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Guide for Cryogenic Fluid Transfer Between Space Systems

New Work Item

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Contents

Foreword

This Cryogenics Fluid Transfer draft standard was prepared by the CONFERS Cryogenic Fluid Transfer Task Force. This standard is focused exclusively on cryogenic fluid transfer in free space and on solar system bodies, excluding Earth. The Servicer or the Client may be the mobile actor.

At the time of approval, the members of the AIAA **On-Orbit Servicing and Assembly Committee on Standards** were:

Member Name 1, Chair	Affiliation
Member Name 2	Affiliation

The above consensus body approved this document in Month 20XY.

The AIAA Standards Steering Committee (Michelle Bailey, Chair) accepted the document for publication in Month 20XY.

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Introduction

This document identifies design guidelines and procedures during proximity operations for cryogenic fluid transfer and cryogenic fluid transfer operations in free space and on celestial bodies, excluding Earth. Providers should consider these guidelines to ensure safe operations and to encourage a healthy On Orbit Servicing (OOS) industry and surface cryogenic transfer activities. It is intended to provide guidance to developers and operators of both the Servicer Spacecraft and Client Space Object. International law, treaties, and agreements have been researched for compliance and reference.

This document builds upon a foundation of CONFERS (https://satelliteconfers.org) documents including the On-Orbit Guiding Principles, the On-Orbit Recommended Design and Operational Practices, and On-Orbit Servicing (OOS) Mission Phases (Figure 1) which are the foundation of the international standard (ISO 24330 Space Systems – Rendezvous and Proximity Operations (RPO) and On-Orbit Servicing Programmatic Principles and Practices). The scope of the Cryogenic Fluid Transfer Guide is within the context of services for #9 in Figure 1, specifically, the outlined Fluid Transfer activity. It is notable that the consortium allows for cryogenic fluid transfer between systems that are not spacecraft (e.g., lunar surface systems) and so defines a “servicer space object” and “client space object.” For this document, “servicer spacecraft” and client spacecraft” are used generically, independent of location.

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There are no patent licensing issues associated with the content of this guide.

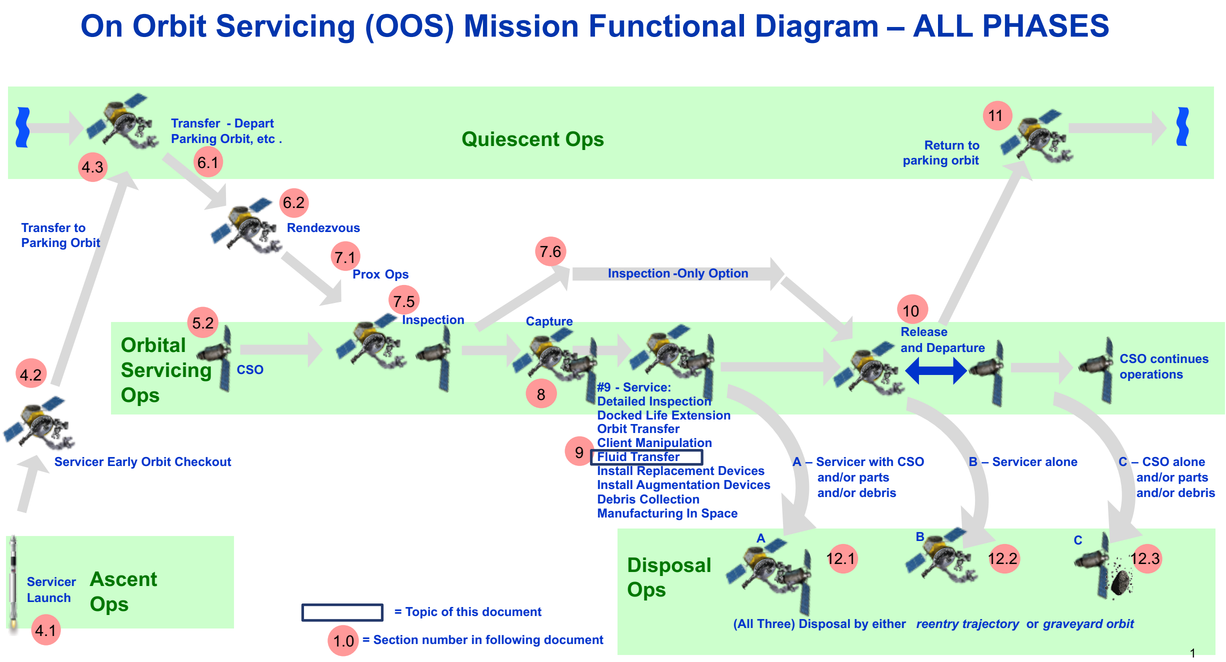

Figure 1. OOS Mission Functional Diagram (ref ISO 24330) showing scope of this document

