vehicle body loads during ascent.

The aeroshell is mounted atop the FSE and serves two primary functions. First, it protects the pilot and drogue chutes from the high aerodynamic and thermal loads generated during reentry. Second, it is used to deploy the pilot and drogue chutes upon acceleration away from the FSE at the appropriate reentry altitude. It has no ascent loads of any significance.

The frustum provides a structural interface between the first stage and the upper stage and resists the large ascent body loads. Because the frustum is not required to react loads during descent, after separation of the first stage from the upper stage, it is ejected from the first stage and is allowed to burn up during reentry.

The two separation joints ensure compliance with the required separation sequence.

Future optimization of the structures are planned to minimize weight and enhance vehicle performance. These efforts will include an evaluation of various design types including, but not limited to, ring and axial stringer, isogrid, orthogrid, and honeycomb. In addition, a range of materials will be considered including various aluminums, titanium, and composites. Finally, manufacturing methods including welded, bolted, forged, machined and various fiber placement processes will also be assessed.

Separation and Deceleration System

The first stage booster of the Ares launch vehicle is recovered and reused as is the present Shuttle RSRM. Recovery reduces system life-cycle cost and facilitates the postflight inspection of the expended booster hardware. For a human-rated vehicle, the inspection of flight hardware provides invaluable insight on component margins and system performance in actual flight environments. This valuable feedback data helps maintain a safe, highly reliable product.

There are significant differences between the Ares flight environment and the Shuttle that affect the approach and design of the recovery system. The Ares booster stages at a higher energy state and flies to a much higher apogee. This results in reentry conditions that are not compatible with the existing deceleration system. In addition, the Ares first stage booster uses a heavier five-segment motor that requires larger main parachutes to maintain acceptable splashdown velocities. Therefore, a new deceleration system design is necessary for successful booster recovery.

The major components of the deceleration system are depicted in Figure 6. The function of these components is outlined in time-sequenced order in Table 3. The first event that occurs after staging is the initiation of a pitch plane tumble maneuver, which maximizes needed drag during the free-fall part of the reentry trajectory. Without this maneuver, the booster would not reach an acceptable dynamic pressure condition for parachute deployment at the proper altitude allowing complete deceleration before water impact. The tumble is initiated by four tumble booster separation motors (BSM) that are attached to the frustum.

Shortly after the tumble maneuver, the frustum/interstage is separated when the booster has rotated approximately 180 degrees. Separation velocity between the frustum/

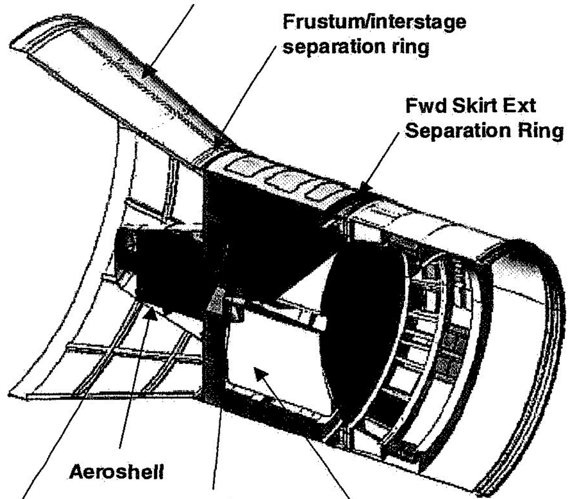


Figure 6. Deceleration and Separation Subsystem Description

Table 3. Post Staging Notional Time Sequence of Events

Key Event	Time (sec)	Altitude (ft)	Velocity (ft/sec)
Separation from Upperstage	130	194,300	6,640
Tumble Motor Fire	133	202,000	6,595
Frustum/Interstage Separation	145	232,000	6,430
Apogee	225	325,000	5,930
Aeroshell Jettison	400	15,600	624
Pilot Chute Deploys	401	15,200	638
Drogue Chute Deploys	403	13,500	580
Fwd. Skirt Ext. Separation	426	5,000	315
Main Chutes Deploy	428	4,400	350
Booster Water Impact	465	0	69

interstage and booster results from the booster's pitch rotation. After this event, the booster is in a reentry configuration. The booster does not maintain an end-over-end tumble through reentry, but eventually decays into a rocking motion in the pitch plane.

Between 16,000 and 15,000 ft altitude, thrusters jettison the aeroshell upon command from the altitude sensor assembly. The aeroshell protects the pilot and drogue parachutes from the high thermal and dynamic pressure environments during reentry. The drogue chute stabilizes the booster in a vertical orientation and, through multiple reefing stages, slows the booster to a velocity (about 300 fps) low enough for main chute deployment.

The three main parachutes are housed in the FSE. Upon a second signal from the altitude sensor assembly, the FSE separation ring separates the FSE from the forward skirt, pulling the main parachutes from the bottom as is presently done on the Shuttle. After several reefing stages, the booster finally impacts the water at approximately 69 ft. per second.

Several trade studies have been completed or are in progress to define the deceleration and separation subsystem design requirements. These include:

- High altitude deceleration approach (pitch tumbling)
- Separation mechanism optimization
- Aeroshell sizing optimization
- Parachute sizing and optimization
- Altitude sensor design
- Water splashdown velocity analyses

These studies will help define the more detailed requirements as we approach system requirements review.

