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Human exploration missions beyond low earth orbit will likely require international cooperation in order to leverage limited resources. International standards can help enable cooperative missions by providing well understood, predefined interfaces allowing compatibility between unique spacecraft and systems. The International Space Station (ISS) partnership has developed a publically available International Docking System Standard (IDSS) that provides a solution to one of these key interfaces by defining a common docking interface. The docking interface provides a way for even dissimilar spacecraft to dock for exchange of crew and cargo, as well as enabling the assembly of large space systems. This paper provides an overview of the key attributes of the IDSS, an overview of the NASA Docking System (NDS), and the plans for updating the ISS with IDSS compatible interfaces. The NDS provides a state of the art, low impact docking system that will initially be made available to commercial crew and cargo providers. The ISS will be used to demonstrate the operational utility of the IDSS interface as a foundational technology for cooperative exploration.

Introduction

Since the beginning of human spaceflight, the need to join elements together in space has been a key capability. The need for this capability is driven largely by economics and physics – it is virtually impossible to build and launch a unitary spacecraft that can perform all expected missions on a single flight from the Earth’s surface.

This capability can support a broad range of needs, such as enabling (inherently small) transportation systems to and from planetary bodies, assembling habitats in space by allowing launch of two or more modules on reasonable sized launch vehicles for space stations/ long transit habitats, and specialized spacecraft for short term missions to arrive and depart from such habitats. For the purpose of this discussion, these needs can be divided in two broad categories – assembly of larger spacecraft, and allowing smaller, specialized spacecraft to come and go from a larger habitat.

The dominant approach to this problem has been docking, where an active spacecraft approaches and captures a passive spacecraft. The Space Shuttle introduced berthing as a method of joining elements in space through the use of its large robotic manipulator; this capability was extended and used by the International Space Station (ISS) to assemble elements delivered by the Space Shuttle.

The assembly of ISS has demonstrated that large space structures can be assembled successfully in orbit, and be supported by smaller crew and cargo transportation systems. This was enabled through the use of several different docking and berthing systems, and even some docking systems adopted for use as berthing systems. These systems have been developed by either the U.S. or Russia for their space programs and are not compatible, in spite of the fact that the basic technical drivers are the common.

From this experience, the ISS partnership recognized the benefit of standardizing a docking and berthing standard. Such a standard could enable rescue of spacecraft by

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different nations, as well as greatly simplify the architecture of any future joint space missions. The partnership is pioneering development of this standard, known as the International Docking System Standard (IDSS). The standard is publically available and open source, available to any organization desiring joint mission capability, including new human space flight nations and commercial entities.

Key Characteristics of Docking and Berthing Systems

Some background on the functions of docking and berthing systems and their historical evolution will be useful in understanding the development of the IDSS.

Docking and berthing systems must perform several key functions to mate two elements in space. First, they must provide allowances for the uncertainties inherent in bring two objects into alignment. They must compensate for and null out any residual forces and moments remaining after contact. They must provide for structural attachment of the two elements, including the loads induced from controlling the combined spacecraft stack and the pressure loads of any pass-through corridor. They must also allow for passing various utilities between the two elements if required. And they must provide for way to separate the spacecraft in the event of a contingency.

These basic required functions can be divided into six major subsystems, described in order of their use in the docking/berthing operation:

1. Course and Fine Alignment System - to compensate for vehicle alignment mismatch due to uncertainties in the navigation/control systems of incoming elements. For docking systems, these uncertainties result from relative navigation between the two bodies, guidance and navigation system, and the attitude control system. These uncertainties are similar for berthing systems where the robotic control system performs these functions.
2. Control System – reads and reacts to the various sensors indicating progress of the system operation such as initial contact; power control and conditioning; system control; thermal control; and health/status monitoring.
3. Soft Capture System – performs initial capture of the two bodies and nulls out any residual forces and moments between them. These systems can be a mechanical or closed loop active control systems; in both cases they provide multiple degrees of freedom for this function. This system includes a means to retract the SCS out of the way of the Hard Capture Systems. For berthing, the soft capture function is often provided by a large robotic manipulator such as the Space Station Remote Manipulator System (SSRMS)
4. Hard Capture System – completes the structural mating of the two bodies. It must carry the loads between the bodies as they operate, and carry the pressure loads of the pressurized tunnel connecting the two elements.
5. Utility Transfer System – provides a means to transfer power, data, video, and fluids between the bodies joined by the docking system.