Guide for Cryogenic Fluid Transfer Between Space Systems

1 Objective

The objective of this guide is to document and distribute industry best practices for transferring cryogenic fluid transfer between space objects and for conducting proximity operations specific to cryogenic propellant transfer before and after mating cryogenic transfer interfaces.

2 Purpose

The purpose of this guide is to ensure consistent and safe operations before, during and after cryogenic fluid transfer and to encourage a healthy On Orbit Servicing (OOS) industry.

3 Scope

While ISO 24330 provides more general spacecraft design and operations requirements for RPO and OOS, this document defines best practices and requirements for the design, verification and operation of prepared in-space cryogenic fluid transfer systems and interfaces. The term "prepared" describes a spacecraft, spacecraft interfaces and other accommodations intentionally designed to enable safe and efficient servicing. Modification of an existing spacecraft cryogenic fluid transfer interface is outside the scope of this document. However, any spacecraft modified to meet the criteria stated herein may be considered "prepared". The term "in-space" describes an environment outside a planetary atmosphere in free space or on a celestial body other than Earth. This document includes requirements and recommendations for both servicer and client spacecraft. The scope addresses cryogenic fluids.

The recommendations in this document are a collection of best practices in the development of any prepared cryogenic fluid transfer systems, interfaces, and operations, to include in-space and celestial body surfaces cryogenic transfer. Figure 2 illustrates the scope of this document, which includes general technical requirements and concept of operations (CONOPS) for prepared in-space cryogenic fluid transfer operations with a refueling example. This document focuses on the operations of the fluid coupling interface and associated combined servicer and client considerations for a specific interface and does not address the servicer spacecraft to client space object capture. The scope of docking or berthing is outside the scope of this document; however, the docking/berthing system and the fluid transfer system need to be compatible, with the docking/berthing system providing sufficient stability and alignment, and/or the fluid transfer accommodating the stiffness and alignment provided by the docking/berthing system.

This document does not specify a particular form factor. The intent is to leverage existing standards to the maximum extent practical and promote progress, safety, capability, reliability, and capacity while not hindering innovation or specific mission requirements. Any successful cryogenic fluid transfer interface hardware that 1) completes qualification and 2) becomes widely adopted could form the basis of a future fluid coupling standard interface design. Content of this document intends to inform an "interface guide," whereas normative statements for form, fit, and function would be addressed in program/project interface specifications.

While the scope is limited to transfer of cryogenic fluids in-space, future versions may be expanded or tailored. It should also be made clear that this document focuses on the "in-space" fluid transfer. While the same interface may be used for pre-launch ground fueling, requirements for such features/capabilities are not considered within the scope of this document. Specific requirements and guidelines appliable to use for ground fueling or refueling are contained within SSCMAN91-710V3, Range

Safety User Requirements Manual - Ground and Launch Personnel, Equipment, Systems, and Material Operations Safety Requirements or other Range documents.

