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Surface Systems and Interface Standardization

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A key contribution to surface systems sustainability on Lunar and planetary surfaces is commonality between hardware and software interfaces. Generic interfaces for data, power, and fluids will reduce risk, promote interoperability, and define standard interfaces across surface exploration projects and programs. Standardized interfaces would be advantageous for improving efficiency and reducing overall complexity, which are critical considerations for future space exploration. Furthermore, it will provide cost reductions to NASA's Artemis program over its life cycle (in Operations & Maintenance (O&M) and Logistics). Unique proprietary interfaces if considered or allowed would not only increase complexity but also add cost to the programs. Of course, understanding what will work and not work effectively in these unique environments such as the lunar surface is important. These unique environments require much needed intelligent design, prototyping, comprehensive testing, and field experience, utilizing consensus on common interface solutions. This paper focuses on identifying previous common aerospace interface solutions, current Artemis surface architecture, and defining guiding principles for surface interface standards.

Nomenclature

ABC = *Artemis Base Camp*
DOE = *Department of Energy*
DTAU = *Dust Tolerant Automated Umbilical*
FSP = *Fission Surface Power*
GMRO = *Granular Mechanics and Regolith Operations*
HEOMD = *Human Exploration and Operations Mission Directorate*
HLS = *Human Landing System*
IDA = *International Docking Adapter*
IDD = *Interface Definitions Document*
IDSIS = *International Deep Space Interoperability Standards*
ISRU = *In-Situ Resource Utilizations*
ISS = *International Space Station*
LAT = *Lunar Architecutre Team*
LDTC = *Lunar Dust Tolerant Connector*
LPGF = *Large Profile Grapple Fixture*
LTV = *Lunar Terrain Vehicle*
NEMA = *National Electrical Manufacturers Association*
O&M = *Operations and Maintenance*
ORU = *Orbital Replacement Unit*
PR = *Pressurized Rover*
SA = *Strategy and Architecture*
SH = *Surface Habitat*
SORI = *Small ORU Robotics Interface*
USB = *Universal Serial Bus*

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I. Introduction

Space exploration on lunar and planetary surfaces will require the use of various surface systems which will need to interface with one another. These systems will communicate and share information, use and distribute power, and transfer fluids for sustainable surface operations. Such systems can range from landers, surface habitats, mobility systems, cargo, logistics, and In-Situ Resource Utilizations (ISRUs). Previous and current programs have developed space interoperability standards that help reduce potential risks of interface integration. A goal of the Artemis program is to establish a sustained human presence on the lunar surface that would be a training ground for future Mars exploration. Therefore, it is beneficial to identify interface standards between the surface assets to help mitigate risk and reduce complexity in the harsh environments of space exploration.

Standardization across a surface architecture yields numerous benefits. It drives commonality, reusability, and interoperability, enables technology infusion, reduces operations and logistics costs, and promotes a multi-use philosophy. Standardization of hardware and software interfaces, components, processes, procedures, tools, and repair kits creates an effective, cost-efficient, and sustainable architecture throughout its lifecycle. It also provides common frameworks for infusing new capabilities as they mature and implementing automation and autonomy across the architecture. Standardization results in an open surface architecture that is affordable, robust, and flexible while promoting partnerships and cost-sharing.

