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PREFACE

INTERNATIONAL RENDEZVOUS SYSTEM INTEROPERABILITY STANDARDS

This Rendezvous Standard establishes a standard interface to enable on-orbit crew operations, fully automated rendezvous & docking and joint collaborative endeavors utilizing different spacecraft.

Configuration control of this document is the responsibility of the International Space Station (ISS) Multilateral Control Board (MCB), which is comprised of the international partner members of the ISS. The National Aeronautics and Space Administration (NASA) will maintain the Rendezvous Standards under Human Exploration and Operations Mission Directorate (HEOMD). Any revisions to this document will be approved by the ISS MCB.
INTERNATIONAL RENDEZVOUS SYSTEM INTEROPERABILITY STANDARDS CONCURRENCE
FEBRUARY 2018

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Executive Director, Human Space Programs
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1.0 INTRODUCTION

This International Rendezvous System Interoperability Standard is the result of collaboration by the International Space Station (ISS) membership to establish interoperable interfaces, terminology, techniques, and environments to facilitate collaborative endeavors of space exploration in cis-Lunar and deep space environments.

Standards that are established and internationally recognized have been selected where possible to enable commercial solutions and a variety of providers. Increasing commonality while decreasing unique configurations has the potential to reduce the traditional barriers in space exploration: overall mass and volume required to execute a mission. Standardizing interfaces reduces the scope of the development effort and allows more focus on performance instead of form and fit.

The information within this document represents a set of parameters enveloping a broad range of conditions, which if accommodated in the system architecture support greater efficiencies, promote cost savings, and increase the probability of mission success. These standards are not intended to specify system details needed for implementation nor do they dictate design features behind the interface, specific requirements will be defined in unique documents.

1.1 PURPOSE AND SCOPE

The purpose of the Rendezvous Standards is to provide basic common design parameters to allow developers to independently design compatible rendezvous operations. Additionally, the purpose of the Rendezvous Standards is to lower development cost, decrease operational complexity, and improve safety and mission success. By standardizing operational philosophy, phases, terminology and instrumentation, the Deep Space Gateway & Transport (DSG&T) will utilize international partnerships and cooperation.

The scope of rendezvous covers the following:

- **Rendezvous**: From an initial relative maneuver, up to first mechanical contact. This phase begins when the visiting vehicle (an active, or chase vehicle) is confirmed to be in an orbit established relative to the target vehicle’s state/orbit.
  - Departure operations are also included within the rendezvous concepts, and commence at vehicle separation.
  - The scope will also include nominal and off-nominal scenarios.
  - Rendezvous shall include all operations in close proximity to the target vehicle. These include port relocation and fly-around.

- **Docking**: Commences at nominal first mechanical contact, up through mating. All operations associated with docking are covered in the International Docking System Standard (IDSS) Interface Definition Document (IDD).
Berthing: Commences at nominal first mechanical grapple/grasp with robotic arm, up through mating. All robotic operations associated with berthing shall be covered by robotic operations documentation, starting after grapple.

This document will cover all aspects of Rendezvous for cis-Lunar spacecraft operations, as well as future exploration missions/operations as it applies to DSG&T.

1.2 RESPONSIBILITY AND CHANGE AUTHORITY

Any proposed changes to this standard by the participating partners of this agreement shall be brought forward to the International Rendezvous System Interoperability Standard committee for review.

Configuration control of this document is the responsibility of the International Space Station (ISS) Multilateral Control Board (MCB), which is comprised of the international partner members of the ISS. The National Aeronautics and Space Administration (NASA) will maintain the International Rendezvous System Interoperability Standards under HEOMD Configuration Management. Any revisions to this document will be approved by the ISS MCB.

1.3 PRECEDENCE

This paragraph describes the hierarchy of document authority and identifies the document(s) that take precedence in the event of a conflict between content. Applicable documents include requirements that must be met. If a value in an applicable document conflicts with a value herein, then the system may need to be able to meet both values at different times.

Reference documents are either published research representing a specific point in time, or a document meant to guide work that does not have the full authority of an Applicable document. If a value in this document conflicts with a value in a referenced document, then it should be assumed that the value here was deliberately changed, based on new data or a special constraint for the missions discussed.
2.0 DOCUMENTS

2.1 APPLICABLE DOCUMENTS

The following documents include specifications, models, standards, guidelines, handbooks, and other special publications. Applicable documents are levied by programs with authority to control system design or operations. The documents listed in this paragraph are applicable to the extent specified herein. Inclusion of applicable documents herein does not in any way supersede the order of precedence identified in Section 1.3 of this document.

IDSS IDD
- International Docking System Standard (IDSS) Interface Definition Document (IDD), Revision E, October 2016

2.2 REFERENCE DOCUMENTS

The following documents contain supplemental information to guide the user in the application of this document. These reference documents may or may not be specifically cited within the text of this document.

DSG-16-32
- Rendezvous and Docking Standards Recommendation, ISS Exploration Capabilities Study Team – Rendezvous Standards Team, January 2017

SSP 30219
- Space Station Reference Coordinate Systems, Rev K, NASA International Space Station Program, July 2016

SSP 50808
- ISS to Commercial Orbital Transportation Services (COTS) Interface Requirements Document (IRD), Revision F, September 2014

SSP 50235

IDSS-GUIDE-001
- Navigation and Alignment Aids Concept of Operations and Supplemental Design Information
3.0 INTERNATIONAL RENDEZVOUS SYSTEM INTEROPERABILITY STANDARDS

3.1 GENERAL

The goal of establishing standards and agreeing on other assumptions is to maximize the success of future human spaceflight missions conducted as international partnerships. The ability of components, systems, or vehicles delivered from multiple sources to work together as an effective system is important to the success of actual missions. Good collaboration can make technology development and system maturation more efficient, by sharing the lessons learned and failures that drive requirements. Using standard assumptions can also make development more efficient by making tests conducted by one partner relevant and valid to multiple partners.

This document is focused on issues that drive system performance so much that they could rule out some technologies, and on issues that most directly affect interoperability between partner systems.

The following subsections describe the system interfaces for the International Rendezvous System Interoperability Standards.

3.1.1 DESCRIPTION OF RENDEZVOUS

The following subsections describe the system interfaces for the International Rendezvous System Interoperability Standards.

Rendezvous, regardless of whether it is automated or conducted by crew, is among the most challenging operations during a spaceflight mission. Failure to rendezvous and dock has implications for mission success and crew survival.

To date, only nation states have conducted successful human rendezvous and docking, an indication both of the costs and complexity involved. Rendezvous systems have also been highly customized and optimized as an integrated system for each mission.

Examples exist throughout human spaceflight of rendezvous problems, starting in the 1960s with both Soviet and US programs, and continued through the ISS Program.

All examples to date have relied on the implementing nation state controlling both sides of the interface, namely the passive and active vehicle rendezvous systems.

In the case of an international standard, each interface must be adequately defined to assure full compatibility and cooperation between the rendezvous systems from many different providers.

Terminology has also been traditionally customized to each Program. This results in reduced operational carry over between programs, and lost opportunity. Even within a Program, the terminology can be different from vehicle to vehicle.

Rendezvous techniques are limited by orbital mechanics and vehicle characteristics, however there are still large variations between the techniques across current users.
3.1.2 ENGINEERING UNITS OF MEASURE

All parameters use the metric SI system, with the English units in parentheses provided for reference (where/when applicable).

3.1.3 RENDEZVOUS DEFINITIONS

The following subsections describe the definitions of the terms to be used in the context of spacecraft rendezvous.

3.1.3.1 PHASES

Explanation of the different flight phases as part of a standard assures both consistent application of terms but also assure common operations for joint missions. The phases pair fairly closely with the decision points. Objective is to clarify the high-level phases to avoid confusion when discussing these terms.

- **Launch and Insertion** – This phase begins at ignition for launch and ends when the Visiting Vehicle (VV), also referred to as the chaser, is confirmed to be ready for trans lunar/mars injection burn (TLI/TMI). The goal of this phase is to deliver the VV into a TLI/TMI point. During this phase, the VV control teams typically operate independently with some basic planning and data coordination being performed with the Deep Space Gateway (DSG) control team (e.g. state vector and maneuver plan exchange, communication coverage planning, timeline planning.)

- **Transfer** – This phase begins when the VV is confirmed to be ready for TLI/TMI and ends when it is confirmed to be in an orbit established in cis-lunar space. The goal of this phase is to move the VV from Earth orbit to the DSG orbit or from the DSG orbit to Earth orbit. During this phase, the VV control team typically operates independently with some basic planning and data coordination being performed with the DSG control team (e.g. state vector and maneuver plan exchange, communication coverage planning, timeline planning.) For transit to the DSG orbit, the DSG and VV control teams will begin integrated operations toward the end of this phase to support the “GO for Rendezvous Orbit Entry” decision.

