National Aeronautics and
Space Administration

Engines Element, Space Launch System Program
Marshall Space Flight Center AL 35812

Exploration Upper Stage Engine (EUSE)

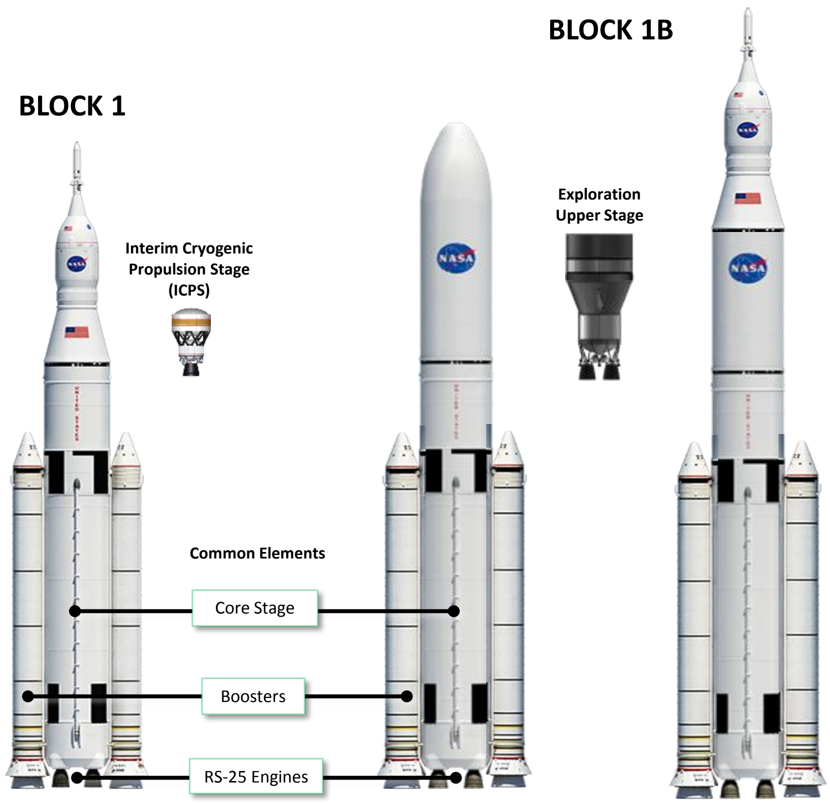
Request for Information

Introduction

The National Aeronautics and Space Administration (NASA) invites Industry to submit a response to this inquiry to assist NASA in the planning for development of a new Exploration Upper Stage Engine (EUSE). Industry response to this Request for Information (RFI) is requested within the context of the requirements and general approach described in the following sections and the associated appendix.

Background

The first launch vehicle being designed, developed, and built as part of the NASA Space Launch System (SLS) Program is designated as the Block 1 configuration. Beyond this initial configuration, a potential upgrade – tentatively designated as the Block 1B vehicle – is being studied by NASA.



For this upgraded configuration, the vehicle core stage, core stage engines, and boosters remain unchanged. The Block 1B vehicle would replace the Interim Cryogenic Propulsion Stage (ICPS) with a more powerful upper stage called the Exploration Upper Stage (EUS), which would provide for fulfillment of more ambitious missions beyond the capabilities of the Block 1 vehicle and provide greater mission margin at comparable vehicle costs. The EUS design concept is for a high-performance, liquid oxygen / liquid hydrogen stage configured to use a cluster of four rocket engines. The initial planning for conceptual design considerations is for the EUS to accommodate the use of the RL10 engine. Responses to this RFI are intended to provide input for an examination into the potential for developing and using alternate engines that meet stage interfaces. NASA desires to minimize development time for an engine and to reduce manufacturing/production costs while still meeting NASA programmatic, technical, design, construction, and workmanship approaches and standards for human rating. NASA is interested in a first launch of the EUS as part of the SLS Program in 2021.