A. Previous and Current Common Interface Standards

Standardized interfaces are used every day in households, automobiles, and the workplace. They allow users to charge their cell phones, power appliances, and computers by plugging a standard National Electrical Manufacturers Association (NEMA) connector into a standard NEMA outlet. Computers use industry-standard Universal Serial Bus (USB) ports to interface with peripheral devices. These interfaces enable users to use systems safely and efficiently. Standard interfaces are also used throughout the space industry to improve interoperability between systems and vehicles. Space Shuttle, International Space Station (ISS), and Gateway programs have and will utilize these standards. A few examples of the standards adhered to by ISS and Gateway systems include the International Docking System Standard (IDSS)[1] and the International Deep Space Interoperability Standards (IDSIS)[2]. In past and current programs identifying common interface standards allowed for an ease of integration of payloads without the use of multiple adapters for each payload. For example, exterior payloads on the ISS design their interface to a single design which is also utilized by launch vehicle providers that transfer the payloads from the ground to the ISS. These standards have been proven to be beneficial for the space industry with allowing for the reduction in cost for multiple interface designs. The challenging perspective is that the designs of common interfaces must be adaptable to future iteration. The docking/berthing systems on station have gone through multiple iterations and now have multiple configurations to dock/berth spacecraft. For example, the crew Dragon and Starliner dock to the International Docking Adapter (IDA) and the Cygnus and HTV berth using the Common Berthing Mechanism. If a single docking design was identified in the initial formulation of the ISS design, then there would not be a need for multiple docking/berthing adapters on the ISS. The IDSS and IDSIS helps to mitigate this for future interfaces utilized in space.

IDSS establishes a standard docking interface to enable on-orbit crew rescue operations and joint collaborative endeavors utilizing different spacecraft on the ISS. It details the physical geometric mating interface and design loads requirements. The standard has derived the design for the IDA that has been successfully demonstrated for commercial crew systems like the SpaceX crew Dragon capsule. The IDA will also be used for future commercial crew capsules like the Boeing Starliner and may be applied to the Gateway for visiting vehicles.

In a partnership between ISS Agencies, a set of IDSIS were drafted in 2018 and released in 2019. IDSIS have been collaboratively prepared

Figure 1. Crew Dragon Capsule Docking with the IDA[9]

with the goal of defining interfaces and environments to facilitate cooperative deep space exploration endeavors. The standards focus on topics prioritized in this early phase of exploration planning and focus on eight discipline areas which include avionics, communications, ECLSS, power, rendezvous, robotics, thermal, and software. Gateway is applying these standards for external payloads to be documented in their Interface Definitions Document (IDD). Some examples of systems on Gateway that have adopted the IDSIS are the Small ORU Robotics Interface (SORI) and the Low Profile Grapple Fixture (LPGF)[5]. Although the IDSIS plays a key role in deep space, there have not been any defined standards for surface systems that will require a similar need for the Artemis campaign. The team reviewed IDSIS, previous space program's standards, and industry robotic interface standards referenced in Table 1 to initialize already known standards that could help aid in the development of surface interface standards.

Table 1. Reference Robotic Standards Related to Interfaces

Document Number	Document Description
ISO 9409-1	Manipulating industrial robots -- Mechanical interfaces -- Part 1: Plates
ISO 9409-2	Manipulating industrial robots -- Mechanical interfaces -- Part 2: Shafts
ISO 9787	Robots and robotic devices -- Coordinate systems and motion nomenclatures
HEOMD-003-07	International External Robotic Interface Interoperability Standards (IERIIS)

B. Artemis Overview

The Artemis campaign[3] promotes sustainability on the lunar surface and future Mars missions. To prepare for Mars, NASA defines the Artemis Base Camp (ABC) as the first sustainable foothold on the lunar frontier. The three primary mission elements of ABC are the Lunar Terrain Vehicle (LTV) that transports crew and cargo around the site, the Pressurized Rover (PR) for long-duration trips away from ABC, and the Surface Habitat (SH) which will enable short-stays for up to four crew on the lunar South Pole. Figure 2 provides an overview of the development of the ABC and preparation for Mars.

Figure 2. Artemis: Extending Lunar Missions to Prepare for Mars[3]

The Human Landing System (HLS) will be the primary mode of transportation to and from the lunar surface, which may include a stop at Gateway. The IDSIS will likely be used to establish standard interfaces between the HLS and Gateway but once HLS arrives at the surface there will be a need for a set of interface standards that can promote effective and efficient surface operations for delivering cargo/payloads or transferring commodities from one surface system to another. These standards will have to concentrate on the early architectural elements of the Artemis campaign like the LTV, PR, and SH. These standards will also require similarity to previous/current interfacing standards to ensure easy of integration from systems on Earth to another surface. Although this may appear challenging to accomplish, there has already been work performed to develop a generic interface in NASA and commercial companies. One example is the Dust Tolerant Automated Umbilical (DTAU)[6] which is an umbilical designed to transfer fluids and power between ISRUs and can be used as a baseline for future studies.