- **Rendezvous** – This phase begins when the VV is confirmed to be in an orbit established in cis-lunar space relative to the DSG (also referred to as the target) and ends at docking/berthing start.
  - **Far Rendezvous** – This phase brings the VV closer to the DSG, while still protecting the ability to passively abort the approach on a trajectory that is operationally safe. Space-to-space communications has been confirmed and that the VV has transitioned to relative navigation. The decision to NO-GO the Approach Initiation (AI) burn will lead to considering either VV disposal, VV return to Earth, or VV re-rendezvous.
  - **Close Rendezvous** – Includes the operations within the approach sphere:
- **Approach** - During this phase the VV transitions to the approach axis while staying outside the Keep-Out Sphere (KOS). Once the VV has reached the approach axis it then enters the KOS while staying within the pre-analyzed approach corridor.

- **Fly-around** – Consists of a VV maneuver during approach or departure in which the VV transitions to another approach axis, or circumnavigates the DSG and returns to an approach axis.

- **Departure** - For release and departure, the phase commences upon physical separation, either docking mechanism push-off or grapple release, from the DSG. This phase is complete when the VV is confirmed to be departing the DSG on a trajectory that is operationally safe and the VV is outside the Approach Sphere (AS).

- **Proximity Operations** (Prox Ops) – This phase encompasses multiple phases defined above: approach, fly-around, and undocking and departure. This is used extensively within the NASA ISS community to cover all maneuvers performed within the approach ellipsoid (AE).

- **Docking** – Defined as the docking mechanism contact, capture and hard-mate. After first contact, rendezvous phase is complete. This phase is owned by the docking mechanism.

- **Berthing Capture** - Defined as the physical robotic capture of the visiting vehicle. Rendezvous phase is completed at first contact. This phase is owned by the robotics operations.

- **Undocking** – Defined as the physical separation of the two vehicles.

- **Release** – Defined as the physical release by the robotic arm of the visiting vehicle.

- **Retreat** – Defined as the VV increasing its relative range with respect to the DSG, aiming at a predefined hold point.

- **Hold** – In this phase, the VV maintains its relative position with respect to the DSG such that it neither approaches nor retreats from the DSG.

- **Free Drift** – In this phase the DSG’s and the visiting vehicle’s translational and rotational control are inhibited. This phase is initiated at first contact for docking, or at VV command for berthing.

- **Abort** – This phase is initiated automatically or by crew (chaser or target) for the VV to perform a separation sequence (thruster firing), which places VV on a safe trajectory departing from DSG.

### 3.1.3.2 OPERATIONAL REGIONS AND ZONES

The VV shall not enter the following regions prior to a predefined maneuver that takes the VV inside those regions. To manage the risk associated with rendezvous
operations, four regions have been defined. These regions are used as references to determine when critical events will occur. The regions are as follows:

1. **Rendezvous Sphere** (RS) – The RS is a 10 km (TBC 3-1) radius sphere around the DSG center of mass and is used to govern the Rendezvous Orbit Entry (ROE) decision. A shape larger than the AS is needed to balance the risk associated with the large dispersions expected from the ROE burn.

2. **Approach Sphere** (AS) – The AS is a 2 km (TBC 3-2) radius sphere centered at the DSG center of mass.

3. **Keep-out Sphere** (KOS) – The KOS is 200 m (TBC 3-3) radius sphere centered at the DSG center of mass.

4. **Approach/Departure Corridors** – The Approach and Departure corridors are ±10° (TBC 3-4) centered to the docking port axis within the KOS.

**Rationale:**

For the DSG, safety regions will be defined based on relative dynamics, configuration of the DSG, and navigation accuracy (both DSG and VV). Safety regions are critical to contributing to mission safety and success, and have an impact of expected performance of GN&C.

![ FIGURE 3-1 NOTIONAL CONCEPT OF ZONES AND CORRIDORS](image)

### 3.1.3.3 INTEGRATED OPERATIONS

Integrated Operations refers to the mode of authority structure used by the operations team, in which all commanding is approved through the Lead Control Center. Integrated
Operations begin before the VV is on a trajectory that will enter the AS, and terminate when the VV is outside the AS and confirmed to be on a safe free drift trajectory.

### 3.1.3.4 DECISION POINTS

To execute a VV mission to or from the DSG, there will be a series of decisions, that start with the mission management team and then will be handed off to the operations team and the visiting vehicle. Time delay considerations need to be accounted for in the decision process. The VV shall implement the following decision points during RPOD:

1. **Element Readiness** (Program Level Decision)

2. **GO for Rendezvous Orbit Entry** (Operations Team Decision) – The VV shall transition to an orbit established in cis-lunar space before beginning the rendezvous operation. “Go” enables VV to continue operations into the Rendezvous Sphere (RS).

3. **GO for Approach Initiation** (Operations Team Decision) – The Approach Initiation (AI) burn is the first burn that is allowed to target into the Approach Sphere (AS).

4. **GO for Final Approach** (Operations Team Decision) – This decision allows the vehicle to proceed inside the Keep-out Sphere (KOS), but requires that the vehicle stay within a predefined approach corridor.

5. **GO for Docking/Capture** (Operations Team Decision) – This is the final decision to allow the vehicles to have contact. For cis-Martian operations this decision may ultimately be combined with the GO for Final Approach (to accommodate communication delay if decision is Earth/LCC based).

6. **GO for Undock/Release** (Operations Team Decision) – This decision will result in the VV returning to free flight.

7. **GO for Return to Deep Space Gateway** (Mission Management Decision) – This decision implies that the vehicle has implemented a hold point or abort compliant with the KOS/AS/RS constraints. Returning to DSG shall be compliant with nominal approach constraints, as defined above.

### 3.1.3.5 CHECK POINT

The VV approach trajectory shall include predefined decision points where the VV will not proceed on the approach if it has not received “GO” command from the associated ground operator, DSG crew or the VV crew. The rules of what should be considered in the check point design shall be standardized. The VV may have additional non-mandatory checkpoints, where an approaching or separating vehicle may perform additional actions such as station-keeping, wait for additional “go/no-go” decisions, or perform trouble-shooting in contingency situations.

**Note:**

- Decision points and check points are vehicle specific, defined by trajectory design and VV’s performance.
Decision points are mandated by DSG operation, and check points may be added at the discretion of each VV. Decision Points are common across all participants.

Check points may be added at the discretion of each VV.

Rationale:

In order not to limit the development of each VV, design of check points should not be standardized as is the case of ISS rendezvous. However, the guidelines for designing check points should be standardized to increase the mission safety.

3.2 INTERFACES

Unless otherwise stated, the features called out in this section and its subsections shall be implemented on International Rendezvous System Interoperability Standards systems; these are requirements which must be met to ensure International Rendezvous System Interoperability Standards compatibility between systems of different origin. Each requirement is specified only once with its required value and tolerance (if applicable).

3.2.1 OPERATIONAL PRINCIPLES/PROCEDURES

3.2.1.1 TIME INFORMATION

A synchronized, unified time information shall be maintained by all vehicles in the Deep Space Gateway (DSG) architecture, including visiting vehicles. The DSG maintains the orbit master clock with the Ground master clock providing synchronization pulse, and the synchronization pulse is also received by the Visiting Vehicle (VV). Once vehicles are within inter-vehicle communication range, the times are exchanged and the offsets are computed. The notional concept is depicted in Figure 1. It is anticipated that this synchronization is worked between Communications and Tracking, Avionics and Rendezvous through the Systems Engineering and Integration to ensure proper time synch across the whole system.
3.2.1.2 COORDINATE SYSTEMS

Coordinate systems are required to convey spacecraft location and properly exchange information.

3.2.1.2.1 CELESTIAL COORDINATE SYSTEMS

Inertial reference frames are required to understand the location and pointing of each spacecraft, in absolute and relative states. This Standard will utilize the International Celestial Reference Frame (ICRF), which is in itself a recognized international standard, and maintained by the International Earth Rotation and Reference Systems service.

International Celestial Reference System (ICRS): This system is intended to serve as the inertial reference system and its location is determined with respect to hundreds of celestial quasar sources.

- **Origin**: The origin is at the barycenter of the solar system centered at the Sun.
- **X-axis**: To the vernal equinox in the Earth-Sun equatorial plane
- **Y-axis**: In the Earth-Sun equatorial plane completed by $Y = Z \times X$
- **Z-axis**: Points to the celestial North Pole as defined from Earth.
Earth Centered Inertial Frame (J2000): This frame is practically aligned with the ICRS with axis deviation in the range of 5.1 milli arc second.