Avionics, Electrical, and TVC Systems

The CLV avionics and control system provides the means to control first stage powered flight as well as all necessary prelaunch testing and checkouts. The first stage avionics and control system is baselined to be fault tolerant and support all functions from booster initiation through parachute deployment. During ascent, the first stage will not be required to provide any computing and control functions, but will be required to respond to all commands issued from the upper stage. The majority of the CLV avionics system components will be housed in the equipment section forward of the solid rocket motor forward segment. This location will provide a watertight enclosure and protection from all flight environments. The CLV avionics system will: 1) provide the necessary electrical power for the first stage system (no power will be required from the upper stage), 2) provide flight-critical communication with the upper stage by using three Mil-Std-1553 data buses, 3) provide a separate communication link with the upper stage for non-critical engineering data for transmission to ground receiving stations, 4) provide data and video storage capacity, which can be downloaded after flights, 5) provide all recovery functions after separation from the upper stage, and 6) provide nozzle steering using the Shuttle legacy TVC system.

The Ares first stage avionics architecture is divided into five subsystem elements: 1) power system, 2) command and control, 3) pyrotechnic control, 4) flight data instrumentation, and 5) TVC. The following section briefly describes each of the five subsystem elements graphically depicted in Figure 7.

Power System: controls and monitors two sources of power. The first source is provided by ground operation while the CLV is on the mobile launch platform (MLP). Onboard batteries provide power for ascent. The power system switches between the ground power supply and the batteries before the launch, conditions the power as required, and monitors the status of the power source. Major elements of the power system are the battery and power distribution unit.

Command and Control: contains the following three main components:

Booster Control Unit (BCU): de-multiplexes commands and provides discrete commands to various first stage functions including the thrust vector actuator (TVA) and multiplexes flight-critical data for transmission to the upper stage if required. All upper stage and ground commands come into the BCU.

Rate Gyro Assembly: provides angular rate information of the vehicle to the upper stage via a flight-critical data bus.

Hydraulic Power Unit Controller (HPUC): controls using an auxiliary power unit.

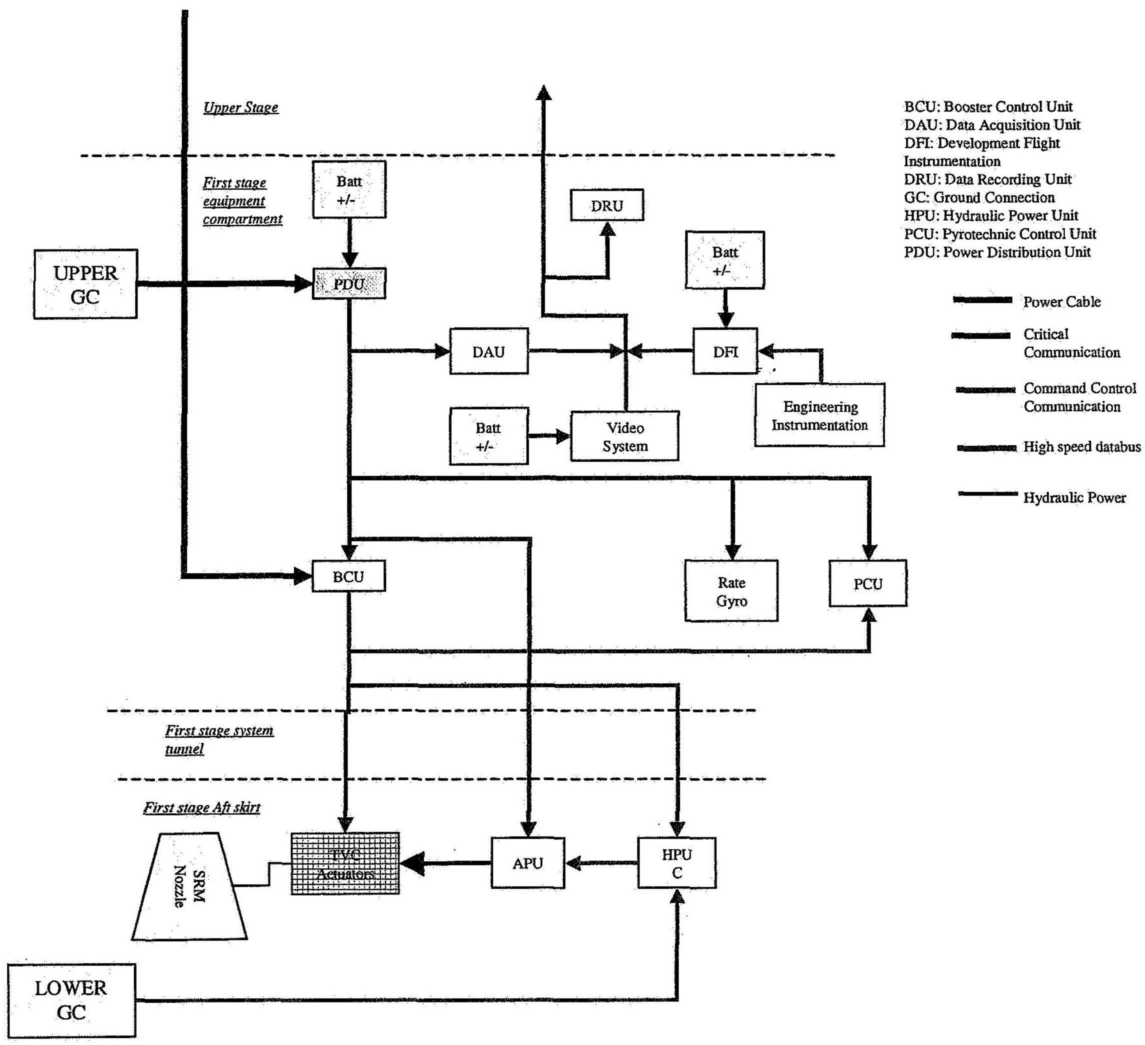


Figure 7. Avionics Architecture

The hydraulic power unit monitors the turbine speed through signals received from two magnetic pickup units located in the turbine shaft and controls the fuel flow to the gas generator. Two HPUCs will control the two Shuttle heritage auxiliary power units and provide the APU out function, which accelerates one turbine should the other fail to operate so first stage flight can be accomplished.