II. Surface Systems

Developing a standardization strategy for surface interfaces begins with analyzing current architecture on the lunar surface. The use of lunar assets baselined for the early missions of the Artemis campaign helps identify what types of interfaces are necessary and promotes commonality between the surface systems. The lunar surface architecture will consist of mobile (LTV and/or PR) and stationary (SH) elements. Figure 3 identifies an example of notional shared interfaces between a mobile and stationary element like the LTV and the SH. These systems will communicate and share data, as well as distribute power and transfer fluids for sustainable surface operations. Standardized interfaces will facilitate new future commercial and international partnerships that can enhance the surface architecture of the lunar outpost. Interface compatibility and increased commonality between interfaces help meet the goal of establishing lunar infrastructure capabilities for sustainable missions that benefit all partners. Design attributes of these standardized interfaces will be reliability, dust tolerance, reusability, commonality, the safety of the crew and mission, and the ability to be automated or operate autonomously to safely transfer fluids, power, data, and future commodities.

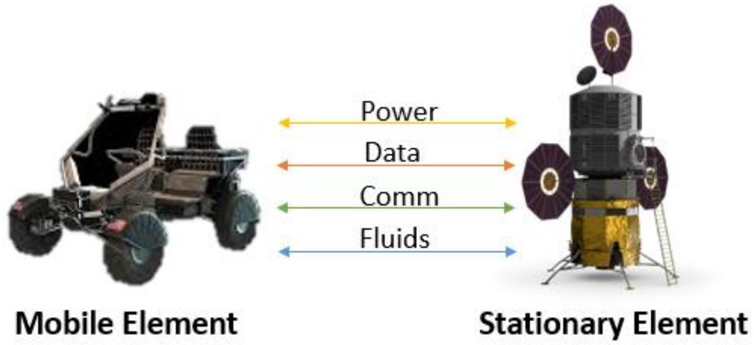

Figure 3. Illustration of notaional shared interfaces beetween a mobile and stationary element

The Fission Surface Power (FSP) system[8] is another emerging surface system that is in the early formulation process and currently being projected as an early Artemis architecture surface system. NASA is currently partnered up with the Department of Energy (DOE) and industry to design a flight-ready small fission reactor powered by low-enriched uranium. The FSP should be able to provide 40 kWe of continuous power for at least 10 years in the lunar environment. Plans for a small and lightweight fission surface power will ensure a robust presence on the Moon. Astronauts will take advantage of a reliable power supply to explore the Moon. FSP in conjunction with solar cells, batteries and fuel cells can provide the power to operate rovers, conduct experiments and use the Moon's resources to produce water, propellant, and other supplies for life support on the moon. The FSP will be the power hub for lunar surface assets, and it will benefit from a standard interface due to its purpose of providing power to multiple lunar surface assets with different power range criteria.

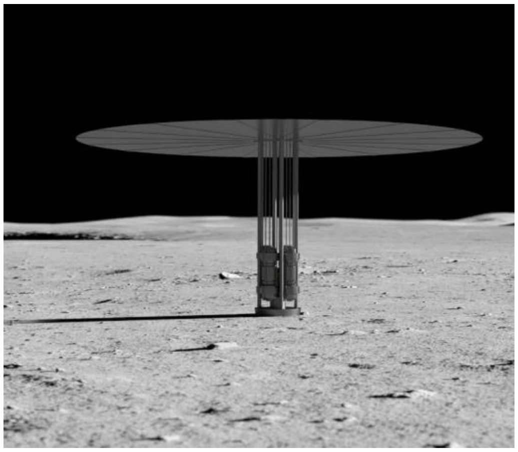

Figure 4. Illustration of a conceptual fission surface power system on the moon[8]

Subsequent missions will focus on assembling a sustainable lunar base. Lunar assets for solar energy/storage and electrical power are a high priority due to extended periods of darkness on the south pole. Mechanical connections and subsystems build a solid infrastructure for the lunar base. Umbilical connections for transfer of fluids, electrical, video, and data/communications will be required. Commonality of those interfaces is important for prototype testing, cost containment, and keeping complexity to a manageable level. Developmental testing of the interfaces including verification, validation, and certifications is important for surface assets.