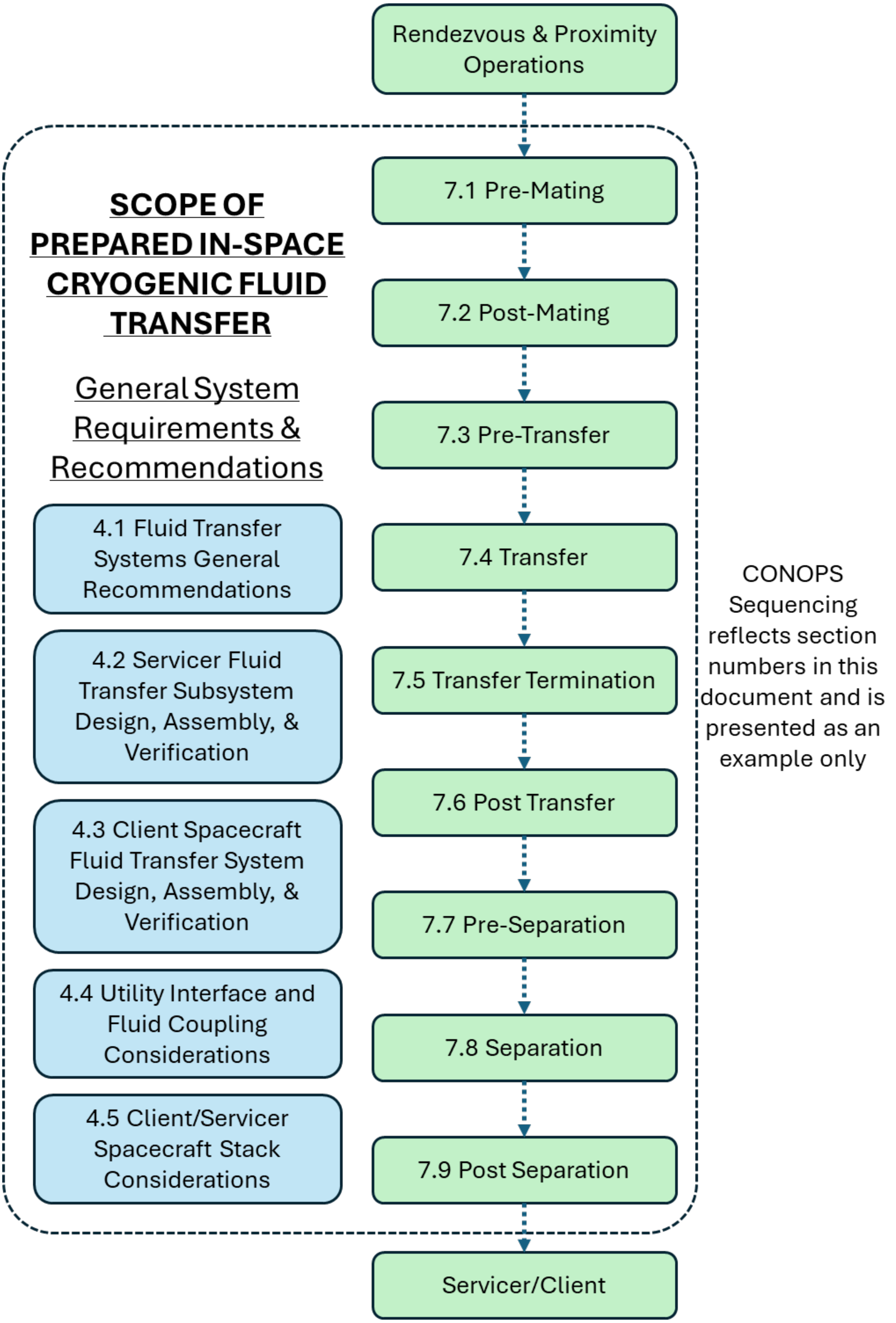

Figure 2. Scope, including general system requirements and recommendations and CONOPS for Cryogenic Fluid Transfer Operations

4 Relevant Documents

The following documents are referred to in the text in such a way that some or all of their content constitutes the requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

Tailoring is a process by which individual requirements or specifications, standards, and related documents are evaluated and made applicable to a specific program or project by selection, and in some exceptional cases, modification, and addition (e.g., for human spaceflight or fluid leak rates) of requirements in the standards.

For a specific program or project, the requirements defined in this guide may be tailored to match the actual requirements of the particular program or project. Tailoring of requirements shall be undertaken in agreement with the procuring authority where applicable

ISO 24330 Space Systems – Rendezvous and Proximity Operations (RPO) and On-Orbit Servicing (OOS) Programmatic Principles and Practices

NASA STD 5017A Design and Development Requirements for Mechanisms

AIAA S-155 Spacecraft Fiducial Markers

SMC-S-016 Thermal Test Guide for Upper Stages

GSFC-STD-7000, General Environmental Verification Standard (GEVS) for GSFC Flight Programs and Projects