Engine Description

The current concept for the EUSE is that it is a high-performance liquid oxygen / liquid hydrogen rocket engine consistent with the stage-to-engine interface of the RL10 engine. The EUSE would be designed, developed, built, and certified for flight consistent with NASA design, construction, workmanship, and qualification standards and other technical and programmatic requirements associated with human rating considerations including configuration management, reliability analysis, and safety assessment processes. It would be the broader objective for any proposed engine development effort to minimize the development cost impacts to NASA and to achieve cost-efficient production and operations in the long term. Preliminary, notional technical requirements for the EUSE are provided in Appendix A.

Requested Response Topics

The specific objective of this RFI is to solicit information that may potentially enhance NASA's planned approach for EUSE development and assist in developing the acquisition strategy. Comments are requested but not limited to any of the following topics:

- Engine configuration conceptual design, performance, and capabilities;
- The viability of the inclusion within an engine development activity of certain main propulsion system elements including, for example, thrust vector control systems, feed lines, or other ancillary systems; Proposed long-term affordability considerations including the use of advanced manufacturing methods, minimization of fixed production infrastructure costs, and minimization of variable production and operations costs;
- Suggested engine development program including top-level schedule and rough, order-of-magnitude required funding profiles;
- Suggestions for potential cost sharing opportunities between industry and the Government;
- Suggested means for achieving compliance with the intent of NASA technical and programmatic standards and processes consistent with a human-rated program;
- Notional top-level concept of operations including engine fabrication, assembly, calibration and acceptance, and delivery to stage integration site (Michoud Assembly Facility, New Orleans, LA).

If a respondent wishes to provide a broader input beyond the topics described above or beyond the technical scope of the EUSE as described in Appendix A, then it is requested that such alternate responses be submitted separately. However, if a respondent includes an alternate approach than that described in Appendix A, the respondent shall identify which, if any, of the requirements and objectives in Appendix A could not be met or would need to be revised to accommodate the alternate approach. The respondent should also identify the cost implications, both impacts and savings, associated with the suggested changes to those requirements.

Contract Type / Incentive Arrangement

NASA is interested in Industry inputs regarding contract type and incentive arrangements that properly balance risk and reward excellent performance. Traditionally the type of effort envisioned would include some form of an award fee or an incentive fee arrangement. NASA is interested in your input with regards to moving towards a Fixed Price contract arrangement – potentially in the development phase but most likely in the longer term – that will allow Industry to obtain a higher return on investment for achieving cost savings. We request any input regarding incentive arrangements to include previous experiences that worked well plus any non-traditional ideas on contract types and incentives.

Teaming Arrangements

NASA is also interested in Industry inputs regarding potentially advantageous and synergistic teaming arrangements amongst potential suppliers. Such arrangements or partnerships could offer the opportunity to achieve long-term affordability goals, bring into the arena new and potentially innovative partners, and encourage broader participation for both this suggested engine development effort and related NASA activities. We request any input regarding teaming arrangements to include previous experiences that worked well, advice with regards to potential pitfalls, and any non-traditional ideas that apply to this topic.

Commercialization

NASA does not wish to preclude the potential commercial use of engine or engine component designs. We are interested in industry input on approaches that NASA should take in the development or acquisition process to avoid creating barriers to commercialization.

Response Instructions

Any organization that intends to respond to this RFI is requested to email a "Notice of Intent" to the Point of Contacts (POC) listed below within 7 business days of this RFI posting date. However, failure to submit a notice of intent does not preclude anyone from submitting a response. Note that organizations interested in submitting may also be interested in recent progress at MSFC in the arena of additive manufacturing to be presented at the Wernher von Braun Memorial Symposium, October 27-29, 2014 at the University of Alabama in Huntsville. Additional information on the symposium may be found at www.astronautical.org.

The information obtained will be used by NASA for planning and acquisition strategy development. NASA will use the information obtained as a result of this RFI on a non-attribution basis. Providing data/information that is limited or restricted for use by NASA for that purpose would be of very little value and such restricted/limited data/information is not solicited. No information or questions received will be posted to any website or public access location. NASA does not plan to respond to the individual responses. This RFI is being used to obtain information for planning purposes only and the Government does not presently intend to award a contract at this time. As stipulated in FAR 15.201(e), responses to this notice are not considered offers and cannot be accepted by the Government to form a binding contract. This RFI is subject to FAR 52.215-3.