A set of standards will evolve as the types of interfaces are analyzed, refined, and base-lined. Those principles and standards are applied for generic interface prototyping and development. Interfaces not requiring actual surface contact (data transfer, command and control, etc.) will also benefit from commonality. Agencies and businesses involved with Artemis will share communications frequently to ensure efficient lunar asset design, development, and implementation.

III. Interface Standardization

Since standardized interfaces would be beneficial for improving efficiency and reducing overall complexity, identifying more specific considerations for future space exploration would be useful. Though not an exhaustive list, the principles outlined below in Tables 2-6 provide suggestions and guidance for arriving at a surface architecture's generic standard. Maintainability and reliability are key factors to be considered early in the design cycle. Designing the interface so it can be readily repaired or replaced with COTS items will allow for diversity of supply chains and improve the mean time to repair the faulty hardware. Robustness is necessary to withstand harsh lunar environments, including dust/contamination, extreme thermal temperatures. An internationally accepted set of units, for measurement, etc., will be utilized. When interfaces are defined, they will be shared with the aerospace/exploration community to collect feedback, additional technical details, and/or consensus.

Table 2. General Interface Design Principles

Interface Component	Guiding Principle Description
General Design	- Develop a detailed con-ops to define the full functional requirements of the interface. - Use non-mechanical approach, if possible, to establish the interface, such as wireless communication and power transfer. - If a mechanical system is required, minimize complexity, part count, and mass. - Units of measurement are coordinated between surface system stakeholders
Umbilical System	- The active side of the interface contains the moving components that align, latch, and mate the connectors and couplings. Active side preferred on mobile element that interfaces with multiple other elements (i.e. on rovers). - The passive side of the interface has minimal complexity and moving parts making it a better candidate for multiple instances. Passive side is preferred on fixed components (i.e. lander, pallet, etc.)
Corrosion control	- Corrosion control is important to ensure function performance of the interface. - The interface should be analyzed for potential impacts from corrosion. - Processes should be implemented to avoid cold welding of metallic components.
Materials	- Provide lubrication or coatings to avoid surface damage and galling. - Materials used on the interface should be per NASA-STD-6016. - Processes should be implement to avoid galling of fasteners of other metal to metal contact surfaces.
Redundancy	- Redundancy is required to ensure the reliability and safety of the critical functions. - Implement manual/backup override function to mate/demate. - Analyze/eliminate critical single failure points in latching mechanism and actuators.
Maintainability/ Accessibility	- Interfaces should be accessible by EVA in case an anomaly arises that requires direct human intervention.

	- The interface should have the ability to be maintained either by person or a robotic system. - Software used for the interface should be designed to be maintainable and upgradable. - The interface should be designed for maintainability IAW NASA-STD-8729.1.
Safety and Reliability	- Basic functional level safety criteria. In addition, the interface should comply with all applicable NASA program safety requirements. - The interface should be fail safe. The generic interface system will be designed so that it fails in a safe mode or operational mode. - The interface should have single fault tolerant design for critical functions.
Position Feedback	- Provide feedback to ensure that the interface is fully mated before transferring commodities, and to avoid leakage and possible damage to the hardware. - The interface should have feedback to verify good mate/demate is achieved with each connector.
Connection Inspection	- Adding verification to ensure the interface is operating as designed, increases safety, and aids in troubleshooting interface functions. - Provide local visual and/or other means to observe interface functions/operations remotely.
Testing	- Testing best practices based on sited requirements should be used to ensure hardware design integrity. - Interface flight hardware, design, development and testing should be IAW NASA-STD-5001; GSFC-STD-1000; SLS-STD-159. - Use prototypes to test proof of concept for automatic and/or manual connect/disconnect.
Software	- Software should be designed to be robust and provide feedback and diagnostics to the operator. - Interface mate/demate control software should have two independent lines of command to demate the interface. - Software should be tested and verified through the full con-ops operational sequence from launch to end of life. - Interface control software should reside with the surface element which houses the active half of the interface. - The software should have health monitoring and diagnostic capability to monitor and troubleshoot interface operational problems.

