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SATELLITE SERVICING CAPABILITIES OFFICE (SSCO)

RESTORE-L MISSION LEVEL 2 REQUIREMENTS

Goddard Space Flight Center
Greenbelt, Maryland

National Aeronautics and
Space Administration

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Questions or comments concerning this document should be addressed to:

NASA/Goddard Space Flight Center
SSCO, Code 408
Attention: Configuration Management Office
Greenbelt, Maryland 20771

SATELLITE SERVICING CAPABILITIES OFFICE

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OPEN ITEMS

Whenever specific data needed for this document is either unknown or unavailable at the time the current document version is released, a marker is inserted into the text as a placeholder. The marker consists of a prefix – either “TBD,” “TBR,” or “TBS” – and a sequential ID number and will be enclosed in angle brackets. As each TBD/TBR/TBS is solved, the updated text is inserted in each place where that TBD/TBR/TBS appears in the document and the item is removed from the tables below. As new items are created, they will be added to these lists in accordance with the above described numbering scheme. Original TBDs/TBRs/TBS’s will not be renumbered.

"To Be Determined" Items

"To Be Resolved" Items

Item No.	Location	Summary	Actions to Close	Assignee	Due Date
TBR-14	3.4.4.1 LEO-211	Client predicted orbit determination data to within +/- 100 m <TBR>, 3 sigma,...	Coordinate Client OD data content and delivery with the Client flight ops team. Develop a navigation error budget for the client rendezvous and adjust conops to minimize risk.	MSE, OPS, and RPO Teams	

"To Be Supplied" Items

1 INTRODUCTION

1.1 PURPOSE

This document establishes functional, performance, interface, and design constraint requirements for the Restore-L Mission. This mission will demonstrate several technologies essential to robotic servicing of spacecraft by providing refueling services to a government client satellite. Nominally, this mission will provide propellant to an operational earth-sensing satellite nearing the end of its propellant lifetime and is described in more detail in paragraph 1.6 below.

This document is a mission-level (Level 2) document and sits in the hierarchy depicted in Figure 1-1.

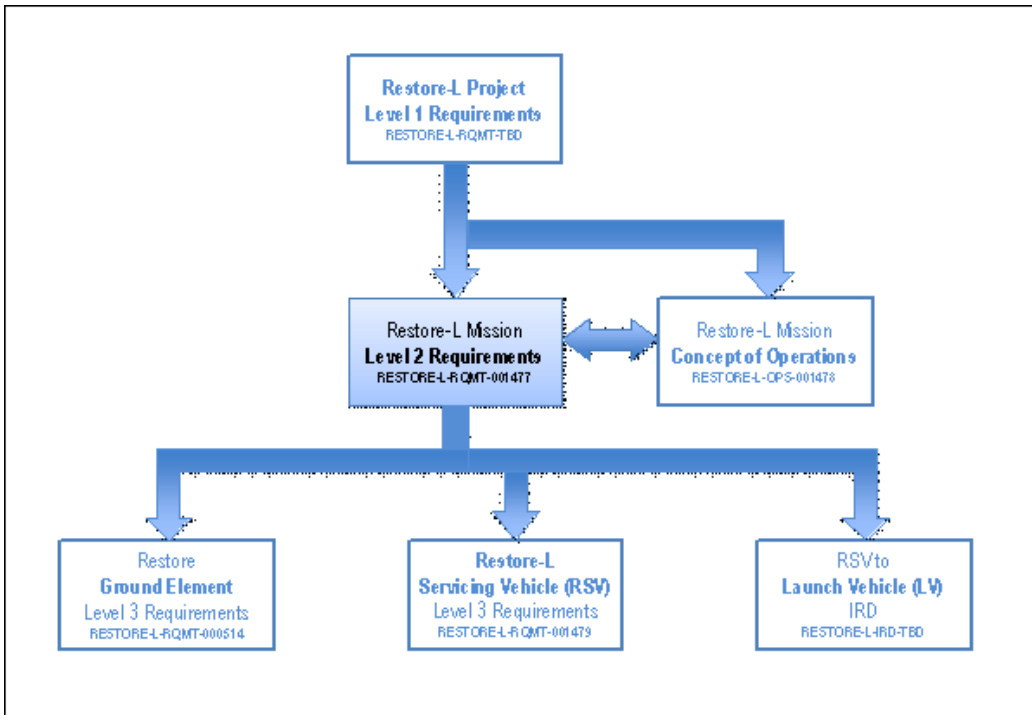

Figure 1-1 Restore-L Document Hierarchy

1.2 ORGANIZATION

This document is organized into seven major sections to which appendices may be added as required. Section 1 is this Introduction. Section 2 identifies other documents referenced herein. Section 3 gives the detailed design requirements and is discussed in more detail below. Section 4 provides information about verifying compliance with the requirements of Section 3. Section 5 usually provides details to a vendor for packaging and delivery of the assembled hardware. It is not applicable to this mission-level document, but may be included in lower level documents. Section 6 is a place for notes and other information that may help interpret and understand the requirements as intended. Lastly, Section 7 is a list of abbreviations and acronyms.

Section 3 is the core of this document and is divided into seven key subsections. The general Mission Architecture is defined in section 3.1. The functional and performance requirements for the mission are contained in section 3.2 and generally identify what Restore-L must do. Interface requirements are given in Section 3.3. Section 3.4 identifies a number of design constraints and is organized by engineering discipline. Section 3.5 covers operational requirements and, lastly, Sections 3.6 and 3.7 provide safety and mission assurance requirements, respectively.

Each requirement in Section 3 includes an ID number that can be used to cross-reference the requirement in the Dynamic Object Oriented Requirements System (DOORS®) requirements database.

1.3 CONTENT STATUS

The data in this document represent current requirements definition in all cases except for those noted with a To Be Determined (TBD), a To Be Resolved (TBR), or a To Be Supplied (TBS). ‘TBD’ indicates the need for data that are currently not known. ‘TBR’ indicates that the data supplied are the best information available, but the final details must be confirmed or resolved. ‘TBS’ indicates that the data exist but are not available at the time of this writing. All TBD, TBR, and TBS items are listed in the front of this document.

1.4 CHANGE PROCEDURE

The SSCO (Code 408) Configuration Management (CM) Office (CMO) maintains configuration control of this document. Once baselined, all changes, including removal of a "TBD," "TBR," or “TBS,” will require a Configuration Change Request (CCR) to be processed through the SSCO Configuration Management System.

1.5 VERB APPLICATION

Statements containing the verb “shall” are binding requirements. The verbs “should” and “may” are used for stating non-mandatory goals or denoting a statement of best practice. The verb “will” is used in a statement of fact, expected occurrence, or declaration of purpose.

1.6 MISSION DEFINITION

1.6.1 GENERAL DESCRIPTION

The Restore-L Mission will provide refueling services to a client satellite located in Low Earth Orbit (LEO) to extend its science-collection mission. The Mission architecture is illustrated in Figure 1-2. It is comprised of three mission elements: a Servicing Vehicle, a Ground Element, and the Launch Vehicle.

The Restore-L Servicing Vehicle (RSV) is the servicing agent. It flies out to a client satellite with a propellant load, performs the refueling service using robotic arms and tools, and then departs to a safe orbit to either await the next client or prepare for decommissioning or reentry.

The Launch Vehicle element consists of the Expendable Launch Vehicle (ELV) and corresponding support services. Also contained within the Launch Vehicle element are the integration and processing facilities and support functions – including the spacecraft-specific pad ground support equipment (GSE) and associated local ground control system – that are required once the spacecraft arrives at the launch site.

The Ground Element is comprised of the facilities, systems, networks and personnel required to operate the mission. It will include a mission operations center linked to the NASA Integrated Service Network (NISN). The payload teleoperations team may or may not be collocated with the vehicle operations team.