- **Origin**: Earth’s center
- **X-axis**: Pointing to the vernal equinox
- **Y-axis**: In the Earth-Sun equatorial plane completed by $Y = Z \times X$
- **Z-axis**: Points to the celestial north pole as defined from Earth.

Lunar Centered Inertial Frame (LCI): This frame is inertia l with the X and Y axes in the Moon orbital plane around the Earth. This plane is different from the equatorial one as it has an inclination of about 5 deg with respect to the ecliptic plane and the Earth has 23.5 deg with respect to the ecliptic plane, leading to a difference of 17.5 deg with respect to the equatorial plane. The frame is obtained by rotation of the J2000 inertial frame.

- **Origin**: Center of the Moon
- **X-axis**: At the ascending node of the lunar orbital plane to the equatorial plane measured from the vernal equinox (J2000 X-axis)
- **Y-axis**: In the Moon orbital plane completed by $Y = Z \times X$
- **Z-axis**: Normal to the lunar orbital plane and rotating the J2000 Z-axis by 17.5 deg around the X-axis.

Synodic Rotating Frame (SRF): This is a rotating frame located along the Earth-Moon line. It is used for reference and definition of other frames. (This is also known as the EM-ROT frame)

- **Origin**: At the Cis-Lunar Lagrange point $L_2$
- **X-axis**: Along the Earth-Moon line pointing from the Earth to the Moon
- **Y-axis**: In the Moon orbital plane completed by $Y = Z \times X$
- **Z-axis**: Normal to the lunar orbital plane in the celestial north direction

Local Vertical Local Horizontal (LVLH) [TBR 3-1]: This is the primary frame used to represent all the relative motion dynamics and kinematics. It will be the same frame used for the Rendezvous and Docking. The definition will be valid for Near Rectilinear Halo Orbits (NRHO) whose instantaneous orbital plane can be defined with respect to the SRF..

- **Origin**: At the center of mass of the target spacecraft (DSG)
- **X-axis**: $X = Y \times Z$ which is in the direction of the DSG velocity vector
- **Y-axis**: Normal to the instantaneous orbital plane and in the opposite direction of the orbital momentum vector
- **Z-axis**: From the DSG COM to the Moon COM.
**Orbital Frame (ORB):** This frame is mostly used to define the position of the spacecraft on the respective orbits.

- **Origin:** The orbital focal point, Moon or Lagrange
- **X-axis:** From the focal point in the orbital plane to the location of the spacecraft, measured at an angle from the ascending node.
- **Y-axis:** Completed by \( Y = Z \times X \)
- **Z-axis:** Same as the Z-axis of the LCI frame.

### 3.2.1.2.2 VEHICLE COORDINATE SYSTEMS

Spacecraft based coordinate systems shall include structural, body, docking, and grapple fixtures (if applicable) at a minimum. Corridors and keep out zones are tied to vehicle reference frames.

**Geometrically Fixed Frame (GFF) [TBR 3-2]:** This frame is used to specify the location of equipment on the spacecraft and serves as the main mechanical reference.

- **Origin:** Located at the intersection of the longitudinal axis of the spacecraft with the docking port contact flange plane.
- **X-axis:** Parallel to the longitudinal axes of the spacecraft and forward pointing from the docking port.
- **Y-axis:** Parallel to a line orthogonal to the longitudinal axis and going through the point between the 2 SADMs on port side
- **Z-axis:** \( Z = X \times Y \)

**Spacecraft Body Frame:** Used for the dynamics and kinematics of the spacecraft.

- **Origin:** Spacecraft COM
- **X-axis:** Parallel to the GFF\(_x\)
- **Y-axis:** Parallel to the GFF\(_y\)
- **Z-axis:** Parallel to the GFF\(_z\)

**Metrology Frame:** This is the sensor frame in which the range and Line Of Sight (LOS) is measured. The frame is ideally parallel to the GFF, but might have a rotation matrix to account for if the sensor is canted with respect to the docking axis.

- **Origin:** The origin is specified in the GFF and located likely at the center of the sensing chip.
- **X-axis:** Ideally parallel to the GFF\(_x\)
- **Y-axis:** Ideally parallel to the GFF\(_y\)
- **Z-axis:** Ideally parallel to the GFF\(_z\)
Chaser Docking Frame (DC) [TBR 3-3]: This frame specifies chaser spacecraft’s docking port frame with respect to its body frame. For the final approach in 6-DOF, this is the frame around which the GNC will be controlling and not the body frame.

- **Origin**: It has its origin at the same location as the GFF frame.
- **X-axis**: Parallel to the GFF\_x
- **Y-axis**: Parallel to the GFF\_y
- **Z-axis**: Parallel to the GFF\_z

### 3.2.1.2.3 DSG COORDINATE SYSTEMS

Geometrically Fixed Frame (GFF) [TBR 3-2]: This frame is used to specify the location of equipment on the spacecraft and serves as the main mechanical reference. It is also known as body-fixed frame (index zero)

- **Origin**: Located at the intersection of the longitudinal axis of the pressurized elements and the docking plane between the power and propulsion element and the 1\textsuperscript{st} pressurized element launched.
- **X-axis**: Parallel to the longitudinal axis of the pressurized element positive towards the opposite docking port from the power/prop bus
- **Y-axis**: Parallel to the center line normal vector of the radial port on starboard side.
- **Z-axis**: Z = X x Y

DSG Body Frame [TBR 3-4]: Used for the dynamics and kinematics of the spacecraft including its attitude with respect to the LVLH frame.

- **Origin**: Spacecraft COM
- **X-axis**: Parallel to the GFF\_x
- **Y-axis**: Parallel to the GFF\_y
- **Z-axis**: Parallel to the GFF\_z

Target Docking Frame Longitudinal (DT) [TBR 3-5]: This frame will describe the target spacecraft’s port location and its attitude with respect to the LVLH needed for docking port to port.

- **Origin**: Located at the intersection of the longitudinal axis of the pressurized elements and the docking plane of the port opposite the one towards the power/prop bus.
- **X-axis**: Parallel to the GFF\_x but in the opposite direction. This in order to have the target and chaser docking ports parallel ideally and only an X-axis shift when in docked position.
- **Y-axis**: Parallel to the GFF\_y
Target Docking Frame Radial (DT) [TBR 3-5]: This frame will describe the target spacecraft’s port location and its attitude with respect to the LVLH needed for docking port to port.

- **Origin**: Located at the geometrical center of the docking port opening and in the docking port plane.
- **X-axis**: Orthogonal to the GFF\(_x\) and pointing towards the longitudinal axis. This in order to have the target and chaser docking ports parallel ideally and only an X-axis shift when in docked position.
- **Y-axis**: Parallel to the GFF\(_y\)
- **Z-axis**: Parallel to the GFF\(_z\)

### 3.2.1.3 SAFETY GUIDELINES

Standard safety guidelines shall be defined. The Rendezvous Standards team specifies that the VVs shall have the following capabilities and/or data:

- Systems are 1-fail operative, 2-fail safe
- Independent and dissimilar sensor cross-check (utilizing the DSG based data)
  - Range and range-rate data
  - For docking, 6-DOF prior to and during docking (within approach corridor)
  - For automated berthing/capture, 6-DOF prior to and in the berthing box
- Crew monitoring (telemetry, audio and video)

### 3.2.2 TRAJECTORY SAFETY

#### 3.2.2.1 APPROACH SPHERE (AS)

See definition in section 3.1.3.2. Prior to the VV’s approach initiation (AI) maneuver, all VV coast trajectories shall not intercept the AS for a minimum of 24 hours (TBC 3-5).

#### 3.2.2.2 KEEP OUT SPHERE (KOS)

See definition in section 3.1.3.2. The KOS shall only be entered via the approach corridor after authority to proceed (ATP) has been granted. Fly-around inside KOS shall be along a pre-defined corridor (that has been analyzed and authorized).
3.2.2.3 ABORT

The VV shall execute abort commands issued automatically by its onboard systems, initiated by the onboard crew, or by external commands that places the VV on a 24-hour safe free drift trajectory (TBC 3-6).

Note:

- In ISS Rendezvous, passive abort (PA) and Collision Avoidance Maneuver (CAM) are defined. The VV must be able to execute a Collision Avoidance Maneuver (CAM) at all times for all mission phases. During a CAM, the vehicle must stop closing (decreasing relative range) and then establish an opening rate (increase relative range). For ISS rendezvous, a CAM must put the vehicle on a 24-hour safe free drift trajectory. The safe free-drift trajectory duration for cis-lunar operations needs to be defined based on vehicle kinematics/dynamics.

- It should be considered to have a CAM capability issued from the DSG to the VV (in particular when supporting rendezvous operations with a small robotic element such as the lunar ascent stage) to ensure DSG safety.