Table 3. Mechanical Interface Design Principles

Interface Component	Guiding Principle Description
Structural-Mechanical Interfaces	- Structural interfaces should be designed to safely function at all applicable loading conditions. - Interface connections should transfer loads, provide alignment and mate/de-mate motion to the connectors and couplings. - Connection between mechanical and structural components should be designed to the existing principles that can be found in, IAW NASA-STD-5001. - In case of off-nominal conditions at the interface that could prevent de-mating, the structural interfaces should have the means to separate. - In case of an emergency de-mate the interface connectors should be automatically placed in a safe condition (sealed, de-pressurized, de-energized, etc.)
Mechanisms	- Keeping mechanisms simple and minimizing moving parts is important for reliability. - Fastening systems should be designed IAW NASA-STD-5020. - Factors of safety should be IAW NASA-STD-5017 and NASA-STD-5001. - Mechanisms should be designed IAW NASA-STD-5017.
Mating/De-mating	- Mate/De-mate of the interface is a critical function which needs to be thoroughly understood with detailed con-ops. - Automated and tel-operated interfaces should be designed to be mated/de-mated by robotic systems and should include features for gripping/manipulation of the interface IAW ISO-9409-1 and -2. - Human operated interfaces should be designed with the ability to be mated/de-mated by a human operator. Manual connectors and couplings interfaces ergonomic design should be IAW MIL-STD-1472. - All interfaces should have a means to verify and communicate mated/de-mated condition.
Latching	- Latching mechanisms are used to secure the mated interface components and must be designed to withstand loads and accommodate positional errors. - Separation loads for fluid couplings must include the pressurized and unpressurized states. - Interfaces should be latched when mated. - In general use light weight, reliable, high cycle mechanisms. - The latching system should support structural mass and connector/coupling separation loads of the mated interface. - Latching systems should be single fault tolerant and be able to separate in cases of single component failure.
Alignment	- Alignment of the interface components before mating operations is critical to proper functioning. - Consider the use of alignment pins, visual marks, or other means to verify the two halves of the interface are properly aligned before mating. - The interface should have the ability to self-align the connectors and couplings. - The connectors and couplings used in the interface should have compliance to accommodate small misalignments. - Coordinate systems for robotic mating should be IAW ISO-9787.

	- The interface should provide verification of proper alignment before mating operation can begin. - The interface should have the capability for manual alignment. - On initial approach the two mating surfaces should not be assumed to be aligned for mating.
Mass	- Flight hardware should be low/optimized launch mass to reduce cost of the mission. - Mass is an important consideration and should be minimized during the design process. - Design goal should be to optimize the design for the lowest mass of interfaces, connectors, and couplings. - The mass of the interface should be added to the corresponding surface element mass.
Loads	- The interface needs a load reacting structure to operate properly. These can include umbilical plates, lathing mechanisms, support arms, housing enclosures etc. - Analyses of the interface loads should be performed for all stages of the Con-ops. - Provide for load-reacting structure on both sides of the interface which can withstand the worst-case loads. - Umbilical connectors and couplings i.e. fluid and electrical disconnects, should be treated as non-load bearing.

