University of Florida
Mechanical and Aerospace Engineering

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SUBORBITAL LUNAR TRANSPORT SYSTEM REQUIREMENTS

APPROVED FOR USE IN

EAS4700 SECTION 1029 SPRING SEMSETER 2022

ONLY

1.0 INTRODUCTION

1.1 SCOPE & PURPOSE

This specification establishes the performance and design requirements for the Suborbital Lunar Transport (SLT) as allocated from EAS4700 Spring Course Description. Requirements in section 3.2 define the performance of the SLT as a whole. Requirements in sections 3.3 through 3.6 are constraints with which the SLT must comply. The performance requirements herein are applicable during nominal operations, maintenance, and contingency events. This document is applicable to the assembly and assembly complete stage of the SLT.

1.2 CHANGE AUTHORITY/RESPONSIBILITY

Proposed changes to this document shall be submitted via a Change Request (CR) to the Suborbital Lunar Transport Program Control Board (SPCB) for consideration and disposition. All such, requests will be submitted via the most current version of the Suborbital Lunar Transport Configuration Management Change Process document EAS4700-CR-001.

1.3 CONVENTION AND NOTIFICATION

The Suborbital Lunar Transport Program defines its implementation of requirement verbs as follows:
a. “Shall” – Used to indicate a requirement that is binding, which must be implemented and its implementation verified in the design.
b. “Should” – Used to indicate good practice or a goal which is desirable but not mandatory.
c. “May” – Used to indicate permission.
d. “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.
e. "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

1.4 MEASUREMENT UNITS

The Suborbital Lunar Transport Program will utilize NIST SP811, Guide for the Use of the International System of Units (SI) for standardization and conversion of the units of measure.

2.0 DOCUMENTS

For the purpose of this document, the term 'document' can also refer to 'digital artifacts,' 'models,' or 'viewpoints' as needed to convey and exchange configuration managed data or information. An objective of the Gateway Program is to evolve into a digital engineering environment and away from the traditional document-based approach for capturing data, reports and baselines.

2.1 APPLICABLE DOCUMENTS

The following documents may include specifications, models, standards, guidelines, handbooks, and other special publications that are called out in sections 3.2 through 3.6. The documents listed in this paragraph are applicable to the extent specified herein. Designations authorized by the Program Manager and established for applicable documents consist of:

• **Type 1** documents or standards are those that contain requirements the Program **must meet** as written.

• **Type 2** documents or standards are those that contain requirements the Program can either **choose** to **adopt** or **accept an alternate proposal.**

• **Type 3** documents or standards are those that represent the 'best practices' observed by or normally used by NASA over the substantial development history of both human and non-human spaceflight missions. The Program **does not need to** either formally **adopt** the documents or **recommend an alternate.**

TABLE 2.1-1 TYPE 1 APPLICABLE DOCUMENTS

Document Number	Document Title	Revision
NASA-STD-3001	NASA SPACEFLIGHT HUMAN-SYSTEM STANDARD VOLUME 2: HUMAN FACTORS, HABITABILITY, AND ENVIRONMENTAL HEALTH	Latest
NASA-STD-4003	Electrical Bonding for NASA Launch Vehicles, Spacecraft, Payloads, and Flight Equipment	Latest
NASA-HDBK-4002	Mitigating In-Space Charging Effects-A Guideline	Latest