Rationale:

In order to ensure the DSG safety, automatic abort functions would be necessary as is the case in ISS rendezvous. Standard rules for abort operations would increase mission safety.

3.2.2.4 CORRIDORS

Several "corridors" are defined for ISS visiting vehicles. The DSG shall have corridors, which will be used in cis-lunar rendezvous.

3.2.2.4.1 APPROACH CORRIDOR

See definition in section 3.1.3.2.

The VV’s approach to the DSG within the KOS shall be within a predefined corridor, standardized for all Visiting Vehicles. Corridor sizing and definition shall follow guidelines, utilizing information such as docking contact conditions (IDSS requirements), velocity profile, vehicle dynamics, vehicle keep out zones, structural clearance, etc. Approach corridors shall be defined that apply to all incoming vehicles to minimize multiple corridor definitions.

3.2.2.4.2 DEPARTURE CORRIDOR

See definition in section 3.1.3.2.

The VV shall depart from the DSG within the predefined corridor specified for each VV. The rules of what should be considered in the corridor sizing shall be standardized.
Rationale:

- In ISS rendezvous, all VVs are required to depart from the ISS within the predefined corridor, which is defined mainly by the monitoring capability of the ISS and the VV's performance.

3.2.2.4.3 RELOCATION CORRIDOR

The VV shall perform port relocation in predefined corridor with respect to the DSG. The relocation corridor is a combination of approach corridor, departure corridor and a fly-around corridor inside the KOS. Exact sizing should take into account DSG elements (module size/shape, and articulating appendages such as solar arrays and communications antennas) and VV sizing and dynamics.

Note:

- An example of ISS port relocation is shown below. The Russian port relocation corridor is within the ISS keep out sphere (KOS).

![FIGURE 3-2 ISS RUSSIAN VEHICLE RELOCATION CORRIDOR](image)

Rationale:

*Configuration of the relocation corridor(s) should be standardized to ensure DSG safety. These will be a function of appropriate orbit(s) and vehicle dynamics.*

3.2.2.4.4 ABORT CORRIDOR

The following subsections describe the various abort corridors that should be utilized.
3.2.2.4.4.1 AUTOMATIC ABORT CORRIDOR (AAC)

When VV flies in automated mode, the VV shall monitor the predefined “Automatic Abort Corridor” and perform an abort automatically if it senses a corridor violation. The upper limit of the AAC shall be ±7.5° (TBC 3-7).

3.2.2.4.4.2 MANUAL ABORT CORRIDOR (MAC)

The VV crew, DSG crew (or ground operator) shall monitor a predefined “Manual Abort Corridor” and execute an abort command to the VV if they sense the violation of manual abort corridor. The size of MAC must be larger than the AAC, plus monitoring errors (camera pointing errors, attitude errors, etc.), yet smaller than the monitoring capability (i.e. smaller than the camera Field-of-Views (FOV)). The MAC shall be ±10° (TBC 3-8).

3.2.2.5 MATING ENVELOPES

3.2.2.5.1 DOCKING ENVELOPE

Refer to the IDSS IDD, table 3.3.1.1-2, Initial Contact Conditions. The docking envelope is comprised of closing rate, lateral rate, pitch/yaw rate, roll rate, lateral misalignment, pitch/yaw misalignment and roll misalignment.
3.2.2.5.2 CAPTURE VOLUME

Capture volume shall be standardized and should be covered in the International External Robotic Interfaces Standard (IERIS).

3.2.2.5.3 DEPARTURE/RELEASE POINT

Departure/release point shall be standardized and should be covered in the IERIS.

3.2.2.6 SAFETY CLEARANCE

3.2.2.6.1 STRUCTURAL CLEARANCE

A standard structural safety clearance shall be defined specific to the particular docking port.

*Note:*
- Structural Safety clearance will be defined based on the DSG’s configuration, docking mechanisms and attachment points.

*Rationale:*

For collision avoidance, minimum clearance between the structure of the VV and the DSG should be defined.

Structural safety clearance has an impact on the VV’s design. Agreeing on them early on, contributes to reducing the development cost of the VV.

3.2.2.6.2 PLUME IMPINGEMENT AND CONTAMINATION

Plume impingement and contamination joint analysis process shall be standardized, but should be done so at System Engineering and Integration level, not at the Rendezvous Standards level. The plume impingement/contamination requires exchange of vehicle requirements, thruster models and capabilities during the project design, and are used to perform cyclical analyses, that enable design modifications to minimize impacts to the DSG. Listed below are the necessary data products and analyses that will determine the impacts to the DSG and VV trajectory.

1. Data: VV thruster plume model, thruster locations and orientations

2. Trajectory: VV relative trajectory (Monte Carlo analysis) that includes jet firing histories (jets fired, pulse-width, etc.). Each corridor (docking port) shall be analyzed. Contingency cases shall also be included (thruster failures, sensor failures, capture failures, etc.).

3. Analyses: The trajectories with plume models are analyzed to determine the impacts on DSG.

   a. Objective is to determine if the loads (force and torques on the appendages, and thermal loads) are within acceptable loads on DSG (articulating elements such as solar arrays). If loads unacceptable, provide feedback to trajectory design for changes and repeat the cycle (steps 2 & 3).
b. Erosion and contamination effects are analyzed for undue harm/stress to the DSG.

Rationale:

Since plume impingement from the VV may impact the trajectory of the DSG, pressure and thermal input due to plume impingement should be restricted to the acceptable amount. Need to include impacts of DSG onto VV.

3.2.2.7 SECONDARY STATE DETERMINATION

Assessment of relative navigation correctness shall be performed, based on at least two independent and dissimilar sources of navigation data. Dissimilar, secondary state determination shall be implemented in addition to the visiting vehicle’s vehicle main navigation loop.

Secondary navigation data shall be used for safety assessment.

Secondary navigation data can be used for main data navigation verification.

Secondary state navigation can be used as navigation to perform automated rendezvous. In this case, source of navigation data shall be redundant.

The source of secondary state navigation data shall be located on DSG; however, secondary state can be hosted on the visiting vehicle.

Secondary state navigation data shall be accessible in the place of use.

Secondary state navigation data shall be determined at hold/check/decision points and during safety critical phases.

Secondary state navigation shall determine relative range, range rate and VV position in approach corridor during final approach.

Secondary state navigation shall determine full 6DOF relative state during the last stage of final approach from 20 m (TBC 3-9) to docking or autonomous capture.

Secondary state navigation data delay and frequency shall allow fulfilling safety requirements. Data shall be time tagged.

Rationale:

Safe joint operations require that all incoming vehicles compute and transmit a secondary, dissimilar range and range-rate data. This data is used by crew (VV and DSG where applicable) to evaluate the VV’s navigation performance. Maintaining a secondary system on VV can impact vehicle design.

3.2.3 INTER-VEHICLE TELEMETRY

3.2.3.1 STANDARD TELEMETRY OVERVIEW

Telemetry data provided to/from the DSG and from/to the VV shall contain the data specified in the standard telemetry list, described in 3.2.3.3 STANDARD TELEMETRY CONTENT. Standard telemetry data shall be expressed in the common units and
representations, and measurement shall have a standard definition of where/how it was measured. (i.e. from what point to what point the measurement should be made, or, from what frame to what frame the attitude should be represented). Also, the definition of vehicle status in the standard telemetry, such as the VV's flight mode (approach, retreat, hold, depart, etc.) shall be standardized, and in line with the DSG definitions.

Note that, since some parts of the data will be vehicle-specific, inter-vehicle telemetry should have some undesignated allocations for vehicle-specific data.

*Rationale:*

*Standard telemetry list will help crew-display development, reduce crew workload including training, and increase efficiency.*

*Standardization of systems and representations in which the telemetry data described would reduce complexity for both crews and flight software. It would contribute to not only promoting interoperability but also increasing mission safety and cost reduction.*

### 3.2.3.2 STANDARD TELEMETRY FORMAT

The standard telemetry data shall be transmitted in compliance with the “DSG communication standard”.

### 3.2.3.3 STANDARD TELEMETRY CONTENT

This following subsections describe the standard telemetry data, which shall be shared between the DSG and VV during RPOD and transmitted between the vehicles: VV to DSG and DSG to VV.

#### 3.2.3.3.1 TIME

This is the time stamp indicating the time when the data is obtained, not when it is transmitted. The VVs and the DSG shall utilize a unified synchronized reference time in UTC with Modified Julian Date format, as stated in section 3.2.1.1.

Time information shall be provided for each data included in the standard telemetry, since the obtained time of individual data may differ and shall be expressed in common time reference or, if not, the additional clock drift information shall be provided.