1.6.2 OPERATIONAL CONCEPTS

Restore-L is targeted for launch in December 2019 using an ELV. The ELV will insert the RSV into a LEO at an optimal location to service the client satellite. The RSV will use both ground-generated and on-board navigation solutions to rendezvous with the client, and then perform an autonomous capture. After client capture, the assigned servicing tasks will be performed by ground-based teleoperators. When all servicing tasks are complete, the RSV will release the client, back away to a safe distance, and then depart to its transit orbit.

Upon completion of its primary client mission, Restore-L may continue operations as part of an extended mission phase to refuel a second client. The duration of the extended mission is dependent on the required sequence of events and orbital position of the second client satellite.

At the end of the Restore-L Mission, the RSV will be decommissioned in accordance with NASA policy. The mission could also include the capability to refuel a second client, but that is not currently in the baseline.

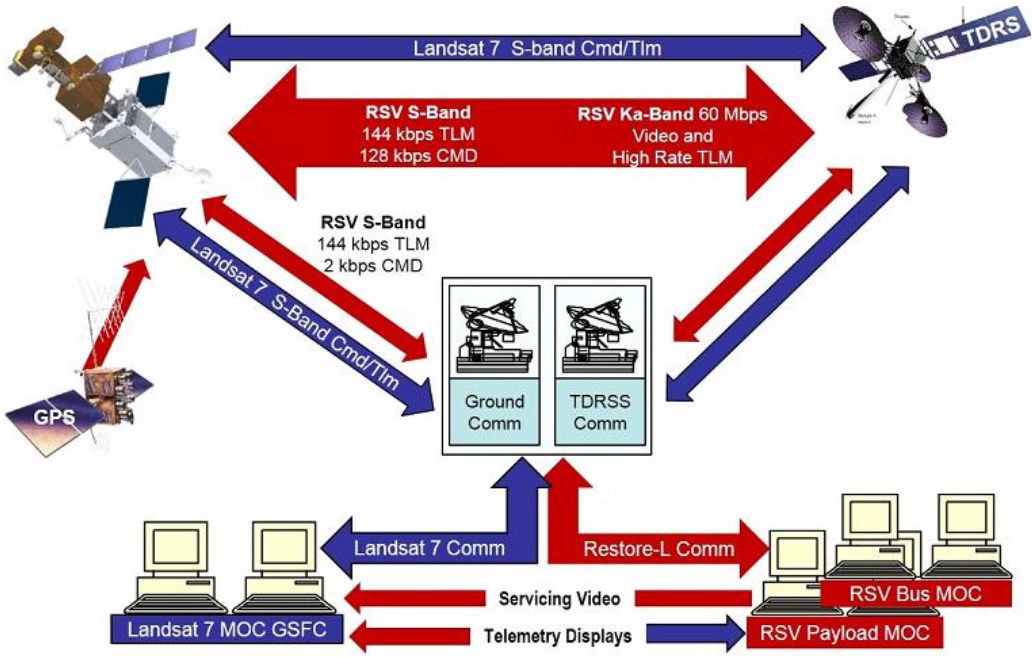

Figure 1-2 Restore-L Mission Architecture

1.6.3 INTERFACE DESCRIPTIONS

1.6.3.1 External Interfaces

Restore-L has one primary external interface: the Client Satellite. This interface includes multiple physical contacts tailored to the specific servicing tasks. Other interactions with the client include thermal, electrostatic discharge (ESD), electromagnetic compatibility (EMC), and client telemetry. Restore-L will not provide power or data services to the client, nor will Restore-L receive client telemetry directly from the client satellite. All client commanding and telemetry will be handled through the client's ground networks.

1.6.3.2 Internal Interfaces

Internal mission interfaces are between mission elements and include RSV-to-launch vehicle integration and RSV-to-ground communication links.

1.6.4 MISSION SUCCESS

Restore-L is a Class C Mission with six core Level 1 Objectives:

1. Restore-L shall rendezvous with and inspect a client satellite in Low Earth Orbit (LEO).

2. Restore-L shall perform an autonomous capture of a client satellite.

- The ability to perform autonomous proximity operations, approach and grapple

3. Restore-L shall perform teleoperated robotic servicing tasks.

- The ability to perform on-orbit robotic tasks by ground-based teleoperators.
- Does not include the transfer of propellant.

4. Restore-L shall refuel a Government-owned satellite in LEO.

- The ability to transfer propellant from onboard RSV tanks to the client tanks.

5. Restore-L shall demonstrate relocation of a client satellite.

6. Restore-L shall release and safely depart from a client satellite.

Mission Success has been defined in terms of the risk consequence towards meeting these six objectives and will be scored separately for each one. Various levels of achievement and the corresponding Risk Consequence score have been defined in Table 1-1.

Table 1-1 Restore-L Mission Risk Consequence Definitions

Risk Severity Score	1 No impact to Level 1 Objective	2 Minor impact to Level 1 Objective	3 Moderate impact to Level 1 Objective	4 Major impact to Level 1 Objective	5 Cannot meet Level 1 Objective
Objective	*Level of Accomplishment*				
1. Rendezvous and Inspection [RESL-3]	Successful rendezvous and full imaging with desired quality.	Successful rendezvous; adequate imaging with limited views or quality.	Successful rendezvous; unable to collect adequate imaging to evaluate client at planned range.	Successful rendezvous; unable to collect any imaging	Unable to rendezvous.
2. Autonomous Capture [RESL-4]	Successful autonomous grapple	Successful RSV control in capture box, but no autonomous grapple	Adequate RSV control in capture box; completed manual grapple.	Adequate RSV control in capture box; unable to grapple.	Unable to perform autonomous relative navigation and control
3. Teleoperated Robotics [RESL-5]	Completed all planned teleoperated tasks necessary to berth, refuel, and release	Completed at least one teleoperated task			Unable to perform any teleoperated task or command
4. Refueling [RESL-6]	Sufficient fuel transferred to allow 3 yrs operations (110 kg TBR)	Unable to transfer full allocated propellant (110 kg)			Unable to transfer any propellant
5. Relocation [RESL-7]	Relocated client per plan with full control and stability	Relocated client, but with limited control or stability			Unable to relocate client
6. Release [RESL-8]	The Client is left in a safe and stable state, within its control authority.			The Client sustained damage that precludes it from operating on station	The Client sustained damage that renders it immediately inoperable

Minimum Mission Success

1.7 COORDINATE SYSTEMS

Restore-L Mission coordinate systems are defined and controlled in RESTORE-L-SPEC-000602, Restore-L Mission Coordinate Systems.

1.8 SYSTEM OF UNITS

In accordance with NASA policy NPD 7120.4D, Restore-L will use the International System of Units (commonly known as the Systeme Internationale (SI) or Metric System of measurement) for design, development, and operations.

Whenever a number is given as the measure of some quantity, the units used will accompany the number. Standard units to be used for various quantities are given in Table 1-2 below. Standard metric prefixes (e.g., centi, milli, kilo) may be used where appropriate with any of these units.

All data exchanged with Restore-L Mission partners, participating organizations, and contractors that work in legacy units will be in metric units with the equivalent English units in parentheses.