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6. Emergency Separation System – provides a dissimilar way to separate the spacecraft in the vent of emergency or systems failure; these are often pyrotechnic systems.

Some technical implementations may use additional subsystems to support their operation, however minimum functionality can be described with these 5 subsystems.

Evolution of Docking and Berthing Systems

Historically, implementing these functions have resulted in three broad classes of docking and berthing systems. They are the probe & cone system, the peripheral system, and the Common Berthing System (CBM) used on ISS. The ISS today uses versions of all these systems both in its structure as well as in support of visiting crew and cargo vehicles.

In the early days of human spaceflight, both the U.S. and Russia developed variations of the probe & cone system. The Apollo program used this system to dock the Capsule system with the Lunar Lander, and later the Skylab space station. Evolutionary versions of the Russian system fly on today's Soyuz and Progress vehicles.

Probe & Cone systems have a probe assembly on the active spacecraft that engages a cone on the passive spacecraft. The probe slides down the surface of the cone until the soft capture system is engaged; at this point the system is retracted until the hard capture system can be engaged to finalize the mating operation. These systems tend to be the lightest of the mating systems and have the largest capture envelope of any of the systems. On the other hand, their load carry capabilities tend to be relatively small as they are sized to accommodate crew and cargo transport vehicles. In addition, the nature of the probe system can limit the use of the system since it is basically single sided – in other words, the role of the active and passive spacecraft cannot be reversed. In addition, the probe system must be removed from the pressurized mating tunnel and stored to allow for crew and cargo passage, adding an operational complexity.

The Apollo-Soyuz Test Program at the end of the cold war opened the door to cooperation between the U.S. and Russian programs to work together on docking system development. Since both countries desired to demonstrate their ability to be the active docking spacecraft, a new androgynous system was developed that eliminated the probe and cone alignment system. A system of alignment petals was conceived to provide for the course alignment function; this type is known as a peripheral system. Following ASTP, the Russians continued to develop the system which became known as the Androgynous Peripheral Attach System (APAS). APAS was originally intended to be used on the Buran Space Shuttle, where the large mass of the spacecraft required a very robust load carrying system for the hard capture system.

Following the success of ASTP, both programs again diverged, with the U.S. pursuing the Space Shuttle as a means to place and return large payloads from orbit, while the Russian program focused on developed a succession of space stations. Eventually, by the

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beginning of the 1990s, the U.S assembled an International Partnership to develop the Space Station Freedom, while the Russians were assembling the Mir Space Station. The Russian program continued developed and refinement of both the APAS and Probe & Cone systems. During this period, the U.S. began development of the CBM has a means to join the large modules planned for Freedom.

In 1993, the U. S. led partnership developing Freedom invited the Russians to join the program, the resulted program became known as the International Space Station. The completed ISS uses multiple docking and systems in its construction and to support ongoing operations, including the APAS, Probe & Cone, and CBM.

As part of the development of the ISS Program, The U.S. and Russia agreed to a series of precursor flights of the Space Shuttle to the Mir Space Station. This resulted in a design decision to adapt the APAS system to the Shuttle for use as the means to dock Shuttle and Mir; this concept was extended to use two passive APAS ports on the ISS in order to accommodate Shuttle dockings to the new vehicle.

Low Impact Technology

The Space Station Freedom design concept called for assembling a large number of elements carried to orbit by the Space Shuttle. These elements would then be assembled using berthing by the large manipulator systems available on both the Shuttle and Station. The initial concept called for the Shuttle to dock with the expanding station stack, however concerns quickly arose for both initial contact and fatigue life from the large mass of the Shuttle contacting the stack during docking.