*Rationale:*

*Any information sent should have a timestamp included for time synchronization, relative navigation and situational awareness.*

#### 3.2.3.3.2 DATA VALIDITY (TBC 3-10)

This is a validity flag indicating whether each transmitted data is valid or not.

Data validity shall be individually provided for each data included in the standard telemetry.
Rationale: Need to have mechanism in place to ensure that the sender and receiver properly process data and identify whether it is valid or invalid. This could be with a data validity flag, times stamps, or omitting sending invalid data (don't send bad data).

3.2.3.3.3 ABSOLUTE NAVIGATION DATA

This is absolute position, velocity, attitude, and angular rate of the host vehicle (the vehicle transmitting the data: the VV or the DSG) measured by ground operation or onboard measurement.

The reference point of position and velocity measurements shall be vehicle’s estimated COM and expressed in ICRF inertial frame. The attitude shall be expressed as a quaternion representing the rotation of vehicle’s body frame with respect to ICRF inertial frame. Quaternion shall be defined as having the scalar term in the first element. The angular rate shall be expressed in the vehicle’s body frame.

Rationale:

The VV can use this data as an option for the DSG state knowledge when the Space-to-ground link is lost.

The DSG can use this data as an option for VV state knowledge when the proximity communication is established.

The DSG can use this information for confirmation of the VV’s expected state by comparing it with the relative navigation data provided from the VV.

3.2.3.3.4 RELATIVE NAVIGATION DATA (VV TO DSG)

This is relative position, velocity, attitude, and angular rate of the VV with respect to the DSG, based on the navigation sensor(s) and the estimation filters onboard the VV. If the VV estimates a secondary solution, it shall also be transmitted to the DSG, in the same manner/form as the primary relative navigation solution.

Regarding relative position and velocity, the following two data sets with different reference points shall be transmitted, when available:

- Relative position/velocity between the COMs of the VV and the DSG expressed in the DSG-centered LVLH frame.

- Relative position/velocity between mechanical interface points expressed in the DSG docking/berthing frame. Mechanical interface points will be as follows:
  - (for docking) the origins of the docking mechanism’s Soft Capture System onboard the vehicles.
  - (for berthing) the capture point and the origin of the grapple fixture onboard the VV.

When required during docking and berthing operations, relative attitude shall be transmitted as a quaternion representing the rotation of the VV docking frame with respect to the DSG docking frame. Relative angular rate shall be expressed as the
rotation rate of each axis of the VV docking frame with respect to each axis of the DSG docking frame.

*Rationale:*

*The relative navigation data from the VV will be used by the DSG crew for monitoring, to cross check the DSG’s own relative navigation data, as well as used to trigger a CAM if needed.***

### 3.2.3.3.5 RELATIVE NAVIGATION DATA (DSG TO VV)

This is relative position, velocity, attitude, and angular rate of the VV with respect to the DSG, based on the navigation sensor(s) and the estimation filters onboard the DSG.

When available, the range and range-rate shall be transmitted from the DSG to the VV.

Regarding relative position and velocity, the following two data sets with different reference points shall be transmitted, when available:

- Relative position/velocity between the COMs of the VV and the DSG expressed in the DSG-centered LVLH frame.
- Relative position/velocity between mechanical interface points expressed in the DSG docking/berthing frame. Mechanical interface points will be as follows:
  - (for docking) the origins of the docking mechanism’s Soft Capture System onboard the vehicles.
  - (for berthing) the capture point and the origin of the grapple fixture onboard the VV.

When required during docking and berthing operations, relative attitude shall be transmitted as a quaternion representing the rotation of the VV docking frame with respect to the DSG docking frame. Relative angular rate shall be expressed as the rotation rate of each axis of the VV docking frame with respect to each axis of the DSG docking frame.

*Rationale:*

*The relative navigation data from the DSG will be used by the VV crew for monitoring and to cross check the VV’s own relative navigation data. The data can be used as redundant data for the VV’s own GNC navigation.***

### 3.2.3.3.6 VV FLIGHT MODE

The flight mode information of the VV shall be transmitted from the VV to the DSG. The vehicle flight mode should be in line with the phases defined in section 3.1.3.1.

*Rationale:*

*VV’s flight mode will be provided to the DSG and used for monitoring and go/no-go decisions.*
In order to avoid confusion and misunderstanding, definition of the VV flight mode provided to the DSG will be standardized.

### 3.2.3.3.7 VEHICLE STATUS

This is critical health and status information on the host vehicle.

The DSG status information transmitted from the DSG to the VV shall be as follows:

<table>
<thead>
<tr>
<th>Data Description</th>
<th>State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control mode, DSG Health</td>
<td>(TBD 3-1)</td>
</tr>
<tr>
<td>DSG from/to Ground Comm status</td>
<td></td>
</tr>
<tr>
<td>DSG Carrier Lock status</td>
<td>LOCK/UNLOCK</td>
</tr>
<tr>
<td>DSG Bit lock status</td>
<td>LOCK/UNLOCK</td>
</tr>
<tr>
<td>DSG RX Power level</td>
<td>** dB</td>
</tr>
<tr>
<td>DSG TX ON/OFF</td>
<td>ON/OFF</td>
</tr>
<tr>
<td>DSG TX Power level</td>
<td>** dB</td>
</tr>
<tr>
<td>DSG from/to VV Comm status</td>
<td></td>
</tr>
<tr>
<td>DSG Carrier Lock status</td>
<td>LOCK/UNLOCK</td>
</tr>
<tr>
<td>DSG Bit lock status</td>
<td>LOCK/UNLOCK</td>
</tr>
<tr>
<td>DSG RX Power level</td>
<td>** dB</td>
</tr>
<tr>
<td>DSG TX ON/OFF</td>
<td>ON/OFF</td>
</tr>
<tr>
<td>DSG TX Power level</td>
<td>** dB</td>
</tr>
<tr>
<td>Error Status</td>
<td></td>
</tr>
<tr>
<td>(ex. Caution and Warning Message)</td>
<td>None/Error code</td>
</tr>
<tr>
<td>(OR, standard status flag indicating the criticality of the error)</td>
<td></td>
</tr>
<tr>
<td>Status of docking mechanism</td>
<td>(* Refer to IDSS IDD)</td>
</tr>
<tr>
<td>Relative Navigation Source Status</td>
<td>Status SENSORS</td>
</tr>
<tr>
<td></td>
<td>Filter status</td>
</tr>
</tbody>
</table>

The VV status information transmitted from the VV to the DSG shall be as follows:
<table>
<thead>
<tr>
<th>Data Description</th>
<th>State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abort delta-V</td>
<td>Abort delta-V vector in DSG-centered LVLH</td>
</tr>
<tr>
<td>(** Zero vector means passive abort)</td>
<td></td>
</tr>
<tr>
<td>VV from/to Ground Comm status</td>
<td>VV Carrier Lock status LOCK/UNLOCK</td>
</tr>
<tr>
<td></td>
<td>VV Bit lock status LOCK/UNLOCK</td>
</tr>
<tr>
<td></td>
<td>VV RX Power level ** dB</td>
</tr>
<tr>
<td></td>
<td>VV TX ON/OFF ON/OFF</td>
</tr>
<tr>
<td></td>
<td>VV TX Power level ** dB</td>
</tr>
<tr>
<td>VV from/to DSG Comm status</td>
<td>VV Carrier Lock status LOCK/UNLOCK</td>
</tr>
<tr>
<td></td>
<td>VV Bit lock status LOCK/UNLOCK</td>
</tr>
<tr>
<td></td>
<td>VV RX Power level ** dB</td>
</tr>
<tr>
<td></td>
<td>VV TX ON/OFF ON/OFF</td>
</tr>
<tr>
<td></td>
<td>VV TX Power level ** dB</td>
</tr>
<tr>
<td>Error status</td>
<td>None/Error code</td>
</tr>
<tr>
<td>(** OR, standard status flag indicating the criticality of the error)</td>
<td></td>
</tr>
<tr>
<td>Maneuver Countdown Timer</td>
<td>±** seconds</td>
</tr>
<tr>
<td>Next maneuver delta-V</td>
<td>Delta-v vector in DSG-centered LVLH</td>
</tr>
<tr>
<td>Status of docking mechanism</td>
<td>(* Refer to IDSS IDD)</td>
</tr>
<tr>
<td>Primary Relative Navigation Source</td>
<td>Status SENSORS Filter status</td>
</tr>
<tr>
<td>Secondary Relative Navigation Source</td>
<td>Status SENSORS Filter status</td>
</tr>
</tbody>
</table>
Rationale:

This information is important for the VV crew to know if the DSG is ready or not for approach and docking, and vice versa (if applicable to manned DSG).

This information would be used for trouble shooting to understand the state of the vehicle when the ground communication of the vehicle is interrupted.