Table 1-2 Standard SI Units for Restore

Quantity	**SI Unit and Symbol**
Length - hardware dimensions - orbital distances	meter (m) kilometer (km)
Area	square meter (m^2)
Volume	cubic meter (m^3)
Time	second (s)
Acceleration	m/s^2
Mass	kilogram (kg)
Angles	degrees (deg) or radians (rad)
Angular Velocity	rad/s
Moment of Inertia	$kg*m^2$
Angular Momentum	$kg*m^2/s$
Power	watt (W)
Force	newton (N)
Pressure	pascal (Pa)
Torque	newton-meter (N-m)
Frequency	hertz (Hz)
Energy	joule (J)
Electric Current	ampere (A)
Temperature	degrees Celsius (°C or deg-C)
Thermal Conductivity	W/m-°C
Thermal Capacitance	J/g-°C
Liquid Flow	liters/minute (l/min)

2 RELATED DOCUMENTS

2.1 APPLICABLE DOCUMENTS

Document Number	Document Name
GSFC-STD-1000F	Goddard Space Flight Center Rules for the Design, Development, Verification, and Operation of Flight Systems
GSFC-STD-7000A	General Environmental Verification Standard (GEVS)
NPD 7120.4D	NASA Engineering and Program/Project Management Policy
NPR 2810.1A	Security of Information Technology (Revalidated with Change 1)
NPR 7150.2	Software Engineering Requirements
NPR 8621.1B	NASA Procedural Requirements for Mishap and Close-Call Reporting, Investigating, and Recordkeeping
NPR 8715.3C	NASA General Safety Program Requirements
NPR 8715.6A	NASA Procedural Requirements for Limiting Orbital Debris
NPR 8715.7A	Expendable Launch Vehicle (ELV) Payload Safety Program
RESTORE-L-RQMT-000518	Restore-L Mission Assurance Requirements (MAR)
RESTORE-L-SPEC-001804	Restore Mission Natural and Induced Operating Environments Specification
SSCO-PROC-000519	SSCO Configuration Management Procedures, 408-PG-1410.2.1

2.2 REFERENCE DOCUMENTS

Document Number	Document Name
RESTOR-L-PLAN-001805	Restore-L Verification and Validation Plan
RESTORE-L-SPEC-000602	Restore-L Mission Coordinate Systems

2.3 PRECEDENCE

If there is conflict between the above documents and the technical requirements specified herein, this document would take precedence.

3 REQUIREMENTS

3.1 MISSION ARCHITECTURE

3.1.1 MISSION ELEMENTS

The Restore-L Mission shall consist of the following three (3) Mission Elements:

1. Restore-L Servicing Vehicle (RSV)
2. Launch Vehicle (LV)
3. Ground Element (GE)

[LEO-61]

Rationale: Sets basic framework for ConOps and Level 3 hardware.

3.1.2 MISSION PHASES

The Restore-L Mission shall consist of the following mission phases:

1. Launch
2. Transit
3. AR&D*
4. Servicing
5. Departure
6. Decommissioning

[LEO-63]

Rationale: Sets basic framework for ConOps

**AR&D stands for Autonomous Rendezvous and Docking, but the label for the phase is "AR&D".*

3.1.3 GROUND INTERVENTION

The Restore-L Mission shall include ground commanded aborts, pre-specified authority to proceed (ATP) points and pre-specified override points. *[LEO-65]*

Rationale: Sets a framework to integrate human-in-the-loop checks and other safety features into the ConOps.

3.1.4 MINIMUM COMMUNICATIONS

The Restore-L Mission shall have a minimum set of communications for critical events. Minimum communications needed for each event will be developed in the Restore-L ConOps and codified in the Mission Rules. *[LEO-66]*

Rationale: Communication with the spacecraft is critical to success of each mission phase and is a key criterion at each ATP.

3.1.5 LOST COMMUNICATIONS

The Restore-L Mission shall abort activities or take corrective actions if communication is lost during any critical event. *[LEO-68]*

Rationale: The ground is in the loop for many of the mission critical functions and the RSV must be able to stop those functions if com is lost. For example, during propellant transfer, the ground monitors the client pressures and stops the transfer when needed since that data is not available on board. If comm is lost, the RSV must stop the transfer immediately to protect the client.

3.1.6 TELEOPERATED SERVICING

The Restore-L Mission shall use teleoperated robotic arms to perform servicing tasks. *[LEO-67]*

3.2 CAPABILITY AND PERFORMANCE REQUIREMENTS

3.2.1 SERVICES PROVIDED

3.2.1.1 Refueling

The Restore-L Mission shall demonstrate the capability to refuel a Client satellite. *[LEO-52]*

Rationale: The goal of this mission is to extend a client's operational life by 3 to 5 years.

3.2.1.2 Relocation

The Restore-L Mission shall demonstrate the capability to relocate a Client satellite. *[LEO-55]*

Rationale: This is a core capability for future servicing missions.

3.2.1.3 Remote Survey

The Restore-L Mission shall demonstrate the capability to provide a visual survey of a Client satellite. *[LEO-56]*

3.2.2 RESERVED

3.2.3 SERVICING OPERATIONS

3.2.3.1 Insertion/Transit Orbit

The Restore-L Mission shall place the RSV in a nominal transit orbit 5 km below the *Client Servicing Orbit* defined in the Client ICD. The specific launch parameters will be determined in conjunction with the final mission timeline. *[LEO-74]*

Rationale: Using a transit orbit 5 km below the Servicing Orbit allows space to align the RSV orbit with the client. It is preferable to launch directly into this transit orbit, but the final targeted orbital elements for launch are dependent upon the specific client and launch date, as well as the LV selected. A client-specific ICD will be written once the client is finalized and will contain the final agreed-to servicing altitude.

3.2.3.2 Rendezvous and Capture

The following requirements provide a minimum framework in which to define a safe operating environment in the vicinity of the client. Details will be filled out in the Restore-L ConOps document and ultimately in the Flight Rules.

3.2.3.2.1 Rendezvous

The Restore-L Mission shall rendezvous with a non-cooperative client satellite in a *Client Rendezvous Orbit* defined in the Client ICD. *[LEO-87]*

Rationale: Restore-L cannot rely on help from the client to determine and execute the navigation path.

3.2.3.2.2 Outer Keep Out Sphere

The RSV shall penetrate a 4 km sphere centered on the client only with ATP from the Ground. *[LEO-89]*

Rationale: Given that we may wish to start autonomous operations at Co-Elliptic 2 start, this ATP is a good test of the command and control logic.

3.2.3.2.3 Middle Keep Out Sphere

The RSV shall penetrate a 400 m sphere centered on the client only with ATP from the Ground and valid on-board bearing and range measurements. *[LEO-90]*

Rationale: The 400 m KOS is the go/no-go ATP for starting Co-Elliptic 3.

3.2.3.2.4 Inner Keep Out Sphere

The RSV shall penetrate a 50 m sphere centered about the client only with ATP from the Ground, valid on-board bearing and range measurements, and when the RSV has relative attitude knowledge of the client to within 10 deg. *[LEO-91]*

Rationale: The 50 m KOS is the go/no-go for exiting the Safety Ellipse onto the v-bar.

3.2.3.2.5 Passively Safe Trajectories

The Restore-L Mission, while outside the Inner Keep-Out Sphere, shall use rendezvous and proximity operations trajectories that are passively safe for a minimum of 24 hrs. after a maneuver . *[LEO-92]*

3.2.3.2.6 Client Survey

The Restore-L Mission shall provide imagery of the client's grapple and berthing site(s) to ground planners prior to entering final capture. *[LEO-95]*

Rationale: Allows ground crew to check for obstructions in the grapple and berthing areas.

3.2.3.2.7 Client Capture

Restore-L Mission shall autonomously capture a non-cooperative client satellite that is in free drift with inertial rotation rates up to 0.1 deg/s RSS. *[LEO-96]*

Rationale: Client is assumed to be in a stable inertial hold, but is commanded to free drift just prior to capture. Free drift of the client is required to avoid conflicts between respective ACS systems. Due to close proximity to client, RSV maneuvers must be autonomous to alleviate comm delays inherit in ground controlled maneuvers.

3.2.3.3 Mated Operations

3.2.3.3.1 Situational Awareness

The Restore-L Mission shall provide live situational awareness imagery of the RSV work sites, berthing site, and client work site(s). *[LEO-103]*

Rationale: Ground operators need visual cues to ensure full situational awareness of on-orbit operations and conditions.