NASA-STD-5020	Requirements for Threaded Fastening Systems in Spaceflight Hardware	Latest
NASA-STD-5019	Fracture Control Requirements for Spaceflight Hardware	Latest
NASA-STD-5017	Design and Development Requirements for Mechanisms	Latest
NASA-STD-5012	Strength and Life Assessment Requirements for Liquid-Fueled Space Propulsion System Engines	Latest
NASA-STD-5006	General Welding Requirements for Aerospace Materials	Latest
NASA-STD-5002	Load Analyses of Spacecraft and Payloads	Latest
NASA-STD-5001	Structural Design and Test Factors of Safety for Spaceflight Hardware	Latest
NASA-HDBK-5010	Fracture Control Implementation Handbook for Payloads, Experiments, and Similar Hardware	Latest
NASA-STD-6016	Standard Materials and Processes Requirements for Spacecraft	Latest
NASA-STD-6012	Corrosion Protection for Space Flight Hardware	Latest
NASA-STD-7012	Leak Test Requirements	Latest
NASA-STD-7009	Standard for Models and Simulations	Latest
NASA-STD-7002	Payload Test Requirements	Latest
NASA-STD-7001	Payload Vibroacoustic Test Criteria	Latest
NASA-HDBK-7009	NASA HANDBOOK FOR MODELS AND SIMULATIONS: AN IMPLEMENTATION GUIDE FOR NASA-STD-7009	Latest
NASA-STD-8739.12	Metrology & Calibration	Latest
NASA-STD-8719.24	NASA Expendable Launch Vehicle Payload Safety Requirements (Base + Annex)	Latest

2.2 TECHNICAL AUTHORITY STANDARDS AND REQUIREMENTS

This section identifies the Technical Authority (TA) Standards and Requirements and designations. The Program Manager and TAs are responsible for determining how these standards and requirements are applied depending on the specified type. There are currently no Type 1 TA Standards and Requirements identified.

Type 2 documents are those that contain requirements the Program can either **choose** to **adopt** or **accept an alternate proposal**.

The Element or Module provider will be allowed to propose alternate requirements within documents that they consider to meet or exceed the intent of the Type 2 designation to the Program Manager. Any 'Applicable' document listed in a Type 2 document is also considered to be Type 2 unless specified otherwise. The Element or Module will assess equivalency of the

requirements and risk to the Program and present the evidence to the NASA TAs and Program Manager for approval. The process for accepting alternates is defined in DSG-PLAN-007, Gateway Systems Engineering Management Plan, Section 5.5.8 Standards.
Type 3 documents are those that represent the 'best practices' observed by or normally used by NASA over the substantial development history of both human and non-human spaceflight missions. The Program **does not need to** either formally **adopt** the documents or **recommend an alternate.**

TABLE 2.2-1 TYPE 2 TECHNICAL AUTHORITY DOCUMENTS

Document Number	Revision	Document Title
AIAA S-111	2005	Qualification and Quality Requirements for Space Solar Cells
AIAA-S-112	A-2013	Qualification and Quality Requirements for Space Solar Panels
	Latest	
	Latest	
	Latest	
	Latest	
	Latest	
	Latest	
	Latest	
	Latest	
	Latest	
	Latest	
	Latest	
	Latest	
	Latest	
	Latest	
	Latest	
	Latest	
	Latest	

2.4 ORDER OF PRECEDENCE

In the event of a conflict between the text of this specification and the references cited herein, the text of this specification takes precedence. Nothing in this specification, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

3.0 DESCRIPTION AND REQUIREMENTS

3.1 SYSTEM DESCRIPTIONS AND DESIGN CONSIDERATIONS

The purpose of the SLT is to provide robust support of the extended exploration of Earth's satellite the Moon.
The SLT is intended to be an evolvable reusable and multi functioned vehicle capable of delivering 200 Kg payloads up to 300 Km from a permanent crewed station at Shackleton Crater (Shackleton Crater Station) at the Lunar South Pole to exploration crews at forward bases of operation who may require emergency supplies or replacement hardware. It also has the capability to deliver and recover scientific rovers to and from sites of interest on the lunar surface. The baseline SLT is intended to be semi-autonomous / tele-operated by crews at Shackleton Crater Station, the lunar Gateway station or Earth.

3.1.1 System Description

The SLT is a rocket powered vehicle with the capability of carrying either a small pressurized payload canister, an unpressurized payload rack or a rover based on the Boston Dynamics SPOT robot. The SLT has the capability of navigating to a specific location and land with a high degree of precision and avoid terrain that would result in damage to or loss of the SLT and/or its payload. The SLT is capable of safing hazardous systems automatically to facilitate operations with astronauts on the lunar surface. Payload deployment may be either autonomous (without human interaction) or manual (relying upon human interaction) depending on the payload's operational or mission requirement.