3.2.4 INTER-VEHICLE COMMUNICATION INTERFACE

The inter-vehicle (vehicle to vehicle) communication interface during rendezvous shall be standardized. This standard is owned by the C&T standard team.

Note:

- RF interface in physical layer, such as frequency, modulation, coding/decoding, data rate, power, and polarization, and data interface in logical layer, such as packet format, encryption and authentication, are subject to standardization.

- Antenna coverage of the DSG needs to support approaches to all possible docking ports.

Rationale:

Standardization of inter-vehicle communication interface would contribute to promote interoperability and reduce complexity in the DSG system, resulting in total cost reduction as well. Additionally, standard communication interfaces will be necessary to enable remote piloting.

3.2.5 CREW CAPABILITY

Crew functions during rendezvous are crew monitoring and crew commanding. These crew capabilities shall be implemented and utilized either on visiting vehicle and/or on DSG depending where crew is present.

Implementation of crew capabilities on DSG is standardized. Crew capabilities of manned visiting vehicle supersedes DSG.

3.2.5.1 DSG CREW CAPABILITY

DSG crew monitoring and DSG crew commanding shall be standardized as a nominal DSG-crew capability.

3.2.5.1.1 DSG CREW MONITORING

DSG Crew monitoring consist of relative motion monitoring and VV/DSG vehicle status assessment.

Relative motion monitoring by crew is obligatory function in case of manned vehicle. It shall use independent data source which isn’t used in the VV navigation loop. For example, the source of independent monitoring data could be visual information or dissimilar independent navigation sensor or combination of different sources.
Relative motion monitoring by crew shall cover KOS up to vehicles capture. It shall ensure relative motion safety for all motion maneuvers even beyond nominally required fault tolerance.

Required set of parameters for relative motion monitoring:
- position in approach/departure/relocation corridor;
- range and range rate;
- relative attitude.

Precision and measurement domain for each parameter shall be enough to detect safety areas violation.

Each DSG docking port shall be equipped with visual camera aligned with docking port axis. Location of camera shall allow monitoring of required motion parameters.

For visual monitoring, DSG shall use visual camera installed either on DSG or VV. Utilizing of VV-based camera is desirable to ensure visual monitoring during fly around and relocation maneuvers.

Maximum delay in visual image and telemetry data transfer shall not affect rendezvous safety.

Vehicle status assessment is an external check of equipment or systems based on telemetry data. Visiting vehicle and DSG shall have their own checklists with minimum required state of involved systems and critical equipment to proceed to next operation. These checklists shall be verified by crew at decision point as part of GO criteria for Docking, Undocking, etc.

Visual monitoring displays and telemetry data shall be standardized. Sections 3.2.3 and 3.2.6 describes the standard contents/formats of telemetry data and standard for visual monitoring.

3.2.5.1.2 DSG CREW COMMANDING

DSG Crew shall be able to issue time-critical commands to initiate safety provision maneuvers. Minimum list of required commands:
- Rendezvous suspend
- Rendezvous resume;
- Collision Avoidance Maneuver;

Additional commands to control visiting vehicle onboard equipment may be implemented using standard communication protocol.

Visiting vehicle may have manual piloting function. Manual piloting function can be implemented by Visiting Vehicle crew (manual piloting), by DSG crew (remote piloting) or Ground (ground piloting).
Remote piloting is an extension to DSG crew commanding capability, dedicated to perform approach, departure or relocation of visiting vehicle.

Following requirements shall be implemented on visiting vehicle and DSG for remote piloting function:

- DSG shall have unified control post for visiting vehicle monitoring and control, with video display, telemetry data overlays, crew hand controllers and control panel;
- Redundant bidirectional radio channel between DSG and VV shall be implemented for crew commands and crew hand controller signals with minimum bandwidth of 9.6 Kbps;
- Video camera shall be installed on visiting vehicle. It shall be aligned with VV docking port axis and operated using DSG-based targets. Video image shall be transferred to DSG control post with minimum image quality 576i@10fps (720p@25fps is recommended);
- Maximum total delay accounting all contributors (crew hand controller signals direct link and video image return link) is 1.0 second;
- Visiting vehicle shall be able perform translation maneuvers along 3 axes upon crew hand controller signals. Translational hand controller controls visiting vehicle linear acceleration;
- Visiting vehicle shall be able to follow attitude rate around 3 axes based on crew hand controller signals. Attitude hand controller controls visiting vehicle attitude rate. Visiting vehicle shall be able perform attitude stabilization w.r.t. DSG nominal attitude;

Crew command format and interface shall be standardized.

3.2.6 COMMON GUI’S AND OPS PRODUCTS

Graphical User Interfaces (GUIs) and operational (OPS) products for crew monitoring shall be standardized. GUIs and OPS products will consist of monitoring displays, crew commanding hardware/software, and, if appropriate, remote piloting hardware/software/displays.

Note:
- Monitoring display is standardized in ISS operations to the US Nodes: Looking at the existing standard SSP 50313; Display and graphics commonality standard. Currently, it is not standardized across all of the ISS monitoring capabilities.

3.2.7 DEMONSTRATION REQUIREMENT

Visiting vehicle shall have demonstration flight program, which includes demonstration of all safety maneuvers. All rendezvous related equipment including but not limited: navigation sensors, propulsion system, communication system etc., which have no flight
heritage and cannot be fully exercised outside of the space environment, shall have flight approval prior to or received during demonstration mission.

Final approach with visiting vehicle capture to DSG is allowed after successful implementation of demonstration flight program.

If execution of safety maneuvers could prevent docking/berthing (e.g. Collision Avoidance Maneuver), those safety maneuvers could be demonstrated in full scale after VV undocking/unberthing (contributes to mission success by performing abort demonstration after delivery is complete).

3.3 PERFORMANCE

Define allowable performance characteristics of standard.

In addition to the physical geometric interface requirements, a set of common design parameters enveloping the reference missions and conditions is provided. (Insert any system/hardware specific performance parameters). Other common design parameters, if accommodated in the (insert standard) design, increase the probability of successful (insert standardization).

3.3.1 SECONDARY STATE DETERMINATION SYSTEM (SSDS)

Figure 3-3 shows the assumed sensor availability in the establishment of a reference scenario. As a baseline, to transition from RF communication ranging to the SSDS occurs at 750m distance. A target extended range mode where the VV is at 5km of the DSG will also be defined.

![Figure 3-3 Sensor Availability Assumptions](image)

**FIGURE 3-3 SENSOR AVAILABILITY ASSUMPTIONS**
3.3.1.1 SSDS MISSION LEVEL PERFORMANCE REQUIREMENTS

Based on the reference scenario presented in TBD 3-2, the following mission level performance requirements, presented in Table 3-1, were derived.