3.2.3.3.2 Servicing Conditions

The Restore-L Servicing Vehicle shall be capable of performing the services identified in Paragraph 3.2.1 at all points along the orbit. *[LEO-104]*

Rationale: Maximum effectiveness will be achieved if there are no "dead zones" along the orbit where operations must pause until the RSV moves out of such a zone.

3.2.3.4 Departure

The Restore-L Mission shall release the client and conduct an autonomous departure. *[LEO-111]*

Rationale: The RSV must move away from the client safely and quickly upon release.

3.2.4 MISSION LIFE

3.2.4.1 Ground Storage

The RSV shall remain flight-worthy for at least two (2) years of ground storage. *[LEO-119]*

3.2.4.2 Operating Orbits

The RSV shall operate at Low Earth Orbits (LEO) between 650 km and 750 km altitude and at 98.2 +/- 0.5 deg inclination. *[LEO-120]*

Rationale: This orbital environment is centered about the Landsat 7 orbit.

3.2.4.3 Mission Duration

The Restore-L Mission shall have a primary mission lifetime of one (1) year. *[LEO-121]*

Rationale: One year is sufficient for the servicing demonstration mission without imposing increased cost due to longer mission lifetime.

3.2.4.4 On-Orbit Check-Out

The Restore-L Mission shall complete an on-orbit RSV check-out within 30 days after launch. *[LEO-122]*

3.2.4.5 Mission Close-Out

The Restore-L Mission shall decommission the RSV in accordance with NPR 8715.6A at the end of its mission. *[LEO-124]*

3.2.5 SERVICEABILITY

3.2.5.1 Cooperative Interfaces

The Restore-L Mission shall be designed for potential cooperative refueling on a subsequent mission. *[LEO-126]*

Rationale: Features that will allow for refueling the RSV on a subsequent mission, but have low impact to the basic Bus and Payload designs should be included to maximize the potential range of capabilities demonstrated by the vehicle.

3.2.5.2 Refuellable

The Restore-L Mission shall be refuellable while on orbit. *[LEO-127]*

3.3 INTERFACE REQUIREMENTS

3.3.1 LAUNCH VEHICLE INTERFACES

The RSV shall be compatible with the following launch vehicles:

Atlas V

Falcon 9

[LEO-131]

Rationale: Allows maximum flexibility in launch schedule and options.

3.3.2 CLIENT INTERFACES

3.3.2.1 Client Safe Configuration

The Restore-L Mission shall perform its capture and servicing tasks without violating the client's safe operating attitude and configuration as documented in the client ICD. *[LEO-137]*

Rationale: Mission operations must be designed within the safe limits of the client.

The Client ICD takes precedence and, at a minimum, should address the following parameters:

a) limits on duration of solar incidence on client vehicle radiators

b) limits on shadowing of client vehicle solar arrays

c) limits on off-pointing of client solar arrays from the sun

d) limits on exposure of components to direct sunlight

e) limits on occultation of client vehicle ground telemetry link

f) limits on occultation of client vehicle attitude sensors prior to capture/release

3.3.2.2 Reserved

3.3.3 GROUND INTERFACES

3.3.3.1 Mission Operations Center

The Restore-L Mission shall provide a mission operations center from which to conduct all on-orbit operations. *[LEO-144]*

3.3.3.2 Ground Monitoring

The Restore-L Mission shall provide ground monitoring of onboard autonomous functions. *[LEO-145]*

Rationale: Provides an independent check of on-board functions, and allows ground over-ride if the RSV incurs on-orbit anomalies.

3.3.4 COMMUNICATIONS, COMMAND, AND TELEMETRY

3.3.4.1 Primary Communications Network

The Restore-L Mission shall use the NASA Tracking and Data Relay Satellite System (TDRSS) for primary communications between the RSV and the mission operations center. *[LEO-151]*

Rationale: Establishes a key design boundary for both the RSV and Ground.

3.3.4.2 Contingency Communications Network

The Restore-L Mission shall use the Near-Earth Network (NEN) for contingency and/or emergency communications with the RSV. *[LEO-152]*

Rationale: Establishes a key design boundary for both the RSV and Ground.

3.3.4.3 Primary Uplink Capability

The Restore-L Mission communications system shall receive, demodulate, and process ground commands transmitted from the mission operations center at S-Band frequencies with a required Achievable Data Rate (ADR) of 128 kbps through the primary network. *[LEO-154]*

Rationale: Minimum command rate needed to support teleoperated robotics.

3.3.4.4 Contingency Uplink Capability

The Restore-L Mission communications system shall receive, demodulate, and process ground commands transmitted from the mission operations center at S-Band frequencies with a required Achievable Data Rate (ADR) of 2 kbps through the contingency network. *[LEO-155]*

3.3.4.5 S-Band Downlink Capability

The Restore-L Mission communications system shall transmit low data rate telemetry and video to the mission operations center at S-Band frequencies using multiple telemetry formats and data rates with required ADR's up to and including 144 kbps through the primary or the contingency network. *[LEO-156]*

Rationale: Provides health and status telemetry for RSV subsystems.

3.3.4.6 Ka-Band Downlink Capability

The Restore-L Mission communications system shall transmit live and recorded video and high data rate engineering telemetry to the mission operations center at Ka-Band frequencies using multiple video/telemetry formats with required ADR's up to and including 60 Mbps through the primary network. *[LEO-157]*

Rationale: Minimum bandwidth needed to provide sufficient visual and command feedback to the teleoperators on the ground.

3.3.4.7 Command Authentication

The Restore-L Mission shall authenticate all commands sent to the RSV. *[LEO-159]*

Rationale: Conforms to NASA security requirements NPR 2810.1A.

3.3.4.8 Communications Encryption

The Restore-L Mission shall encrypt all communication links using a validated Federal Information Processing Standards (FIPS) Security Level 2 method. *[LEO-160]*

Rationale: Conforms to NASA security requirements NPR 2810.1A.

3.3.4.9 Communications Coverage

3.3.4.9.1 Data Access During Pre-Launch

The Restore-L Mission shall be capable of receiving and processing RSV engineering telemetry while the RSV is mated to the LV from pre-launch through liftoff. *[LEO-166]*

Rationale: Needed to monitor PTS and other safety-critical parameters.

3.3.4.9.2 Coverage During Critical Events

The Restore-L Ground Element shall provide near-continuous uplink and low-rate downlink communications coverage for RSV during post-insertion and health and safety operations. *[LEO-167]*

Rationale: Needed to maintain monitoring of all critical systems.

3.3.4.9.3 Coverage During AR&D

The Restore-L Ground Element shall provide near-continuous uplink and low-rate telemetry/video downlink communications coverage for the RSV during AR&D operations. *[LEO-168]*

Rationale: Provides video stream to ground-based RPO simulators that monitor and mimic on-board operations.

3.3.4.9.4 Coverage During Telerobotic Operations

The Restore-L Ground Element shall provide near-continuous uplink, low-rate telemetry, and high-rate video downlink communications coverage for the RSV during telerobotic servicing operations. *[LEO-169]*

Rationale: Provides video stream to ground-based Robot simulators that monitor and mimic on-board operations. Also provides ground operators with imagery for situational awareness.

3.3.4.10 Concurrent Communications

The Restore-L Mission shall allow command and telemetry communications with the RSV concurrently with client mission operations center (MOC) command and telemetry communications with the client satellite. *[LEO-170]*

3.3.4.11 Bit Error Rate (BER)

The Restore-L Mission shall have an end-to-end bit error rate (BER) less than 1E-5 after applying physical layer decoding, not including re-transmission. This applies to commands, telemetry and data. *[LEO-171]*

3.3.4.12 Latency

The Restore-L Mission shall have a maximum round-trip command/data transmission latency of 6 seconds from the sending of a command by the robot operator, through transmission and execution by the RSV, until the response is displayed at the robot control station. *[LEO-172]*

Rationale: Robot Controllers can tolerate up to 6 sec delay without slowing down the robot operating speeds. Current best estimate of the round-trip robot command loop is between 2 and 4 sec.

