APPENDIX A
Space Launch System (SLS) Advanced Development Technical Information

1.0 INTRODUCTION

The Space Launch System (SLS) is a heavy-lift vehicle that has a capability above the current United States (US) lift capacity to support an efficient and affordable means to meet multiple launch missions. These missions include human exploration beyond Earth orbit (BEO), low Earth orbit (LEO), to the International Space Station (ISS) and assembly of large and complex structures in space. Other mission profiles that can be supported by the SLS include science-based missions for deep space astronomy and solar system exploration. SLS will also be capable of supporting commercial-based missions. For crewed missions, the SLS, Orion – Multi-Purpose Crew Vehicle (MPCV), and launch pad elements work together as a human-rated system architecture. The SLS is human rated with abort capabilities for configurations of the integrated stack with the Orion-MPCV. The SLS will be interchangeable within a block configuration with any payload type (Orion-MPCV, cargo, or Orion-MPCV + cargo) such that no significant changes in SLS processing flow are required.

The SLS elements and line replaceable units (LRU) below the payload adapter will be interchangeable at the launch center. This supports the interchange of a core first stage, core upper stage, boosters, engines (first or upper stage), or LRUs, due to vehicle anomalies or manifest changes. The payload adapter will provide a common interface to the vehicle core first stage or core upper stage while supporting various configurations of payloads and/or Orion-MPCV. The interchanging of SLS configurations (either within block configurations or across blocks) will not impact the Ground Systems Development and Operations Program (GSDOP) architecture.

Initial SLS Block 1 flights will support Orion-MPCV only, Orion-MPCV with an interim cryogenic propulsion stage (iCPS), and cargo-only configurations.

SLS will have the largest payload lifting capacity of any previous national launch vehicle: initially a 70 metric ton class evolving to a 130 metric ton class. The launch vehicle requirements and configuration are currently under development. The SLS architecture is compatible with any payload type such that no significant changes in the SLS design, certification, or processing flow will be required. Figure 1 shows block upgrades being targeted to evolve the SLS vehicle from the 70 metric ton configuration with a solid booster to the 105 metric ton and 130 metric ton configurations utilizing either a solid or liquid booster. Figures 2, 3, and 4 show further details of each proposed vehicle block configuration (Block 1, 1A, and 2).

This SLS Advanced Development NASA Research Announcement (NRA) is targeting upgrades or advanced development concepts that will improve affordability, reliability, and performance of Block 1A.

The technical information provided herein identifies the SLS vehicle baseline which each Offeror shall use to develop their advanced development concept(s) and work efforts. For additional information, refer to "Space Launch System (SLS) Program Launch Vehicle Specification [SLS-SPEC-032]" and "Affordable Upper Stage Engine Program (AUSEP) Technical Requirements Specification" in Appendices B and C.

The acquisition strategy of the interim cryogenic propulsion stage (iCPS for Block 1) is currently being determined and information is available in the Interim Cryogenic Propulsion Stage Request For Information (SLS-SPIO-2012). Proposals relative to iCPS are outside the scope of this solicitation.

This NASA Research Announcement (NRA) is not intended to solicit work efforts for a cryogenic propulsion stage (CPS). However, for work efforts addressing the Affordable Upper Stage Engine (AUSE), any content associated with a CPS should be limited to trades, analyses, and assumptions required to inform and enable AUSE efforts.

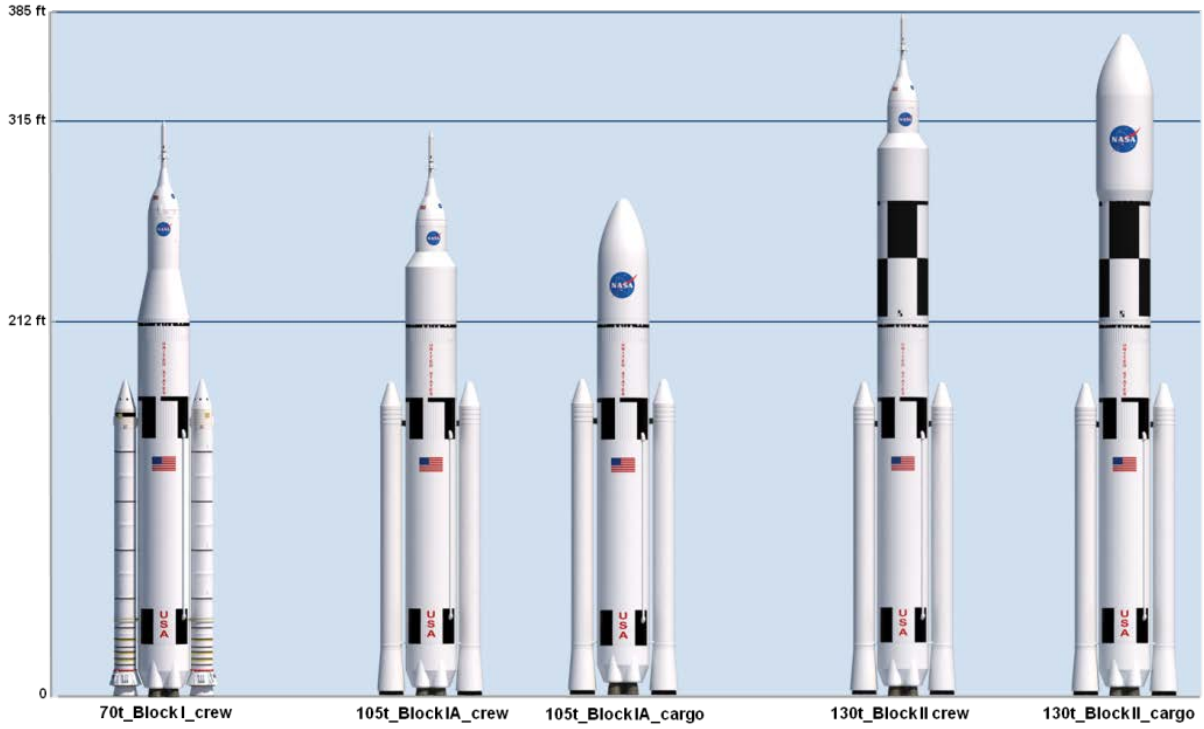
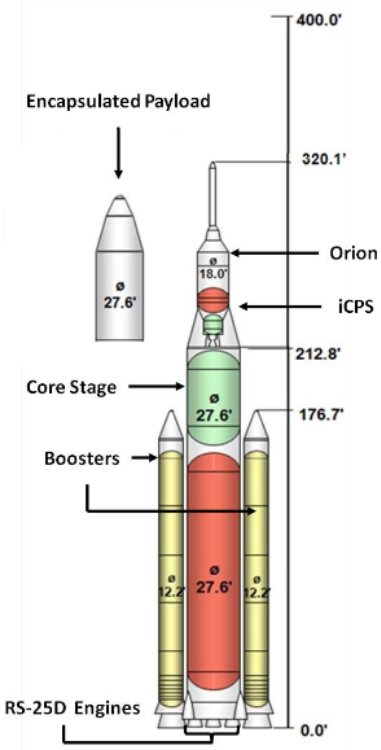
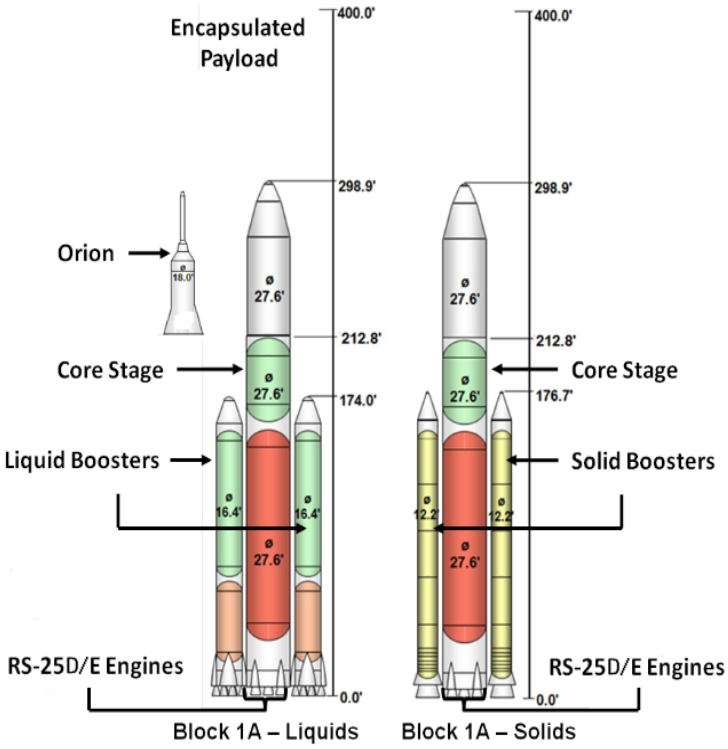


Figure 1. SLS Vehicle Configurations



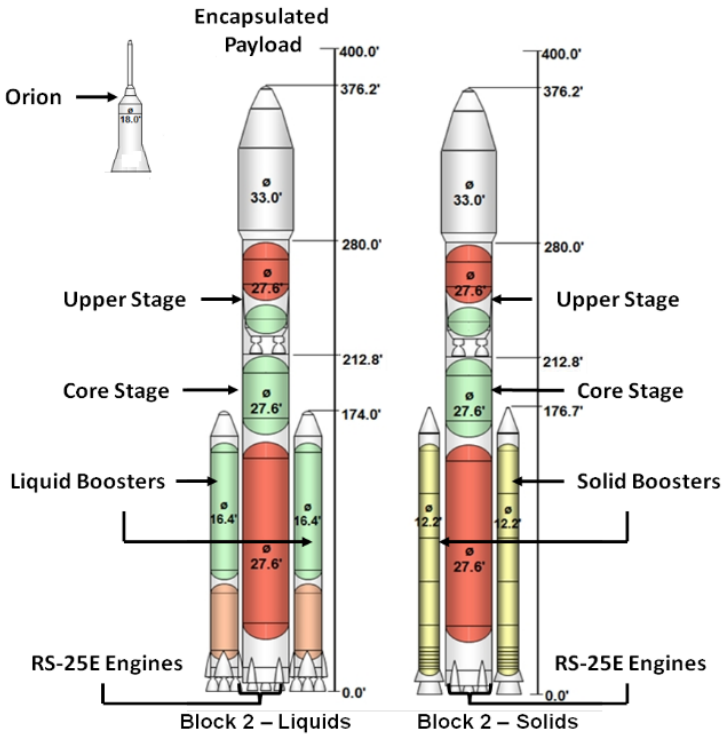
- Two 5-segment expendable SRBv
- Solid rocket fuel for the 5-segment SRB is polybutadiene acrylonitride (PBAN)
- Core stage with four RS-25D engines
- Core stage will be common across subsequent blocks
- Booster Thrust vector control (TVC) utilizes STS SRB heritage hardware
- Capable of carrying an Orion-MPCV, Orion-MPCV + iCPS, or cargo payload. Cargo payloads will be responsible for orbit stabilization

Figure 2. Block 1 Vehicle Configuration and Details



- Encompasses the replacement of the SRB with a new expendable advanced booster (SRB or LRB)
  - With LRB version having Refined Petroleum (RP-1) propellant
- Advanced booster attaches at the same points as the 5-segment SRB
- Incorporates the RS-25D or RS-25E engines on the core stage
  - Four engines on the core stage
- May utilize a LH2/LOX upper stage with one or more Affordable Upper Stage Engines
- Same height as the Block 1 configuration

Figure 3. Block 1A Vehicle Configuration and Details



- Block 2 upgrade adds an upper stage that derives from the core stage
- Two J-2X engines on the upper stage
- Upper stage will use the same propellant as the core stage
- **This NRA is not soliciting Block 2 upgrades to the vehicle**

Figure 4. Block 2 Vehicle Configuration and Details

2.0 REFERENCE LAUNCH VEHICLE DESCRIPTION

This section provides information for the baseline vehicle (Block 1), booster stage (solid or liquid propellant), core stage, upper stage, and non-propulsive payload element (NPE). This information should be used by the Offerors to develop their proposals. The SLS baseline is a 1.5 stage evolving to a 2.5 stage launch vehicle based on a liquid oxygen (LO2)/liquid hydrogen (LH2) rocket engine core. Architecture studies have shown this configuration meets the cost and schedule constraints, balances stakeholder objectives, supports the industry base, and enables early Orion-MPCV flight tests.

Orion-MPCV is outside the scope of this solicitation.

2.1 Booster Stage Description

All of the SLS configurations provide booster attachments with booster forward thrust takeout support. The 70 metric ton vehicle (Block 1) booster stage is a metallic 5-segment solid rocket booster (SRBv), including aft segment/nozzle assembly, replaced by subsequent block upgrades to an advanced booster with either solid rocket boosters (SRBs) or liquid rocket boosters (LRBs). The two-phased booster approach leverages Space Transportation System (STS)/Ares hardware for initial flights (early blocks) and then advanced boosters phased in for Block 1A and

subsequent blocks. Boosters consist of a liquid propellant or solid propellant propulsion system, as well as subsystems for structural support, thrust vector control (TVC), power, avionics, instrumentation, propellant (and fluid management as needed per design), mating/attachment and separation, and range safety.

The Advanced Booster Engineering Demonstration and Risk Reduction (ABEDRR) NRA (NNM12ZPS001N) is currently soliciting proposals. Proposals relative to Advanced Booster concepts and associated risk reduction efforts and demonstrations are outside the scope of this solicitation.

2.2 Core Stage Description

The Block 1 core stage configuration (70 metric ton) is a LO2/LH2 rocket stage with four RS-25 engines and TVC technology existing from shuttle-derived designs. The core stage for Block 1, as defined by the outer mold line and vehicle interfaces, will be common across subsequent blocks (Block 1A and 2). The core stage is being designed for structural load (thrust takeout) of the boosters as well as the structural load path for the upper stage and payload.

2.3 Non-Propulsive Payload Element Description

The non-propulsive payload element (NPE) consists of the cargo payload adapter (CPA) and fairing. The SLS will provide the CPA that interfaces to the payload and the fairing that encapsulates the payload. There will be a common CPA interface that will be used across all blocks (those with core and upper stage) of the SLS. For ground operations, the CPA is primarily a mechanical interface with a power and commodities umbilical pass-through to the payload for use at the pad and Vehicle Assembly Building (VAB). Health and status data for cargo-only payloads that require monitoring during the ground and ascent phase will pass through the CPA to the ground through the SLS data path.

The payload fairing interfaces with the CPA. The payload fairing interface will be common across SLS configurations. The payload fairing will provide access panel(s) for nominal use: e.g., limited life item loading in the VAB or pad. The Block 1and 1A vehicle configurations will have a 27.6 ft diameter payload fairing, and the Block 2 vehicle configuration will have a 33 ft diameter payload fairing.

The CPA is an in-house design effort and is considered outside the scope of this solicitation; however, the Block 1A fairing is considered within the scope of this solicitation.

2.4 Upper Stage Description

The Block 2 vehicle configuration adds an upper stage that derives from the core stage with two J-2X engines on the upper stage. This NRA is not soliciting Block 2 upgrades to the vehicle.

2.5 Affordable Upper Stage Engine Description

The US Government has identified a need for an Affordable Upper Stage Engine Program (AUSEP). The Affordable Upper Stage Engine Program (AUSEP) Technical Requirements Specification (Appendix C) outlines the performance, design, development, and test requirements for the AUSE.

3.0 GENERAL OPERATIONAL INFORMATION

3.1 Ground Support Equipment

The SLS support equipment goal is to provide the most affordable implementation of SLS ground operations in support of the SLS elements. To accomplish this, SLS ground support equipment (GSE) will endeavor to use common, reusable GSE wherever practical. The GSE will support both the transportation to, and ground operations at, the test and launch sites. GSE acquisition planning will leverage off of the Ares designs and cost effective utilization of existing hardware from STS and other launch vehicle systems. This existing GSE, located at NASA Centers and other Government agencies, will be utilized based on availability, suitability, and cost. Vehicle-level GSE is considered to be GSE that is used on more than one element or uses design concepts that are common to more than one element. Vehicle-level GSE will be provided by the SLS Program. Element-level GSE is considered to be GSE that is unique to a single element and will be provided by the Element.

The electrical GSE (EGSE) used to test the vehicle at the launch site will be developed by the SLS Program and the GSDOP. The EGSE will be designed to interface with the GSDOP Ground Operations Control System (GOCS). Remote access, if required, will be via the GOCS. Special test equipment (STE) used for contingency operations within the SLS will be developed by the SLS Program. The STE will be portable, such that it can be easily carried across umbilical access arms for contingency operations. Vehicle tests will be capable of being monitored by support engineering teams from remote sites.

3.2 Pre-Launch Fault Management

If the SLS launch vehicle experiences a failure during prelaunch checkout, operations personnel can troubleshoot and isolate the failure to the LRU level. An effective fault detection and

isolation system is critical to ensure system availability and requires early integration into the flight and ground hardware design. Direct access to LRUs is needed, as accessibility is a key parameter in hardware and software design. The impact of maintenance to all other components should be minimized through the design process.

3.3 Launch Pad Check-Out

Once at the pad, the mobile launcher (ML) is connected to the pad interfaces to re-establish services to SLS, Orion-MPCV, and/or payload. A health check and status (HC&S) is performed at the pad. After rollout, the SLS will be ready to launch within a week to minimize the need for limited life items and consumable servicing during pad operations.

3.4 SLS Flight Operations

The SLS will provide automated and autonomous flight operations on board during launch and ascent. Human rating requires that the integrated vehicle complete each mission with full automated and autonomous capability in case of loss of communication. The SLS launch vehicle flies to the ascent target by managing the states and modes of the integrated vehicle systems, managing failures, providing power to all the integrated subsystems and elements, performing guidance, navigation, and control (GN&C), and providing propulsion to the integrated stack. The SLS monitors vehicle health and status and controls the integrated vehicle trajectory. SLS will provide attitude control (maintain attitude and perform attitude positioning) of the stack during ascent operations for all missions. However, in an off-nominal situation, the SLS can be commanded to terminate thrust (after solid booster separation) from remote sources. The SLS will provide a Range Safety command radio frequency (RF) interface for all missions.

3.5 Tracking

SLS will provide two independent tracking sources to support Range Safety tracking requirements. Tracking sources will be via C-band radar and the vehicle's guidance and navigation system. The inertial guidance data will be provided via the communications data paths defined above.

3.6 Vehicle Guidance

During first stage flight, the guidance function employs an open-loop guidance algorithm, i.e., the attitude commands come from table lookups in a table of pre-mission computed Euler pitch, yaw, and roll angles vs. altitude. After booster separation, the guidance function employs closed-loop guidance called the Powered Explicit Guidance (PEG) algorithm. Both guidance algorithms are based on the STS.

3.7 Abort-to-Orbit

Abort-to-Orbit (ATO) aborts are performed following a premature shutdown or other failure of the propulsion system, and where the MPCV propulsion system has sufficient capability to complete a safe orbit insertion and a de-orbit burn. The SLS will not preclude the use of the iCPS for an ATO. The ATO mode maximizes SLS performance following engine failures or other performance anomalies during powered flight to allow the Orion-MPCV to achieve a minimum orbit. An ATO may invoke modified powered flight targets in the onboard guidance system to utilize overall SLS propulsion system capability as efficiently as possible. Selecting an ATO can result in significant loss of major mission objectives, but preserves some on-orbit time to assess mission options and optimize re-entry plans.

For uncrewed missions, the SLS will continue to seek mission accomplishment until propellant is depleted. Engine-out is a mission option depending on mass-to-orbit requirements and funding.

3.8 Telemetry

Instrumentation critical to ground and flight operations will be implemented on every flight. Instrumentation needed for engineering post-flight analysis will be implemented on every flight. Temporary flight-specific instrumentation may be implemented to satisfy developmental flight test objectives.

The SLS supports Communications & Tracking (C&T) and contains a flight safety system for range safety operations. The SLS performance engineering data is transmitted from the SLS to the ground and recorded. The SLS will have physically – and functionally – separate mission-critical and non-mission critical avionics. Data will be collected via the Communications and Tracking Network (CTN) and sent to the MSFC Huntsville Operations Support Center (HOSC).

3.9 Sustaining Engineering

Sustaining engineering operations will be focused on vehicle production and engineering services, block upgrades, infrastructure maintenance, launch operations, and post-flight analysis. A block upgrade approach will be periodically applied to address design changes to improve operability, previous flight anomalies and marginal performance trends, manufacturing affordability improvements, obsolescence issues, etc. Production and engineering services will focus on maintaining the vehicle production schedule in support of the Program manifest. Sustaining engineering operations will include post-flight analysis and performance assessments for each SLS flight. Data services are provided, including recording, archiving, and retrieving data for authorized NASA users. This data will be used to identify improvements in design, manufacturing processes, and ground processing for future flights. This post-flight analysis will

include performance trends, failure causes and effects, root cause analysis, imagery analysis, reliability and maintainability trends, and safety hazards. Engineering analysis tools and models will be provided to assess the post-flight performance. Data will be used to identify improvements in design, manufacturing processes, and ground processing for future flights. Safety issues will be addressed immediately in the production flow as necessary. Other issues will be forwarded to block upgrade planning.

4.0 SLS BLOCK UPGRADE IMPLEMENTATION PHILOSOPHY

SLS is dividing the large task of creating a 130 metric ton launch capability into a sequence of incremental projects. Each block upgrade is a design and development project that will combine mature technical developments with lessons learned. The phasing and prioritization of the block upgrades will be based on funding, mission and payload schedules, agency resources, and the maturity of the proposed SLS upgrades. The planning for the block upgrades will be conducted in coordination with the Human Architecture Team (HAT) and the SLS Program Office to minimize disruption and maximize benefits.

The evolutionary approach to SLS upgrades will adapt mature technologies and implement them in the SLS operational environment. The path to 'on-ramping' an upgrade may include a high fidelity prototype on a flight demonstration, test in the SLS System Integration Lab (SIL), or test in other high fidelity test facilities in an affordable and timely manner. Many of these incremental upgrades to improve affordability, reliability, or performance will be grouped together into an SLS block upgrade. Block upgrades may or may not coincide with a major transition of capabilities (Block 1 to 1A to 2).

5.0 ADVANCED DEVELOPMENT TOPICS

This NRA entitled "Space Launch System (SLS) Advanced Development" solicits proposals from both industry and academic entities for innovative ideas in key topic areas. These improvements should improve SLS affordability, reliability, or performance within a constrained fiscal schedule. While there are other paths for science and basic technology developments, SLS seeks to facilitate the incorporation of mature technical solutions into the unique elements and environments of SLS in program-phased block upgrades. Proposed work efforts solicited by this NRA should be of a maturity level to support timely implementation into the Block 1A vehicle configuration. This NRA also solicits work efforts that are <u>not</u> upgrades to the vehicle, but support the development of the vehicle, such as studies, analytical tools, or databases. The technical areas below represent potential proposal areas, but are not meant to exclude other innovative concepts to evolve the baseline SLS vehicle to its full capability.

Note: The acquisition strategy of the interim cryogenic propulsion stage (iCPS for Block 1) is currently being determined and information is available in the Interim Cryogenic Propulsion Stage Request For Information (SLS-SPIO-2012). Proposals relative to iCPS are outside the scope of this solicitation.

Note: This NASA Research Announcement (NRA) is not intended to solicit work efforts for a cryogenic propulsion stage (CPS). However, for work efforts addressing the AUSE, any content associated with a CPS should be limited to trades, analyses, and assumptions required to inform and enable AUSE efforts.

Note: Orion – MPCV is outside the scope of this solicitation.

Note: The Advanced Booster Engineering Demonstration and Risk Reduction (ABEDRR) NRA (NNM12ZPS001N) is currently soliciting proposals. Proposals relative to Advanced Booster concepts and associated risk reduction efforts and demonstrations are outside the scope of this solicitation.

Note: The CPA is an in-house design effort and is considered outside the scope of this solicitation; however, the Block 1A fairing is considered within the scope of this solicitation.

Note: This NRA is not soliciting Block 2 upgrades to the vehicle.

5.1 Broad Advanced Development Topics

The successful evolution of SLS from the initial 70 metric ton vehicle to the 130 metric ton vehicle will require advanced models, processes, and designs for vehicle, propulsion, structural, and avionics systems. Meeting SLS program goals requires an emphasis on affordability while maintaining appropriate levels of reliability and performance.

Concept Development, Trades, and Analyses: This area of interest includes advanced development and systems engineering work efforts that support SLS upgrades to improve affordability, reliability or performance. The focus is on the SLS vehicle system. Work efforts may include demonstrations, tests, designs, trade studies, or analyses. In general, proposals in this area should be multi-discipline or multi-element in nature. Improved design tools and design methodologies will facilitate concept development, higher fidelity trade studies, and environments prediction. Another area for consideration is vehicle integration with other architecture elements. Work efforts shall be technical, not programmatic or business.

Propulsion: Advancements in propulsion are necessary for liquid engines, main propulsion systems, and solid rocket motors. This includes systems, subsystems and components, as well as

the various smaller liquid engines and solid motors associated with large launch systems and cryogenic in-space stages. There is also a necessity for the development of AUSE requirements and an assessment of functionality; the impact on affordability, reliability, and performance should also be addressed. Advances in hardware are sought that reduce both development and operational costs while increasing system commonality and maintaining appropriate levels of reliability and performance. Improved high-fidelity design tools and design methodologies will facilitate many of these hardware improvements; therefore, advances are sought that add fidelity to or validate these design tools, including prototyping and simulation. Work efforts may include demonstrations, tests, designs, trade studies, and/or analyses.