Pyrotechnic Control Unit (PCU): provides all pyrotechnic event discrete signals including recovery functions, motor firing, hold-down postfiring, separation firing, nozzle exit cone jettison, chute deployments, and aeroshell jettison.

Flight Data Instrumentation (FDI): consists of the following three main components:

Data Acquisition Unit (DAU): provides excitation, signal conditioning, and encoding of the operational instrumentation. Each DAU in the FDI subsystem will interface with a non-critical high-speed data bus to provide a subset of monitored data to the CLV upper stage for downlink. Each DAU will record digital data internally and in the data recording unit. Each DAU will receive power from one of the operational instrument power distribution units, and will be electrically isolated from each other and from all other electrical equipment except the operational instrument channel from which it draws electrical power.

Data Recording Unit (DRU): Two units provide onboard data storage from video systems and the DAU for data transmitted to the ground. To avoid bandwidth limitations for ground telemetered data, the DRU will be capable of recording many more channels of engineering data than normally possible. During flight, data will be stored in the DRU and downloaded after recovery of the motor. The DRU will interface via the video/ developmental flight instrumentation (DFI) data bus to the DFI master and the video controllers and via the first stage internal data bus to the DAUs, BCUs, PCUs, and HPUCs.

Developmental Flight Instrumentation (DFI): will fly on the first few missions to collect and monitor the performance of the Ares first stage.

Thrust Vector Control (TVC): provides pitch and yaw control during ascent. Roll control is an upper stage function. The TVC system is located in the SRB aft skirt and consists of two separate hydraulic power units that supply hydraulic power to the heritage TVC electro-hydraulic servo-actuators to effect mechanical positioning of the SRB nozzle in response to steering commands.

Future design updates before preliminary design review include instrumentation system simplification, changes to accommodate crew abort functions, and changes to the heritage TVC to improve areas of the system.

Ordnance and Range Safety Systems (RSS)

Ares first stage pyrotechnic devices are required to support motor functions such as motor ignition, separation, and motor case recovery sequences. Other pyrotechnic and avionics devices are necessary for range safety.

The top-level design requirements for pyrotechnics include: 1) reliability, 2) fault tolerance, and 3) flight separation. These requirements are allocated to component specifications that require testing, redundancy, and specific functionality to verify upper-level requirements.

There are twelve pyrotechnic events identified for the first stage. These events are tabulated in Table 4 and mapped in Figure 8.

Some pyrotechnic events are still being studied and may not be required, such as a pilot chute mortar (9) and interstage/frustum separation thruster (7). Conversely, as the first stage design matures, additional pyrotechnic

Table 4. Pyrotechnic Events

1. MLP Hold-down Separation	7. Interstage/Frustum Thruster
2. First Stage Motor Ignition	8. Aeroshell Ejection*
3. First Stage/Upper Stage Separation Initiation	9. Pilot Chute Mortar Thruster*
4. First Stage/Upper Stage Separation BSM Ignition	10. Parachute Pyrotechnics*
5. Booster Tumble Motor Initiation*	11. FSE Separation*
6. Interstage/Frustum Separation*	12. Exit Cone Severance*