3.3.4.13 Latency Variations

During a single communications pass between two loss of signal events, the round-trip transmission latency shall not vary by more than 1.0 sec. *[LEO-173]*

Rationale: The latency of the round-trip robot command loop will vary as the spacecraft traverses its orbit. Bounding the latency variation between LOS events insures the latency remains within the bounds of the telerobotic control delay mitigation technique used for the pass.

3.3.4.14 Client Telemetry

The Restore-L Mission shall have access to client telemetry in accordance with the client agreement and client ICD. Note: Neither the RSV nor the Ground Element is required to obtain telemetry directly from the client satellite. *[LEO-174]*

Rationale: Need to monitor client temps & pressures during refueling ops.

3.4 DESIGN CONSTRAINTS

3.4.1 MECHANICAL DESIGN

3.4.1.1 Total Mass

The total RSV wet mass, at launch, shall be equal to or less than 6600 kg (14,550 lbs). *[LEO-181]*

Rationale: The maximum mass that is compatible with all LVs listed in 3.3.1 above. This value has significant margin over the estimates provided by the Bus Study vendors. This margin will be held back as Project Reserves.

3.4.1.2 Launch Mass Allocation

The RSV mass shall be allocated as follows:

a. RSV (wet, includes Client prop) 4525 kg

b. Transferable Client Propellant 300 kg minimum

c. Launch Vehicle Adapter 75 kg

d. Project/System Reserve (30%) 2000 kg

[LEO-182]

Rationale: The RSV mass allocation is a maximum design limit consistent with the Spacecraft Bus Study estimates. The client propellant allocation will maximize servicing capabilities and flexibility while remaining within LV limits. System Reserve is consistent with GOLD Rules.

3.4.2 ELECTRICAL DESIGN

Reserved.

3.4.3 THERMAL DESIGN

The Restore-L Mission shall use the on-orbit environmental parameters defined in RESTORE-L-SPEC-001804 for thermal design and analysis. *[LEO-202]*

3.4.4 GUIDANCE, NAVIGATION, AND CONTROL DESIGN

3.4.4.1 Client Orbit Determination

The Restore-L Mission shall acquire client predicted orbit determination data to within +/- 100 m <TBR>, 3 sigma, with respect to the ECI frame. *[LEO-211]*

Rationale: RSV needs the client's absolute state sent up so it can time the co-elliptic burns as it maneuvers closer to the client.

3.4.4.2 Reserved

3.4.5 PROPULSION DESIGN

Reserved.

3.4.6 COMMUNICATIONS DESIGN

Reserved.

3.5 OPERATIONAL FACTORS

3.5.1 ENVIRONMENTS

3.5.1.1 Natural Environments

The Restore-L Servicing Vehicle shall operate while exposed to the Low Earth Orbit (LEO) natural environments for the mission life given in paragraph 3.2.4.3 (LEO-121) above. *[LEO-229]*

Rationale: Each space mission has a unique set of environmental requirements that apply to all flight segment elements.

3.5.1.2 Induced Environments

3.5.1.2.1 LV Induced Environments

The RSV shall survive exposure to the launch environment for the launch vehicle(s) identified in Paragraph 3.3.1 (LEO-131) above. *[LEO-234]*

3.5.1.2.2 Client Induced Environments

The RSV shall operate while exposed to the electromagnetic environment induced by close proximity operations with client satellites. *[LEO-235]*

Rationale: Client will likely have some transmitters on, e.g. H&S telemetry over omni antennas, while mated with RSV.

3.5.2 RELIABILITY

3.5.2.1 Redundancy

The Restore-L Mission shall have no single point failures (SPF) that prevent

- Availability of minimum essential engineering data and command capability required for flight safety,
- Performance of any function necessary to meet minimum mission success criteria

[LEO-238]

3.5.2.2 Two-Fault Tolerance During AR&D

A. The Restore-L Mission shall be two-fault tolerant against collision with the client. *[LEO-242]*

Rationale: In the event of a single fault prior to initiation of the autonomous rendezvous and capture sequence, the RSV must be able to continue the mission (complete the capture) while maintaining the capability to abort the sequence and perform a collision avoidance maneuver (CAM) if required. If a second fault occurs during this sequence, that fault must not remove the CAM capability.

B. The RSV shall automatically abort the autonomous rendezvous and capture sequence if a failure occurs that leaves the system zero fault tolerant for performing a collision avoidance maneuver. *[LEO-243]*

Rationale: If at any point during the sequence the vehicle is in a state where one additional fault could result in inability to perform the abort (and CAM), the vehicle will abort the sequence.

3.5.2.3 Two-Fault Tolerance During Servicing

The RSV shall be two-fault tolerant against client damage that degrades the client's operational capability. *[LEO-244]*

3.5.2.4 Exceptions

Exceptions will be managed and documented in accordance with the process defined in the Restore-L Reliability Plan.

3.5.3 MAINTAINABILITY

3.5.3.1 Integration and Test

The RSV design should give due consideration to accessibility, testability, and interchangeability throughout its mission life. *[LEO-246]*

3.5.3.2 Reserved

3.5.4 SECURITY

The Restore-L Mission shall comply with policies and guidelines set forth in NPR 2810.1A, Security of Information Technology, as related to unclassified missions. *[LEO-249]*

3.5.5 HUMAN FACTORS

Reserved.

3.5.6 EXTENSIBILITY

The Restore-L Mission hardware designs shall be extensible to future Low Earth Orbit (LEO) and interplanetary robotic servicing missions at ranges of 0.7 AU to 2.0 AU, including Orion and ARRM. *[LEO-256]*

Rationale: Several Servicing Payload functions are common among more than one mission, and it is more cost-effective to have a single design that operates in all applicable regimes. Note that human-in-the loop, joystick-type telerobotics is not practicable beyond lunar orbits due to time lags, therefore this function only needs to look at LEO to translunar orbits in its design.

3.6 SAFETY

3.6.1 GENERAL SAFETY

The Restore-L Mission shall comply with NPR 8715.3C, NASA General Safety Requirements. *[LEO-258]*

3.6.2 FLIGHT SAFETY

3.6.2.1 Deleted

3.6.2.2 Unattended Operations

The Restore-L Mission shall operate safely in a transit phase while unattended by ground personnel for up to 90 hrs. *[LEO-261]*

Rationale: Operating safely without ground intervention during an extended quiescent transit state will allow the Mission to optimize personnel schedules. Ninety hours covers from 3 PM Friday to 9 AM Tuesday to span a 3-day week-end.

3.6.2.3 Orbital Debris

The Restore-L Mission shall comply with NPR 8715.6A. This includes RSV hardware, as well as client hardware removed by the RSV. *[LEO-262]*

3.6.2.4 Separation During Transit

The Restore-L Mission shall maintain a radial separation of at least 2 km with respect to non-client operational LEO satellites. *[LEO-263]*

Rationale: The Conjunction Assessment Risk Analysis (CARA) Team uses an ellipsoid "monitor volume" of 2 km radial, 25 km in-track, and 25 km cross-track.