Manufacturing, Structures and Materials: The focus of this topic area is the innovative use of advanced materials and manufacturing processes to produce more affordable and higher performance structures, systems, and subsystems. Advances may include composite dry structures or tankage for lighter weight and increased performance. The use of composite materials will also increase the need for improved analytical tools to both meet damage tolerance requirements and to reduce the volume of testing. The need for better analytical tools applies to metallic structures as well, with a special emphasis on understanding friction stir weld processes and lightweight alloys. SLS will need to make increased use of digital and virtual methods to reduce the cost of design, manufacturing, and inspection. As SLS manufacturing and design continue to evolve, the material obsolescence and environmental compliance issues of the Shuttle-era designs, such as Thermal Protection Systems (TPS), will also require solutions. Next generation materials or new uses of existing materials, both metallic and non-metallic, will be part of making SLS more affordable.

Avionics and Software: The focus of this topic area is the innovative upgrade of SLS avionics, sensors, power, and software subsystems to provide sustainable robust vehicle performance. Upgrading SLS avionics will enable improved navigation, increased internal redundancy and self-checks, and simplified test, check-out, and troubleshooting equipment. Avionics modernization tasks, such as qualification of new flight data busses and using Grade B/industrial parts for non-safety critical functions, represent a paradigm shift enabling sustainable and affordable technologies. Improved flight computers and model-based-design systems will provide opportunities for more configurable GN&C, optimized integrated vehicle health management, and expanded real-time failure performance and recovery. The subsystems and components that generate and control the energy to steer and control SLS need enhancements to improve efficiency, safety, and environmental compliance.

5.2 Focused Advanced Development Topics most suitable for Academia

The following items briefly describe smaller, focused topic areas deemed to be suitable to the capabilities, resources and experience of academic institutions. Work efforts in these topic areas may include demonstrations, tests, designs, trade studies, software development, or analysis.

- Develop an improved statistical methodology to avoid excess conservatism. This could include integrated vehicle design limit loads, material property knock-down factors, and other areas where multiple statistical inputs are applied or stacked.

- Study alternatives to integrated vehicle ground vibration testing and the associated risk.

- Conduct studies to show motor and/or engine start transient pressure wave formation, modification by launch pad geometry, and travel from source to launch vehicle surfaces. There is specific interest in the influence of various parameters, such as motor or engine pressure rise rate; open, vented, and closed ducts; duct length; water spray and water deluge. Technology advancement examples are: Source waveform definition through computational methods and inverse methods, computations validated with experiments, and models of relevant physical processes.

- Study effects of fluid loading and pressurization on vibroacoustic response of the integrated vehicle. Taking these parameters into account, identify potential solutions to reduce the vibroacoustic response and therefore the environments for design.

- Study recent developments in high electrical energy density devices (e.g., batteries, high density capacitors, fuel cells, or other energy devices) for aerospace environments. Electrical energy devices in aerospace applications are peak current limited. This drives designs to higher stored energy than is actually required, resulting in larger, heavier, and more expensive power supplies. This study should encompass all high energy density technology that is commercially available and discuss others that are expected in the near future.

- Increase fidelity and accuracy in the Loci family of Computational Fluid Dynamics (CFD) design tools while maintaining or reducing simulation execution time in three broad areas.

    - First, general code improvements are sought. The Loci framework should be improved to: (1) Better utilize new supercomputer technologies such as conventional central processing units (CPUs) with massive core-counts, (2) Utilize unconventional approaches with graphical processing unit (GPU) type

processors and (3) Complement new supercomputer technology by developing massively parallel matrix solver algorithms. Also, development of low dissipation and high order unstructured CFD algorithms to complement the use of hybrid Reynolds Averaged Navier Stokes/Large Eddy Simulation (RANS/LES) CFD algorithms are sought. Finally, there is need for the development of automatic, high quality, unstructured mesh generation capabilities to more completely realize the potential of hybrid RANS/LES CFD methods.

- Second, liquid propulsion design capability can be improved by development of multidisciplinary (fluid plus structural) simulation capability to address difficult SLS problems of interest such as propellant tank sloshing, immersed phase damping in pumps and turbines, nozzle side load predictions, launch-pad ignition overpressure and acoustic environment mitigation. Also, development of two-phase fluid capability is sought for applications such as propellant tank sloshing, pump cavitation, accumulators for pogo mitigation, subcritical atomization and combustion models and launch-pad ignition over-pressure mitigation.

- Third, solid propulsion design capability can be improved by (1) Development of increased-fidelity representations of flow/combustion at propellant surface including its contribution to internal acoustic phenomena in the motor, (2) Development of efficient, high-fidelity capability to simulate motor ignition and early burn, (3) Development of computationally efficient two-phase capability to model aluminum droplets and slag and (4) Development of a computationally efficient, physics-based erosive burning capability.

- Design and execute bench-scale validation tests (producing spatially and temporally resolved data suitable for quantitative CFD code validation) and/or relevant detailed validation simulations of processes relevant to liquid rocket engine combustion dynamics and instabilities. It is preferable, but not mandatory, that the experimental and computational efforts be linked.

- Develop experimental databases that accurately characterize nozzle loads in the following areas: (1) Nozzle thermal loading, especially the near-wall physics that are responsible for thermal environment. Data should be acquired as a function of key nozzle design parameters at relevant conditions both with, and without, film cooling. Parallel high-fidelity CFD simulations using the Loci-CHEM CFD code are also desirable. (2) Unsteady fluid dynamics present in liquid rocket nozzle start and shutdown transients where the key areas of interest are (a) Pressure fluctuations and their distribution throughout the nozzle as well as the resultant nozzle off-axis force and (b) Acoustic fields, both near- and far-field, generated by the nozzle fluid dynamics. Measurement

and/or characterization of the velocity field of the internal and external flows responsible for the pressure fluctuations and/or acoustics fields are also desirable.

- Acquire sufficiently detailed data for characterizing heat transfer coefficients in two-phase flows of cryogenic propellants (using liquid nitrogen as a simulant) with and without ingested inert gases. The heat transfer coefficients will be used in a Propulsion System Model for characterizing thermal environment in feed systems for chilldown of cryogenic transfer lines and propellant transfer, loading and recirculation. Tests can be conducted over a pressure range from atmospheric to 70 psia and $20 < Re < 100{,}000$ and $1.5 < Pr < 2.0$. A detailed uncertainty analysis must be provided and the data must be presented with appropriate error bars.

- Simulating the internal environment found in the aft end of solid rocket motors using subscale hardware, acquire test data to determine the extent the alumina/aluminum-carbon reaction. The propellant must be sufficiently aluminized (>15% by weight) and the tests conducted over a sufficient time span to reliably determine the reaction extent. The data will be used to improve and validate computational tools that model nozzle erosion.

- Identify the chemistry-specific design limitations of credible non-toxic propellants (e.g. ammonium dinitramide (ADN), hydroxylammonium nitrate (HAN), hydrazinium nitroformate (HNF) and peroxide-based propellants) for propulsion storage and feed system components such as valves, lines, tanks, controls and instrumentation. Also, suggest methods to validate these limitations through laboratory testing that accounts for key mission parameters such as time, temperature and pressure. Considering the common materials of construction for these components, this effort should also develop a rating methodology that will allow for material selection based on these key mission parameters.

- Develop a method for integrating design, material selection, and manufacturing processes as applied to large-scale single production units, in order to decrease the risk to budget and schedule. The focus of this should be to improve affordability by smoothing transitions or handoffs between disciplines and using virtual methods to eliminate multiple prototypes and rework.

- Develop methods for applying General-Purpose Graphics Processing Unit (GPGPU) capabilities to non-destructive evaluation (NDE) technologies. GPGPU can enhance NDE inspections by reducing the processing time associated with the analysis of large data sets. Another application could be to use this platform to combine data sets from

two or more NDE modalities to create an amalgam of images (drawings, photographs, and inspection results) for a more detailed, easier to interpret result.

- Develop an analytical, physics-based model for prediction of compression after impact (CAI) failures of carbon fiber composite laminates. The basis for the physics based analytical tool would be data obtained from 'interrupted' testing (to near failure) followed by forensics on the specimens to determine failure mechanism.

- Develop methods to monitor friction stir weld parameters such as load and torque, during the weld process, to predict and spatially resolve suspected defect regions. The data from these methods will initially be incorporated with traditional NDE methods and ultimately advanced to provide feedback control.

- Determine, through test and analytical or numerical techniques, the effects of delamination on crack growth, fracture toughness, or potential crack arrest in aluminum-lithium (Al-Li) material alloys. The understanding of delamination behavior is needed to successfully design attachment points and to predict through-thickness crack growth.

- Design robust, adaptive guidance logic for off-nominal flight conditions, including engine-out and actuator-out scenarios during SLS ascent. This would involve analytical modeling and simulation of the vehicle sensors and dynamics in order to thoroughly test the logic. The guidance logic should, for instance, determine in real time the vehicle GNC failure and whether or not to continue with the mission, abort to orbit, or target to a lower energy orbit. Similar design and guidance will be needed for the various SLS vehicle configurations.

- Develop avionics hardware packaging concepts for various avionics elements. These concepts should not be heavier than existing state-of-the-art. This topic shall consider internal and external box interconnects, including those between individual printed circuit boards, enclosures (housings), and for thermal dissipation. Reliability, assembly cost, ease of fabrication and weight are primary considerations. Outputs for this work should include three-dimensional designs and preliminary environmental analysis.

- Design and validate test set ups and procedures for corona testing of high voltage power electronics, cabling, and electric actuators in a flight-like configuration. Testing must simulate altitude ascent conditions and record test results using electronic measurement circuitry, such as commercially available partial discharge (corona) detection systems. Data obtained from these tests would be used to develop design and construction standards and qualification procedures for upgrades to high voltage avionics and electric TVC systems.

- Develop real-time video compression, encoding algorithms, and processing techniques that will reduce bandwidth while maintaining high quality imagery in the regions of interest. Compressed output will maintain a fixed bandwidth and should be compatible with existing data transport formats.

- Develop a wireless communication protocol compatible with a launch vehicle environment in which jamming, interference, ionospheric plasma, and pyrotechnic compatibility may be present. Protocols that can be implemented with minimal changes to existing hardware would enable this technology to save weight, reduce integration times, and allow easier additions of non-critical instrumentation.

- Design and evaluate a mechanically simple optical window and imaging lens system to provide low distortion images of SLS hardware during ascent and staging events, while protecting the imaging sensor. Onboard imagery systems are often hampered by window clarity when impacted by condensation and deposited debris. Develop a method to ensure maximum image clarity in harsh environments that does not produce debris itself and adds very little complexity to the imagery system.

APPENDIX B

Space Launch System (SLS) Program Launch Vehicle Specification

[SLS-SPEC-032]

National Aeronautics and
Space Administration

SLS-SPEC-032

REVISION A

RELEASE DATE: JANUARY 26, 2012

SPACE LAUNCH SYSTEM (SLS) PROGRAM
LAUNCH VEHICLE SPECIFICATION

Approved for Public Release; Distribution is Unlimited.

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REVISION AND HISTORY PAGE

Status	Revision No.	Change No.	Description	Release Date
Baseline	–		Baseline per PCBD SV2-01-0007, dated 12/1/11; (CR SLS-00003R1) PCN SV00003	12/01/11
Revision	A		Rewrite of Spec; CR SLS-0023; PCN SV00034; PCBD SV2-01-0025	1/26/12

NOTE: Updates to this document, as released by numbered changes (Change XXX), are identified by a black bar on the right margin.

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1 SCOPE

1.1 System Identification

The Space Launch System (SLS) includes the following major elements:

- Stages (Core Stage and Upper Stage)
- Liquid Engines (Core Stage and Upper Stage)
- Boosters (solid or liquid)
- Spacecraft and Payload Integration elements (payload fairings, payload adapters, Interim Cryogenic Propulsion Stage (ICPS))

This specification establishes requirements for the Space Launch System (SLS), hereafter referred to as SLS or the SLS Vehicle. Programmatic requirements for SLS are captured in Section 3.2.16. SLS requirements were derived from ESMD-HEC.Reqt-6.2011, ESMD/SOMD Human Exploration Capabilities Requirements, dated 6-30-2011, and ESD 10012, Exploration Systems Development (ESD) Concept of Operations.

1.2 System Overview

The SLS will continue the tradition of United States human spaceflight, serving as a follow-on to the Space Shuttle, which was retired in 2011. The SLS is being developed to provide heavy-lift capability to enable human exploration missions beyond Earth orbit (BEO), which supports NASA's strategic goal of extending and sustaining human activities across the solar system. The SLS will deliver applicable exploration elements safely to desired orbits, providing sufficient lift mass and volume to execute the desired missions. The SLS will provide:

- An initial lift capability of > 70* (Block 1) to 105 (Block 1A) metric tons evolvable to the ultimate capability of 130 metric tons (Block 2) to a –47 × 130 nm orbit.

  *Block 1 is required to deliver 57 metric tons to a higher (–50 × 975 nm) orbit.
- A design that is derived from legacy hardware.
- Capability to lift the Orion Multi-Purpose Crew Vehicle (MPCV).
- Capability to lift science, commercial, or other government agency payloads.
- Capability to be a backup system for International Space Station (ISS) cargo and crew delivery.

The concept of operations for SLS can be found in SLS-PLAN-020, Space Launch System (SLS) Program Concept of Operations (Con Ops) Document. A more detailed description of the SLS Block configurations is contained in Section 3.1.

1.3 Document Overview

This SLS specification was written using MIL-STD-961E, Defense and Program-Unique Specifications Format and Content, and MIL-HDBK-520, Systems Requirements Document Guidance, as guidance, and is in accordance with MSFC Standard Data Requirement Description (DRD) STD/SE-RQMT.

Accordingly, Section 2 lists all applicable documents listed in Sections 3, 4, and 5 of this specification. Section 3 contains detailed requirements, performance requirements, design constraints and all other technical SLS requirements pertaining to the launch vehicle. Section 4 contains provisions for verification of Section 3 requirements, Section 5 contains traceability of this specification's requirements to Agency-level requirements, and Section 6 contains applicable appendices. Programmatic requirements and planning (e.g., Safety & Mission Assurance Plan, Systems Engineering Management Plan, Configuration & Data Management, Risk Management, etc.) are covered in SLS-PLAN-001, SLS Program Plan, and its associated documentation.

1.4 Change Authority/Responsibility

The NASA Office of Primary Responsibility (OPR) for this document is EV72.

Proposed changes to this document shall be submitted by an SLS Program change request (CR) to the SLS Program Control Board (PCB) for disposition. All such requests shall adhere to SLS-PLAN-008, SLS Program Configuration Management Plan.

2 DOCUMENTS

2.1 Applicable Documents

The documents listed in this section are specified in sections 3, 4, or 5 of this specification. This section does not include documents cited in other sections of this specification or recommended for additional information or as examples. While every effort has been made to ensure the completeness of this list, specification users are cautioned that they must meet all specified requirements of documents cited in Sections 3, 4, or 5 of this specification, whether or not they are listed in Section 2.

2.1.1 Government Documents

2.1.1.1 Specification, Standards and Handbooks

The following specifications, standards, and handbooks, of the exact revision listed below, form a part of this specification to the extent specified herein.

ESMD-HEC.Reqt-6.2011 6/30/11	ESMD/SOMD Human Exploration Capabilities Requirements
ESD 10012 10/20/11	Exploration Systems Development (ESD) Concept of Operations
SLS-PLAN-020 10/27/11	SLS Program Concept of Operations (Con Ops) Document
SLS-MDL-068	SLS Program Vehicle Functional Analysis Model (VFAM)
SLS-SPEC-048	SLSP Integrated Vehicle Coordinate System
SLS-SPEC-044-01	Space Launch System Program (SLSP) Vehicle Design Environments Volume 1: Aerodynamic
SLS-SPEC-044-02	Space Launch System Program (SLSP) Vehicle Design Environments Volume 2: External Aero-Thermal
SLS-SPEC-044-03	Space Launch System Program (SLSP) Vehicle Design Environments Volume 3: Interface and Shared Compartment Thermal
SLS-SPEC-044-04	Space Launch System Program (SLSP) Vehicle Design Environments Volume 4: Acoustic
SLS-SPEC-044-05	Space Launch System Program (SLSP) Vehicle Design Environments Volume 5: Shock and Vibration
SLS-SPEC-044-06	Space Launch System Program (SLSP) Vehicle Design Environments Volume 6: Compartment Venting
SLS-SPEC-044-07	Space Launch System Program (SLSP) Vehicle Design Environments Volume 7: Natural Environments

SLS-SPEC-044-08	Space Launch System Program (SLSP) Vehicle Design Environments Volume 8: Blast
SLS-SPEC-044-09	Space Launch System Program (SLSP) Vehicle Design Environments Volume 9: Debris
SLS-RQMT-019	SLSP Electrical, Electronic, and Electromechanical (EEE) Parts Management and Control Requirements Document
SLS-RQMT-045	SLSP Vehicle Design Environments Integrated Vehicle Loads
SLS-SPEC-028	SLSP Integrated Vehicle Structural Design
SLS-SPEC-049	SLSP Integrated Vehicle Outer Mold Line (OML) Specification
SLS-RQMT-040 1/5/12	SLSP Electromagnetic Environmental Effects (E3) Requirements
SLS-RPT-037	SLSP Integrated Master Timeline
SLS-SPEC-043	SLSP Ground Operations Specification
SLS-SPEC-118	SLSP Flight Operations Specification
SLS-SPEC-030-01	Space Launch System Program (SLSP) Support Equipment Specification Volume I: Planning
SLS-SPEC-030-02	Space Launch System Program (SLSP) Support Equipment Specification Volume II: Design and Construction Requirements
SLS-SPEC-030-03	Space Launch System Program (SLSP) Support Equipment Specification Volume III: Derived Requirements
SLS-SPEC-030-04	SLSP Support Equipment Specification Volume IV: Multi-Purpose Transportation System Interface Control Document (ICD)
SLS-SPEC-079	SLSP Vehicle Management Specification
SLS-RQMT-114	SLSP Tailored AFSPCMAN 91-710 Eastern Range Requirements
SLS-<**TBD-027**>	SLSP Human System Integration Requirements
MPCV-70026	Orion-MPCV to SLS IPE Interface Requirements Document (IRD)
MPCV-T-029600	Orion-MPCV to SLS Interface Control Document - Hardware
MPCV-T-029601	Orion-MPCV to SLS Interface Control Document - Software
SLS-<**TBD-005**>	SLSP IPE to Payload ICD
SLS-ICD-052	SLSP to Ground Systems Development and Operations ICD

SLS-ICD-031 12/15/11	SLSP to Communications and Tracking Network (CTN) ICD
SLS-ICD-039	Stages to Engines ICD
SLS-ICD-021	Core Stage to Booster ICD
SLS-ICD-029	Stages to IPE ICD
SLS-SPIO-RQMT-004	SLS Interim Cryogenic Propulsion Stage Requirements
MIL-STD-1522, Revision A, Notice 3, 9/04/92	Standard General Requirements for Safe Design and Operation of Pressurized Missile and Space Systems
MIL-STD-130, Revision N 12/17/07	Department of Defense Standard Practice, Identification Marking of U.S. Military Property
NASA-STD-5009 4/7/08	Nondestructive Evaluation Requirements for Fracture-Critical Metallic Components
NASA-STD-5017 6/13/06	Design and Development Requirements for Mechanisms
NASA-STD-5019 1/7/08	Fracture Control Requirements for Spaceflight Hardware
NASA-STD-6016 7/11/08	Standard Materials and Processes Requirements for Spacecraft
NSTS-08307, Change 10 12/17/10	Space Shuttle Criteria for Preloaded Joints
NASA-STD-4003 9/8/03	Electrical Bonding For NASA Launch Vehicles, Spacecraft, Payloads, And Flight Equipment
NPR 7150.2, Revision A 11/19/09	NASA Software Engineering Requirements
JSC 20793, Revision B 04/1/06	Crewed Space Vehicle Battery Safety Requirements
MSFC-SPEC-164, Revision C, 3/1/10	Cleanliness of Components for use in Oxygen, Fuel, and Pneumatic Systems, Specification For
MSFC-SPEC-3635 12/05/11	Pyrotechnic System Specification
MSFC-STD-3663 Draft 1	MSFC Standards for Configurable Logic Device Developments
NASA-STD-5001, Revision A 8/5/08	Structural Design and Test Factors of Safety for Spaceflight Hardware
NASA-STD-6008 7/11/08	NASA Fastener Procurement, Receiving Inspection, and Storage Practices for Spaceflight Hardware

TOR-2003(8583)-2896	Space Systems - Flight Pressurized Systems
NASA-STD-5012 6/13/06	Strength and Life Assessment Requirements for Liquid Fueled Space Propulsion Systems Engines
MIL-STD-1540, Revision D 1/15/99	Product Verification Requirements for Launch, Upper Stage, and Space Vehicles.
NASA-HDBK-7005 3/13/01	Dynamic Environmental Criteria
NPD 8710.5, Revision D 3/12/08	Policy for Pressure Vessels and Pressurized Systems
NPR 8705.2B, Change 1 12/7/09	Human-Rating Requirements for Space Systems
NPR 8715.6, Revision A 5/14/09	NASA Procedural Requirements for Limiting Orbital Debris
NASA-STD-8719.9, Change 1 10/1/07	Standard for Lifting Devices & Equipment
NASA-STD-8719.12 1/29/10	Safety Standard for Explosives, Propellants, and Pyrotechnics
NASA-STD- 8719.17 9/22/06	NASA Requirements for Ground-Based Pressure Vessels and Pressurized Systems (PV/S)
NASA-STD 8739.1, Rev. A, Change 2, 3/29/11	Workmanship Standard for Polymeric Applications on Electronic Assemblies
NASA-STD 8739.4, Change 6 3/29/11	Crimping, Interconnecting Cables, Harnesses, and Wiring
NASA-STD 8739.5, Change 2 3/29/11	Fiber Optic Terminations, Cable Assemblies, and Installation
MPCV 70024, Revision E 11/19/10	Orion-MPCV Program Human-System Integration Requirements
J-2X-SE-0001, Version 4.2 1/8/10	J-2X Element Requirements Document (ERD)
CxP 72262, Revision D 1/12/12	J-2X Engine to Ares I Upper Stage Interface Control Document (ICD)
Ares-USO-MP-25633 4/8/2010	Process Specification – Welding Aerospace Flight Hardware
CP320R0003B, SCN 275	SSME Contract End Item Engine Specification
CP320R0053, Revision G	J-2X Engine System Specification
10CEI-0001, U6/CN 396	Solid Rocket Booster Contract End Item Specification

CPW1-3600F, SCN 451	Reusable Solid Rocket Motor Contract End Item Specification

2.1.1.2 Other Government Documents, Drawings, and Publications

The following other Government documents, drawings, and publications, of the exact revision level shown, form a part of this specification to the extent specified herein.

Reserved.

2.1.1.3 Non-Government Publications

The following documents, of the exact revision listed below, form a part of this specification to the extent specified herein.

AIAA S-080 1/1/98	Space Systems – Metallic Pressure Vessels, Pressurized Structures and Pressure Components
AIAA S-81A 1/1/06	Standard for Space Systems – Composite Overwrapped Pressure Vessels (COPVs)
AIAA S-111 1/1/05	Qualification and Quality Requirements for Space Solar Cells
ANSI/ESD S20.20 2/11/07	ESD Association Standard for the Development of an Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies and Equipment
IPC-2221, Revision A 5/1/03	Generic Standard on Printed Board Design
IPC-2222, Revision A 12/1/10	Sectional Design Standard for Rigid Organic Printed Boards
IPC-2223, Revision B 5/1/08	Sectional Design Standard for Flexible Printed Boards
IPC-6011 7/1/96	Generic Performance Specification for Rigid Printed Boards
IPC-6012, Revision C 4/1/10	Qualification and Performance Specification for Rigid Printed Boards
IPC-6013, Revision B 1/1/09	Qualification and Performance Specification for Flexible Printed Boards
SAE ARP 5412, Revision A, 02/1/05	Aircraft Lightning Environment and Related Test Waveforms

ASTM MNL 36 1/1/07	Safe Use of Oxygen and Oxygen Systems: Handbook for Design, Operations, and Maintenance
GEIA-STD-0005, Change 1, 6/1/06	Performance Standard for Aerospace and High Performance Electronic Systems Containing Lead-Free Solder
IPC J-STD-001, Revision D, 2/1/05	J-STD 001D, Requirements for Soldered Electrical and Electronic Assemblies
IPC J-STD-001DS Amendment 1, 9/1/09	Space Applications Electronic Hardware Addendum to J-STD 001D, Requirements for Soldered Electrical and Electronic Assemblies
SAE AS5553 4/1/09	Counterfeit Electronic Parts; Avoidance, Detection, Mitigation, and Disposition
ANSI/AIAA G-095 1/1/04	Guide to Safety of Hydrogen and Hydrogen Systems

2.2 Reference Documents

The following documents contain supplemental information to guide the user in the application of this document.