Part of the motor case recovery system

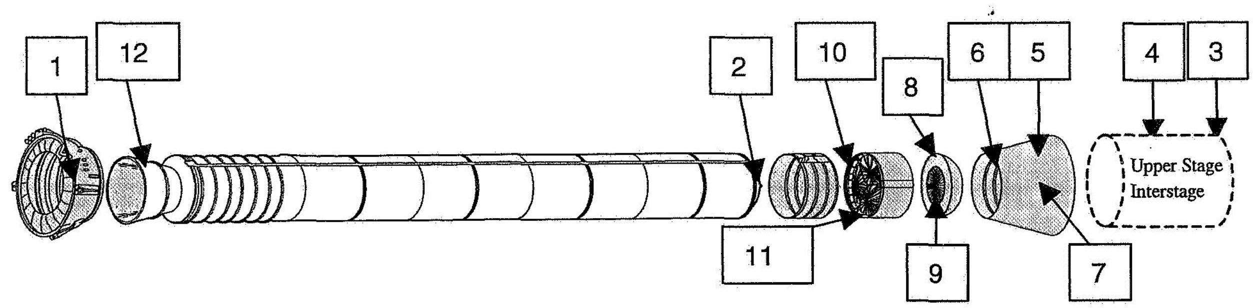


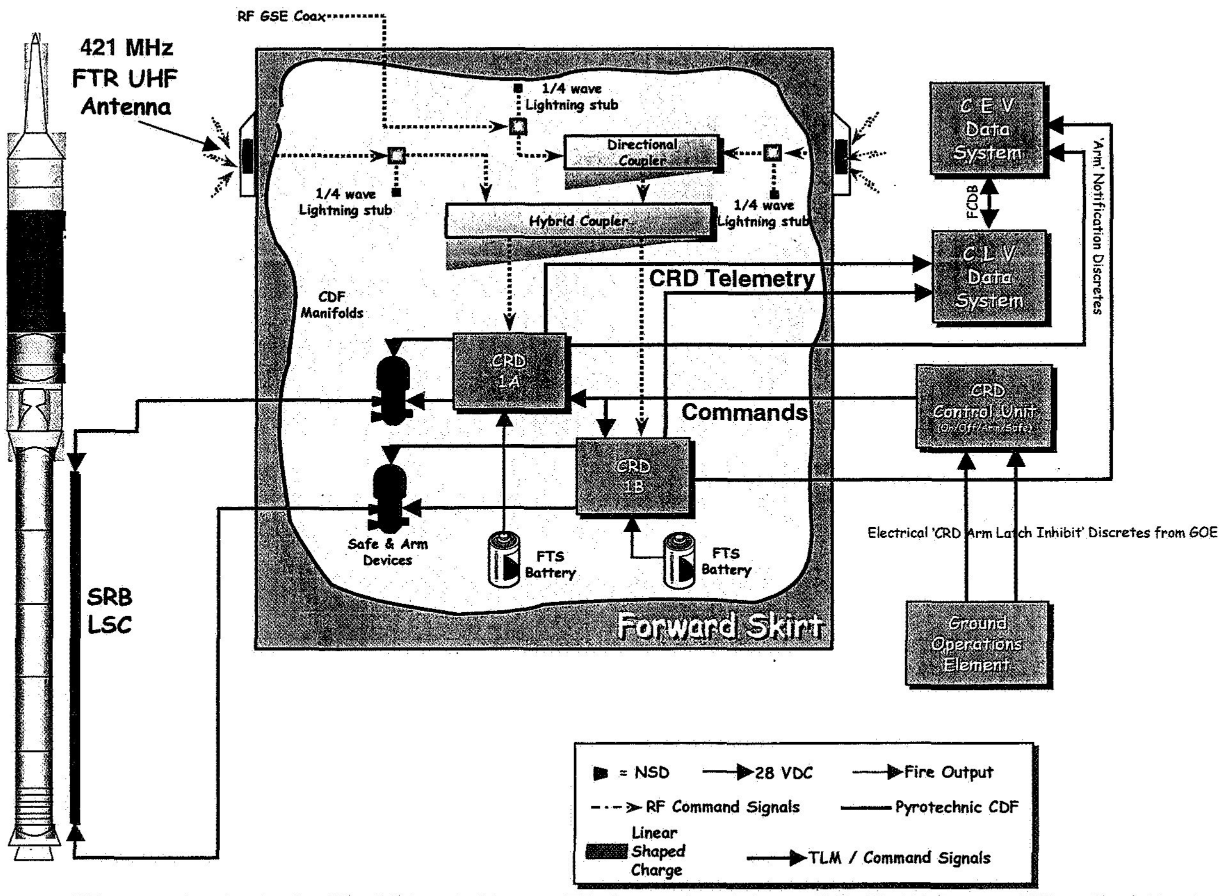
Figure 8. Location of CLV Pyrotechnic Events

events may be required. Of the currently identified twelve events, seven are similar to the Shuttle baseline. These twelve events will consist of common pyrotechnic components or building blocks arranged in a pyrotechnic train. These building blocks are detonators, manifolds, explosive transfer lines (ETL), separation systems, and initiators.

Trade studies are being conducted of some of the building block items including Shuttle ETL versus updated ETL, and linear-shaped charge separation systems versus frangible joint separation systems. A formal study is currently evaluating the replacement of the NASA standard initiator (NSI) with a semi-conductor bridgewire initiator.

The Range Safety System flight termination system (FTS) requirements are allocated from specific system requirements and AFSPCMAN 91-710, as tailored for Ares. The architecture for the first stage FTS is found in Figure 9.

The FTS baseline design will maximize the



Note: CRD = command receiver decoder, NSD = NASA standard detonator, FTR = frequency transmission rate, UHF = Ultra-high Frequency, SRB = solid rocket booster, LSC = linear shaped charge, CDF = confined detonating fuse, CEV = crew exploration vehicle, TLM = telemetry

Figure 9. First Stage Flight Termination System Architecture

use of Shuttle heritage components including the command receiver decoder, couplers, and antennas with some modifications. One necessary departure is the incorporation of an initiation delay to accommodate the launch abort system (LAS). This delay will allow the LAS to function prior to initiation of the destruct event, thus allowing the acceleration of the astronauts to a safer distance from the booster.

FTS studies include electronic versus pyrotechnic delay, and extending the destruct charge to include the aft motor segment.

Aft Skirt

The aft skirt provides structural support for the Ares first stage on the launch pad. The skirt utilizes spherical attach points to the MLP to transfer natural and induced loads from the vehicle through the aft skirt to the MLP. For liftoff and flight, the aft skirt provides aerodynamic protection, thermal protection, and mounting provisions for the TVC subsystem (Figure 10). The aft skirt is also reusable, and must survive water impact loads in addition to the harsh saltwater and sea state environments. The aft skirt has a conical shape with a 146-in. minor diameter, a 208.2-in. major diameter, and is 90.5-in. long. This shape accommodates attachment to the aft dome attach tang of the RSRMV and provides sufficient clearance for the nozzle at full gimbaled travel of the TVC system. The aft skirt has an integral stringer/skin construction welded to four forged hold-down posts with bolted-in circumferential rings fabricated from 2219 aluminum. Internal gussets and clips have been added to stiffen the structure and minimize water impact damage. The aft skirt kick ring provides the necessary structural clevis attach points to the RSRMV, which bolts to the aluminum aft skirt and is machined from a rolled ring forging of D6AC steel. Thermal curtains are mounted between the aft skirt and the RSRMV nozzle for thermal protection of the interior aft skirt structure and TVC system components. A liftoff umbilical for electrical functions and power, and the heated gaseous nitrogen purge probe are located on the aft skirt aft circumferential ring web and mates with the MLP (Figure 10).