Space Force Manual 91-710 Range Requirements

AIAA S-080 Space Systems - Metallic Pressure Vessels, Pressurized Structures, and Pressure Components

AIAA S-081 COPVs

AIAA G-082 Composite Pressure Vessels

GSFC-EEE-INST-002, Instructions for EEE Parts Selection, Screening, Qualification, and Derating

ISO 24113 Space Systems - Space Debris Mitigation Requirements

ISO 24330 Space Systems – Rendezvous and Proximity Operations (RPO) and On-Orbit Servicing (OOS) Programmatic Principles and Practices

ISO 14952, Space systems — Surface cleanliness of fluid systems

ISO 23835, Space Systems — Mechanism design and verification (equivalent to NASA STD 5017)

MIL-STD-461, Electromagnetic Emission and Susceptibility Requirements for The Control Of Electromagnetic Interference Characteristics of Subsystems and Equipment.

NASA STD 5017Design and Development Requirements for Mechanisms (equivalent to ISO 23835 above)

SLS-SPEC-159 Cross-Program Design Specification for Natural Environments (DSNE)

5 Terms and Definitions

For the purposes of this document, the following terms and definitions may be used in discussions and agreements between the Servicer Provider and Client and are provided for information and understanding.

5.1 **Docking:** When a Servicer Spacecraft executes a controlled trajectory to effect a rigid connection with a Client Space Object.

5.2 **In-Space Servicing (I-SS):** Activities by a Servicer Spacecraft that requires rendezvous and/or proximity and mating operations on orbit or on an extraterrestrial surface.

5.3 **Servicing Operations:** Action provided by Servicer Spacecraft to the Client Space Object, including but not limited to: inspection, capture, docking, berthing, relocation, refueling, life extension, removal, combined stack control, repair, upgrade, assembly, manufacturing, un-docking, un-berthing, release.

5.4 **Servicer Spacecraft:** Spacecraft performing the servicing action.

5.5 **Cryogenic Fluid Transfer:** Movement of space system cryogenic fluids from one volume to another.

5.6 **Active Fluid:** The fluid that is being prepared for transfer, being transferred in real time, and being safed after transfer.

5.7 **Mating:** When two objects or interfaces make and maintain an intentional physical connection.

5.8 **Cryogenic Fluid:** a liquid with a boiling point of 120 K or below in one standard atmosphere.

5.9 **Utility Interface:** An interface between the servicer spacecraft and the client spacecraft that contains servicing functions such as fluid, structural, power, data, etc.

5.10 **Venting:** An external release of a fluid from a confined volume to reduce pressure.

5.11 **Propellant conditioning:** Any process required to ensure the propellant is at the desired thermodynamic state before initiating transfer.

5.12 **No-vent Fill:** A fluid transfer process by which during transfer, the receiver tank does not discharge fluid to the surrounding environment and no fluid is lost.

5.13 **Vented Fill:** A fluid transfer process by which during the filling of the tank, the receiver tank is venting fluid overboard to prevent the pressure from exceeding the allowable operational pressure of the fluid system.

5.14 **Propellant Management Device:** A device within a tank that constrains the fluid dynamics of the liquid fraction within the tank in a prescribed configuration when in microgravity environments.

5.15 **Liquid Acquisition Devices:** A device within a tank that positions the liquid fraction to ensure bubble-free liquid is positioned over the tank outlet. Liquid Acquisition Devices are a subset of Propellant Management Devices.

5.16 **Vapor Pressure:** The pressure exerted by a vapor that is in equilibrium with its solid or liquid form.

5.17 **Saturation Pressure:** The pressure in a two-phase, pure fluid that is constant with a given temperature as the fluid changes from 100% vapor to 100% liquid. The saturation pressure is a function of temperature for a given fluid.

5.18 **Total Pressure:** The sum of all the partial pressures of the different fluids within the system.

5.19 **Partial pressure:** The pressure that would be exerted by one of the gases in a mixture if it occupied the same volume on its own.

5.20 **Cryocoupler:** A uni-directional or bi-directional flow mechanism designed for operation at cryogenic temperatures (< 120 K) that when successfully joined will allow for safe transfer of fluid from one side to the other. A cryocoupler may also be called a cryogenic fluid coupler.