SLS-PLAN-001	SLS Program Plan
SLS-PLAN-008 10/27/11	SLS Program Configuration Management Plan
SLS-PLAN-003	SLS Program Systems Engineering Management Plan
SLS-PLAN-009	SLS Program Verification and Validation Plan
SLS-PLAN-025	SLS Program Integrated Logistics Supportability Plan (ILSP)
SLS-PLAN-064	SLS Program Probabilistic Risk Assessment Plan
SLS-RQMT-014 10/28/11	SLS Program Safety & Mission Assurance (S&MA) Requirements
SLS-RQMT-015 10/28/11	SLS Program Hazard Analysis Requirements
SLS-RQMT-016 10/28/11	SLS Program FMEA/CIL Requirements
SLS-RPT-076	SLS Program System Safety Analysis Report (SSAR)

NASA-STD-8719.14A Process for Limiting Orbital Debris
12/8/11

3 REQUIREMENTS

The conventions used in this specification, which indicate requirements, goals, and statements of fact, are as follows:

- "Shall" – Used to indicate a requirement that is binding, which must be implemented and its implementation verified in the design.
- "Should" – Used to indicate good practice or a goal which is desirable but not mandatory.
- "May" – Used to indicate permission.
- "Will" – Used to indicate a statement of fact or declaration of purpose on the part of the government that is reflective of decisions or realities that exist and are to be taken as a given and not open to debate or discussion.
- "Is" or "Are" – Used to indicate descriptive material.

Rationales, included for many of the requirements, are intended to provide clarification, justification, purpose, and/or the source of a requirement. In the event that there is an inconsistency between a requirement and its rationale, the requirement always takes precedence.

3.1 Space Launch System (SLS) Design Baseline

This section defines the SLS design baseline. Shown as a part of each block configuration in Sections 3.1.1 through 3.1.3 are the capabilities, features, and/or design decisions that are baselined and, as such, are to be treated as design constraints. Performance and mass design constraints for the SLS liquid engines and boosters are shown in Table 3.1-1.

Table 3.1-1: SLS Element Performance & Mass Constraints

Engines

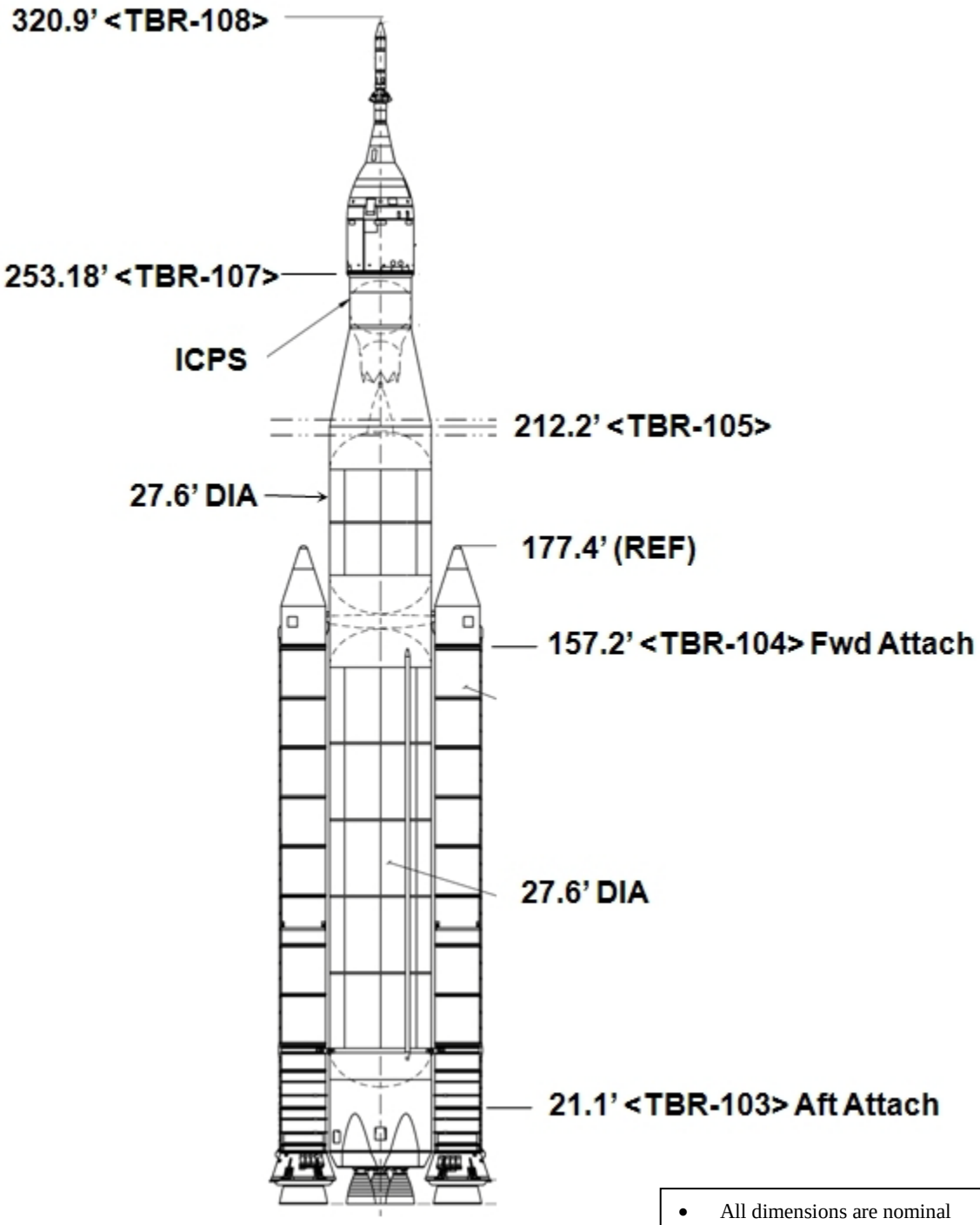
	RS-25D	**RS-25E**	**J-2X**
Maximum Power Level (%RPL)	109	111 <**TBR-001**>	100
Throttle Range	65–109%	65–111%	100%
Mixture Ratio Range	5.85 to 6.10 +/– 1%	5.85 to 6.10 +/– 1%	5.5
Mass (lb)	7,816	NTE 8,156	5,400
Min Vac Thrust @ Max Pwr (lbf)	511,117	515,700	276,450
Min Vac Isp @ Max Pwr (s)	452.3	450.8	435

Booster

	5-Segment SRB
Propellant Type	PBAN
Dry mass (lb)	221,319 <**TBR-002**>
Prop load (lb)	1,392,194 <**TBR-003**>
SRB Thrust Trace	RSRMV-08910
Recoverable/Re-useable	No/No

3.1.1 Block 1 Configuration

The Block 1 SLS configuration (~70 metric ton), shown in Figure 3.1.1-1, is comprised of a 27.6-foot nominal outer wall diameter (cryogenic pressure vessels excluding thermal protection system foam and flanges) core stage, with propulsion provided by two five-segment polybutadiene acrylonitrile (PBAN) solid rocket boosters and four RS-25D liquid hydrogen (LH_2)/liquid oxygen (LO_2) core stage engines. Both the boosters and the core stage engines (otherwise known as Space Shuttle Main Engines) are existing hardware developed under the Constellation and Space Shuttle Programs, respectively. For Orion MPCV missions, the SLS launch vehicle will include two payload adapters. For Orion MPCV mission without an ICPS, the SLS launch vehicle will allocate necessary ballast to the SPIO/ISPE. For cargo missions, the SLS will include a cargo payload adapter (CPA) and a payload fairing.



SLS-1000X

- All dimensions are nominal
- Dimensions marked (REF) are for reference only and not controlled by this specification
- Figure is not intended to represent the number of core stage engines installed
- All dimensions are measured from nozzle exit plane

Figure 3.1.1-1: Block 1 Configuration

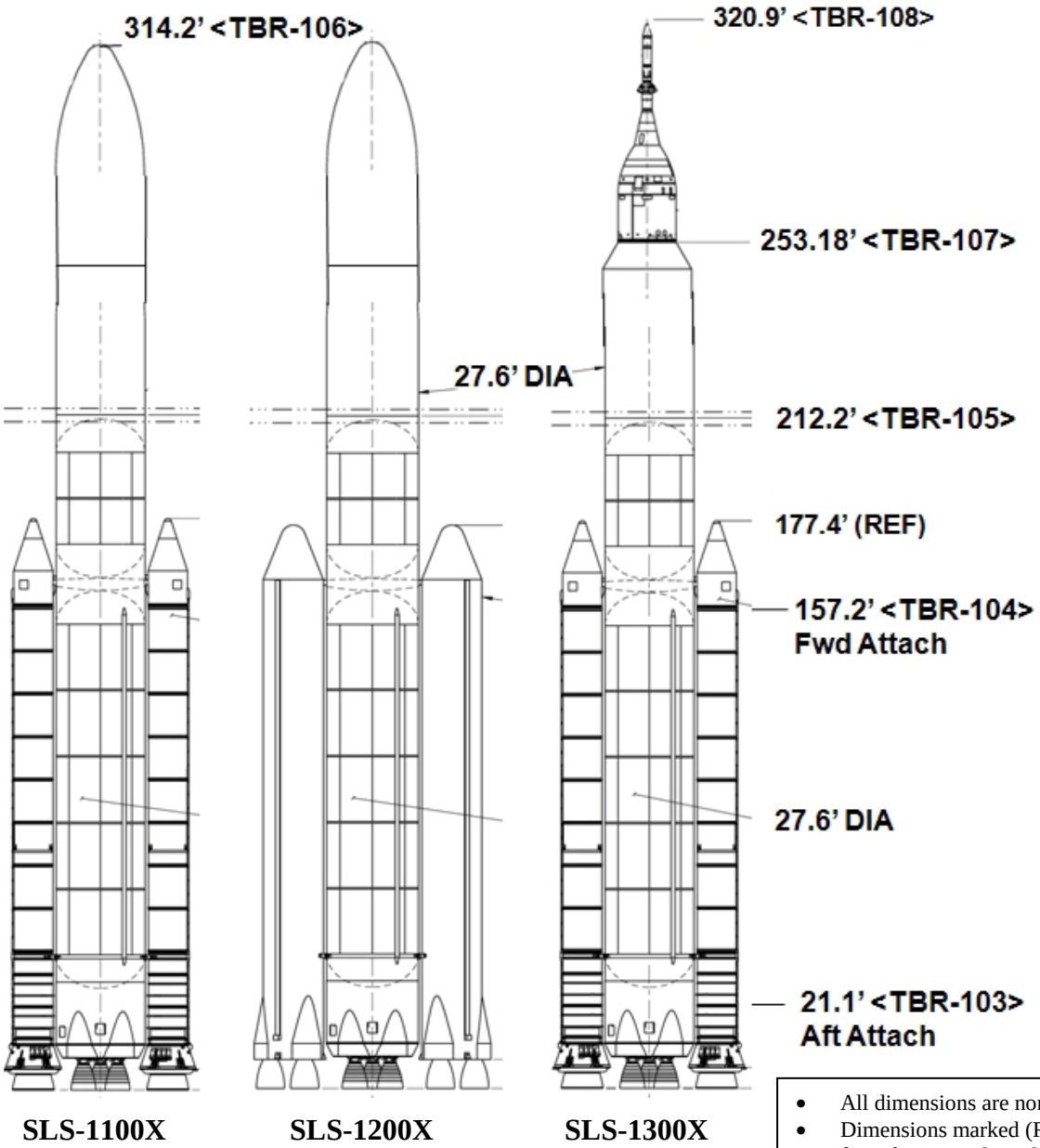
3.1.1.1 Block 1 Design Constraints

Listed below are design constraints and/or decisions that are baselined as part of the Block 1 design.

- Payload adapter(s).
- Includes Avionics Unit.
- SLS Vehicle design will include provisions for development flight instrumentation.
- Core Stage Engine design will include pogo suppression.
- Core Stage and Booster design will provide imagery of mission critical and safety related events.
- No reaction control system on core stage.
- Mobile launcher stabilizer interface.
- Ares-style vehicle support posts.
- Booster forward thrust takeout.
- Core stage structurally stable without pressurization during all phases of ground transportation and processing.
- Space Transportation System (STS) heritage booster separation.
- ICPS for Orion MPCV Early Test Flight missions.
- Boosters support vehicle on mobile launcher.
- 5-segment PBAN Boosters – 7.22 expansion ratio nozzle with 155.8" exit plane outer diameter.
- Utilize STS heritage solid rocket booster thrust vector control (TVC) for boosters.
- Utilize heritage solid rocket booster thrust vector control (TVC) for core stage engines <**TBR-119**>.
- 4 RS-25D core stage engines.
- Core stage engine gimbal capability will be limited to 8 degrees.
- Heritage booster hardware will meet design-to launch reliability and maintainability.
- Heritage RS-25D hardware will meet demonstrated launch reliability and maintainability.

3.1.2 Block 1A Configuration

The Block 1A configuration (~105 metric ton), shown in Figure 3.1.2-1, introduces the new competitively-procured boosters (solid or liquid) in place of the five-segment PBAN boosters and utilizes four RS-25D or 25E core stage engines. The payload fairing is a two-piece configuration, which maximizes payload volume while still retaining the ability to process the payload and vehicle in existing Kennedy Space Center (KSC) facilities.



- All dimensions are nominal
- Dimensions marked (REF) are for reference only and not controlled by this specification
- 1400X Vehicle (MPCV on 1200X Vehicle) not shown
- Figure is not intended to represent the number of core stage engines installed
- All dimensions are measured from nozzle exit plane

Figure 3.1.2-1: SLS Vehicle - Block 1A Configuration

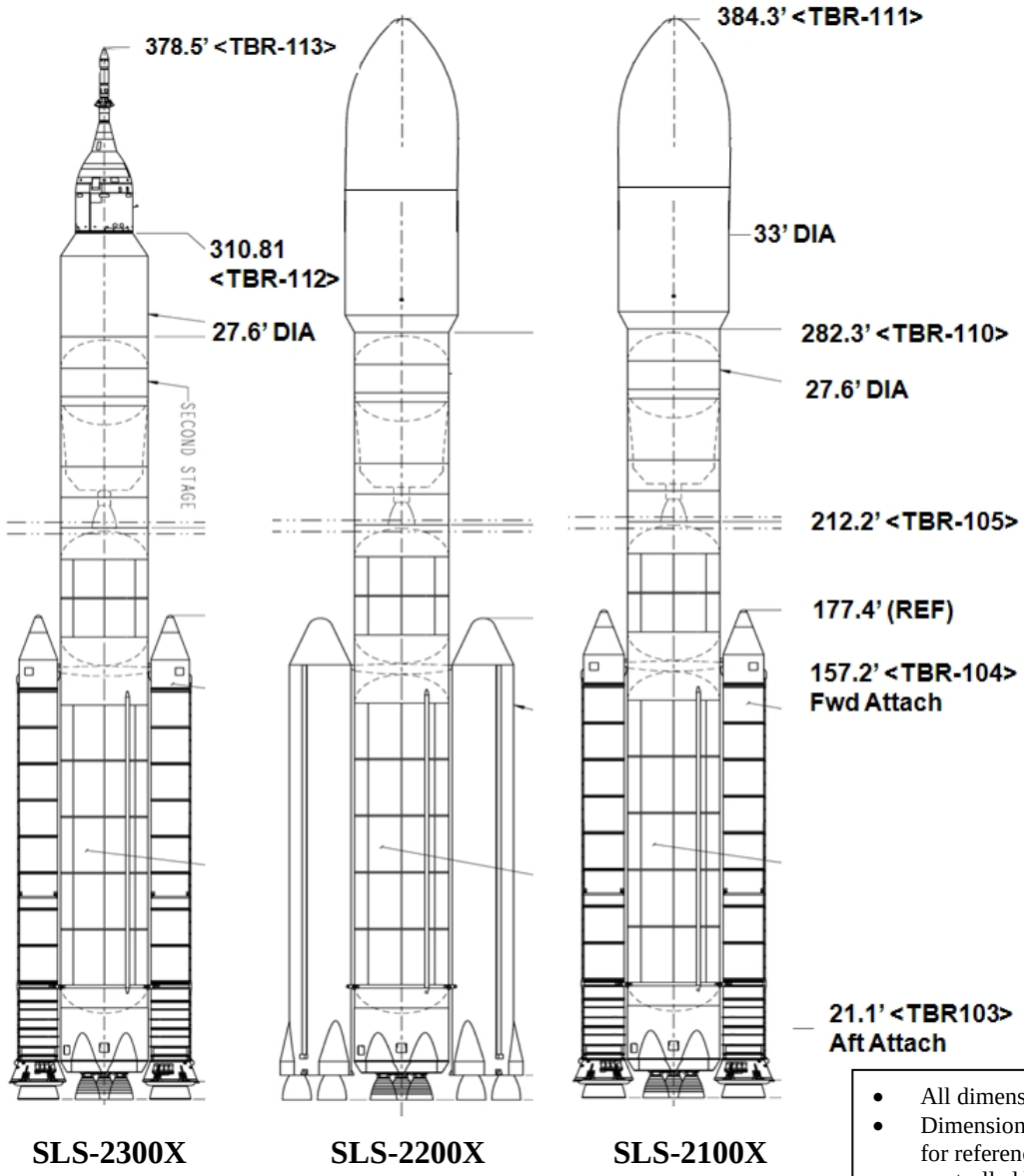
3.1.2.1 Block 1A Design Constraints

Listed below are the design constraints and/or decisions that are baselined as part of the Block 1A design. Items in bold italic are changes from the Block 1 configuration.

- Payload adapter(s).
- Includes avionics unit.
- SLS vehicle design will include provisions for developmental flight instrumentation.
- Core stage engine design will include pogo suppression.
- Booster design, if liquid, will include pogo suppression.
- Core stage and booster design will provide imagery of mission critical and safety related events.
- No reaction control system on core stage.
- Mobile launcher stabilizer interface.
- Booster forward thrust takeout.
- Core stage and booster (if liquid) structurally stable without pressurization during all phases of ground transportation and processing.
- Booster separation provided by booster element.
- Boosters support vehicle on mobile launcher.
- ***Competitively-procured Boosters.***
- Utilize heritage solid rocket booster thrust vector control (TVC) for core stage engines <**TBR-119**>.
- 4 RS-25D or ***25E*** core stage engines.
- Core stage engine gimbal capability will be limited to 8 degrees.

3.1.3 Block 2 Configuration

The Block 2 configuration (~130 metric ton), shown in Figure 3.1.3-1, will utilize the core stage developed for the Block 1 configuration, four or five RS-25E LH_2/LO_2 core stage engines, two competitively-procured (liquid or solid) boosters, and a new 27.6-foot-diameter upper stage. The upper stage will be powered by two J-2X LH_2/LO_2 engines, initially developed under the Constellation Program. As with the Block 1A configuration, the cargo version of the evolved SLS vehicle will include a payload adapter and two-piece payload fairing. For Orion MPCV missions, the SLS vehicle may be required to accommodate other payloads in addition to Orion MPCV.



- All dimensions are nominal
- Dimensions marked (REF) are for reference only and not controlled by this specification
- 2400X Vehicle (MPCV on 2200X Vehicle) not shown
- Figure is not intended to represent the number of core stage engines installed
- All dimensions are measured from nozzle exit plane

Figure 3.1.3-1: SLS Vehicle – Block 2 Configuration

3.1.3.1 Block 2 Design Constraints

Listed below are design constraints and/or decisions that are baselined as part of the Block 2 design. Items shown in bold italic are changes from the Block 1A configuration.

- Payload adapter(s).
- Includes avionics unit.
- SLS vehicle design will include provisions for developmental flight instrumentation.
- Core stage engine design will include pogo suppression.
- Booster design, if liquid, will include pogo suppression.
- Upper stage design will include pogo suppression.
- Core stage, upper stage and booster design will provide imagery of mission critical and safety related events.
- No reaction control system on core or ***upper stage***.
- Mobile launcher stabilizer interface.
- Booster forward thrust takeout.
- Core stage, upper stage and booster (if liquid) structurally stable without pressurization during all phases of ground transportation and processing.
- Booster separation provided by booster element.
- Boosters support vehicle on mobile launcher.
- ***2x J-2X upper stage engines.***
- ***Core-upper stage separation system.***
- Competitively-procured booster.
- 4–5x RS-25E core stage engines.
- When there are 5 core stage engines, the center engine will be fixed (i.e., no TVC on the center engine).
- Core stage engine gimbal capability will be limited to 8 degrees with a center engine keep out zone.

3.1.4 Functional Avionics Architecture

The functional avionics architecture for the SLS Block 1 configuration is as shown in Figure 3.1.4-1. The purpose of this figure is to identify which avionics functions have been allocated to which SLS Elements. Specific details of internal and external interfaces are defined in the appropriate ICDs. Architectures for subsequent configurations are <**TBD-008**>.

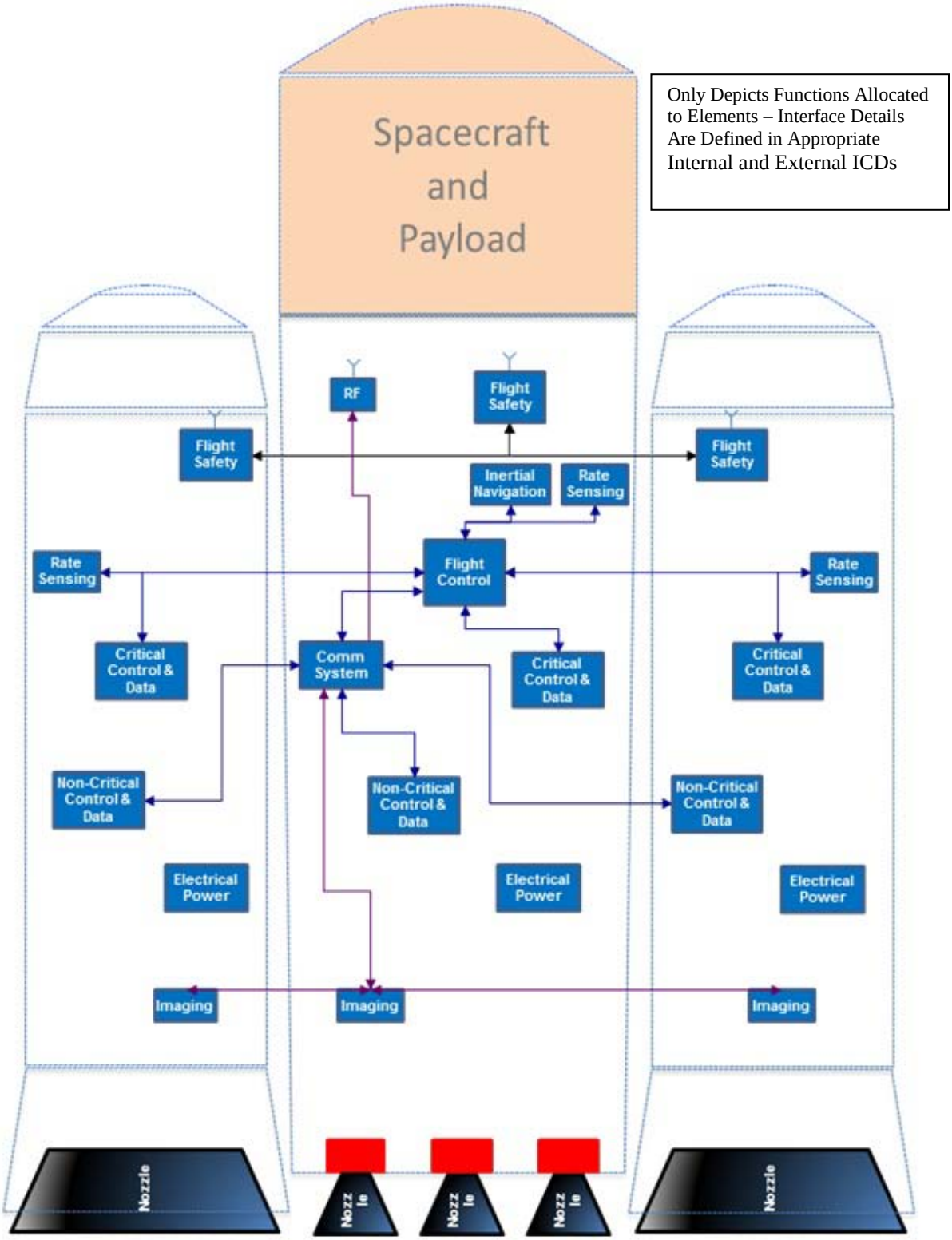


Figure 3.1.4-1: Block 1 Functional Avionics Architecture

3.2 System Requirements

This specification establishes requirements for the Space Launch System (SLS) launch vehicle, hereafter referred to as the SLS vehicle. These requirements were derived from ESMD-HEC.Reqt-6.2011, ESMD/SOMD Human Exploration Capabilities Requirements, dated 6-30-2011, ESD 10012, Exploration Systems Development (ESD) Concept of Operations, SLS-PLAN-020, SLS Program Concept of Operations, and SLS-MDL-068, SLS Program Vehicle Functional Analysis Model (VFAM).

3.2.1 Vehicle Management

The SLS will be capable of certain functionality during the various phases of vehicle development, processing, operation, and disposal. Detailed vehicle management design constraints and control models are contained in SLS-SPEC-079**,** SLS Program Vehicle Management Specification, which is imposed for SLS development in Section 3.2.12.