<table>
<thead>
<tr>
<th>Requirement Code</th>
<th>Title</th>
<th>Description</th>
<th>Rationale/Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRQ-PRF-SSDS-001</td>
<td>Target Acquisition Time</td>
<td>The SSDS shall automatically perform acquisition of the VV within 90 seconds when the target is in the operational field of view and range.</td>
<td>Minimize manual operation and operation time.</td>
</tr>
<tr>
<td>MRQ-PRF-SSDS-002</td>
<td>Tracking Update Rate</td>
<td>The SSDS shall provide raw navigation data at least twice per second (2Hz) with a target of 4 times per second (4Hz).</td>
<td>Typical GNC requirement.</td>
</tr>
<tr>
<td>MRQ-PRF-SSDS-003</td>
<td>Coverage Area</td>
<td>The SSDS FOV shall cover an area greater than 45° x 20° (TBR).</td>
<td>Lots of motion expected in plane and little out of plane. Mounting on a robotics platform would alleviate FOV constraints (except for initial acquisition).</td>
</tr>
<tr>
<td>MRQ-PRF-SSDS-004</td>
<td>Bearing Mode LOS Bias</td>
<td>The SSDS LOS (Az, El) RSS measurement bias shall be less than 0.3° (3-sigma). Intermediate values can be linearly interpolated.</td>
<td>Draper analysis [Draper-2015] uses 0.333° at 1 sigma for LOS camera</td>
</tr>
<tr>
<td>MRQ-PRF-SSDS-005</td>
<td>Bearing Mode LOS Noise</td>
<td>The SSDS LOS (Az, El) RSS measurement noise shall be less than 0.15° (3-sigma). Intermediate values can be linearly interpolated.</td>
<td>Draper analysis [Draper-2015] uses 0.05° at 1 sigma for LOS camera</td>
</tr>
<tr>
<td>Requirement Code</td>
<td>Title</td>
<td>Description</td>
<td>Rationale/Note</td>
</tr>
<tr>
<td>------------------</td>
<td>----------------------------</td>
<td>-------------------------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>MRQ-PRF-SSDS-006</td>
<td>Bearing Mode Range Bias</td>
<td>The SSDS bearing range RSS measurement bias shall be less than 0.5% of the target range.</td>
<td>Draper analysis [Draper-2015] uses 0.33m to 7m (for 1m to 1.5km) for 1 sigma</td>
</tr>
<tr>
<td>MRQ-PRF-SSDS-007</td>
<td>Bearing Mode Range Noise</td>
<td>The SSDS bearing range RSS measurement noise shall be less than 0.5% of the target range.</td>
<td>Draper analysis [Draper-2015] uses 0.33m to 7m (for 1m to 1.5km) for 1 sigma</td>
</tr>
<tr>
<td>MRQ-PRF-SSDS-008</td>
<td>6DOF Pose Bias</td>
<td>The SSDS LOS 6DOF relative pose RSS measurement bias shall be less than 2cm at the minimum docking range and less than 1m at the maximum 6DOF range (3-sigma). Intermediate values can be linearly interpolated.</td>
<td></td>
</tr>
<tr>
<td>MRQ-PRF-SSDS-009</td>
<td>6DOF Pose Noise</td>
<td>The SSDS LOS 6DOF relative pose RSS measurement noise shall be less than 2cm at the minimum docking range and less than 1m at the maximum 6DOF range (3-sigma). Intermediate values can be linearly interpolated.</td>
<td></td>
</tr>
<tr>
<td>MRQ-PRF-SSDS-010</td>
<td>6DOF Relative Attitude Bias</td>
<td>The SSDS LOS 6DOF relative attitude RSS measurement bias shall be less than 0.5° at the minimum docking range and less than 5° at the maximum 6DOF range (3-sigma). Intermediate values can be linearly interpolated.</td>
<td>IDSS can tolerate 4°.</td>
</tr>
<tr>
<td>MRQ-PRF-SSDS-011</td>
<td>6DOF Relative Attitude Noise</td>
<td>The SSDS LOS 6DOF relative attitude RSS measurement noise shall be less than 0.5° at the minimum docking range and less than 5° at the maximum 6DOF range (3-sigma). Intermediate values can be linearly interpolated.</td>
<td>IDSS can tolerate 4°.</td>
</tr>
</tbody>
</table>
3.4 VERIFICATION AND TESTING

N/A

Note: Need to include some statements that verification of many of the items described in this document need to be completed at a systems level, including interaction between two (2) vehicles. Verification of items presented in the Rendezvous Standards will not follow other standards such as Power, Avionics or Communications and Tracking, which have clearly defined items that are quantifiable and measurable.

How to verify corridors, approach sphere, keep out sphere, etc.
4.0 FUTURE TOPICS FOR POSSIBLE STANDARDIZATION
N/A
### APPENDIX A  ACRONYMS AND ABBREVIATIONS

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-DOF</td>
<td>Six Degrees of Freedom</td>
</tr>
<tr>
<td>AAC</td>
<td>Automatic Abort Corridor</td>
</tr>
<tr>
<td>AE</td>
<td>Approach Ellipsoid</td>
</tr>
<tr>
<td>Al</td>
<td>Approach Initiation</td>
</tr>
<tr>
<td>AS</td>
<td>Approach Sphere</td>
</tr>
<tr>
<td>ATP</td>
<td>Authority To Proceed</td>
</tr>
<tr>
<td>CAM</td>
<td>Collision Avoidance Maneuver</td>
</tr>
<tr>
<td>CSA</td>
<td>Canadian Space Agency</td>
</tr>
<tr>
<td>DOF</td>
<td>Degree Of Freedom</td>
</tr>
<tr>
<td>DSG</td>
<td>Deep Space Gateway</td>
</tr>
<tr>
<td>DSG&amp;T</td>
<td>Deep Space Gateway and Transport</td>
</tr>
<tr>
<td>ESA</td>
<td>European Space Agency</td>
</tr>
<tr>
<td>GNC</td>
<td>Guidance, Navigation and Control</td>
</tr>
<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
</tr>
<tr>
<td>IDD</td>
<td>Interface Definition Document</td>
</tr>
<tr>
<td>IDSS</td>
<td>International Docking System Standard</td>
</tr>
<tr>
<td>IERIS</td>
<td>International External Robotic Interoperability Standard</td>
</tr>
<tr>
<td>IRD</td>
<td>Interface Requirements Document</td>
</tr>
<tr>
<td>ISS</td>
<td>International Space Station</td>
</tr>
<tr>
<td>JAXA</td>
<td>Japan Aerospace Exploration Agency</td>
</tr>
<tr>
<td>KOS</td>
<td>Keep Out Sphere</td>
</tr>
<tr>
<td>LEO</td>
<td>Low Earth Orbit</td>
</tr>
<tr>
<td>LIDAR</td>
<td>Light Detection and Ranging</td>
</tr>
<tr>
<td>MAC</td>
<td>Manual Abort Corridor</td>
</tr>
<tr>
<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
</tr>
<tr>
<td>PA</td>
<td>Passive Abort</td>
</tr>
<tr>
<td>PAL</td>
<td>Phase Alternating Line (video format)</td>
</tr>
<tr>
<td>RF</td>
<td>Radio Frequency</td>
</tr>
<tr>
<td>ROE</td>
<td>Rendezvous Orbit Entry</td>
</tr>
<tr>
<td>RPOD</td>
<td>Rendezvous, Proximity Operations and Docking</td>
</tr>
<tr>
<td>RS</td>
<td>Rendezvous Sphere</td>
</tr>
<tr>
<td>RSC-E</td>
<td>Rocket and Space Corporation – Energia</td>
</tr>
<tr>
<td>SLS</td>
<td>Space Launch System</td>
</tr>
<tr>
<td>SSDS</td>
<td>Secondary State Determination System</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------</td>
</tr>
<tr>
<td>SSP</td>
<td>Space Station Program</td>
</tr>
<tr>
<td>TBC</td>
<td>To Be Confirmed</td>
</tr>
<tr>
<td>TBD</td>
<td>To Be Determined</td>
</tr>
<tr>
<td>TBR</td>
<td>To Be Resolved</td>
</tr>
<tr>
<td>TLI</td>
<td>Trans Lunar Injection</td>
</tr>
<tr>
<td>TMI</td>
<td>Trans Martian Injection</td>
</tr>
<tr>
<td>VV</td>
<td>Visiting Vehicle</td>
</tr>
</tbody>
</table>
APPENDIX B  GLOSSARY

ABORT
The chase vehicle performs a separation sequence which places it on a safe trajectory which departs from the target vehicle.

APPROACH ELLIPSOID (AE)
Refer to SSP 50808

APPROACH INITIATION BURN (AI)
The Approach Initiation (AI) burn is the first burn that is allowed to target into the Approach Sphere (AS).

APPROACH SPHERE (AS)
The AS is a sphere around the center of mass of the Deep Space Gateway. It defines a region around the DSG that the VV shall not enter without approval. If VV becomes disabled during RPOD, it shall not enter the AS based on its own trajectory dynamics (free drift trajectory does not take VV into AS).

ATTACHED
The portion of the trajectory in which the target vehicle and the chaser vehicle are physically connected.

AUTOMATED SYSTEM
A system which executes its commands as it is programmed to do and perform its closed loop control, which is predesigned and reference signals are precomputed. It needs external intervention for changes and re-planning.

AUTOMATIC CONTROL
An automatic control loop, a controller compares a measured value of a process with a desired set value, and processes the resulting error signal to change some input to the process, in such a way that the process stays at its set point despite disturbances. This closed-loop control is an application of negative feedback to a system.

Process that is executed to completion without human intervention; however, the ground or crew can observe and confirm the state/status and actions performed by the vehicle.

AUTONOMOUS SYSTEM
Autonomous control systems must perform well under significant uncertainties in the plans and the environment for extended periods of time and they must be able to compensate for system failures without external intervention. The system is able to adapt to external measured changes without external intervention and it possesses the capability to perform re-planning and self-adaptation to new situations with no external intervention.

BERTHING
The act of robotically mating two vehicles.
CAPTURE
The act of robotically capturing a vehicle, typically assumed with robotic arms/devices, or soft capture system within docking mechanisms.

CHASE OR CHASER VEHICLE
Is an active spacecraft during rendezvous with a target vehicle. The chaser vehicle targets and executes a primary set of maneuvers during rendezvous.

CHECK POINT
A predefined location on the vehicle’s trajectory where the VV will not proceed on the approach if it has not received “GO” command from the associated ground operator, Deep Space Gateway crew or the VV crew.