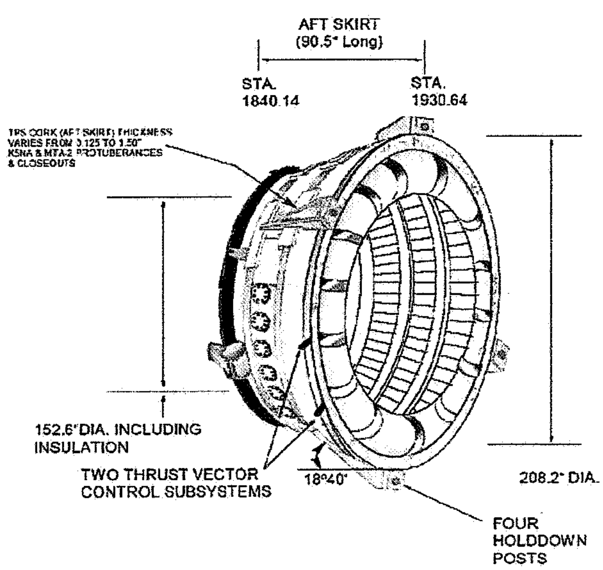


Figure 10. Aft Skirt Assembly

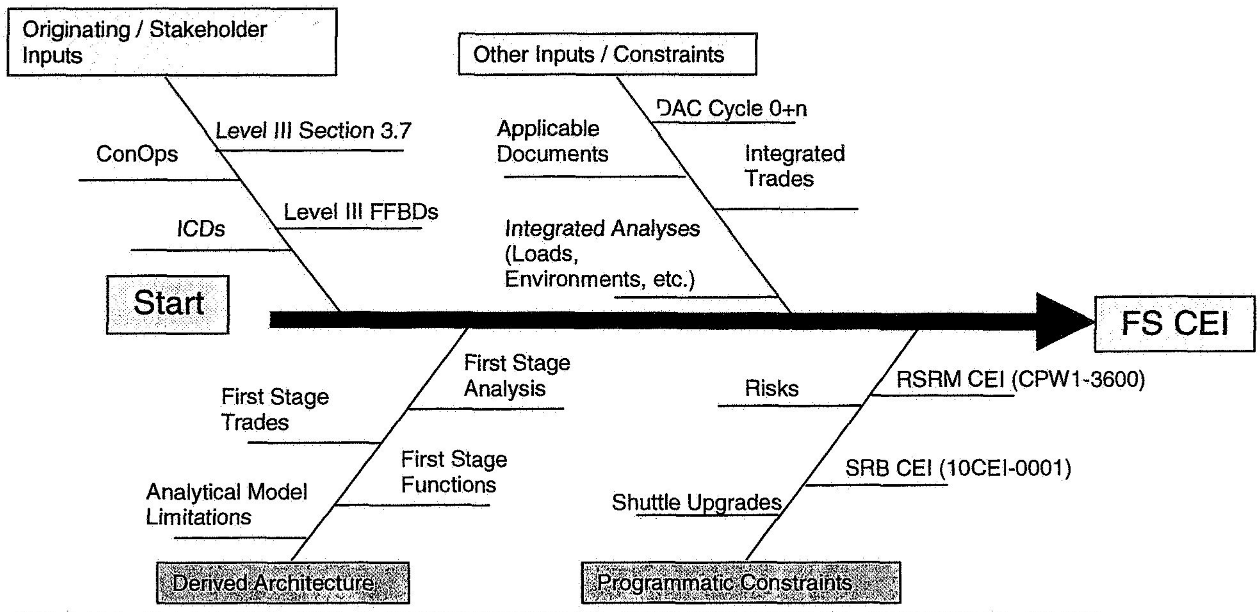
The aft skirt will be modified from the Space Shuttle to the CLV first stage configuration by removing the aft BSMs and plugging the attach holes, designing an avionics support structure to attach the APU speed controller boxes, making accommodations for increased capacity for the T-0 umbilical up the systems tunnel, new thermal curtain replacement design, and additional external thermal protection material for the structure. On-pad Ares wind loads are critical and can exceed Shuttle main engine startup loads for the aft skirt requiring a significant structural beef-up and/or the addition of an on-pad vehicle damper/support structure.

SYSTEMS ENGINEERING METHODOLOGY

Requirements Generation

There are various sources for the technical requirements applicable to the first stage as shown in Figure 11. Definition of technical requirements will involve converting needs, goals, and objectives to technical requirements in order to capture constraints and conduct requirements analysis and traceability.