5.21 **Cryogenic Fluid Line Conditioning:** Operations that prepare a transfer line prior to or after flowing cryogenic fluid. The preparation process entails going from an arbitrary or specified start state to a desired specified state.

5.22 **Cryogenic Tank Conditioning:** Operations that prepare a tank prior to or after receiving cryogenic fluid. This preparation process entails going from an arbitrary or specified start state to a desired specified end state.

5.23 **Ullage Volume:** The vapor or gaseous volume of a tank that contains both liquid and gas.

5.24 **Cryogenic Fluid Stratification:** The temperature or compositional gradients of fluids within a cryogenic system.

Note: Without mixing in an unsettled/microgravity environment, temperature gradients might be found throughout the liquid and vapor phases of a fluid. Compositional gradients are found within a multi-species phase such as natural gas or helium pressurant mixed with a propellant.

5.25 **Propellant Purity:** The compositional mixture of the propellant fluid with other propellant and non-propellant species within it.

Note: This might include both intentionally (pressurant type) included fluidic impurities and un-intentionally (contaminates from production) included fluidic impurities. Purity can be specified in either %mol or %mass.

5.26 **Bubble-Free Cryogenic Fluid:** A liquid that is free of all bubbles of any gas or vapor, including both the like fluid of the liquid and any pressurant gas.

5.27 **Mass Transfer Gauging:** The methodology of determining the quantity of fluid mass transferred across an interface.

5.28 **Leak Detection:** Ability to determine an inadvertent release of fluid at an interface or anywhere in the fluid system.

5.29 **Pressure Verification at the Interface:** Ability to quantify total pressure and confirm acceptability on both sides of an interface.

5.30 **Cryocoupler Interface Loads:** Forces and/or moments experienced by a cryogenic fitting.

5.31 **Docking Mechanism:** Device used to join two separate free-flying space vehicles.

5.32 **Active Cryogenic Fluid Transfer Interface:** The side of the cryogenic fluid transfer interface that 'controls' the commodity replenishment process, from guiding the fluid coupling, verifying interface connections, commanding valve openings and closings, and transferring fluids

5.33 **Free Flyer Capture Operations:** A subset of proximity operations where the servicer spacecraft (and potentially client spacecraft) intentionally perform mutually agreed maneuvers and take actions to make and maintain physical contact.

5.34 **Passive Cryogenic Fluid Transfer Interface:** The side of the cryogenic fluid transfer interface that is mostly inactive in the commodity replenishment process.

5.37 **Fluid:** liquid or gas that continuously deforms under an applied shear stress

5.38 **Subcooled Cryogenic Fluid:** A cryogenic fluid that exists solely in its liquid state below its boiling point at its current pressure, without its vapor phase present.

5.39 **Autogenous Pressurization:** The process by which the stored cryogenic fluid is vaporized to create tank pressurant.

5.40 **Non-autogenous Pressurization:** The process by which a separately stored non-condensable fluid is used as the pressurant for the stored fluid.

5.41 **Client Space Object:** The space object being serviced by the servicer spacecraft.

5.42 **Client:** An entity/organization procuring the service.

5.43 **Servicer:** An entity/organization that provides On-Orbit Servicing operations.

5.44 **Saturated Cryogenic Fluid:** a liquid that is at a temperature and pressure where any additional heat or pressure will cause it to boil and turn into vapor

5.45 **Densified Cryogenic Fluid:** a cryogenic fluid that has been cooled below its normal boiling point, making it denser.

5.46 **Structural Interface:** A rigid link between Servicer Spacecraft and Client Space Object that may be separate from the cryogenic fluids interface.

5.47 **MEOP:** Maximum Expected Operating Pressure

6. Spacecraft-to-Spacecraft Cryogenic Fluid Transfer Design Best Practices

The spacecraft-to-spacecraft cryogenic fluid transfer best practices presented in this document are applicable to systems in free space and on celestial bodies other than Earth.

6.1 Design Considerations

The following best practices are recommended when designing new systems that include cryogenic fluid transfer capability.

6.1.1 Fluid Identification

Lines and fittings should have fiduciary markings on them that identify the fluid, its thermodynamic state, and MEOP when in operation.