3.2.2 System Capability Requirements

[SLS.1] SLS Lift Capability – Block 1

The SLS Block 1 vehicle shall deliver a minimum of 62.8 tons <**TBR-004**> (57 metric tons) of payload to an insertion target of –50 × 975 nm (–93 × 1806 km) <**TBR-005**> at 28.5 degrees inclination and an insertion altitude of 87.3 nm (162 km).

Rationale: Analysis of the two ESD 10012 Tactical Timeframe DRMs (Uncrewed BEO Lunar Fly-by and Crewed BEO Lunar Orbit) indicates an SLS Block 1 lift capability of 57 metric tons to this orbit is required to achieve these missions. This lift capability includes MPCV, all associated MPCV systems, the ICPS, and the ICPS-to-MPCV adapter. The lift capability does not include the launch vehicle to spacecraft adapter mass, which must also be carried to the target orbit.

[SLS.2] SLS Lift Capability – Block 1A

The SLS Block 1A vehicle shall deliver a minimum of 115.8 tons (105 metric tons) of payload to an insertion target of –47 × 130 nm (–87 × 241 km) at 28.5 degrees inclination and an insertion altitude of 77 nm (143 km).

Rationale: Modified Level I Requirement. Design Reference Mission analysis indicates that launch vehicles in the 100 metric ton class are necessary to enable early missions. An early lift capability of 105 metric tons allows the architecture to conduct missions to LEO, HEO, GEO, cis-Lunar space, the Lunar surface, and Near Earth Asteroids affordably.

[SLS.3] SLS Lift Capability – Block 2

The SLS Block 2 vehicle shall deliver a minimum of 143.3 tons (130 metric tons) of payload to an insertion target of –47 × 130 nm (–87 × 241 km) at 28.5 degrees inclination and an insertion altitude of 77 nm (143 km).

Rationale: Modified Level I Requirement. Design Reference Mission analysis indicates that as more challenging missions are needed, the launch vehicle lift capacity needs to support a 130 metric ton class capability. The launch system needs to consider this 130 metric ton capability throughout its design to ensure that this capability can be achieved.

[SLS.4] Alternate Means of Delivering MPCV to ISS Orbit Inclination

The SLS vehicle shall be capable of delivering Orion MPCV to an insertion target of –11 × 100 nm (–20.4 × 185.2 km) at 51.6 degrees inclination and an insertion altitude of 70 nm (129.6 km).

Rationale: Level I Requirement. The LEO-ISS Back-Up Crew Delivery DRM is flown with the SLS and the Orion MPCV, with the SLS providing any necessary ballast and launch stack spacers. This DRM is a single launch of up to four crewmembers to and from the ISS and is a back-up to the planned commercial crew capability for transportation to the ISS.

[SLS.5] Payload Fairing Dimensions – Block 1, 1A

The SLS vehicle shall provide a payload fairing with a minimum outer diameter of 27.6 ft (8.4 m) and an overall length (OAL) not to exceed 102 ft (31.1 m).

Rationale: Modified Level I Requirement. The SLS Block 1 and 1A configurations provide a 27.6 ft diameter fairing to launch payloads with large diameter apertures. The 27.6 ft outer diameter provides approximately 1.5 ft radial clearance relative to the required 24.6 ft (7.5 m) internal dynamic envelope. The maximum overall fairing length is constrained by compatibility of the SLS with the KSC processing facilities where it will be integrated for launch.

[SLS.6] Payload Fairing Dimensions – Block 2

The SLS vehicle shall provide a payload fairing with a minimum outer diameter of 33 ft (10 m) and an overall length (OAL) not to exceed 102 ft (31.1 m).

Rationale: Modified Level I Requirement. The SLS Block 2 configuration provides a 33 ft diameter fairing to launch payloads with even larger diameter apertures. The 33 ft outer diameter provides approximately 1.5 ft radial clearance relative to the required 29.9 ft (9.1 m) internal dynamic envelope. The maximum overall length is constrained by compatibility of the SLS with the KSC processing facilities where it will be integrated for launch.

[SLS.7] Orbital Insertion Accuracy

The SLS vehicle shall provide orbital insertion accuracies of:

<u>Block 1</u>
Semi major axis: ± 13 nm (24.1 km) <**TBR-120**>
Apogee: ± 30 nm (55.6 km) <**TBR-121**>
Orbit Plane: ± 0.10

<u>Block 1A and Block 2</u>
Semi major axis: ± 10 nm (18.5 km) <**TBR-008**>
Apogee: ± 8 nm (14.8 km) <**TBR-009**>
Orbit Plane: ± 0.10

Rationale: Modified Level I Requirement. The speed error at MECO is the same for all three Block configurations; however, the different injection orbit for the Block 1 Tactical DRMs leads to different uncertainties in semi-major axis and apogee.

[SLS.8] Service Life – Minimum

The SLS vehicle service life shall be a minimum of 1.0 <**TBR-010**> year.

Rationale: Requirement provides flexibility for hardware utilization taking into account rework, launch delays and manifest changes. Service life quantifies the life expectancy of the launch vehicle starting at completion of vehicle integration, post vehicle stacking. Service life of the elements starts at DD250 acceptance.

3.2.3 System External Interface Requirements

SLS will have the following external interfaces. Interface functions and designs will be worked by the interfacing programs and/or systems and captured in interface control documents (ICDs). In the case of the Eastern Range interface, the results will be captured in SLS-RQMT-114. For the Orion MPCV interface, requirements will be captured in MPCV 70026, MPCV to SLS IPE IRD.
External ICDs, the tailored Eastern Range Requirements and Orion MPCV interface requirements are imposed for SLS development in Section 3.2.12.

- SLS to Ground Systems Development and Operations (GSDO)
- SLS Integrated Payload Element (IPE) to Orion MPCV
- SLS to Payload (cargo missions)
- SLS to Communications and Tracking Network (CTN)
- SLS to Eastern Range

3.2.4 System Internal Interface Requirements

SLS will have the following internal interfaces. Interface functions and designs will be developed by the interfacing SLS elements and captured in ICDs. Internal ICDs are imposed for SLS development in Section 3.2.12.

- Stages (Core and Upper Stage) to Engines (Core and Upper Stage)
- Core Stage to Booster
- Stages (Core and Upper Stage) to IPE

3.2.5 System Internal Data Requirements

Internal data requirements are contained in the SLS internal ICDs.

3.2.6 Adaptation Requirements

Applicable adaptation requirements related to reconfiguration updates of software, data parameters, etc., are imposed at the SLS element level.

3.2.7 Safety Requirements

Programmatic safety and mission assurance requirements are addressed in SLS-RQMT-014, SLS Program Safety and Mission Assurance Requirements.

[SLS.9] Autonomous Liftoff and Ascent

The SLS vehicle shall perform autonomous liftoff and ascent.

Rationale: NPR 8705.2B Requirement. This capability means that the SLS vehicle would not depend on communication with other programs and systems (i.e., GSDO, Orion MPCV, etc.) in order to maintain vehicle function for nominal ascent operations. Contingencies (abort) are excluded from this requirement.

[SLS.10] Failure Tolerance

The SLS vehicle shall be at least single failure tolerant, without the use of emergency equipment and systems, to control catastrophic hazards except where approved for Design for Minimum Risk (DFMR).

Rationale: NPR 8705.2B Requirement. The SLS has established a minimum of single failure tolerance or DFMR to control catastrophic hazards. DFMR ensures the hazards are controlled through a defined process in which approved standards and margins are implemented on proven designs to account for the absence of failure tolerance. Single failure tolerance may not be adequate in all instances to control catastrophic hazards. Thus, the level of failure tolerance needed is commensurate with the severity of the hazard, and likelihood of occurrence. The SLS Program will derive the specific level of failure tolerance and implementation (similar or dissimilar redundancy, backup systems) from an integrated design and safety analysis performed in accordance with SLS-RQMT-015, Space Launch System Program Hazard Analysis Requirement Document, and SLS-RQMT-016, Space Launch System Program FMEA/CIL Requirements Document. For hazards that are verified via probabilistic methods, the verification should include the failure prior to applying probabilistic methods.

[SLS.11] Support Abort Capability for Crewed Missions

The SLS vehicle shall, at a minimum, support Orion MPCV abort capability during ascent for complete loss of ascent thrust/propulsion or loss of attitude or flight path control.

Rationale: NPR 8705.2B Requirement. The requirement specifies the minimum conditions under which the SLS should support an Orion MPCV abort. Additional abort triggers may be identified and, if so, will be captured in SLS-SPEC-079. Abort notification specifics are defined and controlled in SLS IPE to Orion MPCV ICDs.

[SLS.12] Automatic Safing for Crewed Missions

The SLS vehicle shall autonomously execute vehicle safing for determined abort conditions when insufficient time exists for external intervention.

Rationale: NPR 8705.2B Requirement. The SLS architecture needs to provide automatic vehicle safing and crew notification in the cases where the crew does not have time to initiate the response per the Mission and Fault Management model defined in SLS-SPEC-079. Orion MPCV abort notification specifics are defined and controlled in SLS IPE to Orion MPCV ICDs.

[SLS.13] Fault Detection and Notification for Crewed Missions

The SLS vehicle shall detect and provide notification of faults that would result in a catastrophic event.

Rationale: NPR 8705.2B Requirement. The capability to detect faults, based on available measurements, is, coupled with isolation, a key redundancy management tool for mitigating potentially catastrophic failures per the Mission and Fault Management model defined in SLS-SPEC-079. Where redundancy is available, this should result in automatic retention of functionality. However, not all faults are fully recoverable. In such cases abort recommendation to the crew is necessary. Additionally, it is realized that individual faults may not each be

detected, but results of faults may be detected and notification provided. Specifics of the notification of faults will be handled in the SLS ICDs.

[SLS.14] Fault Isolation and/or Recovery for Crewed Missions

The SLS vehicle shall isolate and/or recover from faults that would result in a catastrophic event.

Rationale: NPR 8705.2B Requirement. The capability to isolate faults to a particular level (subsystem string or component) after detection is a key redundancy management tool for mitigating potentially catastrophic failures as defined in SLS-SPEC-079. Where redundancy is available, this should result in automatic retention of functionality. However, not all faults are fully recoverable. In such cases abort recommendation to the crew is necessary. It is acknowledged that not all faults that would cause catastrophic events can be detected or isolated in time to avoid the event.

[SLS.15] Limits on Induced Loads for Crewed Missions

The SLS vehicle shall limit its contribution to induced loads on the crew to those contained in MPCV 70024, MPCV Program Human System Integration Requirements.

Rationale: NPR 8705.2B Requirement. Physical deficiencies or harm can come from excessive loads on humans as difficulty breathing, blurred vision, unconsciousness, vomiting, etc. The vehicle must limit the loads it imparts into the crew module. Limits may be mitigated through a combination of minimizing vehicle loads and attenuation in the crew compartment.

[SLS.16] Abort Environments

The SLS vehicle shall limit the probability of failures that exceed the abort environments as specified in the Abort Environments Table <**TBR-011**> to no greater than 1 in 700 <**TBR-012**> per mission.

Rationale: Modified Level I Requirement. The 1 in 700 means a 0.001429 (or 0.1429%) probability of exceeding the environments outlined in the abort environments table per mission (Launch Abort System (LAS) arming to successful completion of the insertion burn(s) as defined in the mission timeline). The abort environments table will be jointly negotiated between SLS and Orion MPCV to define the limits of ascent abort environments that allow a high likelihood of successful Orion MPCV abort. Environments exceeding the limits in this table are expected to result in LOC. Assessment of SLS contribution to LOC is based on failure probabilities as well as an assessment of the effects of failures on the ability of the crew to successfully abort. The ascent LOC assessment will evaluate all risks from the time the vehicle is crewed through separation of the Orion MPCV from SLS. The requirement is on the mean estimate of the risk.

[SLS.17] Debris Impact Footprint

The SLS trajectory, shall ensure that no surviving debris impact with a kinetic energy greater than 11.1 ft-lbf (15 joules), is closer than 200 nm (370 km) from foreign landmasses (except for the intact booster stage), or is within 27 nm (50 km) from the continental U.S., territories of the U.S., and the permanent ice pack of Antarctica.

Rationale: Suborbital debris from disposable SLS elements must not pose an undue hazard to populated areas. Per NASA-STD-8719.14, the potential for human casualty is assumed for any object with an impacting kinetic energy in excess of 11.1 ft-lbf (15 joules).

3.2.8 Security and Privacy Requirements

SLS security requirements for encoding of range destruct commands to the FSS will be in accordance with SLS-RQMT-114, imposed in Section 3.2.12.

3.2.9 System Environment Requirements

Applicable system environment design requirements are imposed in Section 3.2.12 via SLS Design Environments.

3.2.10 Computer Resource Requirements

Computer resource requirements for SLS elements are contained in element-level documents. Computer resource requirements for ground operations are contained in the SLSP Ground Operations Specification. Computer resource requirements for Flight Operations are contained in the SLSP Flight Operations Specification. Computer resource requirements for Sustaining Engineering are contained in the SLSP Sustaining Engineering Plan.

3.2.11 System Quality Factors

This section contains requirements for system quality factors such as reliability, maintainability and availability.

[SLS.18] Loss of Mission (LOM)

SLS vehicle shall limit the risk of Loss of Mission (LOM) for any SLS mission to no greater than 1 in 200 **<TBR-013>**.

Rationale: Modified Level I Requirement. A 1 in 200 risk is equivalent to a probability of 0.005 of LOM per mission. This is a direct allocation to the SLS for P(LOM) during the ascent phase. For the purpose of analysis, the LOM estimate will include all Loss of Vehicle (LOV) failures from start of tanking to T–0 and all LOM failures from T–0 to successful payload separation. The requirement is on the mean estimate of the risk.

[SLS.19] Launch Availability – Block 1A, Block 2

After the start of launch countdown, the SLS Block 1A and Block 2 vehicle configurations shall have a 0.98 <**TBR-014**> probability with at least a 0.90 <**TBR-015**> confidence level of successfully launching within 30 <**TBR-016**> days of the established launch date, exclusive of weather.

Rationale: Allocation of Level I Requirement. A high level of launch availability is needed to enhance affordability by reducing the cost associated with long launch delays and to support multiple launch mission scenarios. Launch probability due to weather will be tracked as a Technical Performance Measure.

[SLS.20] Launch Reliability – Block 1A, Block 2

The SLS Block 1A and Block 2 vehicle configurations shall have a mean launch reliability of at least the values shown in Table 3.2.11-1.

Rationale: Launch Reliability is one part of the decomposition of Launch Availability. It ensures that the SLS has a high likelihood of launching on a single launch attempt, whether it is the initial launch attempt for a given launch date or follow-on launch attempt after a missed launch. Launch reliability is defined as the probability of not experiencing an SLS hardware/software

failure that would result in a launch scrub and is inclusive of all events from start of launch countdown thru liftoff. Vehicle prelaunch failures that result in catastrophic hazards to the vehicle or flight crew are excluded from Launch Reliability since they are included in Ascent Reliability requirement derived from SLS LOM.

Table 3.2.11-1: SLS Launch Reliability

SLS Block Configuration	Reliability
Block 1A	0.844 <**TBR-017**>
Block 2	0.819 <**TBR-018**>

[SLS.21] Maintenance Down Time – Block 1A, Block 2

The SLS Block 1A and Block 2 vehicle configurations shall be maintainable such that at least 85% <**TBR-019**> of vehicle failures can be repaired with a maximum maintenance down time of 240 <**TBR-020**> hours.

Rationale: Maintenance Down Time (MDT) is one part of the decomposition of launch availability and system readiness. In the event of an SLS failure, the vehicle must be repairable to support additional launch attempts within the 30 days of the launch availability requirement. The percentage of SLS failures that must be repaired is a failure rate weighted average of all credible SLS failures that can occur after start of launch countdown and result in a launch scrub. Vehicle MDT is inclusive of all time from the point a launch scrub is declared until the vehicle is ready to restart countdown for the follow-on launch attempt, exclusive of weather delays.

[SLS.22] Launch Countdown Hold

The SLS vehicle shall be capable of remaining in a countdown hold, in a stable, replenish mode, for at least 4 hours <**TBR-021**>.

Rationale: Examples of drivers for this requirement include weather holds, range safety holds, etc. The launch vehicle will need to be capable of accepting the launch commands from ground control at any point within the window defined. This will include cryo boil-off and re-supply as needed. The expectation is that the launch countdown is in a condition where stable replenish is available throughout the launch window with stable replenish cut-off prior to tank pre-pressurization. This includes provision of any required purges, thermal support, etc.

[SLS.23] Operational Life for Launch Attempts

The SLS vehicle shall be capable of a minimum of 13 <**TBR-022**> cycles, which may be cryo cycles or pressure cycles, in addition to any pre-delivery testing and check-out cycles, before the end of its useful life.

Rationale: For the purposes of this requirement, a cryo plus pressure cycle is post-tanking of propellants and tank pressurization which puts the system in a launch-ready state. This requirement ensures that the fully operational launch vehicle will be able to support a minimum number of launch attempts without fatigue life issues. Useful life is defined as the item's total life

span including servicing life and shelf life with normal preventive maintenance, servicing, repair, and replacement of parts before item is considered unacceptable for further usage.

[SLS.24] Pad Stay Time

The SLS vehicle shall withstand the natural environments at the launch pad for a minimum of 180 <**TBR-023**> days from first exposure, excluding wind loading effects, which are covered by the vehicle coupled loads.

Rationale: The design of, and materials chosen for, the vehicle shall consider the effects of exposure to the natural environments such that material properties used in analysis of the hardware can reflect the actual hardware condition after the minimum exposure time, i.e., either degraded material properties should be defined and used in analyses or materials should be chosen such that properties can be shown to not degrade during that time. Requirement duration is cumulative time and not single event times.

[SLS.25] Internal Access

The SLS vehicle shall provide internal access for nominal operations and repair operations.

Rationale: Internal access is required for some nominal and removal and repair operations.

[SLS.26] Vehicle Stack Time

The SLS vehicle shall be capable of remaining in a stacked configuration for a minimum of 200 <**TBR-024**> calendar days without the need for vehicle destacking.

Rationale: Requirement is to provide operability for scenarios where remaining stacked allows flexibility in meeting downstream launch schedules. This also provides flexibility and avoids operations re-work within the vehicle integration facility to resume the launch flow in an expedited manner. Vehicle stack time does not include integrated element time.

3.2.12 Design/Ops Constraints

[SLS.27] SLS Specific Technical Specifications and Standards

The SLS vehicle shall comply with SLS technical documents listed in Table 3.2.12-1, in accordance with the process defined in SLS-PLAN-003, SLSP Systems Engineering Management Plan.

Rationale: SLS must apply documents, specifications, and standards to its elements in order to adequately ensure quality of end items delivered, and the ability of those end items to meet their functional requirements.

Table 3.2.12-1: SLS Technical Documents & Standards Applicability

SLS Technical Documents & Standards	Stages	Booster	Liquid Engines	Spacecraft & Payload Integration
SLS-SPEC-048	X	X	X	X
SLS-SPEC-028	X	X	X	X
SLS-SPEC-049	X	X	X	X
SLS-RQMT-044, Vol. 1–9	X	X	X	X
SLS-RQMT-045	X	X	X	X
SLS-RQMT-040	X	X	X	X
SLS-RQMT-019	X	X	X	X
SLS-RPT-037	X	X	X	X
SLS-SPEC-043	X	X	X	X
SLS-SPEC-118	X	X	X	X
SLS-SPEC-030	X	X	X	X
SLS-SPEC-079	X	X	X	X
SLS-RQMT-114	X	X		X
SLS-<**TBD-027**>, SLSP Human System Integration Requirements	X	X	X	X
MPCV 70026				X
MPCV-T-029600				X
MPCV-T-029601				X
SLS-<**TBD-005**>**,** SLS IPE to Payload ICD				X
SLS-ICD-052	X	X	X	X
SLS-ICD-031	X			X
SLS-ICD-039	X		X	
SLS-ICD-021	X	X		
SLS-ICD-029	X			X

[SLS.28] Other Technical Specifications and Standards

The SLS shall comply with the intent of the technical documents listed in Table 3.2.12-2, in accordance with the process defined in SLS-PLAN-003, SLSP Systems Engineering Management Plan.

Rationale: SLS must apply documents, specifications and standards to its elements in order to adequately ensure quality of end items delivered, and the ability of those end items to meet their functional requirements. The element will be allowed to propose alternate requirements and

documents that they believe meet the intent of the technical document. The cognizant NASA Technical Authority will evaluate the equivalency of the requirements and documents proposed by the element. It will be the responsibility of the element to demonstrate that a proposed alternate requirement or document fully meets the intent and the requirements of the document(s) listed herein, and obtain formal SLS approval.

Table 3.2.12-2: Other Technical Documents & Standards

Other Technical Documents & Standards	Stages	Booster	Liquid Engines	Spacecraft & Payload Integration
ANSI/AIAA S-080	X	X[2]	X[1]	X
ANSI/AIAA-S-81	X	N/A	N/A	X
MIL-STD-1522	X	X[2]	X[1]	X
MIL-STD-130	X	X[2]	X[1]	X
NASA-STD-5017	X	X[2]	X[1]	X
NASA-STD-5019	X	X[2]	X[1]	X
NASA-STD-6016	X	X[2]	X[1]	X
NSTS-08307	X	X[2]	X[1]	X
NASA-STD-4003	X	X[2]	X[1]	X
NPR 7150.2	X	X[2]	X[1]	X
AIAA S-111	X	N/A	N/A	X
ANSI/ESD S20.20	X	X[2]	X[1]	X
IPC-2221	X	X[2]	X[1]	X
IPC-2222	X	X[2]	X[1]	X
IPC-2223	X	X[2]	X[1]	X
IPC-6011	X	X[2]	X[1]	X
IPC-6012	X	X[2]	X[1]	X
IPC-6013	X	X[2]	X[1]	X
SAE ARP 5412	X	X[2]	X[1]	X
MSFC-SPEC-164	X	X[2]	X[1]	X
MSFC-SPEC-3635	X	X[2]	X[1]	X
MSFC-STD-3663	X	X[2]	X[1]	X
NASA-STD-5001	X	X[2]	X[1]	X
NASA-STD-6008	X	X[2]	X[1]	X
TOR-2003(8583)-2896	X	X[2]	X[1]	X
Ares-USO-MP-25633	X	X[2]	X[1]	X
NASA-STD-5009	X	X[2]	X[1]	X

Other Technical Documents & Standards	Stages	Booster	Liquid Engines	Spacecraft & Payload Integration
NASA-STD-5012	X	X[2]	X[1]	X
MIL-STD-1540	X	X[2]	X[1]	X
NASA-HDBK-7005	X	X[2]	X[1]	X
NPD 8710.5	Fully applicable when operating on a NASA Facility, and when NASA personnel or critical NASA hardware are exposed to the pressure vessel/ pressurized system. For flight hardware, paragraphs 5.b.2–3	X[2]	X[1]	Fully applicable when operating on a NASA Facility, and when NASA personnel or critical NASA hardware are exposed to the pressure vessel/ pressurized system. For flight hardware, paragraphs 5.b.2–3
NPR 8715.6	1.3.10, 1.3.13, 2.1, & Chapters 2 & 3	N/A	N/A	1.3.10, 1.3.13, 2.1, & Chapters 2 & 3
NASA-STD-8719.9	X	X[2]	X[1]	X
NASA-STD-8719.12	X	X[2]	X[1]	X
NASA-STD- 8719.17	X	X[2]	X[1]	X
NASA-STD-8739.1	X	X[2]	X[1]	X
NASA-STD-8739.4	X	X[2]	X[1]	X
NASA-STD-8739.5	X	X[2]	X[1]	X
ASTM Manual 36	X	N/A	X[1]	X
GEIA-STD-005	X	N/A	X[1]	X
IPC J-STD-001	X	X[2]	X[1]	X
IPC J-STD-001DS Amendment 1	X	X[2]	X[1]	X
SAE/AS5553	X	N/A	N/A	X
ANSI/AIAA G-095-2004	X	X[2]	X[1]	X

Note 1: Exception is granted for Core Stage Engine heritage hardware that was developed for the Space Shuttle Main Engine (SSME) under Contract End Item (CEI) specification CP320R003B. Exception is granted for Upper Stage Engine heritage hardware developed for Ares I under CEI specification CP320R0053. Applicability of these technical documents on any Core Stage Engine or Upper Stage Engine heritage hardware that is altered or adapted for use on SLS will be

determined when those proposed changes are identified. This exception only applies to Table 3.2.12-2 and does not apply to any form, fit, function, loads/environments, safety, or performance requirements, which must still be met.

Note 2: Exception is granted for Booster heritage hardware that was developed for the Shuttle Solid Rocket Booster (SRB) and/or Ares I Reusable Solid Rocket Motor (RSRM) under CEI specifications 10CEI-0001 (SRB) or CPW1-3600 (RSRM). Applicability of these technical documents on any Booster heritage hardware that is altered or adapted for use on SLS will be determined when those proposed changes are identified. This exception only applies to Table 3.2.12-2 and does not apply to any form, fit, function, loads/environments, safety, or performance requirements, which must still be met.