3.1.2.1 Sustainability / Upgradability

The SLT should be repairable and provide for upgradability to allow new technology infusion to address obsolescence issues by astronauts with basic tools and facilities on the lunar surface. The SLT is able to be reconfigured by pressure suited astronauts including the removal and replacement of major modules such as, but not limited to, the payload module, a functional module (engine module(s), fuel module(s), navigation module, etc.) or any element with limited life that may have to be performed as part of nominal operation of the SLT thus negating the need for the entire SLT to be decontaminated and brought into a pressurized repair facility for any but the most extensive repairs or modifications.

3.2 REQUIREMENTS

3.2.1 Design Constraints

3.2.1.1 Launch Vehicle Compatibility Requirements

ASD-SLT-01. Launch Vehicle Capability

The SLT shall be capable of launching as a Co-manifested Payloads (CPL) on the Space Launch System (SLS). The SLT should also be compatible with a suitable commercial launch vehicle.

Rationale: Having a commercial launch vehicle & SLS, keeps trade space open for robust support of lunar surface operations, and protects for development issues with co-manifesting, extended flight suspension of SLS, etc. SLS CPLs are available beginning with Block 1B.

ASD-SLT-02. Structural Load Environment

The SLT shall be qualified for structural loads per ESD 30000 Mission Planner's Guide. The SLT should also be compatible with a suitable commercial launch vehicle.

ASD-SLT-03. Shock Loads

The SLT shall be qualified for shock loads per ESD 30000 Mission Planner's Guide. The SLT should also be compatible with a suitable commercial launch vehicle.

ASD-SLT-04. Acoustics Environment

The SLT shall be qualified for Acoustic Loads per ESD 30000 Mission Planner's Guide. The SLT should also be compatible with a suitable commercial launch vehicle.

ASD-SLT-05. Vibration Environment

The SLT shall be qualified for Vibration Loads per ESD 30000 Mission Planner's Guide. The SLT should also be compatible with a suitable commercial launch vehicle.

ASD-SLT-06. Thermal Environment

The SLT shall be qualified for Thermal Loads per ESD 30000 Mission Planner's Guide. The SLT should also be compatible with a suitable commercial launch vehicle.

ASD-SLT-07. Liftoff and Ascent Venting

The SLT shall be qualified for pre-launch purge and ascent venting profiles per ESD 30000 Mission Planner's Guide. The SLT should also be compatible with a suitable commercial launch vehicle.

ASD-SLT-08. Electrical Bonding / Grounding

The SLT shall be compatible with electrical bonding and grounding requirements per ESD 30000 Mission Planner's Guide. The SLT should also be suitable compatible with a commercial launch vehicle.

ASD-SLT-09. SLT Vehicle Mass

The SLT shall have a total mass at launch of not more than 2,000 Kg not including launch vehicle attach hardware.

Rationale: Limiting the SLT mass as low as possible provides flexibility in manifesting with primary payloads.

ASD-SLT-010. Spacecraft Coordinate System

The SLT shall have a spacecraft coordinate system compliant with ESD 30000 Mission Planner's Guide. The SLT should also be compatible with a suitable commercial launch vehicle.

ASD-SLT-011. SLT Center of Gravity

SLT Center of Gravity (CG) shall be calculated and documented and in compliance with ESD 30000 Mission Planner's Guide. The SLT should also be compatible with a suitable

SLT Operational Requirements

ASD-SLT-012. Debris

The SLT shall not generate debris as a consequence of normal operation.

Rationale: Staging, dropping tanks, utilization of descent stages as launch platforms and jettisoning of unneeded hardware pose hazards to humans and facilities in the operational arena as well as contaminating pristine lunar environments.

ASD-SLT-013. Regolith Impingement

The SLT shall minimize the lunar regolith ejected when launching from or landing on unimproved landing sites.

Rationale: Regolith ejected at high speed by rocket exhaust or other similar gaseous venting may cause excessive wear, contamination or other damage to vehicles, suited astronauts, equipment or structures within range of the ejecta.