6.1.2 Provide fluid interface information

There should be communication between the Servicer and Client spacecraft. Information should be provided at interface connectors on the fluid to be transferred (e.g., fluid type, maximum pressure, temperature range, fluid state [liquid, gas, or two-phase], maximum flow rate, receiving tank volumes).

6.1.3 Define relative positions between different fluid interfaces

The design should provide physical characteristics of the interface panel and individual connectors as well as relative positions between individual connectors when multiple connectors, as well as three-dimensional keep out zones.

6.1.4 Closed-loop pre-chill capability

The design should provide the ability to pre-chill transfer servicing and/or receiving lines prior to opening primary and interface valves. Pre-chill fluids, if used, should be captured and not vented in non-emergency situations. Pre-chilling should be done with the cryogenic fluid to be transferred. Pre-chill process should achieve line temperature at liquid temperatures before transfer is initiated.

6.1.5 Confined Volume Protection

The design should include controlled or uncontrolled pressure relief valves with appropriate set points for all confined volumes between the interface plane and supply or receiving tank.

6.1.6 Ensure operational compatibility between servicer and client.

The design should ensure that operational compatibility between the Servicer Spacecraft and Client Space Object, specifically for cryogenic fluid transfer, can be achieved (e.g., pressure, pressure drop, flow rate, fluid state, maximum fill fraction, and alternative operational procedures.)

6.1.7 Acceptable risk of fluid mixing

If a single interface panel accommodates multiple fluid connections, the design should ensure there is a negligible risk of fluid mixing due to interface connector leakage leading to an internal and/or external hazardous condition.

6.1.8 Sensors for safe transfer

The design should include pressure, temperature, flow rate, and mass gauging or level sensors at critical locations to facilitate safe and successful fluid transfer.

The design should include sensors that verify interface connectors are fully mated to indicate readiness to transfer.

6.1.9 Abort considerations

The design should include a means and defined procedures for safe separation of the cryogenic fluid transfer interface in response to off-nominal situations.

The cryogenic fluid transfer interface design should preclude causing harm to the other vehicle involved in the cryogenic fluid transfer process.

Procedures for stopping and/or resuming operations should be defined for anticipated failure modes.

Procedures for walking back to a safe state from any intermediate stage during the refueling process should be defined.

6.1.10 Fluid venting line positioning

The cryogenic fluid transfer design should ensure that vent lines are not pointed toward the other spacecraft involved in the cryogenic fluid transfer process or cause detrimental impact to spacecraft attitude. Vent positioning and pointing should preclude dissimilar propellant mixing during a venting event to avoid combustible mixture.

6.1.11 Identify keep-out zones

The design should identify three-dimensional keep out zones for the other vehicle in the fluid transfer process to avoid undesirable physical contact, sun shadowing, communications blocking, plume impingement, or other interferences. The design should also ensure that the transfer interface is shielded from the sun during the transfer process.

6.1.12 Identify a center of gravity and attitude control constraints

The maximum allowable center of gravity envelope for the joined spacecraft should be defined for controlling spacecraft to ensure control authority can be provided.

The maximum interface loads that can be accommodated at the interface plane (separation, shear, torsion, and twist) should be defined.

The controlling spacecraft should have sufficient control authority to ensure interface loads are not exceeded.

The potential center of gravity shift during the transfer process as a function of time should be defined to ensure control authority can be provided.

6.1.13 Fluid measurement

The design should include a means to measure cryogenic fluid temperature, pressure, quantity, and quality delivered to or received from the fluid transfer interface with values reported at a specified thermodynamic state.

6.1.14 Structural Mating Interface Information

Interface characteristics should be exchanged between the client and servicer that define structural, electrical, and data connector designs and operational conditions as well as clearances between the servicing and receiving halves.

Static loading, shock, and modal frequency analysis should be conducted on the mated spacecraft during the planning process.

7 Concept of Operations

7.1 Pre-Mating

7.1.1 Examination for readiness to mate

The Servicer and Client should jointly examine their systems to ensure each system is properly prepared for mating. This includes affirming which system is performing the mating maneuvers, which system has attitude control responsibility once joined, that each GN&C subsystem is properly configured, that both propulsion systems are ready for transfer, that propellants are stable, and communications between the Servicer Vehicle and Client Spacecraft are established.

7.1.2 Ensure sufficient time to transfer fluid

The Servicer and Client should ensure there is sufficient time to complete the cryogenic fluid transfer process before initiating the mating process.