3.2.13 Personnel Requirements

This section is intended to address the system requirements, if any, to accommodate the number, skill levels, duty cycles, training needs, or other information about the personnel who will use or support the system, including human factors engineering requirements. For SLS, specific personnel requirements for ground processing will be addressed in SLS-SPEC-043, and for flight operations, in SLS-SPEC-118.

3.2.14 Training Requirements

Training will be required to familiarize the flight operations team and the crew with procedures involved in the use of the manual steering mode, if required, and the execution of SLS powered abort modes. Training will also be required to familiarize the launch team with prelaunch nominal and contingency procedures. Specific training requirements for ground processing will be addressed in SLS-SPEC-043. Training requirements for flight operations will be addressed in SLS-SPEC-118.

3.2.15 Logistics-related Requirements

Logistics processes and policies are addressed in SLS-PLAN-025.

[SLS.29] Administrative Logistics Down Time (ALDT) – Block 1A, Block 2

The SLS Block 1 and Block 2 vehicle configurations shall have a maximum ALDT of 192 <**TBR-041**>hours.

Rationale: ALDT is one part of the decomposition of the SLS Maintenance Down-Time (MDT). It ensures that, in the event of a failure of the flight hardware during vehicle assembly and launch operations that there are no delays in maintenance due to an administrative nature, waiting for parts, tools, support equipment, procedures, personnel, transportation, or facilities. If the failure occurred during launch operations, ALDT is inclusive of the time to prep and move the vehicle from the pad to VAB and prep and move the vehicle from the VAB to the pad.

3.2.16 Programmatic Requirements

[SLS.30] Imagery

SLS shall provide imagery of mission critical and safety related events.

Rationale: Engineering quality imagery systems (still and motion) are essential for understanding and assessing the safety and performance of the launch vehicle. This requires an

appropriate suite of camera systems on the vehicle, ground, and possibly airborne and/or ship based. Ground-based imagery will be negotiated and captured in SLS-ICD-052. In addition, appropriate optical markings on the vehicle and ground hardware, along with baseline imagery documenting the preflight vehicle characteristics are required for engineering analysis purposes. With adequate imagery systems in place, appropriate assessments can be performed. In the event of a catastrophic scenario resulting in the loss of crew/mission, imagery will play a major role in the reconstruction of the events and in determining root mean causes.

[SLS.31] Launch Rate

SLS shall support up to 3 launches in a year.

Rationale: Level I Requirement. Exploration DRMs include 1 to 3 launches per mission. The maximum rate of 3 launches per year is not intended to drive SLS production, which is based on one launch every other year.

3.2.17 Packaging Requirements

Packaging requirements for the SLS Program are per <**TBD-010**>. Transportation environments and loads are encompassed by the Launch and Flight Environments and Loads. Specific transportation requirements for support equipment are covered in SLS-SPEC-030.

3.2.18 Precedence and Criticality of Requirements

This section is not applicable to SLS.

3.3 Element Allocated Vehicle Requirements

The requirements in Table 3.3-1 are the vehicle requirements that will define element functional and performance requirements without additional decomposition. Table 3.3-1 requirements will be in addition to the element requirements in Sections 3.3.1 through 3.3.4.

Table 3.3-1: Element Allocated Vehicle Requirements

Reqmt ID	Title	Stages	Liquid Engines	Booster	Spacecraft & Payload Integration
SLS.5	Payload Dimensions – Block 1, 1A				X
SLS.6	Payload Dimensions – Block 2				X
SLS.9	Autonomous Liftoff and Ascent	X	X		X
SLS.10	Failure Tolerance	X	X	X	X
SLS.11	Support Abort Capability for Crewed Missions	X	X	X	X
SLS.12	Automatic Safing for Crewed Missions	X	X	Applicable only for liquid boosters	X
SLS.13	Fault Detection and Notification for Crewed Missions	X	X	X	X
SLS.14	Fault Isolation and/or Recovery for Crewed Missions	X	X	X	X
SLS.22	Launch Countdown Hold	X	X	X	X
SLS.23	Operational Life for Launch Attempts	X	X	Applicable only for liquid boosters	X
SLS.24	Pad Stay Time	X	X	X	X
SLS.25	Internal Access	X		X	X
SLS.26	Vehicle Stack Time	X	X	X	X
SLS.27	SLS Specific Technical Specifications and Standards	X	X	X	X
SLS.28	Other Technical Specifications and Standards	X	X	X	X
SLS.31	Launch Rate	X	X	X	X

3.3.1 Stages

Requirements applicable specifically to the Core Stage and Upper Stage are labeled as such. Requirements applicable to both the Core Stage and Upper Stage, including their associated avionics, are denoted as “Core Vehicle.”

[S.1] Stage Configuration

The Core Stage shall be designed to accommodate five engines with the option of flying with only four engines without redesign of the main propulsion system.

Rationale: For cost savings, the SLS baseline is to utilize a common main propulsion system (MPS) and Core Stage though all vehicle configurations.

[S.2] Thrust Vector Control

The Core Vehicle shall provide thrust vector control capability.

Rationale: Detailed requirements and definition of the model for thrust vector control will be housed in SLS-SPEC-079.

[S.3] Timing Source

The Core Vehicle shall provide vehicle timekeeping.

Rationale: The Core Vehicle must have a centralized timing source that will be used to correlate all other element data to support onboard operation, anomaly investigations, and routine post-processing across all elements. Specifics for the resolution and accuracy of the timing source will be defined in SLS-SPEC-079.

[S.4] Receipt and Execution of External Commands

The Core Vehicle shall execute validated commands received from Orion MPCV, GSDO, and the Range.

Rationale: NPR 8705.2B Requirement. The Core Vehicle houses SLS vehicle avionics that provide integrated command, control, and communications for the launch vehicle.

[S.5] Commanding of Internal Elements

The Core Vehicle shall command SLS vehicle elements.

Rationale: The Core Vehicle houses SLS vehicle avionics that provide integrated command, control, and communications for the launch vehicle.

[S.6] Provide Health and Status Data to GSDO

The Core Vehicle shall provide health and status from all SLS vehicle elements, as defined in the respective SLS element ICDs, to the GSDO during prelaunch operations.

Rationale: NPR 8705.2B Requirement. Vehicle health and status (H&S) is necessary for notification of vehicle health during ground crew checkout and loading operations. Specifics of the H&S to be collected from all elements, including the frequency and protocol, will be documented in the Core Vehicle to appropriate SLS element ICDs. GSDO will provide H&S to external flight operations sites and other entities in accordance with applicable ICDs, which will also govern the content available during specific regimes in the timeline. H&S includes the status of safety inhibits.

[S.7] Provide Health and Status to the Spacecraft & Payload Integration Element

The Core Vehicle shall provide health and status from all elements, as defined in the respective SLS element ICDs, to the Spacecraft & Payload Integration element.

Rationale: NPR 8705.2B Requirement. Collection and relay of vehicle health and status (H&S) to the Spacecraft & Payload Integration element is necessary for notification of vehicle health and vehicle performance during ground processing and ascent. Specifics of the H&S to be collected from all elements, including the frequency and protocol, will be documented in the Core Vehicle to SLS element Interface Control Documents (ICDs). ICDs will govern the content available to various entities during specific regimes in the timeline. H&S includes the status of safety inhibits.

[S.8] Reconfiguration Updates

The Core Vehicle shall accept reconfiguration software, parameters and data products at up to <**TBD-011**> hours prior to launch.

Rationale: Updates to software builds already stored onboard the launch vehicle are required to support software reconfiguration as well as day of launch updates for environments.

[S.9] Core Stage Nominal Usable LH_2 Propellant Loading

The Core Stage shall have a nominal usable LH_2 propellant loading at first Core Stage Engine start command of 307,453 <**TBR-042**> lbm.

Rationale: The amount of total usable propellant (total propellant minus unusables) must be specified in order to ensure that the vehicle can satisfy its performance requirements. It includes usable impulse propellant, (start, mainstage, & shutdown), reserve, and fuel bias.

[S.10] Core Stage Nominal Usable LO_2 Propellant Loading

The Core Stage shall have a nominal usable LO_2 propellant loading at first Core Stage Engine start command of 1,851,846 <**TBR-043**> lbm.

Rationale: The amount of total usable propellant (total propellant minus unusables) must be specified in order to ensure that the vehicle can satisfy its performance requirements. It includes usable impulse propellant (start, mainstage, & shutdown), and reserve.

[S.11] Upper Stage Nominal Usable LH_2 Propellant Loading

The Upper Stage shall have a nominal usable LH_2 propellant loading at first Core Stage Engine start command of 68,526 <**TBR-044**> lbm.

Rationale: The amount of total usable propellant (total propellant minus unusables) must be specified in order to ensure that the vehicle can satisfy its performance requirements. It includes usable impulse propellant, (start, mainstage, & shutdown), reserve, and fuel bias.

[S.12] Upper Stage Nominal Usable LO_2 Propellant Loading

The Upper Stage shall have a nominal usable LO_2 propellant loading at first Core Stage Engine start command of 383,325 <**TBR-045**> lbm.

Rationale: The amount of total usable propellant (total propellant minus unusables) must be specified in order to ensure that the vehicle can satisfy its performance requirements. It includes usable impulse propellant (start, mainstage, & shutdown), and reserve.

[S.13] Nominal Usable Propellant Loading Variation

The variation in Core Vehicle nominal usable propellant loading, at first Core Stage Engine start command, shall be a maximum of ± 1.00% <**TBR-046**>.

Rationale: The minimum usable propellant loading limit, nominal loading, and heaviest core stage and upper stage usable propellant loading at first core stage engine start command are used in trajectory analyses to define induced environments and min/max ascent and re-entry trajectory conditions. The variation of the usable propellant loading is used to define the minimum usable propellant loading (nominal – 3 Sigma) and the heaviest core/upper stage usable propellant loading (nominal + 3 Sigma). The usable propellant loading variation supports the definition of the allowable manufacturing variation for core/upper stage usable propellant loading weights. The sources include the ability of the facility software to maintain the propellant level, the total volume of the tank, propellant density, sensor location, and wave action/surface perturbation. Violations of the usable propellant loading variation limits could invalidate SLS induced environments and min/max ascent and re-entry trajectory conditions.

[S.14] Launch-Ready Hold

The Core Vehicle shall be capable of remaining in a launch-ready state, with propellant tanks pressurized and ready for launch, for a minimum of 3 <**TBR-047**> minutes prior to switching to internal electrical power.

Rationale: This capability allows for brief launch holds while maintaining the capability to launch. This need occurred often in the Shuttle program, where brief no-go calls were resolved.

[S.15] Ascent Telemetry

The Core Vehicle shall transmit health and status from all elements, as defined in the SLS-to-CTN ICD, to the CTN, from terminal countdown through payload separation, concluding 5 seconds <**TBR-048**> after MECO.

Rationale: NPR 8715.2B Requirement. The 3 sigma dispersed MECO plus 5 seconds encompasses the nominal payload separation. Historical precedence shows that having assured access to critical engineering health and status (H&S) in the event of a catastrophic event is crucial to quickly and accurately determining the failure cause and contributing factors. Furthermore, there are no provisions for onboard recording of H&S with later recorder retrieval or playback. Specifics of the H&S to be collected from all elements, including the frequency and protocol, will be documented in the Core Vehicle to SLS element Interface Control Documents (ICDs). ICDs will govern the content available to various entities during specific regimes in the timeline.

[S.16] Core Stage Dry Mass

The Core Stage dry mass shall not exceed values in Table 3.3.1-1.

Rationale: Residuals will be tracked as a Critical Math Model but for the most part result from analysis rather than being a level that is specified.

[S.17] Upper Stage Dry Mass

The Upper Stage dry mass shall not exceed values in Table 3.3.1-2.

Rationale: Residuals will be tracked as a Critical Math Model but for the most part result from analysis rather than being a level that is specified.

Table 3.3.1-1: Core Stage Dry Mass Limits

SLS Configuration	Mass Limit (lbm)
Block 1 Configuration (Figure 3.1.1-1)	181,400 <**TBR-049**>
Block 1A Configuration (Figure 3.1.2-1)	181,400 <**TBR-050**>
Block 2 Configuration (Figure 3.1.3-1) includes Interstage	204,400 <**TBR-051**>

Table 3.3.1-2: Upper Stage Dry Mass Limit

SLS Configuration	Mass Limit (lbm)
Block 2 (Figure 3.1.3-1)	52,400 <**TBR-052**>

[S.18] FTS Time Delay for Crewed Missions

The Core Vehicle shall provide a time delay of 3.1 ±0.8 <**TBR-053**> seconds between FTS "fire" command and FTS pyro ignition for crewed missions.

Rationale: NPR 8705.2B Requirement. Flight termination delay is necessary in order to provide the crew adequate time to clear the debris field and blast wave during an ascent abort. This time delay is particularly critical during core stage flight where booster shutdown is not possible.

[S.19] Core Stage Launch Reliability

The Core Stage shall have a mean launch reliability of at least 0.97 <**TBR-054**>.

Rationale: Launch Reliability is one part of the decomposition of Launch Availability. Launch reliability is defined as the probability of not experiencing a core stage hardware/software failure that would result in a launch scrub and is inclusive of all events from start of launch countdown thru liftoff. Core Stage prelaunch failures that result in catastrophic hazards to the vehicle or flight crew are excluded from launch reliability since they are included in the ascent reliability requirement derived from SLS loss of mission.

[S.20] Upper Stage Launch Reliability

The Upper Stage shall have a mean launch reliability of at least 0.98 <**TBR-055**>.

Rationale: Launch reliability is one part of the decomposition of Launch Availability. Launch reliability is defined as the probability of not experiencing an upper stage hardware/software failure that would result in a launch scrub and is inclusive of all events from start of launch countdown thru liftoff. Upper stage prelaunch failures that result in catastrophic hazards to the vehicle or flight crew are excluded from launch reliability since they are included in the ascent reliability requirement derived from SLS loss of mission.

[S.21] Core Stage Maintainability

The Core Stage shall be maintainable such that at least 85% <**TBR-056**> of Core Stage failures can be repaired within 96 <**TBR-057**> hours, excluding any time necessary to roll back to VAB for repair.

Rationale: Maintainability is one part of the decomposition of Maintenance Down Time. In the event of an SLS failure, the vehicle must be repairable to support additional launch attempts within the 30 days of the launch availability requirement. The percentage of core stage failures that must be repaired is a failure rate weighted average of all credible core stage failures that can occur after start of launch countdown and result in a launch scrub. Core Stage Maintainability is inclusive of manual failure isolation, gain access, setup/teardown ground support equipment (GSE), remove and replace, post-maintenance checkout, and close access.

[S.22] Core Stage Engine Access

The Core Stage shall provide access accommodations such that the time required to gain/close access to the Core Stage Engine for planned maintenance activities, including setup/teardown of necessary internal access GSE, is a maximum of 24 <**TBR-058**> hours.

Rationale: Core Stage Engine access is part of the Core Stage requirement and needs to be separated to set the Engine allocation.

[S.23] Upper Stage Maintainability

The Upper Stage shall be maintainable such that at least 85% <**TBR-059**> of Upper Stage failures can be repaired within 96 <**TBR-060**> hours, excluding any time necessary to roll back to VAB for repair.

Rationale: Maintainability is one part of the decomposition of MDT. In the event of an SLS failure, the vehicle must be repairable to support additional launch attempts within the 30 days of the launch availability requirement. The percentage of upper stage failures that must be repaired is a failure rate weighted average of all credible upper stage failures that can occur after start of launch countdown and result in a launch scrub. Upper Stage Maintainability is inclusive of manual failure isolation, gain access, setup/teardown ground support equipment (GSE), remove and replace, post-maintenance checkout, and close access.

[S.24] Upper Stage Engine Access

The Upper Stage shall provide access accommodations such that the time required to gain/close access to the Upper Stage Engine for planned maintenance activities, including setup/teardown of necessary internal access GSE, is a maximum of 24 <**TBR-061**> hours.

Rationale: Upper Stage Engine access is part of the Upper Stage requirement and needs to be separated to set the Upper Stage Engine allocation.

[S.25] Core Stage Ascent Reliability

The Core Stage shall have a minimum reliability against a critical failure of 0.99961 <**TBR-062**> from start of tanking to successful payload separation.

Rationale: Ascent Reliability is a partial allocation of SLS LOM, and it consists of critical failures in hardware and software during start of tanking to successful payload separation. Prior

to T–0, only failures that result in LOV will be considered a critical failure. This requirement compliments Launch Reliability which consists of non-critical failures that result in a launch scrub. Where MIL-STD-217 predictions are used, environments will be normalized to Airborne Uninhabited Fighter (AUF). The requirement is on the mean estimate of reliability.

[S.26] Core Stage Risk of Uncontained Failure

The Core Stage shall have a maximum risk of uncontained failure due to a Core Stage initiated critical failure of 20% <**TBR-063**> of all Core Stage critical failures.

Rationale: In combination with ascent reliability, this is the SLS effective allocation to Core Stage of the risk of abort environment exceedance. Assessment of SLS contribution to LOC is based on uncontained failure probability as well as an assessment of the effects of uncontained failures on the ability of the crew to successfully abort (abort environments). The ascent LOC assessment will evaluate all risks from the time the vehicle is crewed through separation of the Orion MPCV from SLS.

[S.27] Upper Stage Ascent Reliability

The Upper Stage shall have a minimum reliability against a critical failure of 0.99964 <**TBR-064**> from start of tanking to successful payload separation.

Rationale: Ascent Reliability is a partial allocation of the SLS LOM, and it consists of critical failures in hardware and software during start of tanking to successful payload separation. Prior to T–0, only failures that result in LOV will be considered a critical failure. This requirement compliments Launch Reliability which consists of non-critical failures that result in a launch scrub. Where MIL-STD-217 predictions are used, environments will be normalized to Airborne Uninhabited Fighter (AUF). The requirement is on the mean estimate of reliability.

[S.28] Upper Stage Risk of Uncontained Failure

The Upper Stage shall have a maximum risk of uncontained failure due to an Upper Stage initiated critical failure of 20% <**TBR-065**> of all Upper Stage critical failures.

Rationale: In combination with ascent reliability, this is the SLS effective allocation to Upper Stage of the risk of abort environment exceedance. Assessment of SLS contribution to LOC is based on uncontained failure probability as well as an assessment of the effects of uncontained failures on the ability of the crew to successfully abort (abort environments). The ascent LOC assessment will evaluate all risks from the time the vehicle is crewed through separation of the Orion MPCV from SLS.

[S.29] Minimum Service Life

The Core Vehicle service life shall be a minimum of 15 <**TBR-066**> months.

Rationale: Requirement provides flexibility for hardware utilization taking into account rework, launch delays and manifest changes. Service life quantifies the life expectancy of the Core Vehicle starting at DD250 acceptance, through launch. 15 months assumes 1 year SLS vehicle service life plus 3 months for shipment to the launch facility and stacking operations in the VAB. Service life does not include shelf life.

3.3.2 Liquid Engines

3.3.2.1 Core Stage Engine

Preliminary functional and performance requirements for the Core Stage Engine can be found below. Interfaces for the engine are described in SLS-ICD-039. These interfaces will be applicable to both the RS-25D engines as well as for the RS-25E engines.

[CSE.1] Ascent Reliability

The Core Stage Engine shall have a minimum ascent mission main stage reliability against critical failure of 0.999356 <**TBR-067**> per engine.

Rationale: Ascent Reliability is a partial allocation of the SLS LOM. It consists of critical failures in hardware and software from T–0 to successful engine shutdown. Where MIL-STD-217 predictions are used, environments will be normalized to Airborne Uninhabited Fighter (AUF). The requirement is on the mean estimate of reliability.

[CSE.2] Pre-start and Start Reliability

The Core Stage Engine shall have a minimum per engine pre-start and start reliability against an uncontained failure of <**TBD-012**> from start of tanking to T–0.

Rationale: Pre-start and start reliability is a partial allocation of the SLS LOM for LOV failures before t-0, in addition to contribution to LOC through potential abort environment exceedance. It consists of all uncontained failures due to hardware and software from start of tanking to t-0. This requirement compliments Launch Reliability which consists of non-critical failures that result in a launch scrub.

[CSE.3] Risk of Mainstage Uncontained Failure

The Core Stage Engine shall have a maximum risk of uncontained failure fraction of 30.5% <**TBR-068**> of all Core Stage Engine initiated critical failures.

Rationale: In combination with ascent reliability, this is the primary SLS effective allocation to Core Stage Engine of the risk of abort environment exceedance. Assessment of SLS contribution to LOC is based on uncontained failure probability as well as an assessment of the effects of uncontained failures on the ability of the crew to successfully abort (abort environments). The ascent LOC assessment will evaluate all risks from the time the vehicle is crewed through separation of the Orion MPCV from SLS.

[CSE.4] Reconfiguration Updates

The Core Stage Engine shall accept reconfiguration software, parameters, and data products prior to launch.

Rationale: Updates to software builds already stored onboard the launch vehicle are required to support software reconfiguration as well as day of launch updates for environments.

[CSE.5] Launch Reliability – Block 1A, Block 2

The Core Stage Engine for the Block 1A and Block 2 vehicle configurations (applicable to RS-25E only) shall have a mean launch reliability of at least 0.9846 <**TBR-069**>.

Rationale: Launch reliability is one part of the decomposition of launch availability. Launch reliability is defined as the probability of not experiencing a core stage engine hardware/ software failure that would result in a launch scrub (includes pad aborts) and is inclusive of all events from start of launch countdown thru liftoff. Core stage engine prelaunch failures that result in catastrophic hazards to the vehicle or flight crew are excluded from launch reliability since they are included in the ascent reliability requirement derived from SLS loss of mission.

[CSE.6] Maintainability – Block 1A, Block 2

The Core Stage Engine for the Block 1A and Block 2 vehicle configurations (applicable to RS-25E only) shall be maintainable such that a minimum of 85% <**TBR-070**> of Core Stage Engine failures can be repaired within 72 <**TBR-071**> hours, excluding any time necessary to roll back to VAB for repair.

Rationale: Maintainability is one part of the decomposition of MDT. In the event of an SLS failure, the vehicle must be repairable to support additional launch attempts within the 30 days of the launch availability requirement. The percentage of core stage engine failures that must be repaired is a failure rate weighted average of all credible core stage engine failures that can occur after start of launch countdown and result in a launch scrub (includes pad aborts). Core Stage Engine Maintainability is inclusive of manual failure isolation and remove and replace.

[CSE.7] Minimum Service Life

The Core Stage Engine service life shall be a minimum of 18 <**TBR-072**> months.

Rationale: Requirement provides flexibility for hardware utilization taking into account rework, launch delays and manifest changes. Service life quantifies the life expectancy of the core stage engine starting at its installation onto the core stage, through launch. 18 months assumes 1 year SLS vehicle service life plus 6 months for engine installation, checkout, shipment of the integrated core stage to the launch facility and stacking operations in the VAB. Service life does not include shelf life.

3.3.2.2 Upper Stage Engine

The SLS, in the Block 2 configuration, will utilize J-2X engines designed and developed as part of the Constellation Program. The requirements to which these engines were designed and developed can be found in J2X-SE-0001, J-2X Elements Requirements Document (ERD). Existing interfaces for the engine are described in CxP 72262, J-2X Engine to Ares I Upper Stage Interface Control Document (ICD). The Liquid Engine Office will update these requirements, as applicable, for utilization of the J-2X engines on the SLS upper stage.

[USE.1] Ascent Reliability

The Upper Stage Engine shall have a minimum reliability against a critical failure of 0.9992 <**TBR-073**> per engine.

Rationale: Ascent Reliability is a partial allocation of the SLS LOM. It consists of critical failures in hardware and software from upper stage engine start through shutdown. Where MIL-STD-217 predictions are used, environments will be normalized to Airborne Uninhabited Fighter (AUF). The requirement is on the mean estimate of reliability.

[USE.2] Risk of Uncontained Failure

The Upper Stage Engine shall have a maximum risk of uncontained failure fraction of 20% <**TBR-074**> of all Upper Stage Engine initiated critical failures.

Rationale: In combination with ascent reliability, this is the primary SLS effective allocation to Upper Stage Engine of the risk of abort environment exceedance. Assessment of SLS contribution to LOC is based on uncontained failure probability as well as an assessment of the effects of uncontained failures on the ability of the crew to successfully abort (abort environments). The ascent LOC assessment will evaluate all risks from the time the vehicle is crewed through separation of the Orion MPCV from SLS.

[USE.3] Reconfiguration Updates

The Upper Stage Engine shall accept reconfiguration software, parameters, and data products prior to launch.

Rationale: Updates to software builds already stored onboard the launch vehicle are required to support software reconfiguration as well as day of launch updates for environments.

[USE.4] Launch Reliability

The Upper Stage Engine shall have a mean launch reliability of at least 0.995 <**TBR-075**>.

Rationale: Launch reliability is one part of the decomposition of launch availability. Launch reliability is defined as the probability of not experiencing an upper stage engine hardware/ software failure that would result in a launch scrub and is inclusive of all events from start of launch countdown thru liftoff. Upper stage engine prelaunch failures that result in catastrophic hazards to the vehicle or flight crew are excluded from launch reliability since they are included in the ascent reliability requirement derived from SLS LOM.

[USE. 5] Maintainability

The Upper Stage Engine shall be maintainable such that a minimum of 85% <**TBR-076**> of Upper Stage Engine failures can be repaired within 72 <**TBR-077**> hours, excluding any time necessary to roll back to VAB for repair.