The first step in this process is to evaluate SRB and RSRM requirements for applicability to the Ares first stage design. This step includes eliminating requirements specific to the Shuttle, modifying wording to be specific to the first stage, and evaluating the technical rational for the requirement. This process is represented in Figure 12. The second step is adding allocated requirements from the Ares system requirements document (SRD). This step



Note: ConOps = concept of operation, FFBD = functional flow block diagram, ICD = interface control document, CEI = critical end item, FS = First Stage, CPW = contract end item specification, DAC = design and analysis cycle

Figure 11. First Stage Critical End Item Requirement Sources

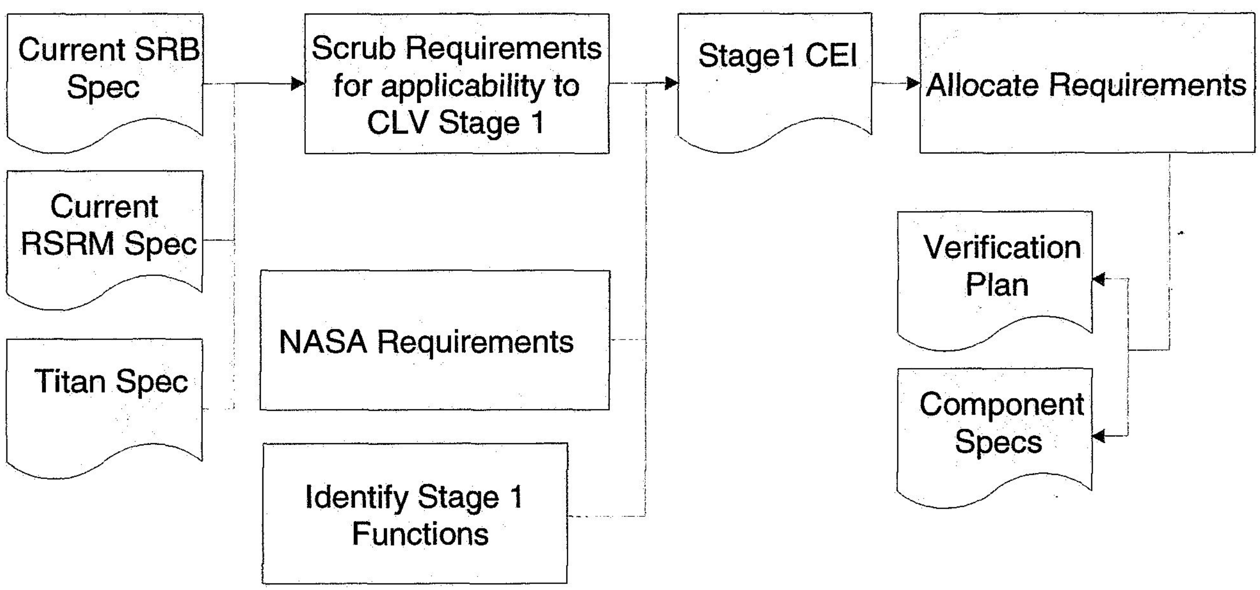


Figure 12. Evaluate SRB and RSRM Requirements

includes comparing the requirements to SRB/RSRM requirements and evaluating the technical rational for these requirements. This process is represented in Figure 13.

Requirements Allocation

System requirements and control are implemented from the top down and products are realized and verified from the bottom up. Requirements will be allocated to each subsystem. Each subsystem program manager and chief engineer will review requirements for applicability to their subsystem.

Requirements Management

Requirements will be developed and managed using a systems engineering software called Teamcenter Systems Engineering (TcSE).

Requirements baselines will be established at the appropriate technical reviews, beginning