Docking systems have historically relied on kinetic energy to complete the initial soft capture. First, energy is needed to overcome friction and allow the alignment system to guide the two mating halves to the contact position. Once the two mating soft capture systems are in alignment, energy is needed to overcome the soft capture system, which has typically been a mechanical latch. Often, a post contact thrusts is required by the incoming vehicle to assure enough energy is available to assure capture. The amount of energy needed for the operation is also a function of the efficiency of the force and moment attenuation system in the soft capture system. Much like the suspension in an automobile, the system must be tuned to the mass of the elements involved.

Historically, mechanical systems have performed the force and moment attenuation system (spring/damper systems). While these systems can operate over a fairly large range of spacecraft mass, their performance is inherently limited to the spring and damper rates selected by the designer for a specific spacecraft class.

The energy delivered to the system is reduced but not eliminated by the attenuation system; any remaining energy is transferred to the spacecraft structure. These forces must be accounted for in the spacecraft design. The concerns over loads drove NASA to consider alternative approaches for design of docking systems. NASA embarked on a

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program to develop an actively controlled attenuation system that could measure forces and moments on contact and react to them, greatly reducing the amount of energy needed to affect capture and hence reduce loads on the docking spacecraft. This has become known as low impact technology.

After an initial development period, the European Space Agency (ESA) partnered with NASA to develop a Low Impact Docking System (LIDS) for the X-38 Crew Return Vehicle. While the X-38 program was ultimately cancelled, both ESA and NASA continued to pursue low impact technology for future space missions.

Today, Low Impact technology is a key NASA technology initiative for use on future space systems.

The International Docking System Standard

From the experiences of ASTP and the ISS, the ISS Partnership realized that standardizing key requirements for docking systems could pay great benefits in future joint space initiatives. Many of the potential human space flight nations have docking systems and therefore creating a standard could ease integration of spacecraft from different nations – and the emerging commercial spaceflight companies. The Partners view this standard as an initial step for all users to agree on docking interfaces.

A joint working group was established by the ISS partnership and considered the key driving requirements. Initially, the discussion targeted the requirements that would enable docking of dissimilar spacecraft to achieve crew rescue; as the discussion evolved the standard was expanded to include other features including support to assembly of larger structures.

The standard was designed to describe the interfacing and basic functional needs allowing different docking systems to mate and function together. It has been deliberately designed to be independent of the technology driving the system; for example the soft capture system can be a mechanical system or use closed loop active control. In other words, the standard assures commonality of function, not commonality of design. In fact, the standard does not provide sufficient information to design docking systems – merely the features it must have to be compatible and perform with a standard-compatible system.

Since all of the nations operating docking systems have versions of peripheral type, it was decided that the standard would be based on this basic design. Since the APAS system has demonstrated a large load carrying capability, this supports using the system to assemble larger elements. It was determined that the ability support berthing should be accommodated, since assembly and relocation of elements by robotic manipulators has been deemed an important capability.

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The IDSS standard has been designed to accommodate the design philosophies and policy goals of the participants. For example, the Russians desired that any system accommodate legacy features to gain benefit from the long operational history; ESA and NASA are interested in low impact technology, and CSA desired berthing accommodation. All of these positions are sound goals and allowed for in the resulting standard.

To date, the standard has been maintained by the ISS Multilateral Control Board; ultimately this standard will be transferred to an appropriate international standards organization for future management.

As of May 2012, the standard accommodates basic docking and berthing needs. Future revisions of the standard are needed to accommodate additional features such as a common utility pass through approach.

The NASA Docking System

NASA views the IDSS as a key enabler for cooperative space missions. As such, it is designing and building an IDSS compatible docking system known as the NASA Docking System. NDS is a next generation system utilizing a closed loop active control system to achieve a low impact soft capture system.