Rationale: Maintainability is one part of the decomposition of MDT. In the event of an SLS failure, the vehicle must be repairable to support additional launch attempts within the 30 days of the launch availability requirement. The percentage of upper stage engine failures that must be repaired is a failure rate weighted average of all credible upper stage engine failures that can occur after start of launch countdown and result in a launch scrub. Upper Stage Engine Maintainability is inclusive of manual failure isolation and remove and replace.

[USE.6] Minimum Service Life

The Upper Stage Engine service life shall be a minimum of 18 <**TBR-078**> months.

Rationale: Requirement provides flexibility for hardware utilization taking into account rework, launch delays, and manifest changes. Service life quantifies the life expectancy of the upper stage engine starting at its installation onto the upper stage, through launch. 18 months assumes 1 year SLS vehicle service life plus 6 months for engine installation checkout, shipment of the

integrated upper stage to the launch facility, and stacking operations in the VAB. Service life does not include shelf life.

3.3.3 Boosters

[B.1] FTS Time Delay for Crewed Missions

The Booster shall provide a time delay of 3.1 ± 0.8 <**TBR-079**> seconds between FTS "fire" command and FTS pyro ignition for crewed missions.

Rationale: Flight termination delay is necessary in order to provide the crew adequate time to clear the debris field and blast wave during an ascent abort. This time delay is particularly critical during core stage flight where booster shutdown is not possible.

[B.2] Ascent Reliability

The Booster shall have a minimum reliability against a critical failure of 0.99954 <**TBR-080**> for each booster from start of tanking through successful booster separation.

Rationale: Ascent Reliability is a partial allocation of the SLS LOM, and it consists of critical failures in hardware and software during start of tanking to successful booster separation. Prior to T–0, only failures that result in LOV will be considered a critical failure. This requirement compliments Launch Reliability which consists of non-critical failures that result in a launch scrub. Where MIL-STD-217 predictions are used, environments will be normalized to Airborne Uninhabited Fighter (AUF). The requirement is on the mean estimate of reliability.

[B.3] Risk of Uncontained Failure

The Booster risk of uncontained failure shall not exceed 30% of total risk of Booster-initiated critical failures.

Rationale: In combination with ascent reliability, this is the SLS effective allocation to Booster of the risk of abort environment exceedance. Assessment of SLS contribution to LOC is based on uncontained failure probability as well as an assessment of the effects of uncontained failures on the ability of the crew to successfully abort (abort environments). The ascent LOC assessment will evaluate all risks from the time the vehicle is crewed through separation of the Orion MPCV from SLS.

[B.4] Launch Reliability – Block 1A, Block 2

The Booster for the Block 1A and Block 2 vehicle configurations shall have a mean launch reliability of at least 0.97 <**TBR-081**>.

Rationale: Launch reliability is one part of the decomposition of launch availability. Launch reliability is defined as the probability of not experiencing a booster element hardware/software failure that would result in a launch scrub and is inclusive of all events from start of launch countdown thru liftoff. Booster prelaunch failures that result in catastrophic hazards to the vehicle or flight crew are excluded from launch reliability since they are included in the ascent reliability requirement derived from SLS loss of mission.

[B.5] Maintainability – Block 1A, Block 2

The Booster for the Block 1A and Block 2 vehicle configurations shall be maintainable such that a minimum of 85% <**TBR-082**> of Booster failures can be repaired within 96 <**TBR-083**> hours, excluding any time necessary to roll back to VAB for repair.

Rationale: Maintainability is one part of the decomposition of Maintenance Down Time. In the event of an SLS failure, the vehicle must be repairable to support additional launch attempts within the 30 days of the launch availability requirement. The percentage of booster failures that must be repaired is a failure rate weighted average of all credible booster failures that can occur after start of launch countdown and result in a launch scrub. Booster Maintainability is inclusive of manual failure isolation, gain access, remove and replace, and post-maintenance checkout.

[B.6] Minimum Service Life

The Booster service life shall be a minimum of 1 <**TBR-084**> year.

Rationale: Requirement provides flexibility for hardware utilization taking into account rework, launch delays, and manifest changes. Service life quantifies the life expectancy of the booster starting at stacking of the aft center segment in the VAB through roll out.

3.3.4 Spacecraft & Payload Integration

Interface requirements for Spacecraft & Payload Integration Element to Orion MPCV interface are described in MPCV 70026. Interface designs are described in MPCV-T-029600 and MPCV-T-029601. Interface functions for non-Orion-MPCV cargo flights are described in SLS-<**TBD-005**>, SLSP IPE to Payload ICD. Interface functions for the SLS Stages element to Spacecraft & Payload Integration element are described in SLS-ICD-029.

[IPE.1] Payload Adapter Dry Mass

Payload adapter dry mass shall not exceed values in Table 3.3.4-1.

Rationale: The payload adapter dry mass affects the liftoff and ascent trajectory of SLS. The dry mass also affects the payload performance capability of SLS. Adapter system mass allocations include all components of the adapter including the separation system and diaphragm.

Table 3.3.4-1: Payload Adapter Dry Mass Limits

Payload Adapter	Mass Limit (lbm)
Launch Vehicle Spacecraft Adapter (LVSA)	11,000 <**TBR-085**>
MPCV Stage Adapter	1,865 <**TBR-114**>
Cargo Payload Adapter (CPA) – Block 1A	8,600 <**TBR-086**>
CPA – Block 2	9,900 <**TBR-087**>

[IPE.2] Maximum Payload Fairing Dry Mass

Payload fairing maximum dry mass shall be per the values in Table 3.3.4-2.

Rationale: The payload fairing dry mass affects the liftoff and ascent trajectory of SLS. The dry mass also affects the payload performance capability of SLS.

Table 3.3.4-2: Payload Fairing Dry Mass Limits

Payload Fairing	Mass Limit (lbm)
27.6 ft diameter (Block 1/1A)	18,000 <**TBR-088**>
33 ft diameter (Block 2)	40,000 <**TBR-089**>

[IPE.3] Payload Frequency and Center of Gravity (CG)

The Payload first fundamental frequency and CG shall be per values in Table 3.3.4-3.

Rationale: The payload frequency and CG affect the liftoff and ascent trajectory of SLS.

Table 3.3.4-3: Payload Frequency and CG

SLS Configuration	Frequency	CG from Adapter Face
Block 1	<**TBD-013**>	<**TBD-014**>
Block 1A	<**TBD-015**>	<**TBD-016**>
Block 2	<**TBD-017**>	<**TBD-018**>

[IPE.4] Integrated Payload Element Service Life

The Integrated Payload Element service life shall be a minimum of 1.75 <**TBR-090**> years, not including the Orion MPCV or Payloads.

Rationale: Requirement provides flexibility for hardware utilization taking into account rework, launch delays, and manifest changes. Service life quantifies the life expectancy of the Integrated Payload Element starting at DD250 acceptance through launch.

[IPE.5] Tanking/Ascent/Payload Separation Reliability

The Integrated Spacecraft & Payload element (ISPE) shall have a minimum reliability against a critical failure of 0.99988 <**TBR-091**> from start of tanking through ascent and successful completion of spacecraft/payload separation.

Rationale: This requirement encompasses ascent reliability through successful spacecraft/ payload separation. Ascent Reliability is a partial allocation of SLS LOM, and it consists of critical failures in hardware and software during start of tanking to successful spacecraft/ payload separation. Prior to spacecraft/payload separation, only ISPE failures that result in LOV will be considered a critical failure. This requirement compliments Launch Reliability which consists of non-critical failures that result in a launch scrub. Where MIL-STD-217 predictions are used, environments will be normalized to Airborne Uninhabited Fighter (AUF). The requirement is on the mean estimate of reliability.

[IPE.6] Payload Fairing Separation Reliability

The Spacecraft & Payload Integration element shall have a minimum reliability for successfully completing payload fairing separation of 0.9998 <**TBR-092**>.

Rationale: This requirement is specific to the successful completion of payload fairing separation for SLS cargo missions. Where MIL-STD-217 predictions are used, environments will be normalized to Airborne Uninhabited Fighter (AUF). The requirement is on the mean estimate of reliability.

[IPE.7] Launch Reliability – Block 1A, Block 2

The Spacecraft & Payload Integration element for the Block 1A and Block 2 vehicle configurations shall have a mean launch reliability of no less than 0.999 <**TBR-093**>.

Rationale: Launch Reliability is one part of the decomposition of Launch Availability. Launch reliability is defined as the probability of not experiencing an SPI hardware/software failure that would result in a launch scrub and is inclusive of all events from start of launch countdown thru liftoff. SPI prelaunch failures that result in catastrophic hazards to the vehicle or flight crew are excluded from launch reliability since they are included in the ascent reliability requirement derived from SLS loss of mission.

[IPE.8] Maintainability – Block 1A, Block 2

The Spacecraft & Payload Integration element for the Block 1A and Block 2 vehicle configurations shall be maintainable such that at least 85% <**TBR-094**> of SPI failures can be repaired within 96 <**TBR-095**> hours.

Rationale: Maintainability is one part of the decomposition of Maintenance Down Time. In the event of an SLS failure, the vehicle must be repairable to support additional launch attempts within the 30 days of the launch availability requirement. The percentage of SPI failures that must be repaired is a failure rate weighted average of all credible SPI failures that can occur after start of launch countdown and result in a launch scrub. SPI Maintainability is inclusive of manual failure isolation, gain access, setup/teardown ground support equipment (GSE), remove and replace, post-maintenance checkout, and close access.

[IPE.9] ICPS Performance

The ICPS shall provide a minimum delta-V of 10,006 ft/sec <**TBR-115**> to 26.7 tons of payload.

Rationale: ICPS is required to support early Orion MPCV Test Flight missions on schedule.

[IPE.10] ICPS Starts

The ICPS shall be capable of a minimum of 3 <**TBR-116**> in-space starts.

Rationale: Three starts assumes 1 start for an orbit raise maneuver, 1 restart for trans-lunar injection burn, and 1 potential restart for stage disposal.

[IPE.11] ICPS Total Liftoff Mass

The ICPS total liftoff mass shall be less than or equal to 71,000 lbm <**TBR-117**>.

Rationale: ICPS total mass includes dry mass plus full propellant load, unusables and GEO kit. Total mass limit does not include any mass allowance for upgrade/modification that may be required for human rating or SLS loads.

[IPE.12] ICPS Attitude Control

The ICPS shall provide 3 axis attitude control.

Rationale: ICPS 3 axis attitude control will ensure attitude rates are within limits prior to spacecraft/payload separation.

[IPE.13] ICPS Receipt and Execution of External Commands

The ICPS shall execute validated commands received from Orion MPCV, GSDO, and the Range.

Rationale: NPR 8705.2B Requirement. The ICPS houses avionics that provide command, control, and communication for the stage on the Orion MPCV Test Flight missions.

[IPE.14] ICPS Provide Health & Status to Orion MPCV

The ICPS shall provide SLS Vehicle health and status, as described in MPCV-70026, to Orion MPCV.

Rationale: NHB 8705.2B Requirement: Collection and relay of vehicle health and status (H&S) to the Orion MPCV is necessary for notification of vehicle health and vehicle performance during ascent and Earth departure. Specifics of the H&S to be provided will be documented in Orion MPCV to SLS IPE IRD and ICDs.

[IPE.15] ICPS FTS Time Delay

The ICPS shall provide a time delay of 3.1 ±0.8 <**TBR-118**> seconds between FTS “fire” command and FTS pyro ignition for crewed missions.

Rationale: Flight termination delay is necessary in order to provide the crew adequate time to clear the debris field and blast wave during an ascent abort.

4 VERIFICATION PROVISIONS

4.1 General

This section identifies activities required to verify that the requirements of Section 3 have been satisfied. Verification approach for the SLS Program is provided in the SLS Verification and Validation Plan.

4.2 Verification methods

The SLS vehicle shall be verified by analysis, demonstration, inspection, test, validation of records or similarity (or a combination thereof) as specified herein to assure compliance with Section 3. Definitions of verification methods are from Marshall Work Instruction (MWI) 8050.1, Verification & Validation of Hardware, Software, and Ground Support Equipment for MSFC Projects.

4.2.1 Analysis

Analysis involves the use of engineering analysis, qualitative assessment, computer modeling, and/or simulations to ensure compliance to the requirement(s). Analysis is a method used in lieu of, or in addition to, testing.

4.2.2 Inspection

Inspection is the physical evaluation to ensure that the requirement(s) has been incorporated or met. Inspection shall be used as the method on the product to satisfy such requirements as construction features, workmanship, dimensions, and physical conditions identified on the engineering documentation (e.g., drawings, Engineering Parts List).

4.2.3 Demonstration

Demonstration is the “acting out” to ensure the requirement(s) has been incorporated or met. Demonstration shall be used as the method on the product to satisfy such requirements as accessibility, replace-ability, and human factors.

4.2.4 Test

Test (e.g., functional, environmental) is the actual operation to ensure that the performance is in accordance with the requirement(s).

4.2.5 Validation of Records

Validation of records is the use of vendor-furnished/supplied manufacturing or processing records to ensure the requirement(s) has been incorporated or met. Validation of records shall be used as the method to satisfy incorporation of requirements for such items as commercial off-the-shelf products and products purchased to standards.

4.2.6 Similarity

Similarity is the process of assessing prior data, configuration, processes, or applications and concluding that the item under assessment is similar or identical to another item that has previously been verified to equivalent or more stringent specifications or validated to an equivalent use or function. Similarity shall only be used when each of the following criteria is met:

1. Engineering evaluation(s) reveals that design configurations between the item under assessment and the similar item would produce the same results if verification/validation activity was performed on the item under assessment.
2. The similar item was designed for and verified/validated to equal or higher environmental (e.g., thermal, stress) levels than those required for the item under assessment.
3. The item under assessment was built by the same manufacturer using the same manufacturing processes and the same quality control procedures as the similar item.
4. Similarity assessment shall undergo an independent evaluation by a technically qualified person or group other than the person(s) performing the assessment.

Similarity shall not be used when either of the following conditions exists:

1. The similar item used in the assessment was itself verified/validated using similarity as the method.
2. Items whose criticality is 1 or 1R (i.e., items whose failure or malfunction could result in loss of vehicle, life, or serious injury).

4.3 Verification matrix

4.3.1 SLS Verification Matrix

The verification requirements for the SLS vehicle will be developed by the SLS Preliminary Design Review. A summary of the verification methods with accompanying rationale is shown in Table 4.3.1-1.

Table 4.3.1-1: SLS Requirements Verification Matrix

Requirement	Title	Method						Verification Method
		A	I	D	T	VR	S	Comments
SLS.1	SLS Lift Capability – Block 1	X			X			Dispersed Monte Carlo analysis. Models anchored with System level tests (wind tunnel, etc.).
SLS.2	SLS Lift Capability – Block 1A	X			X			Dispersed Monte Carlo analysis. Models anchored with System level tests (wind tunnel, etc.).
SLS.3	SLS Lift Capability – Block 2	X			X			Dispersed Monte Carlo analysis. Models anchored with System level tests (wind tunnel, etc.).
SLS.4	Alternate Means of Delivering Orion-MPCV to ISS Orbit Inclination	X			X			Dispersed Monte Carlo analysis. Models anchored with System level tests (wind tunnel, etc.).
SLS.5	Payload Dimensions – Block 1, 1A	X						Analysis of design drawings.
SLS.6	Payload Dimensions – Block 2	X						Analysis of design drawings.
SLS.7	Orbital Insertion Accuracy	X			X			An output of the vehicle performance Monte Carlo analysis. Testing includes items

Requirement	Title	Method						Verification Method
		A	I	D	T	VR	S	Comments
								such as hardware polarity tests. Nominal and Off-Nominal SIL testing to verify bus timing and avionics timing to ensure accurate orbital insertion.
SLS.8	Service Life – Minimum	X		X	X			A vehicle-level analysis to ensure service life is met. Test and demonstration on first Block 1 flights.
SLS.9	Autonomous Liftoff and Ascent	X			X			Inspection of vehicle operations timeline to assure fully autonomous launch and ascent functions. SIL Testing
SLS.10	Failure Tolerance	X			X			Part of integrated safety analysis to be conducted. SIL testing to assure proper vehicle response to detected failures.
SLS.11	Support Abort Capability for Crewed Missions	X			X			SIL testing and analysis to assure abort triggers initiate proper system responses.
SLS.12	Automatic Safing for Crewed Missions	X			X			SIL testing and analysis to assure automatic safing operations are provided for in response to imminent failures.
SLS.13	Fault Detection and Notification for Crewed Missions	X			X			SIL testing and analysis to assure proper vehicle response to detected faults.
SLS.14	Fault Isolation and/or Recovery for Crewed Missions	X			X			SIL testing and analysis to assure proper vehicle response to isolated faults.
SLS.15	Limits on Induced Loads for Crewed Missions	X						Dispersed Monte Carlo analysis.
SLS.16	Abort Environments	X						Probabilistic quantification in accordance with the SLS-PLAN-064.
SLS.17	Debris Impact Footprint	X						Monte Carlo based analysis.
SLS.18	Loss of Mission (LOM)	X						Probabilistic quantification in accordance with SLS-PLAN-064.
SLS.19	Launch Availability – Block 1A, Block 2	X		X				The analysis will be a discrete event simulation that considers prelaunch reliability, maintainability, and ground ops drivers. Verification analysis may incorporate applicable

Requirement	Title	Method						Verification Method
		A	I	D	T	VR	S	Comments
								demonstration data from the first two test flights.
SLS.20	Launch Reliability – Block 1A, Block 2	X		X				The analysis will be a reliability analysis of the vehicle to support a single launch attempt. Verification analysis may incorporate applicable demonstration data from the first two test flights.
SLS.21	Maintenance Down Time – Block 1A, Block 2	X		X				Verified by analysis that considers the likelihood of failure of vehicle hardware/software and the time required to perform the launch scrub turnaround operations and necessary repairs to return the vehicle to readiness for follow-on launch attempt. Verification analysis may incorporate applicable demonstration data from the first two test flights.
SLS.22	Launch Countdown Hold	X			X			Analysis of vehicle capability to keep propellants in a conditioned state ready for pressurization and final countdown. A countdown demonstration test before the first launch of the vehicle will provide confirmation of the ability of the system to tolerate launch countdown holds.
SLS.23	Operational Life for Launch Attempts	X						Analysis to assure the core tanks have enough chill down and pressurization cycles for the number of stated attempts.
SLS.24	Pad Stay Time	X						Analysis to ascertain the vehicle's ability to withstand the environments at the launch pad.
SLS.25	Internal Access	X	X	X				Inspection of drawings, analysis and/or demonstration of tasks to be performed to ensure access adequate for removal and repair operations.
SLS.26	Vehicle Stack Time	X		X	X			A vehicle-level structural analysis to assure the vehicle has adequate structural integrity to withstand the stack time and still be ready for use. Test and demonstration on first Block 1 flights.

Requirement	Title	Method						Verification Method Comments
		A	I	D	T	VR	S	
SLS.27	SLS Specific Technical Specifications and Standards	X	X	X	X	X	X	
SLS.28	Other Technical Specifications and Standards	X	X	X	X	X	X	
SLS.29	Administrative Logistics Down Time (ALDT)	X		X				Verification analysis may incorporate applicable demonstration data from the first two test flights.
SLS.30	Imagery	X			X			CAD based analysis to assure proper camera views along with analysis of design drawings. Avionics test is necessary to verify integrated data path for the imagery. Final test during vehicle countdown demonstration test.
SLS.31	Launch Rate	X						Analysis to ensure the capability to ramp up production (includes manufacturing, assembly, integration, test and transportation) to match required launch rate given sufficient lead time and necessary funding.

5 REQUIREMENTS TRACEABILITY

Table 5-1: System Requirements Trace to Level I Requirements

Reqt ID	Reqt Title	Level I Reqt Trace ID	Level I Reqt Title
SLS.1	SLS Lift Capability – Block 1	R-11	SLS Lift Capability
SLS.2	SLS Lift Capability – Block 1A	R-11	SLS Lift Capability
SLS.3	SLS Lift Capability – Block 2	R-11	SLS Lift Capability
SLS.4	Alternate Means of Delivering MPCV to ISS Orbit Inclination	R-14	Alternate means of delivering Crew to/from ISS
SLS.5	Payload Dimensions – Block 1, 1A	R-12	Payload Dimensions
SLS.6	Payload Dimensions – Block 2	R-12	Payload Dimensions
SLS.7	Orbital Insertion Accuracy	R-13	Orbital Insertion Accuracy
SLS.8	Service Life – Minimum	R-19	Launch Availability
SLS.9	Autonomous Liftoff and Ascent	R-10	Human Rating
SLS.10	Failure Tolerance	R-10	Human Rating
SLS.11	Support Abort Capability for Crewed Missions	R-10	Human Rating
SLS.12	Automatic Safing for Crewed Missions	R-10	Human Rating
SLS.13	Fault Detection and Notification for Crewed Missions	R-10	Human Rating
SLS.14	Fault Isolation and/or Recovery for Crewed Missions	R-10	Human Rating
SLS.15	Limits on Induced Loads for Crewed Missions	R-10	Human Rating
SLS.16	Abort Environments	R-16	Loss of Crew
SLS.17	Debris Impact Footprint	N/A	N/A
SLS.18	Loss of Mission (LOM)	R-18	Loss of Mission
SLS.19	Launch Availability – Block 1A, Block 2	R-19 R-15	Launch Availability Launch Rate
SLS.20	Launch Reliability – Block 1A, Block 2	R-19	Launch Availability
SLS.21	Maintenance Down Time – Block 1A, Block 2	R-19	Launch Availability
SLS.22	Launch Countdown Hold	R-19	Launch Availability
SLS.23	Operational Life for Launch Attempts	R-19	Launch Availability
SLS.24	Pad Stay Time	R-19	Launch Availability
SLS.25	Internal Access	R-19	Launch Availability

Reqt ID	Reqt Title	Level I Reqt Trace ID	Level I Reqt Title
SLS.26	Vehicle Stack Time	R-19	Launch Availability
SLS.27	SLS Specific Technical Specifications and Standards	R-10 R-16 R-18 R-21	Human Rating Loss of Crew Loss of Mission Cost Requirement
SLS.28	Other Technical Specifications and Standards	R-16	Loss of Crew
SLS.29	Administrative Logistics Down Time	R-19	Launch Availability
SLS.30	Imagery	R-16 R-18	Loss of Crew Loss of Mission
SLS.31	Launch Rate	R-15	Launch Rate

6 APPENDIX

Appendix A – Abbreviations

AIAA – American Institute of Aeronautics and Astronautics

ALDT – Administrative Logistics Down Time

ANSI – American National Standards Institute

AUF – Airborne Uninhabited Fighter

BEO – Beyond Earth Orbit

CAD – Computer Aided Design

CDF – Capability Driven Framework

CEI – Contract End Item

CG – Center of Gravity

CIL – Critical Items List

COPV – Composite Overwrapped Pressure Vessel

CPA – Cargo Payload Adapter

CPS – Cryogenic Propulsion Stage

CR – Change Request

CTN – Communications and Tracking Network

CxP – Constellation Program

DFMR – Design for Minimum Risk

DIA – Diameter

DoD – Department of Defense

DRD – Data Requirements Document

DRM – Design Reference Mission

EEE – Electrical, Electronic, Electromechanical

ERD – Element Requirements Document

ESD – Electrostatic Discharge

ESD – Exploration Systems Development

ESMD – Exploration Systems Mission Directorate

E3 – Electromagnetic Environmental Effects

FMEA – Failure Modes and Effects Analysis

FTS – Flight Termination System

FWD – Forward

GEO – Geosynchronous Earth Orbit

GSDO – Ground Systems Development and Operations

GSE – Ground Support Equipment

H&S – Health and Status

HEC – Human Exploration Capability

HEO – High Earth Orbit

ICD – Interface Control Document

ICPS – Interim Cryogenic Propulsion Stage

ILSP – Integrated Logistics Supportability Plan

IMT – Integrated Master Timeline

IPE – Integrated Payload Element

IRD – Interface Requirements Document

ISPE – Integrated Spacecraft and Payload Element

ISS – International Space Station

JSC – Johnson Space Center

km – Kilometer

KSC – Kennedy Space Center

LAS – Launch Abort System

LEO – Low Earth Orbit

LH2 – Liquid Hydrogen

LO2 – Liquid Oxygen

LOC – Loss of Crew

LOM – Loss of Mission

LOV – Loss of Vehicle

LVSA – Launch Vehicle Spacecraft Adapter

MDT – Maintenance Down Time

MECO – Main Engine Cut Off

ML – Mobile Launcher

MPCV – Multi-Purpose Crew Vehicle

MPS – Main Propulsion System

MS – Mission Systems

MSFC – Marshall Space Flight Center

NASA – National Aeronautics and Space Administration

N/A – Not Applicable

NEA – Near Earth Asteroid

nm – Nautical Mile

NPD – NASA Policy Document

NPR – NASA Procedural Requirements

NTE – Not To Exceed

OAL – Overall Length

OFI – Operational Flight Instrumentation

OML – Outer Mold Line

OPR – Office of Primary Responsibility

PBAN – Polybutadiene Acrylonitrile

PCB – Program Control Board

PV/S – Pressure Vessel/System

PWR – Power

RCS – Reaction Control System

REF – Reference

RF – Radio Frequency

RPL – Rated Power Level

RSRMV – Reusable Solid Rocket Motor V (Five-Segment)

S&A – Safe and Arm

S&MA – Safety and Mission Assurance

SBU – Sensitive But Unclassified

SC & PL – Spacecraft & Payload

SIL – Software Integration Lab

SLS – Space Launch System

SLSP – Space Launch System Program

SOMD – Space Operations Mission Directorate

SPIO – Spacecraft and Payload Integration Office

SRB – Solid Rocket Booster

SRR – System Requirements Review

SSAR – System Safety Analysis Report

SSME – Space Shuttle Main Engine

STS – Space Transportation System

TBD – To Be Determined

TBR – To Be Reviewed

TVC – Thrust Vector Control

VAB – Vehicle Assembly Building

VAC – Vacuum

VFAM – Vehicle Functional Analysis Model

Appendix B – Glossary

Caution and Warning – A subset of health and status, caution and warning information or data is collected or generated via the processing of logic utilizing a defined subset of critical measurements. This includes the logic for the determination of abort conditions.