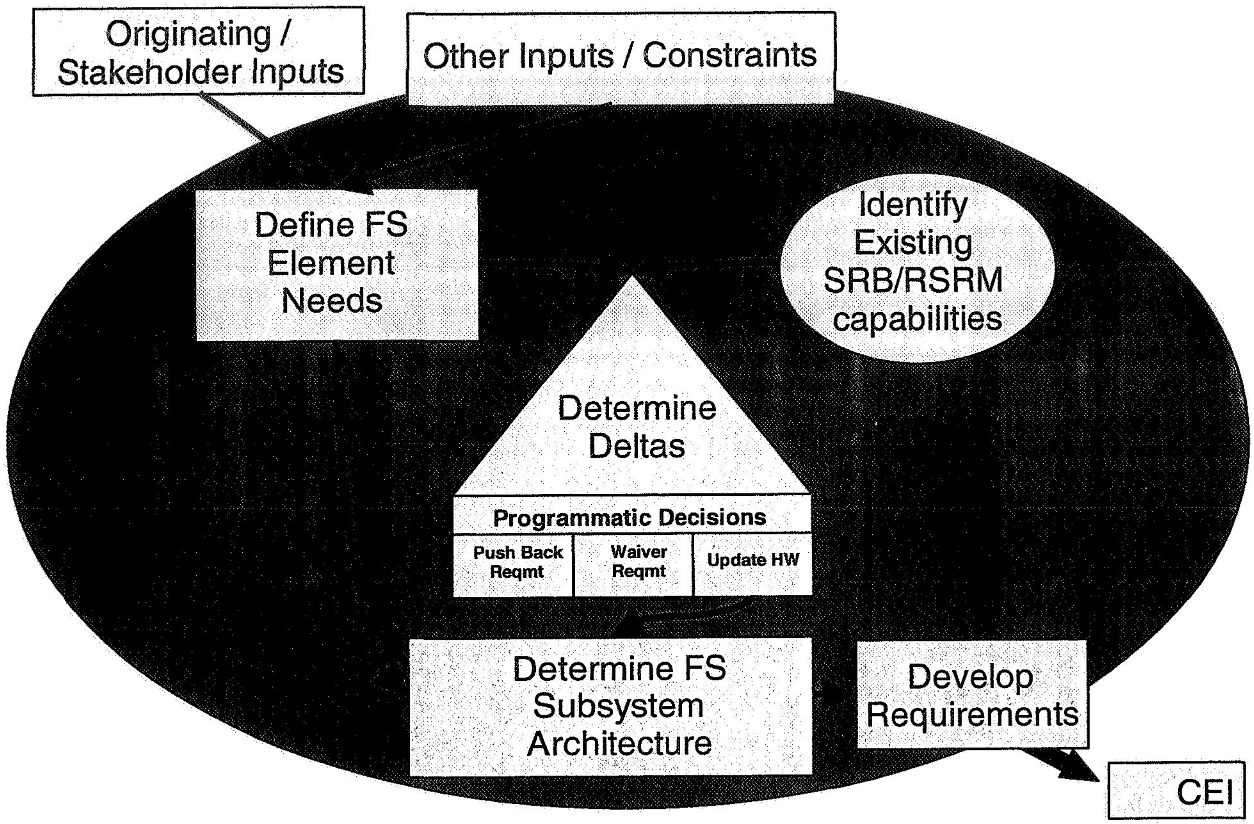


Figure 13. First Stage Requirements Definition Process

with the development of functional and performance baselines at the System Requirements Review. These baselines will progress through the development of the allocated baselines at Preliminary Design Review, which will lead to the product baseline at the time of hardware and software configuration item acceptance. Following approval, each baseline will be put under configuration control.

Verification and Validation Approach

A detailed verification and validation approach ensures that the CLV first stage complies with design, performance, and safety requirements and can be successfully integrated with the CLV upper stage. The general verification approach includes the following:

- Design, development, and qualification phases that lead to a certified design
- Acceptance, preflight, and assembly checkout, integrated testing, flight, and postflight phases which verify each CLV first stage complies with the design requirements
- Applicable verification methods of similarity, analysis, inspection, demonstration, and test
- Facilities and ground support equipment checkouts
- Ground motor tests, ascent development flight tests, and development flight tests

The environmental test requirements, test methods, and test criteria established in the first stage critical end item specification shall be used as guides during testing and verification of the vehicle's avionic, mechanical, hydraulic, and other components, excluding major structural components. A failure or unsatisfactory condition encountered during any phase of the verification program will require reporting.

Verification Logic Flow

A project roadmap will be prepared for each first stage subsystem. Roadmaps will identify design, development, test, and evaluation tasks required from system requirements review to design certification review. Figure 14 outlines the roadmap approach.

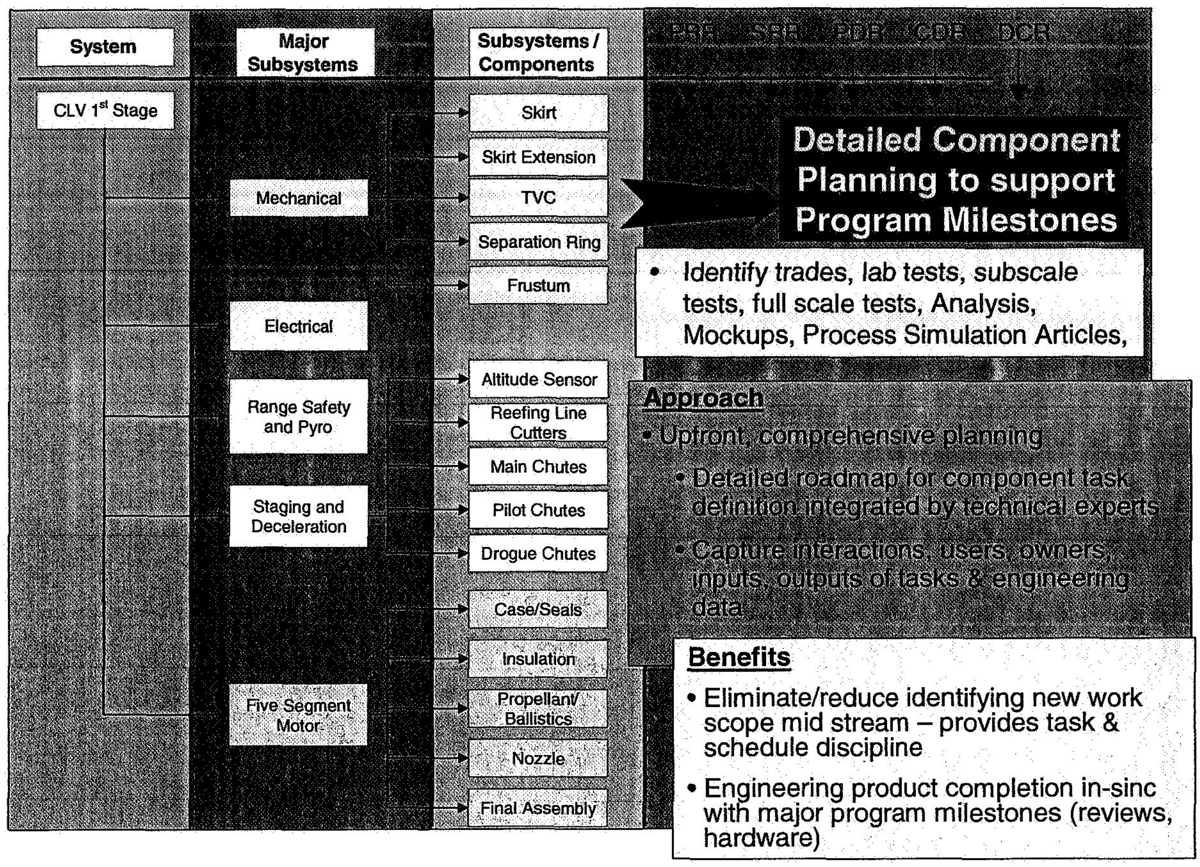


Figure 14. CLV Project Roadmap Approach

Verification Plans

Verification plans will be written for each Ares first stage subsystem or a combination of the subsystems (Figure 15). Each verification plan will address the applicable requirements of the critical end item as well as the applicable subsystem specification.