All responses should be provided in MS Word document format via electronic media. Font should be Times New Roman, size 12. Responses should not exceed 30 pages. Please submit responses no later than October 24, 2014, to NASA/MSFC Office of Procurement, Attn: PS42/Jennifer A. Lawson, Contracting Officer, Marshall Space Flight Center, AL 35812 or via e-mail at jennifer.a.lawson@nasa.gov and cc: Mark York, Contracting Officer at mark.a.york@nasa.gov.

Points of Contact

Primary:
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APPENDIX A

Preliminary EUSE Engine Requirements Document

A.1 Introduction

The purpose of this document is to establish for the NASA Marshall Space Flight Center, Space Launch System (SLS) Program Engines Element Office the preliminary technical requirements for the Exploration Upper Stage Engine (EUSE). These requirements as listed here represent the minimum set necessary to define the engine at a conceptual level. A more expansive and detailed Engine Requirements Document (ERD) will eventually be necessary to define the EUSE as part of the SLS Program.

A.2 Documents

This section contains documents specifically cited as applicable within this ERD. The listed applicable documents and their contents form a part of the overall technical requirements set to the extent specified herein. The NASA standards can be found here: https://standards.nasa.gov/documents/nasa

Document Number	Document Title	Revision	Date
NASA-STD-5012	Strength and Life Assessment Requirements for Liquid Fueled Space Propulsion System Engines	Baseline	Jun 2006
NASA-STD-5017	Design and Development Requirements for Mechanisms	Baseline	Jun 2006
NASA-STD-5019	Fracture Control Requirements for Spaceflight Hardware	Baseline	Jan 2008
NASA-STD-6016	Standard Materials and Processes Requirements for Spacecraft.	Baseline	Jul 2008

A.3 System Design Requirements

This section contains the essential technical requirements that apply to the performance, function, and design of the EUSE. This section is intended to indicate, as definitively as practicable, the minimum requirements that the configuration item, the EUSE, must meet to fulfill its intended purpose. The technical requirements define what the EUSE must do or qualities that the EUSE must have. The requirements of this section would be verified as part of a subsequent engine development effort.

The standard systems engineering convention used in this document which indicates requirements, goals, and statements of facts is as follows:

- Shall – Used to indicate a binding requirement
- Should – Used to indicate a desired goal
- Will, is, or are – Used to indicate a statement of fact

Every design requirement containing a "shall" is binding and must be ultimately verified. Also, general section notes have been included. The section notes are intended to provide clarification, justification, purpose, and/or origin of the requirement.

A.3.1 Engine Description

The EUSE is a liquid-hydrogen/liquid-oxygen rocket engine intended to provide upper stage and in-space propulsion. It is high-performance to fulfill projected mission requirements and it is highly reliable to meet the needs for human space flight.

A.3.2 Engine Qualities

A.3.2.1 Performance

[R.EUSE.2101] **EUSE Nominal Vacuum Thrust**
The EUSE shall provide a nominal vacuum thrust of between 24,000 and 35,000 pounds-force when operating at nominal engine inlet conditions.

[R.EUSE.2102] **EUSE Thrust Precision**
The EUSE shall operate within a tolerance band of ± 2% around the nominal vacuum thrust value at nominal engine inlet conditions.

[R.EUSE.2103] **EUSE Vacuum Specific Impulse**
The EUSE shall provide a threshold minimum vacuum specific impulse of 454 seconds when operating at corrected nominal thrust, mixture ratio, and engine inlet conditions – with an objective (goal) minimum vacuum specific impulse of 462 seconds at the same corrected conditions.

[R.EUSE.2104] **EUSE Nominal Mixture Ratio**
The EUSE shall operate at a nominal overboard mixture ratio (oxidizer/fuel) of 5.55 at nominal engine inlet conditions.