Emergency Systems – Systems (ground or flight) that exist solely to prevent loss of life in the presence of imminent catastrophic conditions. Examples include the launch abort system (LAS), fire suppression systems, and crew escape systems.

Failure – The inability of a system, subsystem, component, or part to perform its required function within specified limits, under specified conditions, for a specified duration.

Failure Tolerance – The ability to continue performing a function after sustaining a failure.

Hazard – A condition, a state, an event, or an activity, internal or external to a system, which has the potential to cause harm.

Health and Status – Data or information, which may be non-critical or critical, representing the health and/or status of SLS vehicle systems and subsystems that is collected, processed, and distributed within the vehicle and to external systems.

Loss of Crew (LOC) – Death of or permanently debilitating injury to one or more crew members.

Loss of Mission (LOM) – Loss of or inability to complete significant/primary mission objectives, which includes Loss of Crew. Each mission is defined with different assumptions and mission objectives. Therefore, specific mission LOM assessments are accomplished evaluating attainment of specific mission objectives, using methods tailored to the specific mission risk drivers and each specific program but consistent with defined NASA Probabilistic Risk Assessment standards.

Service Life – A general term used to quantify the average or standard life expectancy of an item or equipment while in use. When a shelf-life item is unpacked and introduced to mission requirements, installed into intended application (or merely left in storage, placed in pre-expended bins, or held as bench stock) shelf-life management stops and service life begins.

Shelf Life – The total period of time beginning with the date of manufacture, date of cure (for elastomeric and rubber products only), date of assembly, or date of pack (subsistence only), and terminated by the date by which an item must be used (expiration date) or subjected to inspection, test, restoration, or disposal action; or after inspection/laboratory test/restorative action that an item may remain in the combined wholesale (including manufacturer's) and retail storage systems and still be suitable for issue or use by the end user.

Uncontained Failure – A failure mode with failure effects that result in significant damage (e.g., fire, explosion, shrapnel) to surrounding subsystems such that there is little chance that emergency systems or operations, such as abort, could mitigate the failure.

Appendix C – Open Work

C1.0 Table C1-1 lists the comments dispositioned as Forward Work during the SLS Program Vehicle Specification review cycle. These items will continue to be worked as the SLS Program progresses and will be addressed in an upcoming revision should a change be required.

Table C1-1: Forward Work Items

Forward Work Item	Section/ Requirement	Description
FW-1	SLS.4	"The MPCV control mass, or block configuration, needs to be added to this requirement in order to ensure verifiability."
FW-4	Entire Document	Change IPE to ISPE when name is updated in SLS Program DRL.
FW-17	2.0, 3.2.12-2	Add NPR 8715.3C, NASA General Safety Program Requirements
FW-21	Section 4	Define what qualification and acceptance testing will be required.
FW-23	Section 3.3.4	Add ICPS requirement for telemetry, if decision is made to have direct telemetry to CTN.
FW-24	3.1.2.1	Add item for CPS if/when DRMs indicate the addition is appropriate.
FW-25	3.2.2	Consider whether a storage requirement is required for the vehicle and elements as a part of the strategy to implement the 3 launch per year requirement.

Table C1-2. To Be Determined Items

TBD	Section	Description
TBD-005	2.1.1.1	SLSP IPE to Payload ICD
TBD-008	3.1.4	Block 1A and Block 2 Functional Avionics Architectures
TBD-010	3.2.17	Packaging Requirements
TBD-011	3.3.1	Reconfiguration Updates Prior to Launch
TBD-012	3.3.2.1	Core Stage Engine Pre-start & Start Reliability
TBD-013	3.3.4	Block 1 Frequency
TBD-014	3.3.4	Block 1 CG From Adapter Face
TBD-015	3.3.4	Block 1A Frequency
TBD-016	3.3.4	Block 1A CG From Adapter Face
TBD-017	3.3.4	Block 2 Frequency
TBD-018	3.3.4	Block 2 CG From Adapter Face
TBD-027	2.1.1.1	SLS HSIR

Table C1-3. To Be Resolved Issues

TBR	Section	Description
TBR-001	3.1	Maximum Power Level (%RPL) RS-25E

TBR	Section	Description
TBR-002	3.1	Dry Mass 5 Segment SRB
TBR-003	3.1	Prop Load 5 Segment SRB
TBR-004	3.2.2	SLS Lift Capability – Block 1
TBR-005	3.2.2	SLS Lift Capability – Block 1A insertion target
TBR-008	3.2.2	Orbital Insertion Accuracy – semi major axis
TBR-009	3.2.2	Orbital Insertion Accuracy - Apogee
TBR-010	3.2.2	Service Life – Minimum
TBR-011	3.2.7	Aborts Environments Table
TBR-012	3.2.7	Aborts Environments Table
TBR-013	3.2.11	System Quality Factors – Loss of Mission
TBR-014	3.2.11	System Quality Factors – Launch Availability – Probability
TBR-015	3.2.11	System Quality Factors – Launch Availability – Confidence Level
TBR-016	3.2.11	System Quality Factors – Launch Availability – Launching
TBR-017	3.2.11	Block 1A Reliability
TBR-018	3.2.11	Block 2 Reliability
TBR-019	3.2.11	Maintenance Down Time – Vehicle Failures
TBR-020	3.2.11	Maximum Maintenance Down Time
TBR-021	3.2.11	Launch Countdown Hold
TBR-022	3.2.11	Operational Life for Launch Attempts – Cycles
TBR-023	3.2.11	Pad Stay Time
TBR-024	3.2.11	Vehicle Stack Time
TBR-041	3.2.15	Logistics-Related Requirements-ALDT Hours
TBR-042	3.3.1	Core Stage Nominal Usable LH_2 Propellant Loading
TBR-043	3.3.1	Core Stage Nominal Usable LO_2 Propellant Loading
TBR-044	3.3.1	Upper Stage Nominal Usable LH_2 Propellant Loading
TBR-045	3.3.1	Upper Stage Nominal Usable LO_2 Propellant Loading
TBR-046	3.3.1	Nominal Usable Propellant Loading Variation
TBR-047	3.3.1	Launch-Ready Hold
TBR-048	3.3.1	Ascent Telemetry
TBR-049	3.3.1	Block 1 Configuration Mass Limit-Core Stage Dry Limits
TBR-050	3.3.1	Block 1A Configuration Mass Limit-Core Stage Dry Limits
TBR-051	3.3.1	Block 2 Configuration Mass Limit-Core Stage Dry Limits
TBR-052	3.3.1	Upper Stage Dry Mass Limit – Block 2 Mass Limit
TBR-053	3.3.1	FTS Time Delay for Crewed Missions
TBR-054	3.3.1	Core Stage Launch Reliability

TBR	Section	Description
TBR-055	3.3.1	Upper Stage Launch Reliability
TBR-056	3.3.1	Core Stage Maintainability – Failures
TBR-057	3.3.1	Core Stage Maintainability – Repair Hours
TBR-058	3.3.1	Core Stage Engine Access
TBR-059	3.3.1	Upper Stage Maintainability – Failures
TBR-060	3.3.1	Upper Stage Maintainability – Repair Hours
TBR-061	3.3.1	Upper Stage Engine Access
TBR-062	3.3.1	Core Stage Ascent Reliability
TBR-063	3.3.1	Core Stage Risk of Uncontained Failure
TBR-064	3.3.1	Upper Stage Ascent Reliability
TBR-065	3.3.1	Upper Stage Risk of Uncontained Failure
TBR-066	3.3.1	Minimum Service Life
TBR-067	3.3.2.1	Ascent Reliability
TBR-068	3.3.2.1	Risk of Mainstage Uncontained Failure
TBR-069	3.3.2.1	Launch Reliability – Block 1A, Block 2
TBR-070	3.3.2.1	Maintainability – Block 1A, Block 2 – Failures
TBR-071	3.3.2.1	Maintainability – Block 1A, Block 2 – Repair Hours
TBR-072	3.3.2.1	Minimum Service Life
TBR-073	3.3.2.2	Ascent Reliability
TBR-074	3.3.2.2	Risk of Uncontained Failure
TBR-075	3.3.2.2	Launch Reliability
TBR-076	3.3.2.2	Maintainability – Failures
TBR-077	3.3.2.2	Maintainability – Repair Hours
TBR-078	3.3.2.2	Minimum Service Life
TBR-079	3.3.3	FTS Time Delay for Crewed Missions
TBR-080	3.3.3	Ascent Reliability
TBR-081	3.3.3	Launch Reliability – Block 1A, Block 2
TBR-082	3.3.3	Maintainability – Block 1A, Block 2 – Failures
TBR-083	3.3.3	Maintainability – Block 1A, Block 2 – Repair Hours
TBR-084	3.3.3	Minimum Service Life
TBR-085	3.3.4	LVSA Mass Limit
TBR-086	3.3.4	Cargo Payload Adapter – Block 1A Mass Limit
TBR-087	3.3.4	CPA – Block 2 Mass Limit
TBR-088	3.3.4	Payload Fairing – 27.6 ft diameter – Mass Limit
TBR-089	3.3.4	Payload Fairing – 33 ft diameter – Mass Limit

TBR	Section	Description
TBR-090	3.3.4	Integrated Payload Element Service Life
TBR-091	3.3.4	Tanking/Ascent/Payload Separation Reliability
TBR-092	3.3.4	Payload/Fairing Separation Reliability
TBR-093	3.3.4	Launch Reliability – Block 1A, Block 2
TBR-094	3.3.4	Maintainability – Block 1A, Block 2 – SPI Failures
TBR-095	3.3.4	Maintainability – Block 1A, Block 2 – Repair Hours
TBR-103	3.1.1	Solid Booster Aft Attach
TBR-104	3.1.1	Solid Booster Forward Attach
TBR-105	3.1.1	Top of Common Core Stage
TBR-106	3.1.1	Block 1 Cargo Configuration Stack Height
TBR-107	3.1.1	Block 1 Interface Plane Between SLS and Orion MPCV
TBR-108	3.1.1	Block 1 Orion MPCV Configuration Stack Height
TBR-110	3.1.3	Block 2 Stack Height to Top of Upper Stage
TBR-111	3.1.3	Block 2 Cargo Configuration Stack Height
TBR-112	3.1.3	Block 2 Interface Plane Between SLS and Orion MPCV
TBR-113	3.1.3	Block 2 Orion MPCV Configuration Stack Height
TBR-114	3.3.4	MPCV Spacecraft Adapter Mass
TBR-115	3.3.4	ICPS Performance
TBR-116	3.3.4	ICPS Starts
TBR-117	3.3.4	ICPS Total Liftoff Mass
TBR-118	3.3.4	ICPS FTS Delay
TBR-119	3.1.1	Core Stage Engine TVC
TBR-120	3.2.2	Block 1 Insertion Accuracy – Semi major axis
TBR-121	3.2.2	Block 1 Insertion Accuracy – Apogee

APPENDIX C

Affordable Upper Stage Engine Program (AUSEP)
Technical Requirements Specification

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Air Force Space and Missile Systems Center (SMC)

Launch Systems Directorate (LR)

Revision for Space Launch System (SLS)

Advanced Development

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1 Scope

The purpose of this document is to assist the Affordable Upper Stage Engine Program (AUSEP) Engine System Requirements Study via the NASA Research Announcement (NRA) for the Space Launch System (SLS) Advanced Development. The AUSEP Engine System Requirements Study is performed to identify the most cost effective, technically mature alternatives to the aging RL10 engines. Its deliverables include: 1) trade studies and requirements analysis, 2) recurring/nonrecurring costs and schedule, 3) systems engineering plan (including draft test and evaluation plan, risk management, and verification and validation approach).

This specification provides the technical requirements for the AUSEP liquid rocket engine for use on upper stages of medium- and heavy-class launch vehicles, including the Evolved Expendable Launch Vehicle (EELV) family of launch vehicles. The AUSEP engine is also a baseline engine for NASA's Space Launch System (SLS) Block1a Cryogenic Propulsion Stage (CPS) in-space stage. This specification establishes the performance, design, development, and test requirements for a liquid propellant rocket engine, hereinafter referred to as the engine.

The engine shall be a U.S. developed and manufactured liquid oxygen (LOX)/liquid hydrogen (LH2) rocket engine. A common engine will be developed to satisfy the mission propulsion requirements for both the Atlas V Centaur Upper Stage and the Delta IV Cryogenic Second Stage (DCSS). In addition, the Government's intent is to use common engine elements across the EELV and SLS CPS as much as possible. In this document, the term vehicle stage will be used when referring to the Centaur, DCSS, or CPS, since the requirements in this specification cover the joint requirements.

Requirements listed herein are to be considered within a trade space as key factors that drive development and production costs as well as the life cycle cost of the engine and ultimately the launch vehicle. Given these identified trades, final requirements are subject to change, enabling improvements in engine performance, operability, reliability, and cost. The current document guides vendors to develop and evaluate their engine concepts against these requirements with varying technology and manufacturing maturity levels, allowing high-fidelity development and production cost and schedule estimates.

2 Applicable Documents

2.1 Specifications

2.2 Standards

2.3 Handbooks

2.4 Industry Publications

2.5 Non-Government Documents

2.6 Availability of Documents

2.7 Tailoring of Government Specifications and Documents

2.8 Materials and Processes Substitution List

2.9 Reference Documents

3 Requirements

This section contains the essential technical requirements that apply to the performance and function of the engine. This section is intended to indicate, as definitively as practicable, the minimum requirements that the engine must meet to fulfill its intended purpose. The technical requirements define what the engine must do or qualities that it must have. The requirements of this section will be verified for flight qualification.

The generic term "ICD" is used to designate the specific Interface Control Document used to prescribe the conditions at the interface with the vehicle stage. The ICD for the vehicle to the engine is [TBD].

The convention used in this document which indicates requirements, goals, and statements of fact is as follows:

- **Shall** - Used to indicate a binding requirement.
- **Should** - Used to indicate a desired goal.
- **Will** - Used to indicate a statement of fact.

Every design requirement containing a "shall" is binding and must be verified. Goals and statements of fact are non-binding.

3.1 Vehicle Interface

The engine shall operate with the vehicle stage in accordance with the physical layout and dimensions as prescribed in the following sections of the [ICD]:

- Interface Mechanical Loads
- Engine Dynamic Envelope
- Engine Service Envelope

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- Gimbal Block Interface
- Thrust Vector Control Actuators and Structural Attachment
- Oxygen and Hydrogen Propellant Duct Interface Layout
- Fluid and Electrical Interface Panels Layout

3.1.1 Propellants

3.1.1.1 Fuel

The engine shall operate with liquid hydrogen meeting MIL-PRF-27201.

3.1.1.2 Oxidizer

The engine shall operate with liquid oxygen meeting MIL-PRF-25508.

3.1.1.3 ICD Engine Thrust Requirements

The engine shall produce thrust using propellants, liquid hydrogen and liquid oxygen, supplied by the vehicle stage in accordance with the following sections of the [ICD].

- Oxygen and Hydrogen Propellant Inlet Duct Surge Pressure Limits
- Liquid Oxygen and Hydrogen Quality - Propellant Inlet
- Liquid Hydrogen Particulate Matter - Propellant Inlet
- Liquid Oxygen Particulate Matter - Propellant Inlet
- Hydrogen Run Box
- Oxygen Run Box
- Oxidizer System Inert Gas Ingestion
- Propellant Inlet Flow Uniformity: Difference Between Max. and Min. Flow Velocity
- Propellant Inlet Flow Uniformity: Circumferential Fluid Velocity Variation

3.1.2 Cycle

The engine power cycle shall be specified by the engine supplier.

3.2 Performance Characteristics

3.2.1 Steady State Performance

3.2.1.1 Vacuum Thrust

AUSEP Key Design Requirement (KDR): The engine shall provide a vacuum thrust of [30,000] lb_f [+/- TBD lbf] at full power level (FPL)at Standard Inlet Conditions.

3.2.1.1.1 Thrust Oscillation

Thrust oscillations about the engine steady state operating thrust level shall not exceed [± 3.0] percent from nominal in the [TBR] Hertz frequency range, exceptions [TBR]

3.2.1.1.2 Thrust Repeatability

Thrust repeatability shall be within [TBR].

3.2.1.1.3 Throttle Capability

There is no requirement to throttle the engine. However, a design allowing a block upgrade opportunity for throttling (e.g., a ratio of 2:1) is preferable.

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3.2.1.2 Vacuum Specific Impulse (I_{sp})

The engine shall provide a minimum guaranteed vacuum Isp of [TBR] seconds at a mixture ratio of [5.88] at FPL. AUSEP Key Design Requirement (KDR): The engine should provide a minimum guaranteed vacuum Isp of [TBR] seconds at a mixture ratio of [5.88] at FPL.

3.2.1.3 Mixture Ratio Range

The engine shall operate over a mixture ratio of in range of [5.0 to 6.0 $\pm$ 2%] at FPL.

3.2.1.3.1 Mixture Ratio Management

The engine shall have the ability to actively manage the mixture ratio during operation under the direction of the engine control unit.

3.2.1.4 Maximum Single Burn Duration

The engine shall have a maximum single burn duration of [TBR] seconds.

3.2.1.4.1 Mission Burn Duration

The engine shall have a maximum mission burn duration, including all re-starts, of [TBR] seconds.

3.2.2 Altitude Start

The engine shall be designed for altitude start and operation which is defined as 100,000 feet above Mean Sea Level (MSL) or higher.

3.2.3 Start Transient Performance

The time from the receipt of the altitude start signal to 90 percent of rated thrust shall not exceed [TBR] seconds in accordance with the following sections of the [ICD]:

3.2.4 Shutdown Transient Performance

The time from receipt of the shutdown signal to 5 percent rated thrust shall not exceed [TBR] second from any steady-state power level.

3.2.5 Standard Inlet Conditions

Standard propellant inlet conditions for engine start and steady state operation will be as defined in ICD Table [TBD].

3.3 Physical Characteristics

3.3.1 Dimensions

3.3.1.1 Engine System Length

The engine system length from engine apex to nozzle exit shall not exceed [TBR] inches. This length applies for extensible nozzles in the stowed position. In the case of an extendible nozzle, there is no limit on the engine length following deployment.

3.3.1.2 Maximum Engine Width

The maximum diameter of the engine system shall not exceed [TBR] inches.

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3.3.2 Weight

The weight of the engine, including the nozzle extension (if applicable) and flight instrumentation, shall be less than [TBR] lb_m, and in accordance with [AIAA S-120]. AUSEP Key Design Requirement (KDR): The weight of the engine, including the nozzle extension (if applicable) and flight instrumentation, should be less than [TBR] lb_m.

3.3.2.1 Mass Moment of Inertia/Center of Gravity

The engine's mass moment of inertia and center of gravity shall not exceed the limits of the [ICD] (and/or the Source Control Drawing).

3.3.3 Gimbaling

The engine shall meet all functional and performance requirements at any position within the engine gimbal pattern defined in Figure [TBD] Engine Gimbal Pattern, ± [4.5°, TBR], when gimbal motion is actuated by the vehicle stage during pre-launch and in-flight mission operation in accordance with the following sections of the [ICD]:

Figure [TBD] Engine Gimbal Pattern

3.3.4 Pressurization and Purge

3.3.4.1 Autogenous Pressurization

The engine shall be able to provide gaseous hydrogen to the hydrogen propellant tank for autogenous pressurization in accordance with the [ICD].

3.3.4.2 Nitrogen Purge

The engine shall meet all performance and functional requirements using gaseous nitrogen, meeting the requirements of MIL-PRF-27401, supplied by the vehicle stage for pre-launch purges including any actively purged seals in accordance with the following sections of the [ICD]:

- Gaseous Nitrogen Supply Pressure
- Gaseous Nitrogen Supply Temperature
- Gaseous Nitrogen Consumption Rate

3.3.4.3 Helium Pneumatics and Purge

The engine shall meet all performance and functional requirements using gaseous helium, meeting the requirements of MIL-PRF-27407, supplied by the vehicle stage for pre-launch purges including any actively purged seals in accordance with the following sections of the [ICD]:

- Gaseous Helium Supply Pressure
- Gaseous Helium Supply Temperature
- Gaseous Helium Consumption
- Gaseous Helium Consumption Rate

3.3.4.4 Leakage

The engine shall meet all performance and functional requirements with leakage requirements in accordance with the following sections of the [ICD]:

- Ventage

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- External Leakage
- Helium Control System
- Fuel and Oxidizer Propellant Systems

3.3.4.5 Instrumentation

The engine shall include instrumentation required for engine control and instrumentation sufficient for post-flight engine health and performance evaluation including temperature sensors, speed signal generator(s), pressure sensors, and enclosures for mounting and protecting vehicle supplied transducers.

3.3.5 Natural Environments

The engine shall meet all functional and performance requirements defined herein within the range of environmental conditions specified in [TBD] per the following sections:

- Ground Ops, Transport, and Pre-launch Phase Specification
- Transportation to the Launch Site
- Radiant (Thermal) Energy Environment for Ground Operations
- Air Temperature Environment for Ground Operations
- Air Pressure Environment for Ground Operations
- Humidity Environment for Ground Operations
- Aerosol Environment for Ground Operations
- Lightning During On-Pad Operations, in accordance with MIL-B-5087B (2)
- Surface Air Pressure Environment During Launch
- Aloft Air Temperature Environment for Vehicle Ascent
- Aloft Air Pressure Environment for Vehicle Ascent
- Aloft Air Density Environment for Vehicle Ascent
- Natural and Triggered Lightning During Launch and Ascent, in accordance with MIL-B-5087B (2)
- Ionizing Radiation Environment for Launch, Ascent and Re-entry

3.3.6 Induced Environments

The engine shall meet its requirements during and after exposure to the vehicle induced dynamic, thermal, and electromagnetic environments as specified in [TBD].

3.3.7 Micro-Meteoroid and Orbital Debris (MMOD) Environments

The engine shall perform as specified in this document during and after exposure to the Micro-Meteoroid and Orbital Debris Environments requirement of [TBD].

3.3.7.1 Limiting Orbital Debris

The engine shall not release orbital debris larger than 5 mm in any dimension during normal operation. The engine shall be capable of passivation of on-board sources of stored energy and shall be designed to limit the probability of accidental explosion during and after completion of mission operations. The engine shall be designed to minimize reentry expected casualty risk by use of designs and materials that minimize the reentry debris breakup cross section and survivability. [TBR per US Government Orbital Debris Mitigation Standard Practices (USG ODMSP)].

3.3.8 Life

The engine will be designed for a single (1) mission.

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3.3.8.1 Service Life

The engine shall have a minimum service life of [TBD] seconds and [TBD] firings.

3.3.8.2 Storage Life

The engine shall be capable of being stored a minimum of [10] years without refurbishment when protected and maintained per Seller instructions.

3.4 Engine Operation Sequence

The engine will start, operate, shutdown, and restart in accordance with the performance requirements of 3.2.

3.4.1 Pre-Start Cool-down

The engine shall be capable of operation after pre-start conditioning with the following parameters at [TBD location(s)]:

- Temperatures - [TBD].
- Pressures - [TBD].

3.4.2 Nozzle

The nozzle may be either fixed or extensible – but, a fixed nozzle is preferable

3.4.3 Re-Start

The engine shall be capable of accepting a Failure Restart Command in the event of a failure to start on the first start command.

3.4.3.1 Number of In-Flight Re-Starts

The engine shall be capable of at least [TBR] in-flight restarts.

3.4.4 Propellant Tank Blow-Down

The engine shall be capable of propellant tank blow-down. Residual propellants in the vehicle tanks will be discharged through the engine upon completion of the mission and separation of the spacecraft to provide thrust to move the vehicle away from the spacecraft or as required for relieving excessive vehicle tank pressure.

3.4.5 Fail-Safe

The engine shall be designed to be fail-safe.

3.4.5.1 Safe Shutdown

The engine shall be capable of safely shutting down from any steady-state power level.

3.5 Design and Construction

3.5.1 General (Cluster)

The engine should be designed to operate in a maximum cluster of [2] engines. Vehicle Contractors and Government will determine amount of engines in the cluster.

3.5.1.1 Engine Interchangeability

The engine should be designed to be interchangeable with other engine positions within the cluster.

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3.5.1.2 Pressurized Structures

Pressurized structure shall meet the requirements of [AIAA S-080 and SMC-S-016].