7.1.3 Ensure environment is compatible for transfer

The Servicer and Client should confirm the mating will occur in the proper environment (sunlight or shadow) and the spacecraft are in the proper orientation before mating is initiated.

7.1.4 Ensure electrostatic potential is balanced

The Servicer and Client should confirm the electrostatic potential difference between the two spacecraft is within the acceptable limits.

7.1.5 Ensure potential conjunction with space debris does not exist

The Servicer and Client should confirm there is no potential conjunction with other space objects during the window between mating and demating before initiating the mating process.

7.1.6 Interference

The Servicer and Client should confirm there are no obstructions within the mating keep-out volumes before initiating the mating process.

7.1.7 Functional checkout of transfer components

The Servicer and Client should perform functional checkout of cryogenic transfer components before initiating the mating process.

7.2 Mated

7.2.1 Engage the cryocoupler if separate from the mating interface

Once the two spacecraft are mated the cryocoupler can be engaged and verified complete.

7.2.2 Allow time for fluids to stabilize

Propellant Management Devices should be full before transfer begins. There should be adequate time in the servicing schedule for cryogenic fluid sloshing to attenuate after the mating process and the Client and Servicer should confirm cryogenic fluid stability after mating is completed.

7.2.3 Equalize pressure across the interface

The servicer spacecraft and client space object should confirm the pressure on both sides of the interface is equal, to avoid water-hammer effects when opening the transfer valves.

7.2.4 Ensure Transfer Interface is pressure-tight

The servicer spacecraft should measure line pressure in the interface volume to check for leaks at the interface after the mating process is completed.

7.2.5 Ensure Servicer Spacecraft and Client Space Object stack is controllable

The active spacecraft should confirm it can control the combined stack after the mating process is completed. This may require an active maneuver after initial propellant stability is confirmed, followed by a second time period for stability to recur.

7.2.6 Ensure Data Links for cryo fluid transfer are established

The Servicer and Client should confirm data links between the two spacecraft and with ground control centers are established after the mating process is completed.

7.3 Pre-transfer (pre-condition before transfer)

7.3.1 Transfer Quantity

Client and Servicer should agree on the quantity of each cryogenic fluid that is to be transferred.

7.3.2 Transfer Flow Rate Profile

The client and servicing spacecraft should agree on a propellant transfer flow rate profile. Depending on the conditioning of the client tank, it may be beneficial to use lower fill rates when receiver tank is at low-fill and high-fill fractions before ramping up to the maximum flow rate. Similarly depending on the closeout communication protocols, it may be beneficial to perform the final filling portions with a lower than maximum flow rate.

7.3.3 Conditioning Client Spacecraft Cryofluid System

If the Client Spacecraft is to be filled for the first time by a Servicing Spacecraft, it should have a means to precondition the lines and tanks and manage any boil-off gases, such as routing to the Servicing Spacecraft, capturing them internally, or safely venting.

7.3.4 Ensure transfer lines are conditioned properly

The Servicer and Client should confirm transfer lines are properly conditioned and both sides are within defined temperature and pressure limits before initiating cryogenic fluid transfer.

7.3.5 Examining for Readiness to Transfer

The Servicer and Client should jointly examine their systems to ensure each system is properly prepared for transfer. This includes affirming which system is performing the mating maneuvers, which system has attitude control responsibility once joined, that each GN&C subsystem is properly configured, that both propulsion systems are ready for transfer, that propellants are stable, and communications between the Servicer Vehicle and Client Spacecraft are established.

7.4 Transfer

7.4.1 Client Spacecraft should open valves from the interface plane to the receiving tank in sequence

The Client Spacecraft should open its cryofluid transfer line valves in sequence from the interface plane with the Servicing Spacecraft to the receiving tank. Pressure increase above initial opening pressure should occur after all valves are open between Servicer and Client.

7.4.2 Client to confirm all valves are open and ready to proceed

The Client Spacecraft should inform the Servicing Spacecraft that all its valves are open and is ready to receive propellant.

7.4.3 Client to confirm acceptable leakage at interface

The Client Spacecraft should confirm zero leakage, or leakage is below the maximum allowable defined by Servicer and Client in their specific operating procedure documents, and inform the Servicing Spacecraft.