3.6.3 ELV PAYLOAD SAFETY PROGRAM

The Restore-L Mission shall comply with NPR 8715.7A, Expendable Launch Vehicle (ELV) Payload Safety Program. *[LEO-269]*

3.6.4 MISHAPS AND CLOSE CALLS

The Restore-L Mission shall comply with NPR 8621.1B, NASA Procedural Requirements for Mishap and Close Call Reporting, Investigating and Recordkeeping. *[LEO-274]*

3.6.5 RESERVED

3.7 MISSION ASSURANCE

3.7.1 RESTORE-L MISSION ASSURANCE REQUIREMENTS

The Restore-L Mission shall comply with RESTORE-L-RQMT-000518, Restore-L Mission Assurance Requirements (MAR). *[LEO-278]*

3.7.2 GOLD RULES

The Restore-L Mission shall comply with GSFC-STD-1000F, Rules for the Design, Development, Verification, and Operation of Flight Systems (GOLD Rules). *[LEO-279]*

3.7.3 FLIGHT AND MISSION CONTROL CENTER SOFTWARE

The Restore-L Mission shall comply with NPR 7150.2, Software Engineering Requirements. *[LEO-284]*

3.7.4 CONFIGURATION MANAGEMENT

The Restore-L Mission shall comply with SSCO-PROC-000519, SSCO Configuration Management Procedure. *[LEO-289]*

3.7.5 ENVIRONMENTAL TESTING

The Restore-L Mission shall comply with GSFC-STD-7000, Rev A, General Environmental Verification Standard (GEVS). *[LEO-293]*

4 VERIFICATION

Verification is the process of confirming through objective evidence that the payload hardware conforms to the design and performance requirements as specified in Section 3. The Restore-L Verification and Validation Plan, RESTORE-L-PLAN-001805, describes the methods, types, and levels of verification used for the Restore-L Project.

Table 4-1 is the Verification Cross-Reference Matrix (VCRM) for the requirements is given in Section 3. The VCRM shows the verification method to be used and at what level each requirement in Section 3 will be verified. It also shows the parent(s) of each requirement, as well as the Elements to which each has been allocated.

Table 4-1 Payload L4 Verification Cross Reference Matrix

L1 Parent ID	L1 Parent Text	Object Identifier	Para. Number	Obj Heading	Object Short Text	Verif. Level	Verif. Method	Allocations
RESL-1 RESL-19 RESL-22	**4.1 Mission Requirements** a) Rendezvous: Rendezvous with client to within 400 m (TBR). **4.3 Launch Reqts** b) ...compat ble with Atlas V, Falcon 9 **4.4 Ground Sys Reqts** a) ...provide a MOC	LEO-61	3.1.1	Mission Elements	... shall consist of RSV, LV, and GRND mission elements.	Mission	I	RSV LV GRND
RESL-1 RESL-4 RESL-7 RESL-18	**4.1 Mission Requirements** a) Rendezvous: Rendezvous with client to within 400 m (TBR). **4.1 Mission Requirements** d) Telerobotic Servicing: Perform teleoperated robotic tasks related to refueling that spacecraft. **4.1 Mission Requirements** g) Release and Departure: Release and depart without adversely affecting the client's ability to return to an operational state. **4.3 Launch Reqts** a) ...insertion orbit 5 km below Rendezvous *Orbit*	LEO-63	3.1.2	Mission Phases	... shall consist of 8 mission phases: 1) Launch; 2) Transit; 3) Rendezvous; 4) Prox Ops; 5) Capture; 6) Servicing; 7) Departure; 8) Decommissioning	Mission	I	RSV LV GRND OPS
RESL-17	**4.2 Mission an S/C Reqts** i) ...provide ground monitoring of autonomous functions	LEO-65	3.1.3	Ground Intervention	...shall include ground-commanded aborts, ATPs, and overrides.	Mission	I	RSV GRND
RESL-17	**4.2 Mission an S/C Reqts** i) ...provide ground monitoring of autonomous functions	LEO-66	3.1.4	Minimum Communications	...shall have a min set of comm for critical events...	Mission	I	OPS
RESL-11 RESL-17	**4.2 Mission an S/C Reqts** c) ...protect client... **4.2 Mission an S/C Reqts** i) ...provide ground monitoring of autonomous functions	LEO-68	3.1.5	Lost Communications	...abort activities ... if communication is lost during any critical event.	Element	I	RSV
RESL-4	**4.1 Mission Requirements** d) Telerobotic Servicing: Perform teleoperated robotic tasks related to refueling that spacecraft.	LEO-67	3.1.6	Teleoperated Servicing	...perform teleoperated robotic servicing	Element	I	RSV GRND
RESL-5	**4.1 Mission Requirements** e) Refueling: Transfer at least 10 kg <TBR> of hydrazine.	LEO-52	3.2.1.1	Refueling	...transfer prop to extend life by 3 yrs.	Element	I	RSV
RESL-6	**4.1 Mission Requirements** f) Relocation: Alter Client's orbit a minimum of 1 m/s Delta V.	LEO-55	3.2.1.2	Relocation	...relocate a Client satellite.	Element	I	RSV
RESL-2	**4.1 Mission Requirements** b) Inspection: Inspect a client to obtain information needed for berthing.	LEO-56	3.2.1.3	Remote Survey	... shall provide a visual survey of a Client satellite.	Mission	I	RSV GRND
RESL-18	**4.3 Launch Reqts** a) ...insertion orbit 5 km below Rendezvous *Orbit*	LEO-74	3.2.3.1	Insertion/Transit Orbit	...shall place RSV into an insertion/transit orbit 5 km below Rendezvous Orbit ...	Element	I	RSV LV GRND
RESL-1	**4.1 Mission Requirements** a) Rendezvous: Rendezvous with client to within 400 m (TBR).	LEO-87	3.2.3.2.1	Rendezvous	...shall rendezvous with client...	Element	I	RSV
RESL-1	**4.1 Mission Requirements** a) Rendezvous: Rendezvous with client to within 400 m (TBR).	LEO-89	3.2.3.2.2	Outer Keep Out Sphere	...enter outer 4 km KOS only with ATP	Element	I	RSV GRND

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L1 Parent ID	L1 Parent Text	Object Identifier	Para. Number	Obj Heading	Object Short Text	Verif. Level	Verif. Method	Allocations
RESL-1	**4.1 Mission Requirements** a) Rendezvous: Rendezvous with client to within 400 m (TBR).	LEO-90	3.2.3.2.3	Middle Keep Out Sphere	...enter middle 400 m KOS only with ATP and valid client brg & range.	Element	I	RSV GRND
RESL-1	**4.1 Mission Requirements** a) Rendezvous: Rendezvous with client to within 400 m (TBR).	LEO-91	3.2.3.2.4	Inner Keep Out Sphere	...enter inner 50 m KOS only with ATP, brg & range, and valid pose...	Element	I	RSV GRND
RESL-3	**4.1 Mission Requirements** c) Autonomous Capture: Autonomously capture a clinet in low Earth orbit.	LEO-92	3.2.3.2.5	Passively Safe Trajectories	...shall use passively safe trajectories ...	Element	A	RSV GRND OPS
RESL-2	**4.1 Mission Requirements** b) Inspection: Inspect a client to obtain information needed for berthing.	LEO-95	3.2.3.2.6	Client Survey	...shall provide imaging of client berth site...	Element	I	RSV GRND
RESL-3	**4.1 Mission Requirements** c) Autonomous Capture: Autonomously capture a clinet in low Earth orbit.	LEO-96	3.2.3.2.7	Client Capture	...shall capture clients rotating up to 0.1 deg/s.	Element	A	RSV
RESL-2	**4.1 Mission Requirements** b) Inspection: Inspect a client to obtain information needed for berthing.	LEO-103	3.2.3.3.1	Situational Awareness	...shall provide SA imagery of the deck, berthing site, and client.	Element	I	RSV GRND
RESL-17	**4.2 Mission an S/C Reqts** i) ...provide ground monitoring of autonomous functions	LEO-104	3.2.3.3.2	Servicing Conditions	... RSV shall be capable of performinig services at all points along the orbit	Mission	I	RSV GRND
RESL-7	**4.1 Mission Requirements** g) Release and Departure: Release and depart without adversely affecting the client's ability to return to an operational state.	LEO-111	3.2.3.4	Departure	...shall release and conduct autonomous departure.	Element	I	RSV OPS
RESL-10	**4.2 Mission an S/C Reqts** b) ... Class C Mission, except where tailored below...	LEO-119	3.2.4.1	Ground Storage	...2 years ground storage.	Element	I	RSV
RESL-1	**4.1 Mission Requirements** a) Rendezvous: Rendezvous with client to within 400 m (TBR).	LEO-120	3.2.4.2	Operating Orbits	...operate at 650 km to 750 km altitude, and at 98.2 deg inclination.	Element	I	RSV GRND
RESL-1 RESL-2 RESL-6 RESL-7 RESL-10	**4.1 Mission Requirements** a) Rendezvous: Rendezvous with client to within 400 m (TBR). **4.1 Mission Requirements** b) Inspection: Inspect a client to obtain information needed for berthing. **4.1 Mission Requirements** f) Relocation: Alter Client's orbit a minimum of 1 m/s Delta V. **4.1 Mission Requirements** g) Release and Departure: Release and depart without adversely affecting the client's ability to return to an operational state. **4.2 Mission an S/C Reqts** b) ... Class C Mission, except where tailored below...	LEO-121	3.2.4.3	Mission Duration	...primary mission lifetime of 1 yr.	Element	I	RSV GRND
RESL-1	**4.1 Mission Requirements** a) Rendezvous: Rendezvous with client to within 400 m (TBR).	LEO-122	3.2.4.4	On-Orbit Check-Out	...complete C/O within 30 days...	Mission	I	RSV OPS