3.5.1.3 Non-Pressurized Structures

Non-pressurized structures shall meet the requirements of [AIAA-S-110 and SMC-S-016].

3.5.1.4 Factors of Safety

Engine factors of safety shall meet the requirements of [NASA- STD-5012 and SMC-S-016].

3.5.2 Materials and Processes Selections

All materials and processes used in the manufacture of the engine will be subject to Vehicle Contractor and Government approval prior to usage.

3.5.2.1 Finish

The engine finish should meet the requirements of [MIL-F-7179] and be subject to Buyer approval.

3.5.2.2 Finish Combatility

The engine finish should be compatible with Electrical Bonding requirements of [3.5.5.1.1].

3.5.3 Parts

All parts should comply with [MIL-I-6870].

3.5.3.1 Penetrant Inspection

Penetrant inspection should be performed on non-ferromagnetic machined metallic parts, in accordance with [MIL-STD-6866 Type I, Method A or B].

3.5.3.2 Magnetic Particle Inspection

Magnetic particle inspection in accordance with [MIL-STD-1949] should be performed on ferromagnetic machined parts.

3.5.3.3 Ultrasonic Inspection

Prior to machining, raw stock should be ultrasonically inspected in accordance with [MIL-STD-2154, Class A].

3.5.3.4 Weld Inspection

Penetrant or magnetic particle inspection should be performed on welds in accordance with [MIL-STD-6866 Type I Method or B] and [MIL-STD-1949].

3.5.3.5 Radiographic Inspection

Radiographic inspection requirements should meet the requirements of [MIL-STD-453].

3.5.3.6 Cleaning

The engine should be cleaned in accordance with the following:

- External Surfaces: [ISO 14952]
- Internal Propellant System Surfaces: [ISO 14952]
- Internal Pneumatic System Surfaces: [ISO 14952]

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3.5.3.7 Contamination

Engine contamination should be controlled in accordance with [ISO 15388].

3.5.4 Components

All engine components should meet the requirements of their respective component specification [TBD].

3.5.4.1 Engine Valves

All engine valves should be supplied by the engine contractor, and may be either pneumatically or electrically actuated.

3.5.4.1.1 Engine Valves Static Force Margin

All engine valves should have at least [TBR %] static force margin.

3.5.4.1.2 Engine Valves Consumable Usage

All engine valves should minimize the use of electrical power, helium, and nitrogen consumables.

3.5.4.2 Interchangeability

The engine components and subsystems should be designed to be identical in form, fit and function so that they are interchangeable within other engines and subsystems.

3.5.4.3 Line Replaceability

Engine components and subsystems that are designed for line replaceability, should not require adjustment or realignment other than those feasible with support equipment at a field location.

3.5.4.4 Engine Health

The engine shall have the ability to support instrumentation to detect component and subsystem health. The engine shall have the ability to provide the data to predict engine system subsystem and component health for in-flight and post-flight usage.

3.5.5 Electrical and Electronic Requirements

Items containing electrical, electromagnetic, or electronic elements or parts should conform to [MIL-STD-202; MIL-STD-461D].

3.6 Reliability

The engine shall be designed to perform full mission with single mission reliability greater than [0.999] per engine and at [TBR] confidence level.

3.7 Safety

The design of the engine shall be such that all possible sources of danger to personnel or damage to equipment during assembly, disassembly, testing, operation and maintenance conform to the requirements of [AFSPCMAN 91-710 Volumes 1-7].

3.8 Workmanship

The engine shall be fabricated and finished so that appearance, fit, and adherence to specified dimensions and tolerances are observed; and in a manner which will ensure reliable operations in accordance with the requirements specified herein.

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3.9 Maintenance

The engine shall require no scheduled maintenance during its useful life.

3.10 Cost

The cost of an engine shall be a maximum of $[TBD]M (FY12$) per engine per flight. This includes engine production, engine rebuilds, on-site test support, on-sight engine support, and sustained facilitated engineering with a minimum production rate of 9 engines per year for 12+years.

4 VERIFICATION

4.1 General Requirements

The following requirements apply to the verification program to be conducted during design, development, qualification, fabrication and acceptance of the items. The verification process shall provide the customer with the assurance that the item hardware complies with the requirements of this specification. Customer reviews shall involve multiple government agencies and their support staff which includes FFRDC such as Aerospace Corp. Vehicle vendors may be invited to attend reviews to provide constructive feedback. The component shall comply with the quality requirements defined in [TBD - Quality Assurance Plan].

4.1.1 Quality Conformance

The verification method and the relationship to section 3 requirements shall be accomplished as specified in Table I. Methods of verification shall be by analysis, demonstration, inspection and/or test as defined in the following paragraphs:

Analysis: Verification by analysis (A) uses techniques such as statistical or quantitative analysis, computer simulations, and modeling to complete calculations or make comparisons confirming that a product design satisfies the specified functional, performance, interface, or design requirements. Results of Analysis prove that the product design provides the functional or performance capability, margin, and design features specified by a product requirement. An analysis report is required to satisfy this method of verification.

Demonstration: Verification by demonstration (D) is the exercise of the hardware, software, or operation to ensure that qualitatively specified functions can be performed. Demonstration generally does not entail special equipment or sophisticated measuring instrumentation for verification of specific numerical value(s) within the requirement. Demonstration plan and demonstration report is required to satisfy this method of verification.

Inspection: Verification by inspection (I) is examining a product's physical (not functional) characteristics to ensure compliance with the workmanship, quality, physical condition, and dimensional tolerance requirements stated in the product specification or design documentation. Inspection may include a visual confirmation that the product includes special construction features required by the released engineering documentation. Inspection may also include the comparison of software requirements or mechanization equations to program source listings or flow diagrams to verify software or database compliance with software requirements. Inspection may be a review of drawings to ensure interface compliance. A copy of the inspection record/report is required to satisfy this method of verification.

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Test: Verification by test (T) is the quantitative measurement of performance parameters through the application of functional, electrical, or mechanical stimuli, or exposure to a natural or induced environment to determine compliance with specified requirements. Test can also be used in conjunction with analysis to help anchor the analysis with test data. Test typically includes the collection of performance data by acquiring quantitative data. Test plan and test report is required to satisfy this method of verification.

Similarity: Comparison of configuration, design, and environmental capabilities based on prior test results with those requirements specified herein.

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Table I Verification Matrix

Reference Codes: **Verification Method**: A = Analysis D = Demonstration I = Inspection T = Test -- = Not Applicable
Verification Phase: DV = Development Q = Qualification AC = Acceptance CR = Certification

Verification Level: E = Engine Comp = Component LL = Lower Level

SECTION 3 – REQUIREMENTS			SECTION 4 – VERIFICATION		
Section 3 Paragraph Number	**Paragraph Title**	**Phase**	**Method**	**Level**	**Section 4 Paragraph Number**
3.1	Vehicle Interface	DV	I	E	4.1
3.1.1.1	Fuel	DV/Q/CR	T/A	E	4.1.1.1
3.1.1.2	Oxidizer	DV/Q/CR	T/A	E	4.1.1.2
3.1.1.3	ICD Engine Thrust Requirements	DV	T/A	E	4.1.1.3
3.1.2	Cycle	DV/Q/CR	A/I	E	4.1.2
3.2.1.1	Vacuum Thrust	DV/Q/CR	T/A	E	4.2.1.1
3.2.1.1.1	Thrust Oscillation	DV/Q/CR	T/A	E	4.2.1.1.1
3.2.1.1.2	Thrust Repeatability	DV/Q/CR	T/A	E	4.2.1.1.2
3.2.1.1.3	Throttle Capability	DV/Q/CR	T/A	E	4.2.1.1.3
3.2.1.2	Vacuum Specific Impulse (I_{sp})	DV/Q/CR	T/A	E	4.2.1.2
3.2.1.3	Mixture Ratio Range	DV/Q/CR	T/A	E	4.2.1.3
3.2.1.3.1	Mixture Ratio Management	DV/Q/CR	T/A	E	4.2.1.3.1
3.2.1.4	Maximum Single Burn Duration	DV/Q/CR	T	E	4.2.1.4
3.2.1.4.1	Mission Burn Duration	DV/Q/CR	T	E	4.2.1.4.4
3.2.2	Altitude Start	DV/Q/CR	T/A	E	4.2.2
3.2.3	Start Transient Performance	DV/Q/CR	T/A	E	4.2.2.1
3.2.4	Shutdown Transient Performance	DV/Q/CR	T/A	E/LL	4.2.3
3.2.5	Standard Inlet Conditions	DV/Q/CR	T/A	E	4.2.5

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SECTION 3 – REQUIREMENTS			SECTION 4 – VERIFICATION		
Section 3 Paragraph Number	**Paragraph Title**	**Phase**	**Method**	**Level**	**Section 4 Paragraph Number**
3.3.1.1	Engine System Length	DV/Q/CR	D/A/I	E	4.3.1.1
3.3.1.2	Maximum Engine Width	DV/Q/CR	D/A/I	E	4.3.1.2
3.3.2	Weight	DV/Q/CR	D/A/I	E	4.3.2
3.3.2.1	Mass Moment of Inertia/Center of Gravity	DV/Q/CR	D/A/I	E	4.3.2.1
3.3.3	Gimbaling	DV/Q/CR	T/A	E	4.3.4
3.3.4.1	Autogenous Pressurization	DV/Q/CR	T/A	E	4.3.5.1
3.3.4.2	Nitrogen Purge	DV/Q/CR	T/A	E	4.3.5.2
3.3.4.3	Helium Pneumatics and Purge	DV/Q/CR	T/A	E	4.3.5.3
3.3.4.4	Leakage	DV/Q/CR	T/A	E	4.3.5.4
3.3.4.5	Instrumentation	DV/Q/CR	T/A	E	4.3.5.5
3.3.5	Natural Environments	DV	I/A	LL	4.3.6
3.3.6	Induced Environments	DV	I/A	E/C/LL	4.3.7
3.3.7	Micro-Meteoroid and Orbital Debris Environments	DV	A	E/C	4.3.8
3.3.7.1	Limiting Orbital Debris	DV	A	E/C/LL	4.3.8.1
3.3.8	Life	DV/Q/CR	T/A	E	4.3.9
3.3.8.1	Service Life	DV/Q/CR	T/A	E	4.3.9.1
3.3.8.2	Storage Life	DV	T/A	E/C/LL	4.3.9.2
3.4.1	Pre-Launch Cool-Down	DV/Q/CR	T/A	E	4.4.1
3.4.2	Nozzle	DV/Q/CR	T/A	E	4.4.2

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SECTION 3 – REQUIREMENTS			SECTION 4 – VERIFICATION		
Section 3 Paragraph Number	**Paragraph Title**	**Phase**	**Method**	**Level**	**Section 4 Paragraph Number**
3.4.3	Re-Start	DV/Q/CR	T/A	E	4.4.4
3.4.3.1	Number of In-Flight Restarts	DV/Q/CR	T/A	E	4.4.2.1
3.4.3.2	Number of Ground Tests	DV/Q/CR	T/A	E	4.4.2.2
3.4.4	Propellant Tank Blow-Down	DV	D/A	E	4.4.3
3.4.5	Fail-Safe	DV	T/I	E/C	4.4.4
3.4.5.1	Safe Shutdown	DV	T/A	E/C	4.4.4.1
3.5.1	General (Cluster)	DV	A	E	4.5.1
3.5.1.1	Engine Interchangeability	DV	I	E	4.5.1.1
3.5.1.2	Pressurized Structures	DV	I	C	4.5.1.2
3.5.1.3	Non-Pressurized Structures	DV	I	C	4.5.1.3
3.5.1.4	Factors of Safety	DV/Q/CR	A/I	E/C	4.5.1.4
3.5.2	Materials and Processes Selections	DV	I	C	4.5.2
3.5.2.1	Finish	DV	I	E/C	4.5.2.1
3.5.2.2	Finish Compatibility	DV	I	E/C	4.5.2.2
3.5.3	Parts	DV	I	C	4.5.3
3.5.3.1	Penetrant Inspection	DV	I	C	4.5.3.1
3.5.3.2	Magnetic Particle Inspection	DV	I	C	4.5.3.2
3.5.3.3	Ultrasonic Inspection	DV	I	C	4.5.3.3
3.5.3.4	Weld Inspection	DV	I	C	4.5.3.4

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SECTION 3 – REQUIREMENTS			SECTION 4 – VERIFICATION		
Section 3 Paragraph Number	**Paragraph Title**	**Phase**	**Method**	**Level**	**Section 4 Paragraph Number**
3.5.3.5	Radiographic Inspection	DV	I	C	4.5.3.5
3.5.3.6	Cleaning	DV	D/I	E/C	4.5.3.6
3.5.3.7	Contamination	DV	D/I	E/C	4.5.3.7
3.5.4	Components	DV	I	C	4.5.4
3.5.4.1	Engine Valves	DV	I	C	4.5.4.1
3.5.4.1.1	Engine Valves Static Force Margin	DV	I	C	4.5.4.1.1
3.5.4.1.2	Engine Valves Consumables Usage	DV	I	C	4.5.4.1.2
3.5.4.2	Component and Sub-System Interchangeabilty	DV	D/A/I	E/C	4.5.4.4
3.5.4.3	Line Replaceabilty	DV	D/A	E/C	4.5.4.5
3.5.4.4	Engine Health	DV	T/A	E/C/LL	4.5.4.6
3.5.5	Electrical and Electronic Requirements	DV	I	E/C/LL	4.5.5
3.6	Reliability	DV/Q/CR	T/A	E/C	3.6
3.7	Safety	DV	I	E	4.7
3.8	Workmanship	DV/Q/CR	I/D/A	E	4.8
3.9	Maintenance	DV/Q/CR	I/D/A	E	4.9
3.10	Cost	DV/Q/CR	A	E	4.11

BEYOND THIS POINT REMOVED FOR ITAR COMPLIANCE

Approved For Public Release by SMC/LR: This document supports the SLS Advanced Development NRA, a full SBU/ITAR Limited Release version may be shared with qualified vendors upon award.

APPENDIX D
Acronyms List

Abort-to-Orbit	ATO
Advanced Development Office	ADO
Affordable Upper Stage Engine	AUSE
Affordable Upper Stage Engine Program	AUSEP
Aluminum-Lithium	Al-Li
Ames Research Center	AMC
Ammonium Dinitramide	ADN
Basis of Estimate	BOE
Beyond Earth Orbit	BEO
Cargo Payload Adapter	CPA
Central Processing Unit	CPU
Code of Federal Regulations	CFR
Communications and Tracking	C&T
Communications and Tracking Network	CTN
Compact Disk Read Only Memory	CD ROM
Compression After Impact	CAI
Computational Fluid Dynamics	CFD
Contracting Officer Representative	COR
Contractor and Government Entity	CAGE
Cost Accounting Standards	CAS
Cost Accounting Standards Board	CASB
Cryogenic Propulsion Stage	CPS
Data Procurement Document	DPD
Data Requirement Document	DRD
Data Universal Numbering System	DUNS
Dryden Flight Research Center	DFRC
Electrical Ground Support Equipment	EGSE
Equivalent People	EP
Export Administration Regulations	EAR
Federal Acquisition Regulations	FAR
Federal Business Opportunities	FBO
Federally Funded Research and Development Center	FFRDC
General Accounting Office	GAO
General-Purpose Graphics Processing Unit	GPGPU
Glenn Research Center	GRC
Goddard Space Flight Center	GSFC
Graphical Processing Unit	GPU

Ground Operations Control System	GOCS
Ground Support Equipment	GSE
Ground Systems Development and Operations Program	GSDOP
Guidance, Navigation, and Control	GN&C
Health Check and Status	HC&S
Homeland Security Presidential Directive	HSPD
Human Architecture Team	HAT
Human Exploration and Operations Directorate	HEO
Huntsville Operations Support Center	HOSC
Hydrazinium Nitroformate	HNF
Hydroxylammonium Nitrate	HAN
Information Technology	IT
Interim Cryogenic Propulsion Stage	iCPS
International Space System	ISS
International Traffic in Arms Regulations	ITAR
Iran, North Korea, and Syria Nonproliferation Act	INKSNA
Jet Propulsion Laboratory	JPL
John C. Stennis Space Center	SSC
Johnson Space Center	JSC
Kennedy Space Center	KSC
Langley Research Center	LRC
Line Replaceable Unit	LRU
Liquid Hydrogen	LH2
Liquid Oxygen	LO2
Liquid Rocket Booster	LRB
Low Earth Orbit	LEO
Mobile Launcher	ML
Marshall Space Flight Center	MSFC
Multi-Purpose Crew Vehicle	MPCV
NASA Acquisition Internet Service	NAIS
NASA FAR Supplement	NFS
NASA Research Announcement	NRA
NASA Solicitation and Proposal Integrated Review and Evaluation System	NSPIRES
National Aeronautics and Space Administration	NASA
Non-destructive Evaluation	NDE
Non-propulsive Payload Element	NPE
Notice of Intent	NOI
Past Performance Information Retrieval System	PPIRS
Personal Computer	PC
Powered Explicit Guidance	PEG

Principal Investigator	PI
Radio Frequency	RF
Reynolds Averaged Navier Stokes/Large Eddy Simulation	RANS/LES
Safety, Health, and Environmental	SHE
Science, Technology, Engineering, and Mathematics	STEM
Space Act Agreement	SAA
Space Launch System	SLS
Space Transportation System	STS
Special Test Equipment	STE
Sponsored Research Business Activity	SRBA
Solid Rocket Booster	SRB
5-segment Solid Rocket Booster (5 Segment)	SRBv
Statement of Work	SOW
System Integration Lab	SIL
Technology Readiness Level	TRL
Thermal Protection System	TPS
Thrust Vector Control	TVC
United States	US
Vehicle Assembly Building	VAB
Work Breakdown Structure	WBS

APPENDIX E
Subcontractor Information

1. COMPANY NAME: _____

ADDRESS: _____

_____

POINT OF CONTACT/PHONE NUMBER_____

CONTRACT VALUE:_____TYPE OF CONTRACT:_____

BRIEF DESCRIPTION OF WORK: _____

_____

2. COMPANY NAME: _____

ADDRESS: _____

_____

POINT OF CONTACT/PHONE NUMBER_____

CONTRACT VALUE:_____TYPE OF CONTRACT:_____

BRIEF DESCRIPTION OF WORK: _____

_____

3. COMPANY NAME: _____

ADDRESS: _____

_____

POINT OF CONTACT/PHONE NUMBER_____

CONTRACT VALUE:_____TYPE OF CONTRACT:_____

BRIEF DESCRIPTION OF WORK: _____

_____

Note: Offeror may duplicate as necessary for proposal purposes.

APPENDIX F
Element of Price Detail for Contracts

	($K)	Base	Opt 1	Opt 2	Total
1.	Direct Labor Hours				
	Program Administration				
	Engineering				
	Manufacturing				
	Subcontract				
	Total Hours				
2.	Direct Labor Cost				
	Program Administration				
	Engineering				
	Manufacturing				
	Total Direct Labor Cost				
3.	Indirect Labor Cost				
4.	Sub Total Labor				
5.	Non-Labor				
	Material				
	Subcontracts				
	Other Direct Cost				
	Total Non-Labor Cost				
6.	Sub Total Labor and Non Labor				
7.	General & Administrative				
8.	Total Cost				
9.	Profit/Fee				
10.	Less Proposed Corporate Resources (if any)				
11.	Total Cost and Profit				
12.	Proposed Agreement Cost (if any)				
13.	Total Project Price				

Instructions for Element of Price Detail

- Provide a complete element of cost detail in real year thousand dollars for the total, and by Government fiscal year for the proposed period of performance.

- Provide, as attachments, detailed computations of all estimates in each cost category with narratives as required to fully explain each proposed cost as follows.

1. Direct Labor: List the number of hours proposed by the following labor categories: Program Administration, Engineering, Manufacturing, and Major Subcontract.

2. Direct Labor Cost: List individual labor cost by the following labor categories: Program Administration, Engineering, Manufacturing, and Test.

3. Indirect Labor Costs: Identify any applicable indirect cost rate(s) and base(s), including the effective period of the rate, and include the computational basis for the indirect expense pool and corresponding allocation base for each rate.

4. Subtotal Labor: Enter the sum of items 2 and 3.

5. Non-Labor:

    a. Material: Provide general categories of needed supplies, the method of acquisition, and the estimated cost.
    b. Subcontracts: For each proposed subcontractor over 5% of the proposed effort, list the subcontractor by name and the cost proposed. Identify how the subcontractor was selected (competitive or noncompetitive) and how the proposed costs were determined to be fair and reasonable. APPENDIX E shall also be completed for each subcontractor listed.
    c. Other Direct Costs: Includes Travel, Equipment, Consultants, and Other direct costs not covered elsewhere. Attach an itemized list explaining the need for each item and the basis for the estimate.

6. Subtotal Labor and Non-Labor: Enter the sum of items 4 and 5.

7. General and Administrative (G&A) Costs: Identify G&A cost rate(s) and base(s) as approved by the cognizant Federal Agency, including the effective period of the rate. Provide the name, address, and telephone number of the Federal Agency official having cognizance. If unapproved rates are used, explain why, and include the computational basis for the indirect expense pool and corresponding allocation base for each rate.

8. Total Costs: Enter the sum of items 6 and 7.

9. Profit/Fee: Identify the amount of profit/fee being proposed. Explain why the proposed profit/fee is commensurate with the performance risk involved.

10. Proposed Corporate Resources (if any): Subtract item 10 from the cumulative sum of items 8 & 9

11. Total Cost and Profit/Fee: Enter the sum of items 8 through 10.

12. Proposed Agreement Costs (if any): For Prime Contractors submitting proposals with Government Agencies or Centers as subcontractors, these are the costs associated with performance by the Government Agency. Identify the Government Agencies or Centers being proposed, the name and titles of the civil service personnel along with the number of hours being proposed. If your proposal is selected for award, funding for these costs will be provided directly to those Government Agencies via a MIPR or IACRO under the authority of the Economy Act.

APPENDIX G
Budget Summary for Grants

PERIOD OF PERFORMANCE: FROM_____TO_____

	COST
1. DIRECT LABOR (salaries, wages, fringe benefits)	$_____
2. OTHER DIRECT COSTS:	
a. Subcontracts	$_____
b. Consultants	$_____
c. Equipment	$_____
d. Supplies	$_____
e. Travel	$_____
f. Other	$_____
3. INDIRECT COSTS_____%_____	$_____
4. OTHER APPLICABLE COSTS	$_____
5. SUBTOTAL-ESTIMATED COST	$_____
6. LESS PROPOSED COST SHARING	$(_____)
7. TOTAL ESTIMATED COST	**$_____**
8. PROPOSED AGREEMENT COST (if any)	$_____
9. TOTAL PROJECT COST	$_____

Instructions

1. Provide a complete budget summary sheet for year one and separate estimates for each subsequent year

2. Provide as attachments to the budget summary the detailed computations of estimates in each cost category with narratives to fully explain proposed costs.

Budget Support Required for Specific Costs

1. Direct Labor (salaries, wages, and fringe benefits): Attachments should list number and titles of personnel, amount of time to be devoted to the award, and rates of pay.

2. Other Direct Costs:

    a. **Subcontracts** – Attachments should describe the work to be subcontracted, estimated amount, recipient (if known), and the reason for subcontracting this effort.
    b. **Consultants** – Identify consultants to be used, why they are necessary, the time they will spend on the project, and rates of pay (not to exceed the equivalent of the daily rate for Level IV of the Executive Schedule, exclusive of expenses and indirect costs.)
    c. **Equipment** – List separately and explain the need for items costing more than $5,000. Describe basis for estimated cost. General purpose equipment is not allowable as a direct cost unless specifically approved by the grant officer.
    d. **Supplies** – Provide general categories of needed supplies, the method of acquisition, estimated cost. (For Example: Office Supplies, Lab Supplies, etc.)
    e. **Travel** – List proposed trips individually and describe their purpose in relation to the grant. Also provide dates, destination, and number of people where known. (For example; Airfare, Hotel, Per Diem, Registration, Car Rental, etc.)
    f. **Other** – Enter the total direct costs not covered by 2.a through 2.e. Attach an itemized list explaining the need for each item and the basis for the estimate.

3. Indirect Costs – Identify indirect cost rate (s) and base(s) as approved by the cognizant Federal agency, including the effective period of the rate. If unapproved rates are used, explain why and include the computational basis for the indirect expense pool and corresponding allocation base for each rate.

4. Other Applicable Costs – Enter the total of other applicable costs with and itemized list explaining the need for each item and basis for the estimate.

5. Subtotal-Estimated Costs – Enter the sum of items 1 through 4.

6. Less Proposed Corporate Resources (if any) – Enter any amount proposed. If corporate resources are based on specific cost items, identify each item and amount in an attachment.

7. Total Estimated Costs – Enter the total after subtracting items 6. And 7. From item 5.

8. Proposed Agreement Costs (if any): For Prime Contractors submitting proposals with Government Agencies or Centers as subcontractors, these are the costs associated with performance by the Government Agency. Identify the Government Agencies or Centers being proposed, the name and titles of the civil service personnel along with the number of hours being proposed. If your proposal is selected for award, funding for these costs will be provided directly to those Government Agencies via a MIPR or IACRO under the authority of the Economy Act.