ASD-SLT-014. SLT Moments and Products of Inertia

The Moments and Products of Inertia shall be calculated in both the pre- and post deployment configuration of the SLT. Pre-deployment is defined as the SLT configuration when stowed for launch. Post-deployment is defined as the SLT configuration while in its mission mode.

Rationale: The SLT will have to be maneuvered in both stowed for launch and operational configuration.

ASD-SLT-015. SLT Payload Mass Capability

The SLT shall have a payload capacity of 200Kg mass.

Rationale: Having a 200Kg mass capability allows mass margin for tele-operated rovers to collect and return samples, and transport emergency and/or restocking supplies for up to 4 exploration crewmembers.

ASD-SLT-016. SLT Payload Volume Capability
The SLT shall be capable of accommodating a payload having a volume of 1.2m long by 0.5m tall by 0.5m wide.

Rational: A payload volume of 1.2m x 0.5m x 0.5m allows room for tele-operated rovers to collect and return samples, and transport emergency and/or restocking supplies for up to 4 exploration crewmembers.

ASD-SLT-017. SLT Payload Interface
The SLT shall define a standard payload mechanical, electrical and communication interface for all suitable payloads. The interfaces should conform to industry standards established for CubeSat interfaces with launch vehicle providers.

Rational: SLT payloads will be of a size and capability similar to CubeSats and may actually be derived from CubeSats.

ASD-SLT-018. SLT Payload Power Capability
The SLT shall be capable of providing 28V DC power to payloads for the duration of the mission

Rational: A payload may require power to operate during or immediately after the SLT portion of the mission.

ASD-SLT-019. Payload Communication Capability
The SLT shall be capable of accommodating a payload requiring to communicate to surface or space based operators via X-band radio.

Rational: A payload may have an operational requirement to communicate with mission controllers either to receive commands or to transmit data.

ASD-SLT-020. SLT Operational Range Capability
The SLT shall have a payload capacity of carrying a 200Kg mass payload to a maximum operational limit of 300Km and return that mass to the point of origin in one operational cycle without the need for refueling or refurbishment.

Rationale: Having a 300 Km operational range capability allows the SLT to provide timely support from SCS to distant exploration sites more swiftly than a surface rover. It also supports scientific rover operation and sample return from previously unexplored regions.

ASD-SLT-021. Propulsion System Capability
The SLT shall provide a fuel capacity that would support performing a minimum of 1.1 round-trips to the maximum operational limit without refueling.

The SLT may either be capable of delivering itself from lunar orbit or be delivered aboard a Commercial Lunar Payload Service lander.

Rationale: Having a fuel capacity to allow for a 10% margin over the 300 Km design operational range requirement allows the SLT to have the ability to search for an acceptable landing site when operating at the maximum supported range and vectoring to an alternative landing site at SCS.

ASD-SLT-022. Nominal Operating Environment

The SLT shall support full flight and payload support capabilities during Lunar day conditions and up to 72 hours in Lunar night conditions.

Rationale: Emergencies may necessitate delivering critical items during lunar night conditions to stranded crews.

ASD-SLT-023. Off-nominal Operating Environment

The SLT should support limited operational capabilities including, but not limited to communication and temperature maintenance for a period no less than ½ of a Lunar night cycle.

Rationale: The storage location at SCS may experience limited periods of lunar night conditions and the SLT shall be able to communicate health & status during down periods.

ASD-SLT-024. Operational Cycle Capability

The SLT shall have the ability to launch after landing within 20 minutes without refueling within one mission cycle.

Rationale: Having a rapid turnaround capability enhances utility for supporting emergency operations at remote sites and enhances ease of handling at SCS in support of multiple vehicle operations minimizing the need for multiple open launch/landing pads.

ASD-SLT-025. Navigation System Capability

The SLT shall be able to navigate to and land at a designated location with a precision of 10 meter. Terminal guidance shall allow for hazardous terrain avoidance at unimproved landing sites. Navigation may utilize inertial guidance and homing beacons depending on mission needs.

Rationale: Having the ability to precisely navigate to a designated location and avoid hazards to the vehicle without the need for human intervention is essential for safe operation of the vehicle in remote areas. Emergency situations may involve the use of Emergency position-indicating radio beacons.