The NDS has a flexible architecture in order to accommodate a broad range of space vehicles. It is conceived around the concept known as the “black box” – that is, the functions needed to be performed to achieve docking are contained almost entirely within the docking system itself, with very simple interfaces to the host vehicle. The interfaces are limited to structural, power, and a simple command & data format, with some support needed for fault management. All of these interfaces are described in publicly available documentation.

NDS users have a number of configuration options for use of the NDS, such as a fully integrated “tall tunnel” system that includes the avionics integrally mounted or a “short tunnel” allowing for remote avionics mounting, RS-232 or MIL-STD-1553 data bus, and 120VDC or 28VDC operation.

NASA has elected to make IDSS compliance a key part of any future spacecraft program, including Orion and the Commercial Crew vehicles planned for use at ISS. NDS provides a reference design for these users; they will have the choice of building the NDS to print, designing their own IDSS compatible docking system, or acquiring their systems from NASA. Due to export control restrictions, the data package for the system will only be available to users with a valid agreement for use from NASA.

Adapting the ISS to the IDSS

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As part of the evolution to a new era of international docking system standards, NASA and the ISS partners have elected to convert the two U.S. segment docking ports to IDSS compatible interfaces. This is to encourage the use of the standard and demonstrate the performance and utility of the NDS design in particular.

Two adapters are being constructed to convert the existing APAS docking systems to IDSS; these are known as the International Docking Adapters (IDA). The two IDA systems will be launched to the ISS being in late 2014 to support upcoming crew missions to the U.S. segment.

Conclusions

The work done by the ISS Partnership has made progress towards generating an international standard for docking systems. This standard will greatly ease cooperation among nations and simplify the design choices for the merging commercial spaceflight industry. More work remains to extend the foundation this work has established.

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Key Points – Brainstorming

Key system trades

- Range of forces/moments accommodated
- Capture performance. The course alignment function has a direct impact on the capture performance.
- Loads accommodated after hard docking
- Overall mass
- Transfer corridor
- Docking and Berthing
 - Docking allows direct contact
 - Berthing capture by robot, installation/relocating by robot
 - Berthing con does not allow direct departure (current systems)
 - Requires robot grapple – a problem due to comm. Lag for uninhabited systems
- Goal is to achieve standard interface, rather than a standard implementation
 - Allows for multiple technologies
 - Dissimilar redundancy
 - Enable simpler integration between spacecraft – see Apollo-Soyuz
- Peripheral systems
 - Robust load capability
 - Androgynous
 - Pressure tunnel clear of probe system

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- Timeline
 - Initial standard discussions
 - Detailed technical discussion
 - Initial Version signed by MCB
 - Revision A approved by MCB
 - Future revisions....
- NASA and ESA wanted to allow for low impact systems
- CSA wanted berthing as a capability
- Roscomos desired high degree of legacy compatibility
- Led to general philosophy of retaining APAS hard capture geometry, new soft capture accommodations
- Changes needed to APAS (questionable whether I want to include this)
 - Retractable pushers
- Use ISS as a prototype for future
 - Convert existing docking systems to IDSS compatibility
 - Background on IDA
 - Two locations to be installed
- Opportunity to maintain APAS systems with new interface/adaptor
 - MMOD strikes on PMA 2 APAS surface
 - x-connector concerns
- Dictate use by commercial crew vehicles
 - Work closely with them for integration
- Wide range of performance
 - Very light to heavy vehicles
- Consideration of docking system compatibility
 - Rescue
 - Interoperability
- Compatible with different spacecraft
 - Use Russian model of common bolt pattern to host vehicle
- Future of docking standard
 - Expand to future human space flight nations (be careful here)
 - Update based on experience with building compatible systems
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- NDS design considerations
 - Docking systems are hard to design/integrate, so develop “black box” system for spacecraft integration
 - Multiple features (short/tall tunnels, 120VDC and 28VDC)
- IDSS: <http://www.internationaldockingstandard.com/>
- NDS: <http://dockingstandard.nasa.gov/>