[R.EUSE.2105] **EUSE Mixture Ratio Variation**
The EUSE shall provide for commanded, in-run overboard mixture ratio variation within the range of 5.2 to 5.9 at nominal engine inlet conditions.

Section A.3.2.1 Notes:
The engine design point for nominal thrust remains open for trade considerations at the program level. The minimum specific impulse value is a guaranteed minimum that takes into account three-sigma uncertainties in both measurement accuracy and run-to-run variation. The thrust precision requirement takes into account both run-to-run variability and in-run deviation considerations.

Further, the following conditions are to be considered nominal, steady-state (mainstage) inlet conditions for EUSE for the purposes of the above performance requirements:

- Liquid Oxygen Inlet Total Pressure 40 psia
- Liquid Oxygen Inlet Temperature 172 R
- Liquid Oxygen Purity 99.85%
- Liquid Hydrogen Inlet Total Pressure 30 psia
- Liquid Hydrogen Inlet Temperature 39 R

A.3.2.2 Functionality

[R.EUSE.2201] **EUSE Start**
The EUSE shall perform a controlled engine start upon command directly to any planned steady-state, mainstage power level.

[R.EUSE.2202] **EUSE Shutdown**
The EUSE shall perform controlled engine shut-down operations upon command from any power level.

[R.EUSE.2203] **EUSE Mission Profile**
The EUSE shall provide for as many as three engine start, mainstage, and shutdown sequences within a single mission with as much as 5 days of in-space loiter between starts.

[R.EUSE.2204] **EUSE Minimum Net Positive Suction Pressure**
The EUSE shall operate at mainstage with the following minimum net positive suction pressure values at the engine inlet:

- Hydrogen Propellant Inlet 4 psi
- Oxygen Propellant Inlet 6 psi

[R.EUSE.2205] **EUSE Gimbal Flexure**
The EUSE shall provide engine system flexure relative to a fixed thrust mount such that a 4.5-degree circular gimbal pattern can be described by the thrust vector.

[R.EUSE.2206] **EUSE Hydrogen Tank Pressurization Flow**
The EUSE shall provide gaseous hydrogen output flow for stage propellant tank pressurization.

[R.EUSE.2207] **EUSE Oxygen Tank Pressurization Flow**
The EUSE should provide opportunities for heated helium or autogenous gaseous oxygen output flow for stage propellant tank pressurization.

Section A.3.2.2 Notes:
The assumed ambient start and shutdown conditions are to be considered on-orbit or in-space at near-vacuum conditions. If thrust vector control is to be achieved in a manner different than traditional physical engine gimbal (actuated nozzle pointing), then the flexure requirement can be translated to an equivalent requirement more appropriate for the alternative thrust vector control system. With regards to oxygen tank pressurization, various options could be traded in order to achieve an optimal design at the stage level. An engine design that allows for a broader range of options could be beneficial.

A.3.2.3 Characteristics

[R.EUSE.2301] **EUSE Thrust-to-Mass Ratio**
The EUSE shall have a threshold vacuum-thrust-to-dry-mass ratio of not less than 45 [pounds-force/pounds-mass] including associated accessories – with an objective (goal) vacuum-thrust-to-dry-mass ratio of 60 [pounds-force/pounds-mass] including the same accessories.

[R.EUSE.2302] **EUSE Dimensions**
The EUSE shall not exceed maximum static dimensions of 125 inches in length when in launch configuration.

[R.EUSE.2303] **EUSE Life – Starts**
The EUSE shall provide hardware life without component refurbishment for at least five engine starts after engine delivery.

[R.EUSE.2304] **EUSE Life – Seconds**
The EUSE shall provide hardware life without component refurbishment for at least 2,000 seconds after engine delivery.

[R.EUSE.2305] **EUSE Continuous Firing Duration**
The EUSE shall provide at least 800 seconds of continuous hot-fire operation.

[R.EUSE.2306] **EUSE Reliability**
The EUSE shall have a single-engine, mean risk of 1 in 500 for an engine root-cause failure leading to loss of mission across the complete mission profile.

Section A.3.2.3 Notes:
Engine delivery is defined as occurring after any necessary engine calibration, green-run and/or acceptance testing and subsequent post-test inspections and processing.