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RESL-13	**4.2 Mission an S/C Reqts** e) ...decommission per 8715.6A	LEO-124	3.2.4.5	Mission Close-Out	...decommission RSV IAW NPR 8715.6A	Mission	I	RSV GRND OPS
RESL-8	**4.1 Mission Requirements** h) Technology Transfer: Demonstrate technologies that can be used directly by ARM and Orion missions.	LEO-125	3.2.5	Serviceability	...shall demonstrate cooperative on-orbit servicing features.	Mission	I	RSV
RESL-8	**4.1 Mission Requirements** h) Technology Transfer: Demonstrate technologies that can be used directly by ARM and Orion missions.	LEO-126	3.2.5.1	Cooperative Interfaces	...designed for potential cooperative refueling on a subsequent mission.	Element	I	RSV
RESL-8	**4.1 Mission Requirements** h) Technology Transfer: Demonstrate technologies that can be used directly by ARM and Orion missions.	LEO-127	3.2.5.2	Refuellable	...shall be refuelable while on orbit.	Element	D	RSV
RESL-19	**4.3 Launch Reqts** b) ...compat ble with Atlas V, Falcon 9	LEO-131	3.3.1	Launch Vehicle Interfaces	...shall be compatible with the following LVs: Atlas V, Delta IV, Falcon 9	Element	I	RSV
RESL-11	**4.2 Mission an S/C Reqts** c) ...protect client...	LEO-137	3.3.2.1	Client Safe Configuration	...shall perform servicing w/out violating Client's safe operating attitude and config.	Element	A	RSV OPS
RESL-22	**4.4 Ground Sys Reqts** a) ...provide a MOC	LEO-144	3.3.3.1	Mission Operations Center	... shall provide a mission ops center.	Element	I	GRND
RESL-17	**4.2 Mission an S/C Reqts** i) ...provide ground monitoring of autonomous functions	LEO-145	3.3.3.2	Ground Monitoring	...provide ground monitoring of autonomous functions	Element	I	RSV GRND
RESL-25	**6.1 Primary Comm** ...shall use TDRSS for primary comm...	LEO-151	3.3.4.1	Primary Communications Network	...shall use TDRSS as primary comm...	Mission	I	RSV GRND
RESL-26	**6.2 Contingency Comm** ...shall use NEN for contingency comm...	LEO-152	3.3.4.2	Contingency Communications Network	...shall have a contingency comm path...	Mission	I	RSV GRND
RESL-25	**6.1 Primary Comm** ...shall use TDRSS for primary comm...	LEO-154	3.3.4.3	Primary Uplink Capability	...send ground commands over S-band at 128 kbps through primary...	Mission	A	RSV GRND
RESL-26	**6.2 Contingency Comm** ...shall use NEN for contingency comm...	LEO-155	3.3.4.4	Contingency Uplink Capability	...send ground commands over S-band at 2 kbps through contingency...	Mission	A	RSV GRND
RESL-25 RESL-26	**6.1 Primary Comm** ...shall use TDRSS for primary comm... **6.2 Contingency Comm** ...shall use NEN for contingency comm...	LEO-156	3.3.4.5	S-Band Downlink Capability	...send telemetry over S-band at 144 Kbps via primary and contingency...	Mission	A	RSV GRND
RESL-25	**6.1 Primary Comm** ...shall use TDRSS for primary comm...	LEO-157	3.3.4.6	Ka-Band Downlink Capability	...send video over Ka-band at 60 Mbps...	Mission	A	RSV GRND
RESL-23	**4.4 Ground Sys Reqts** b) ...establish security...	LEO-159	3.3.4.7	Command Authentication	...shall authenticate all commands.	Element	D	RSV GRND
RESL-23	**4.4 Ground Sys Reqts** b) ...establish security...	LEO-160	3.3.4.8	Communications Encryption	...shall encrypt all commands...	Element	D	RSV GRND

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RESL-17 RESL-22	**4.2 Mission an S/C Reqts** i) ...provide ground monitoring of autonomous functions **4.4 Ground Sys Reqts** a) ...provide a MOC	LEO-166	3.3.4.9.1	Data Access During Pre-Launch	...shall rec'v and process TLM from pre-launch through lift-off.	Element	D	RSV GRND
RESL-17	**4.2 Mission an S/C Reqts** i) ...provide ground monitoring of autonomous functions	LEO-167	3.3.4.9.2	Coverage During Critical Events	... Ground Element shall provide near-continuous forward and return link comm coverage during post-insertion and health and safety operations.	Element	A	GRND
RESL-17	**4.2 Mission an S/C Reqts** i) ...provide ground monitoring of autonomous functions	LEO-168	3.3.4.9.3	Coverage During AR&D	... Ground Element shall provide near-continuous forward, return, and video return link comm coverage during AR&D operations.	Element	A	GRND
RESL-4	**4.1 Mission Requirements** d) Telerobotic Servicing: Perform teleoperated robotic tasks related to refueling that spacecraft.	LEO-169	3.3.4.9.4	Coverage During Telerobotic Operations	... Ground Element shall provide near-continuous forward, return, and video return link comm coverage during telerobotic operations...	Element	A	GRND
RESL-11	**4.2 Mission an S/C Reqts** c) ...protect client...	LEO-170	3.3.4.10	Concurrent Communications	...shall avoid mutual RF interference.	Element	I	RSV GRND
RESL-25	**6.1 Primary Comm** ...shall use TDRSS for primary comm...	LEO-171	3.3.4.11	Bit Error Rate (BER)	...shall have a BER of 1E-5.	Element	T	RSV GRND
RESL-4	**4.1 Mission Requirements** d) Telerobotic Servicing: Perform teleoperated robotic tasks related to refueling that spacecraft.	LEO-172	3.3.4.12	Latency	...shall have a max 2-way latency of 6 sec ...	Element	T	RSV GRND
RESL-4	**4.1 Mission Requirements** d) Telerobotic Servicing: Perform teleoperated robotic tasks related to refueling that spacecraft.	LEO-173	3.3.4.13	Latency Variations	...shall have a max latency variation of 1.0 sec.	Element	T	GRND
RESL-11	**4.2 Mission an S/C Reqts** c) ...protect client...	LEO-174	3.3.4.14	Client Telemetry	...shall have access to client TLM.	Element	I	OPS
RESL-19	**4.3 Launch Reqts** b) ...compat ble with Atlas V, Falcon 9	LEO-181	3.4.1.1	Total Mass	...RSV wet mass shall be 6600 kg or less	Element	I	N/A - Held at Mission