CORRIDOR
A frustum (truncated pyramid or cone) portion of space with its apex located at the target docking mechanism (or capture box) and its longitudinal axis along the direction of intended approach. The chase vehicle maintains its target relative position within the corridor for approach to and possibly, separations from the target.

CREW
Humans on a space based vehicle

CREW INTERRUPT
A crew executed command sent to the visiting vehicle. The command may be a hold/halt, retreat, abort, or resume.

CREW MONITORING
The crew ability to observe and assess the operation, typically with telemetry and video.

[Note: In most cases there will be a blending of video and telemetry. In some cases, this capability could be used to control a formal hazard. We have general agreement that this would be used for all operations where crew is present.]

DEPARTURE
Trajectory starting with the undocking/release event, which places the visiting vehicle on a safe trajectory.

DISSIMILAR SENSOR
This term is applied to sensors being implemented on a vehicle and refers to the suite of sensors being implemented not being vulnerable to common mode failures. Addresses vulnerability to design issues, environmental sensitivity, and operational usage.

DOCKING
The act of using a docking mechanism to mate with another vehicle

FAIL SAFE
The automated reconfiguration to a state that precludes the propagation of further failures and does not cause hazardous conditions. This does not specifically imply recovery of the function.
FAIL OPERATIONAL
Automated reconfiguration of the vehicle in response to a failure or set of failures in order to recover lost functionality or prevent the loss of functionality. This may be system specific or vehicle wide (i.e., thermal recovery or regaining of attitude control).

FREE DRIFT
The vehicle (chase vehicle and target vehicle) inhibits translational and rotational control. This includes thrusters, control moment gyros, magnetic torquers, etc. This occurs at docking contact/latching or before undocking/departure of the vehicle.

FREE FLIGHT
The portion of the trajectory in which the target vehicle and the chaser vehicle are not physically connected.

GROUND PIOTING
The ability for ground operators to manually pilot a vehicle.

HOLD
The chase vehicle maintains its relative position with respect to the target vehicle such that it neither approaches nor departs from the target.

INDEPENDENT SENSOR
This term is applied to sensors being implemented on the vehicle and refers to sensors not relying on the same power and data connections. Addresses vehicle architecture and vulnerability to single power failure, data connections, etc.

KEEP OUT SPHERE (KOS)
The KOS is the smallest control sphere around the Deep Space Gateway, regulating final approach to DSG. Final approach to the Deep Space Gateway is not permitted inside KOS unless approval is granted.

MANUAL CONTROL
Control input provided by a human operator. This is a general term which includes Manual Piloting, Remote Piloting, Ground Piloting.

MANUAL PILOTING
Refers to action taken by a human to fly the vehicle. The ability for crew to pilot the vehicle.

PROXIMITY OPERATIONS
Vehicle maneuvers that are either within the KOS or RS. These maneuvers may include final approach, fly-around, undocking and departure. This is used extensively within the NASA ISS community to cover all maneuvers performed within the RS.

REMOTE PILOTING
The ability for crew to manually pilot a vehicle they do not occupy. See section 6.6
RENDEZVOUS
This phase begins when the VV is confirmed to be in an orbit established in cis-Lunar space relative to the DSG and ends at docking start.

RENDEZVOUS SPHERE (RS)
The RS is the largest control sphere around the center of mass of the DSG and is used to govern the Rendezvous Orbit Entry (ROE).

RESUME
The chase vehicle maintains its position with respect to the target vehicle such that it continues on the preplanned profile. This function is typically only used during proximity operations.

RETREAT
The chase vehicle increases its range with respect to the target vehicle such that it creates an opening rate. The retreat will proceed to a predefined HOLD point.

SEPARATION
The dynamic process of flying a chaser vehicle away from a target. It results from propulsive forces (thruster or mechanical springs) and/or effects of orbital mechanics.

TARGET VEHICLE
Is primarily a passive spacecraft during rendezvous by a chaser vehicle.

UNDOCKING
The process of a chaser vehicle unlatching and separating from a target vehicle.
APPENDIX C  OPEN WORK

Table C-1 lists the specific To Be Determined (TBD) items in the document that are not yet known. The TBD is inserted as a placeholder wherever the required data is needed and is formatted in bold type within brackets. The TBD item is numbered based on the section where the first occurrence of the item is located as the first digit and a consecutive number as the second digit (i.e., <TBD 4-1> is the first undetermined item assigned in Section 4 of the document). As each TBD is solved, the updated text is inserted in each place that the TBD appears in the document and the item is removed from this table. As new TBD items are assigned, they will be added to this list in accordance with the above described numbering scheme. Original TBDs will not be renumbered.

### TABLE C-1 TO BE DETERMINED ITEMS

<table>
<thead>
<tr>
<th>TBD</th>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-1</td>
<td>3.2.3.3.7</td>
<td>Control mode and DSG health/status in telemetry.</td>
</tr>
<tr>
<td>3-2</td>
<td>3.3.1.1</td>
<td>Reference scenario cited for performance requirements.</td>
</tr>
</tbody>
</table>

Table C-2 lists the specific To Be Resolved (TBR) issues in the document that are not yet known. The TBR is inserted as a placeholder wherever the required data is needed and is formatted in bold type within brackets. The TBR issue is numbered based on the section where the first occurrence of the issue is located as the first digit and a consecutive number as the second digit (i.e., <TBR 4-1> is the first unresolved issue assigned in Section 4 of the document). As each TBR is resolved, the updated text is inserted in each place that the TBR appears in the document and the issue is removed from this table. As new TBR issues are assigned, they will be added to this list in accordance with the above described numbering scheme. Original TBRs will not be renumbered.

### TABLE C-2 TO BE RESOLVED ISSUES

<table>
<thead>
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<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-1</td>
<td>3.2.1.2.1</td>
<td>Local Vertical, Local Horizontal (LVLH) frame definition needs to be refined</td>
</tr>
<tr>
<td>3-2</td>
<td>3.2.1.2.2</td>
<td>Geometrically Fixed Frame (GFF) definition needs to be refined</td>
</tr>
<tr>
<td>3-3</td>
<td>3.2.1.2.2</td>
<td>Chaser Docking (DC) frame definition needs to be refined</td>
</tr>
<tr>
<td>3-4</td>
<td>3.2.1.2.3</td>
<td>DSG Body frame needs to be refined</td>
</tr>
<tr>
<td>3-5</td>
<td>3.2.1.2.3</td>
<td>Target Docking (DT) frame definition needs to be refined.</td>
</tr>
</tbody>
</table>

Table C-3 lists the specific To Be Confirmed (TBC) issues in the document that are not yet confirmed/verified. The TBC is inserted as a placeholder wherever the required data is needed and is formatted in bold type within brackets. The TBC issue is numbered based on the section where the first occurrence of the issue is located as the first digit and a consecutive number as the second digit (i.e., <TBC 4-1> is the first unresolved issue assigned in Section 4 of the document). As each TBC is resolved, the updated text is inserted in each place that the TBC appears in the document and the issue is removed from this table. As new TBC issues are assigned, they will be added to this list in accordance with the above described numbering scheme. Original TBCs will not be renumbered.
removed from this table. As new TBC issues are assigned, they will be added to this list in accordance with the above described numbering scheme. Original TBCs will not be renumbered.

**TABLE C-3 TO BE CONFIRMED ISSUES**

<table>
<thead>
<tr>
<th>TBC</th>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-1</td>
<td>3.1.3.2</td>
<td>Rendezvous Sphere is 10 km</td>
</tr>
<tr>
<td>3-2</td>
<td>3.1.3.2</td>
<td>Approach Sphere is 2 km</td>
</tr>
<tr>
<td>3-3</td>
<td>3.1.3.2</td>
<td>Keep Out Sphere is 200 m</td>
</tr>
<tr>
<td>3-4</td>
<td>3.1.3.2</td>
<td>Approach/Departure Corridor is ±10°</td>
</tr>
<tr>
<td>3-5</td>
<td>3.2.2.1</td>
<td>Coast trajectory shall not intercept AS for 24 hours</td>
</tr>
<tr>
<td>3-6</td>
<td>3.2.2.3</td>
<td>24-hour safe free drift after abort</td>
</tr>
<tr>
<td>3-7</td>
<td>3.2.2.4.1</td>
<td>Automatic abort corridor is ±7.5°</td>
</tr>
<tr>
<td>3-8</td>
<td>3.2.2.4.2</td>
<td>Manual abort corridor is ±10°</td>
</tr>
<tr>
<td>3-9</td>
<td>3.2.2.8</td>
<td>Secondary State Determination from range = 20m</td>
</tr>
<tr>
<td>3-10</td>
<td>3.2.3.3.2</td>
<td>Data Validity section needs to be confirmed/worked with C&amp;T and Avionics</td>
</tr>
</tbody>
</table>