Table 4. Fluid Interface Design Principles

Interface Component	Guiding Principle Description
Fluid couplings/disconnects	- Separate the commodities, fuels and oxidizers in separate cavity (prevent contamination) and use separate connectors. - Fluid couplings should be protected from dust and kept clean. - Minimize size/mass of couplings to meet fluid transfer flow/pressure requirements. - Fluid couplings should be electrically bonded to the interface structure. - Thermal conditioning of the couplings should meet the commodity requirements. - Each half of the disconnect should be self-sealing. - Fuel and oxidizer couplings should be isolated from each other and from electrical connectors. - Fluids transferred through the interface for human habitation can include water, gas, breathing air, liquid and solid waste handling. - Fluids transferred through the interface for operational use can include ambient and cryogenic propellants Hydrogen, Oxygen, Methane, etc.
Purges	- Purging is useful to inert, clean, or safe the interface before or during transfer operations. - Expended commodity such as purge gas can be costly to take on Lunar missions and its use should be minimized. - Purging can be used to clean or prevent dust contamination of the interface. - Purging during Earth based testing and ground operations is required for flammable, hazardous and cryogenic fluid transfers.
Leak detection	- Leak free, or minimal leak fluid transfer should be the goal of the interface design. This is required for conserving of precious commodities, and safe transfer operations. - Fluid connections should provide local leak detection. - The interface should be designed to operate safely or be safely shut down in the event of out-of-spec fluid leak. - A localized leak detection system should be provided for hazardous transfers.
Leakage disposal	- Leak containment can be achieved by providing sealed pockets to separate fluid couplings. - The interface should minimize the leakage of commodities during transfer and mate/de-mate operations. - If leaks are unavoidable, they should be contained to avoid contact/contamination with adjacent hardware when such contact has the potential to cause damage. - Leaked commodities should be routed and vented to safe areas and/or direction to minimize contact with adjacent hardware. - Means of leak detection should be incorporated into fluid transfer interfaces.

Table 5. Electrical Interface Design Principles

Interface Component	Guiding Principle Description
Electrical Connectors	- Electrical connectors should have self-aligning features which prevent damage to the contacts during mating operations. - Electrical connectors should be protected from dust or be dust tolerant. - Electrical connections should be de-energized during mating/demating operations. - Inductive or wireless power transfer is recommended to minimize mechanical complexity. - Data and power hard lines should not be run through the same electrical connector.
Data and Communication Interfaces	- Data and communications can be transferred through the interface but are not controlled by the interface. - Use of wireless data transfer systems can reduce mechanical complexity and the need for dust mitigation, when compared with hard lines. - Wireless communication interface is recommended for data transfer to minimize mechanical complexity. - Use of twisted pairs wiring with overall shield should be used to minimize EMI interference. - Wireless data and communication should use independent frequencies/channels to avoid interference.
Grounding/Bonding	- Charge differential between the two halves of the interface must be equalized before safe connection can occur. - Electrical interfaces grounding and bonding should be designed IAW NASA-STD-4003. - Design for static charge dissipation should be IAW ANSI/ESD S20.20 and NASA-STD-5005. - A bonding connection between the two interface halves should be provided which will make first contact during mating.

Table 6. Environmental Interface Design Principles

Interface Design	Guiding Principle Description
Component selection	- Components need to function in the lunar surface environment and extended periods of time over its life cycle. - Components specified should be compatible with the relevant environment of use. - All components should be certified for the intended use with full certificates-of-compliance of physical and chemical. - All components should be qualified and tested in the relevant environments and with specified margins of performance.
Contamination prevention/Dust Tolerance	- The interface must operate in a dusty surface environment and should be designed to function with contamination present at all stages of operation. - Surfaces of connectors and couplings will be maintained in clean condition prior to mating. - Protection of the interface is required from dust storms, plume impingement, and lofted dust by other means. - The interface should be designed to be dust tolerant and function with dust present in the environment. - The interface should have the ability to be cleaned or to self-clean critical functional areas of the interface. - The interface should protect the connectors and couplings from dust impingement from the natural and induced environments, IAW NASA-STD-3001 V2. - The interface should be tested with relevant simulant for the location of use. - Soft goods sealing material should be compatible with the environment and fluids being used and should be protected from dust.
Electromagnetic compatibility (EMI/EMC)	- Requirement for all space hardware to not generate harmful EMI and must be able to operate with EMI in the adjacent environment. - The interface and all its components should be designed to resist EMI/EMC interference IAW: MIL-STD-461.
Ionizing Radiation	- Analyze all materials for degradation due to ionizing radiation which reduces longevity and reliability of space hardware. - The interface should be designed to withstand radiation IAW SLS-SPEC-159 Ionizing Radiation.