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RESL-19	**4.3 Launch Reqts** b) ...compat ble with Atlas V, Falcon 9	LEO-182	3.4.1.2	Launch Mass Allocation	The RSV mass shall be allocated as follows: a. RSV (wet) 4525 kg b. Client Propellant 300 kg min c. Launch Vehicle Adapter 75 kg d. Project Reserve 2000 kg	Element	I	RSV
RESL-1	**4.1 Mission Requirements** a) Rendezvous: Rendezvous with client to within 400 m (TBR).	LEO-202	3.4.3	Thermal Design	...shall use orbital parameters in RESTORE-L-SPEC-001804 for thermal analysis.	Element	I	RSV
RESL-1	**4.1 Mission Requirements** a) Rendezvous: Rendezvous with client to within 400 m (TBR).	LEO-211	3.4.4.1	Client Orbit Determination	...acquire client OD to within +/- 100 m <TBR>...	Element	I	GRND OPS
RESL-18	**4.3 Launch Reqts** a) ...insertion orbit 5 km below Rendezvous *Orbit*	LEO-229	3.5.1.1	Natural Environments	...operate in LEO environment...	Element	I	RSV
RESL-19	**4.3 Launch Reqts** b) ...compat ble with Atlas V, Falcon 9	LEO-234	3.5.1.2.1	LV Induced Environments	...survive launch environment.	Element	T	RSV
RESL-4	**4.1 Mission Requirements** d) Telerobotic Servicing: Perform teleoperated robotic tasks related to refueling that spacecraft.	LEO-235	3.5.1.2.2	Client Induced Environments	...operate while exposed to client EM emissions.	Element	T	RSV
RESL-10	**4.2 Mission an S/C Reqts** b) ... Class C Mission, except where tailored below...	LEO-238	3.5.2.1	Redundancy	...shall have no SPF ...	Element	A	RSV
RESL-11	**4.2 Mission an S/C Reqts** c) ...protect client...	LEO-242	3.5.2.2.0-1		...shall be two-fault tolerant against collision with the client.	Element	A	RSV
RESL-11	**4.2 Mission an S/C Reqts** c) ...protect client...	LEO-243	3.5.2.2.0-2		...automatically abort the autonomous rendezvous and capture sequence if a failure occurs that leaves the system zero fault tolerant for performing a CAM.	Mission	A	RSV GRND
RESL-10	**4.2 Mission an S/C Reqts** b) ... Class C Mission, except where tailored below...	LEO-244	3.5.2.3	Two-Fault Tolerance During Servicing	...two-fault tolerant against damaging the client ...	Element	A	RSV
RESL-23	**4.4 Ground Sys Reqts** b) ...establish security...	LEO-249	3.5.4	Security		Mission	I A	OPS
RESL-8	**4.1 Mission Requirements** h) Technology Transfer: Demonstrate technologies that can be used directly by ARM and Orion missions.	LEO-256	3.5.6	Extensibility	...the Servicing Payload shall be extensible to future LEO and interplanetary missions.	Element	I	RSV

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RESL-14	**4.2 Mission an S/C Reqts** f) ...comply with 8715.3C Gen Safety	LEO-258	3.6.1	General Safety	... comply with NPR 8715.3C, NASA General Safety Requirements	Mission	I	RSV LV GRND
RESL-15	**4.2 Mission an S/C Reqts** g) ...operate unattended for 90 hrs	LEO-261	3.6.2.2	Unattended Operations	...shall operate while unattended for up to 90 hours.	Element	I	RSV GRND
RESL-13	**4.2 Mission an S/C Reqts** e) ...decommission per 8715.6A	LEO-262	3.6.2.3	Orbital Debris	...shall limit orbital debris.	Element	I	RSV OPS
RESL-12	**4.2 Mission an S/C Reqts** d) ...maintain radial sep of 2 km...	LEO-263	3.6.2.4	Separation During Transit	...maintain 2 km radial separation...	Element	I	GRND OPS
RESL-21	**4.3 Launch Reqts** c) ...comply with ELV Safety	LEO-269	3.6.3	ELV Payload Safety Program	...comply with NPR 8715.7A, ELV Payload Safety	Element	I	RSV LV
RESL-14	**4.2 Mission an S/C Reqts** f) ...comply with 8715.3C Gen Safety	LEO-274	3.6.4	Mishaps and Close Calls	...comply with NPR 8621.1B for mishap and close call reporting	Element	I	RSV LV GRND OPS
RESL-10	**4.2 Mission an S/C Reqts** b) ... Class C Mission, except where tailored below...	LEO-278	3.7.1	Restore-L Mission Assurance Requirements	...shall comply with the Restore-L MAR.	Element	I	RSV LV GRND
RESL-9	**4.2 Mission an S/C Reqts** a) Restore-L shall be a Category 2 project ...	LEO-279	3.7.2	GOLD Rules	... comply with GSFC-STD-1000F GOLD Rules.	Element	I	RSV LV GRND
RESL-10	**4.2 Mission an S/C Reqts** b) ... Class C Mission, except where tailored below...	LEO-284	3.7.3	Flight and Mission Control Center Software	...comply with NPR 7150.2	Element	I	RSV GRND
RESL-9	**4.2 Mission an S/C Reqts** a) Restore-L shall be a Category 2 project ...	LEO-289	3.7.4	Configuration Management	...comply with CM Procedure SSCO-PROC-000519...	Mission	I	RSV GRND OPS
RESL-10	**4.2 Mission an S/C Reqts** b) ... Class C Mission, except where tailored below...	LEO-293	3.7.5	Environmental Testing	...comply with GEVS Rev A.	Element	I	RSV

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5 PREPARATION FOR DELIVERY

Reserved

6 NOTES

Reserved

ABBREVIATIONS AND ACRONYMS

Abbreviation/ Acronym	Definition
ADR	Achievable Data Rate
AR&D	Autonomous Rendezvous and Docking
ATP	Authority to Proceed
AU	Astronomical Unit (distance from Earth to Sun)
BER	Bit Error Rate
CARA	Conjunction Assessment Risk Analysis
CCB	Configuration Control Board
CCR	Configuration Change Request
CG	Center of Gravity
cm	Centimeter
CM	Configuration Management
CMO	Configuration Management Office
dB	Decibel
deg	Degree
deg-C or °C	degrees Celsius
DOORS	Dynamic Object Oriented Requirements System
ECI	Earth Centered Inertial
ELV	Expendable Launch Vehicle
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ESD	Electrostatic Discharge
FDV	Fill/Drain Valve
FIPS	Federal Information Processing Standards
GEO	Geosynchronous Earth Orbit
GSE	Ground Support Equipment
He	Helium
Hz	Hertz
ICD	Interface Control Document (or Drawing)
J	Joule
kbps	kilobits per second
kBps	kilobytes per second
kg	Kilogram
km	Kilometer
KOS	Keep Out Sphere
KOZ	Keep Out Zone
LEO	Low Earth Orbit
LV	Launch Vehicle
m	Meter
MAR	Mission Assurance Requirements
MCC	Mission Control Center
MLI	Multi-Layer Insulation
MOC	Mission Operations Center
N	Newton
NEN	Near Earth Network
NHB	NASA Handbook
NISN	NASA Integrated Systems Network
ORU	Orbital Replacement Unit

Abbreviation/ Acronym	Definition
Pa	Pascal
PTS	Propellant Transfer System (or Subsystem)
RPO	Rendezvous and Proximity Ops
RSS	Root-Sum-Square
RSV	Restore Servicing Vehicle
s or sec	Second
SI	Systeme Internationale (aka Metric System)
SN	Space Network
SPF	Single Point Failure
SSCO	Satellite Servicing Capabilities Office
TBD	To Be Determined
TBR	To Be Resolved
TBS	To Be Supplied
VCRM	Verification Cross-Reference Matrix
W	Watt