A.3.2.4 Configuration

[R.ESUE.2401] **EUSE Valve Actuation Redundancy**
The EUSE shall provide redundant actuation of primary propellant and hot-gas valves used during start, operation, and shutdown the engine.

[R.EUSE.2402] **EUSE Critical Instrumentation**
The EUSE shall provide redundant instrumentation ports for critical instrumentation used for engine control or engine failure identification.

[R.EUSE.2403] **EUSE Off-Mounted Controller**
The EUSE shall accommodate the use a controller unit mounted external to the engine.

[R.EUSE.2404] **EUSE Sea-Level Testing**
The EUSE shall be configurable such that sea-level engine system testing is possible with no component damage.

Section A.3.2.4 Notes:
This section is dedicated to unique requirements arising from human rating and vehicle integration or development considerations. Because both human rating and vehicle development are integrated considerations beyond the scope of just the engine, there could be trade space available for alternative, integrated solutions for achieving the same intent. Note that the sea-level configuration of the engine for testing purposes is not expected to have performance equal to that of the full, flight configuration.

A.3.3 Design and Construction

[R.EUSE.3001] **EUSE Strength and Life Design**
The EUSE shall meet the intent of the requirements of NASA-STD-5012 for strength and life assessments used for engine design.

[R.EUSE.3002] **EUSE Mechanism Design**
The EUSE shall meet the intent of the requirements of NASA-STD-5017 for the design and development of mechanisms on the engine.

[R.EUSE.3003] **EUSE Fracture Control**
The EUSE shall meet the intent of the requirements of NASA-STD-5019 with regards to fracture control assessments and processes used for engine design and fabrication.

[R.EUSE.3004] **EUSE Materials and Processes**
The EUSE shall meet the intent of the requirements of NASA-STD-6016 with regards to materials and processes used for engine design and fabrication.

Section A.3.3 Notes:
As compared to the usual set of applicable documents for a NASA rocket engine, this set as currently listed is minimal. The intent, at this point, is to focus on the key intrinsic aspects of the design. Also, there are no standards cited here for an engine controller system or associated control software based upon the assumption that the engine control function would be stage mounted and government furnished equipment (GFE). However, should this assumption regarding GFE status be altered due to other considerations, then a broader range of applicable design and construction standards related to electrical systems, electronics, and software should be expected.

Further, the language "shall meet the intent" is directly tied to the established process of applicable documents compliance validation as exercised by the Liquid Engines Office of the Space Launch System Program. This risk-based process involves generation of a meets-or-exceeds assessment, the development of a compliance plan, and the processing of formal documentation establishing concurrence from the program element office, NASA engineering, NASA safety and mission assurance, and the contracting officer.

A.3.4 Environments and Interfaces

[R.EUSE.4001] **EUSE Performance and Environments**
The EUSE shall meet its requirements during and after exposure to the induced and natural external environments typical for upper stage and in-space rocket engines.

[R.EUSE.4002] **EUSE Cluster Configuration**
The EUSE shall meet performance and functionality requirements when part of a four-engine cluster where the engine centerlines form a square pattern with 120-inch sides.

[R.EUSE.4003] **EUSE Interface Configuration**
The EUSE shall have an interface to the vehicle physically consistent with the RL10 engine with respect to primary thrust transmission (gimbal block) and liquid hydrogen and liquid oxygen propellant feed line connections.

[R.EUSE.4004] **EUSE Electrical Power Interface**
The EUSE shall use 28 volts direct-current (nominal) electrical power as supplied by the vehicle for any electrical power needs.

[R.EUSE.4005] **EUSE Pneumatic Interface**
The EUSE shall use helium at the following conditions for any pneumatic gas requirements:

- Pressure 425 to 500 psia
- Temperature 300 to 625 R

Section A.3.4 Notes:
The details of the induced environments and interface control documentation represent two pieces of key design considerations to be defined, evolved, and matured as part of the overall development effort. The pneumatics interface conditions could be subject to change with sufficient justification.