The verification plan includes preliminary summaries of each task required for complete verification of the Ares first stage material, component, assembly, part, or manufacturing processes. The similarity, analysis, and inspection summaries serve as the plan for that activity. Test and demonstration summaries are preliminary test planning summaries, which lead to MSFC approved test plans. Verification reports are prepared addressing each of the completed verification activities specified in the verification plan. The verification plans will be baselined at the first stage PDR and will require NASA CLV First Stage Project Office approval.

Detailed Verification Objectives

The verification plan will include verification task summary sheets to outline the detailed verification objectives (DVO) that will define the strategy for showing compliance to the contract end item requirements for the specific task summary sheet. The DVOs will feed into the test plans, analysis, and inspection verification activities. The test plans, analyses, and inspection reports containing the DVOs will be reviewed and approved by the NASA CLV First Stage Project Office.

Verification Traceability and Compliance Document

Teamcenter Systems Engineering (TcSE) will be used to show requirements traceability from the Level III first stage engineering requirements document down to the subsystem level system requirements documents. A master matrix document will be created from TcSE that will provide the compliance traceability to all first stage system requirements document requirements. It will be a living document that will provide a history of the baseline certification and updated to include compliance to all requalification efforts thereafter.

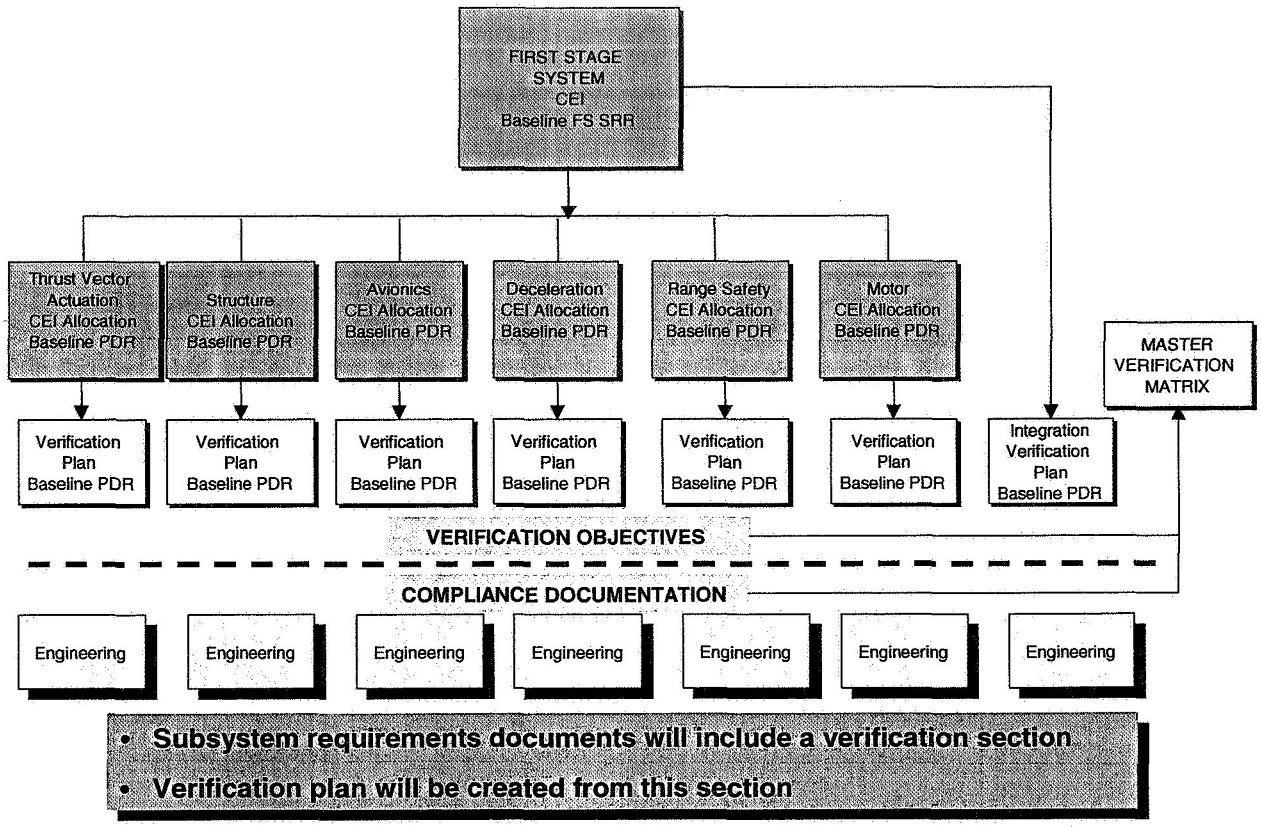


Figure 15. Verification Plan Approach

SUMMARY

We are fortunate to have an exciting and challenging mandate to leave low earth orbit, return to the moon, and travel to Mars. A key element in accomplishing this mandate within the timeframe and fiscal realities set forth by the President and NASA administrator is the utilization of existing hardware and technologies wherever possible and practical. Therefore, CLV first stage will utilize the proven safety, reliability, and low cost of the RSRM as its core element, with only those modifications required to meet the Ares mission. Returning to, and traveling beyond the moon is essential to continuing the basic need humans have to explore and understand. The execution of such a program will result in the furtherance of the state-of-the-art in science and technology and the development of commercial products and markets not yet envisioned.