IV. Conclusions and Forward Work

The initial analysis performed on the early Artemis architecture and the interface principles developed are valuable stepping stones to defining interface standards on the lunar surface and future Mars missions. They identify the need for developing surface interface standards and show the importance of why commonality is an important factor for promoting interoperability and sustainability. Space exploration is challenging, and it is vital to identify standards early in the formulation process of surface systems to reduce integration risk and promote the safe and effective transfer of fluids, data, and power. Cognizance of previous and current program standards ensures new surface standards meet all expectations and requirements for developing generic interfaces for surface systems. The sections outlined below define the next steps required to develop standards that will work effectively in these unique environments. Forward work will warrant intelligent design, prototyping, comprehensive testing, and field experience.

A. Further Define Standards and Specifications

Develop a set of standards and specifications pertaining to mating interfaces for lunar assets. A primary objective is to utilize this set of standards and specifications amongst providers and stakeholders, resulting in the commonality of hardware interfaces. By doing so, complexity and cost can be minimized or at least contained.

B. Software, Communication, and Navigation Development and Studies

Software, communication, thermal, and navigation interfaces are a significant portion of forward work. Development of software would begin as soon as possible. Emulators are necessary to model and test software functionality. Testing of software would begin at the component level and eventually lead to end-to-end system testing. Also, communication and navigation will be studied more in depth. In depth studies of communication and navigation like the LunaNet are underway.

C. Performance Criteria

Performance criteria would include, but are not limited to, electrical power transfer rates, mechanical securing, fluid flow rates, data transmission, signal strength, communication links, connector self-alignment, lunar dust mitigation, transfer of commodities, seals, and optics, all while considering mass and size limitations. Energy storage and charging for electrical components and elements will be identified and quantified. Risk mitigation and safety will be maintained for all hardware mating interfaces. Evaluation of ganging connectors will be useful and implemented where feasible. As designs evolve, areas for optimization and reliability will become apparent.

D. Prototype Development for Early Lunar Surface Assets

Interface incompatibilities of mobile and stationary lunar assets (e.g. LTV, PR, SH, FSP) can be resolved by fabricating, assembling, and testing prototypes. Design, analysis, and assembly of hardware interfaces will be accomplished first at the component level and then proceed into subsystem level. Leveraging prior knowledge and developments of previous projects associated with interfaces will be utilized. For example, DTAU and Lunar Dust Tolerant Connector (LDTC) provide valuable design insight and test data. These projects were developed by the Granular Mechanics and Regolith Operations (GMRO) lab at Kennedy Space Center.

There are three primary interface types are mechanical, fluid, and electrical. General information has been gained from the PR, SH, FSP, and LTV specifications and investigations. As lunar asset designs mature, details pertaining to interfaces will become more refined. Interfaces with stationary and mobile lunar assets (e.g. PR, SH, FSP, LTV) with their respective lander will be included in prototype testing. Mechanical interface prototypes include latching mechanisms, indexing and locking capability when required, structural components, tools, and fasteners. Development of mechanical prototype interfaces will test function, repeatability, reliability, and robustness in simulated lunar environments. Fluid prototypes would show proof of concept to transfer commodities in micro-G and vacuum environments, without exhibiting any leakage. Mating surfaces, including quick-disconnect fittings, will be tested for seal integrity and reliability. Umbilical's for commodities (water, breathing air, propellants, etc.), will have the capability for local leak detection and will be ECLSS compatible where necessary.

The number of prototypes will be optimized per interfaces on each lunar surface asset. Where feasible, types of interfaces will be grouped together to form one connector or coupling. By utilizing COTS hardware, the cost of prototypes will be kept within budget allocations. Also, each prototype will be scalable, increasing or decreasing in size according to the area available on the lander, or lunar assets (e.g. LTV, PR, SH, FSP). After prototypes have been fully tested and are deemed acceptable, the associated interfaces will be shared with other lunar surface asset providers to attain commonality amongst all interface hardware.

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