ASD-SLT-026. Communication System Capability

The SLT shall be able to transmit and receive data and commands with SCS and remote sites either by line of sight or via relay satellite/tower as appropriate for the situation utilizing X-band radio.

Rationale: Having the ability to maintain constant communication with operational controllers at SCS during all phases of SLT mission operation to monitor the SLT's health and issue updated commands to the SLT is critical in the event of anomalies or emergency situations. It also allows for the SLT to be operated as a drone by astronauts performing Extra Vehicular Activities either at SCS or remote sites.

Other Requirements

ASD-SLT-027. End to End testing

A plan shall be developed for SLT end to end testing utilizing guidelines found in the compliance documents section.

ASD-SLT-028. SLT Logo

A graphic shall be created which represents the purpose of the mission. The graphic shall be in a PANTONE format. The graphic size and location on the SLT shall be large enough to be visually seen from 1 meter, with the unaided eye, prior to encapsulation into the SLS payload shroud.

ASD-SLT-029. Mission Operations

A mission plan shall be developed to show the SLT design is capable of navigating with the required precision and able to avoid hazards at landing sites.

Attitude requirements are to be identified by the team.

Rationale: A demonstration of vehicle capabilities is necessary for mission planners to have confidence that the SLT fulfills programmatic needs. Successful completion of this mission plan requirement will mark Initial Operational Capability.

ASD-SLT-030. Specialized Support Equipment

Specialized Support Equipment (SE) needed solely for the refitting, refurbishment, repair and refueling of the SLT on the lunar surface shall be included with the delivery of the first flight unit.

SLT SE may be delivered to SCS as part of a regular logistics support mission, however, delivery of SE for the first mission must be delivered no later than concurrently with the SLT.

Rationale: The mass and or the volume of SE may exceed the capability of the SLT to ferry to SCS from lunar orbit if that method of delivery is selected.

ASD-SLT-031. Delivery

The flight SLT and all necessary flight processing hardware shall be delivered to Kennedy Space Center's Multi Payload Processing Facility for launch site processing no later than nine months prior to launch. Initial launch date is currently scheduled for November 2030.

Rationale: Launch site processing includes post shipment test and checkout, final assembly, flight readiness test and check out, integration into launch vehicle and flight readiness tests such as, but not limited to, bond checks, communication tests and flight closeout inspections.

ASD-SLT-032. Budget

The total amount of money that can be provided ("Total Cost Cap") to the project shall be no greater than $1.5 billion US Dollars (USD) over a 5-year period. Maximum unit cost to build the "launch-ready" SLT shall not exceed: $0.4 billion USD.

The budget report shall show costs comprised of both labor and hardware costs. If the Total Cost Cap is exceeded, then the mission will be canceled.

Cost reduction bonus: As an incentive to reduce the actual total cost of the mission, the project will receive a 10% cash bonus for every USD below the Total Cost Cap. By way of example, if the total project budgeted cost equals $10 million USD then there is a resultant mission project savings of $2 million USD. As a result of this savings, a total of $200,000 USD would be returned to the project as cash, with no restrictions as to how that cash would be spent.

The budget report should indicate profit margins as well.

Safe Assumptions for This Class

For this project the design groups may safely assume the following:

- NASA will purchase the SLT and therefore absorb launch costs.
- SCS will produce needed commodities to refuel the SLT at end of mission.
    - Commodities will include Liquid Oxygen, Liquid Hydrogen and Methane. Oxygen and hydrogen will be harvested form Lunar ice. Methane will be excess fuel not required by Commercial Lunar Payload Service landers and/or Human Landing System landers. Supplemental methane may also be taken from harvested from crew by-products (CO_2 and biological waste).

  - NASA will store the commodities until needed by the SLT.

- The SLT is assumed manifested on the SLS as a default and launcher choice is not required by the teams. However, since other launch vehicles from launch service providers such as SpaceX, Blue Origin and United Launch Alliance, the launch environment analysis will have to cover a series of possible vehicles.