7.4.4 Servicer to open valves from the interface to supply tank

The Servicing Spacecraft should open its valves in sequence from the interface with the Client Spacecraft to the supply tank.

7.4.5 Servicer to confirm all valves are open and ready to proceed

The Servicer Spacecraft should confirm all valves are open and inform the Client Spacecraft that it is ready to proceed.

7.4.6 Begin cryogenic fluid transfer

The Servicing Spacecraft should initiate active cryogenic fluid transfer. Transfer may be induced by creating a pressure differential between the system by increasing the pressure in the supply tank or by activating a pump on the Servicing Spacecraft.

7.4.7 Client and Servicer to monitor transfer process

The Client and Servicer spacecraft should monitor flow rate, pressure, and temperatures during the transfer process and ensure they are within acceptable limits.

7.4.8 Transition Point Notification

The Servicer Spacecraft should notify the Client Spacecraft it has reached a flow rate transition point and await confirmation from the Client Spacecraft before increasing or decreasing the transfer flow rate.

7.5 Transfer Termination

Cryogenic fluid transfer may be terminated because the Client Space Object tank has reached the desired fill level, the desired amount has been transferred, a fault is detected by the Servicer Spacecraft or the Client Space Object, or the Servicer Spacecraft has depleted its supply. Transfer may also be paused temporarily.

7.5.1 Termination by Client Spacecraft

The Client Space Object should notify the Servicer Spacecraft when it reaches the desired fill level, or the agreed-to quantity has been transferred so Servicer Spacecraft can terminate cryogenic fluid transfer.

7.5.2 Termination by Servicer Spacecraft

The Servicer Spacecraft should terminate the cryogenic fluid transfer process after it has transferred the agreed-to quantity of cryogenic fluids or received a terminate command from the Client Spacecraft.

7.5.3 Termination due to faults

The Servicer Spacecraft should terminate the cryogenic fluid transfer if either Client or Servicer Spacecraft detect a fault in the cryogenic fluid transfer process or system. Faults could be excessive leakage, communication breakdown, sensor failure, or other transient events. In case of a fault, all transfer valves should revert to a closed position, bleed valves in the transfer lines should open, and vehicle should return to a safe mode.

7.5.4 Closure of valves from receiving tank to interface

The Client should close valves from the receiving tank to interface in sequence (i.e., flow is already stopped before valves are closed).

7.5.5 Closure of valves from interface to supply tank

The Client Spacecraft should close valves from the interface to the supply tank in sequence and open bleed valves to capture boil-off.

7.5.6 Client to confirm all valves are closed

The Client Spacecraft should confirm all transfer line valves are closed and inform the Servicer Spacecraft

7.5.7 Client to confirm acceptable leakage at interface

The Client Spacecraft should confirm that leakage at the interface is within acceptable limits.

7.5.8 Servicer to close valves from interface to tank

The Servicer Spacecraft should close valves from the interface to the supply tank in sequence and open bleed valves to vent trapped fluids.

7.5.9 Servicer to confirm all valves are closed

7.5.10 Servicer to confirm acceptable leakage at the interface

The Client Spacecraft should confirm there is an acceptable leakage at the interface plane.

7.6 Post-Transfer (Verify transfer process is complete)

7.6.1 Confirm cryogenic fluid quantities transferred

The Servicer Spacecraft and Client Spacecraft should compare the quantity of propellant transferred and received and resolve any differences.

7.7 Pre-Separation (Verify readiness for separation)

7.7.1 Ensure transfers lines are conditioned for separation

The Servicer Spacecraft and Client Spacecraft should ensure the transfer lines at the interface are conditioned for separation.

7.7.2 Examination for separation

The Servicer and Client should jointly examine their systems to ensure that each system is properly prepared for separation. This includes affirming which spacecraft is performing the demating actions and which spacecraft perform the separation maneuver.

7.8 Separation

7.8.1 Disengage cryocoupler, if separate from mating interface

The responsible spacecraft disengages the cryocoupler, if different from the mating interface.

7.8.2 Disengage mating interface

The responsible spacecraft disengages the mating interface.

7.9 Post-Separation

7.9.1 Perform the departure maneuver

The responsible spacecraft performs the departure maneuver.

