CREATING A UNIVERSAL SPACE INTERFACE STANDARD

MARK HEMPSELL
Hempsell Astronautics Limited, 10 Silver Birch Avenue, Stotfold, Herts, SG5 4AR, UK.
Email: mail@hempsellastro.com

The Universal Space Interface Standard (USIS) is a concept that combines the requirements of docking, berthing and launcher payload attachment into a single common interface standard. Such an interface is key to establishing any kind of space infrastructure which can lead to an expansion in the range of space activities. The advantages of standardising human spaceflight docking systems have long been widely recognised, but the background to the USIS concept with its wider applicability was established during Skylon requirement validation exercises. This established that the basic concept of a universal interface was viable and also explored the range of technical and functional options that could be incorporated in it. A requirement specification defining the standard that was suitable for all roles and environments was produced. In view of the promise it showed it was decided to pursue the concept further by establishing an organisation to manage its development. Using a model based on that used by the consumer electronics industry, the USIS Association was conceived as a neutral body that would develop and control the standard. Thus it is a corporate body which is owned by all stakeholders in the USIS; including government space agencies, commercial system operators and the manufacturers of space systems. This would lead to an open standard available to all mankind on an equal basis enabling any space system to connect with any other from any national background.

Keywords: USIS, docking, berthing, launch interfaces

1. INTRODUCTION

1.1 Connecting Interfaces

The Universal Space Interface Standard (USIS) is a concept for a space system to space system physical connection that can undertake:

- the connection between a payload and its launch system,
- the docking connection of free flying spacecraft currently in the context of human spaceflight but also of interest for robotic systems in the future,
- the berthing connection made using manipulator arms normally in the context of assembling human spaceflight facilities in orbit.

The physical connection of between space systems is a fundament aspect of space flight, as all space systems must physically interact with other space systems during their operational life. As a minimum this interaction is between the payload, and the launch system, but in more complex missions, especially those involving human spaceflight, other interactions such as docking supply craft to space stations and berthing modules together to make large structures are also required. These connections are the only physical interface a spacecraft has with the infrastructure that supports it, and thus greatly affect the space system's capability and potential.

Currently such connections are made with a wide variety of what might loosely be called standards, although with so many performing identical roles the term "standard" does seem a misnomer. For example Ariane 5 offers three basic interfaces with diameters 917 mm, 1194 mm and 1663 mm most originally derived from other launch systems, but none are controlled as a recognized and defined standard.

This paper was originally presented at the 66th International Astronautical Congress, Jerusalem. Paper No. IAC-15.D3.2.6.

With regard to docking and berthing systems the current situation is encapsulated by the International Space Station. It has two docking port standards and one berthing standard (Fig. 1). A further docking port standard, the International Docking System Standard (IDSS), will be added, to replace the Androgynous Peripheral Attach System. The docking systems all have mating rings 1.2 m in diameter and the Common Berthing Mechanism mating ring is 2 m.

None of these docking and berthing standards meet both of the two critical requirements for effective operations, firstly androgynous operation and secondly a large enough hatch. Partly as a consequence none of them are fully accepted as an international standard as all are used by only one nation. The failure for standards to be either standard or based on properly conducted requirement generation processes has led to obvious and one may say bizarre problems. For example the crew of a Soyuz cannot be rescued by the crew of another Soyuz because the Soyuz pin cone docking system is not androgynous. The European Automated Transfer Vehicle, (a programme costing around €4 billion) was designed to carry its cargo in the International Standard Payload Racks (ISPR) but could not exchange those racks while attached to the ISS because it used a docking port and only the (different) berthing port can allow an ISPR through it.

Despite the actual situation regarding docking and berthing interfaces the need for an international standard for both operational and safety reasons has long been understood. It was the objective of the Apollo Soyuz Test Project in 1975 [1]. In the mid-nineteen-eighties it was understood to be desirable objective; as demonstrated by the early versions

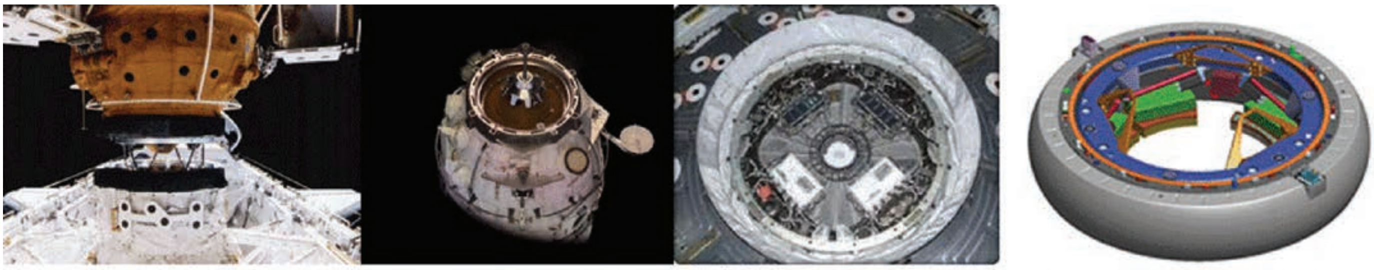

Fig. 1 Docking and Berthing Ports on the International Space Station.

of what became the Common Berthing Mechanism in the Freedom space station programme and in Europe with the initial studies that led to the USIS [2]. In recent times the ISS partners developed the IDSS which the USA will use on its commercial crew delivery system [3] (but it has failed to be adopted by the other crew system developments in either USA or Russia despite both nations being key participants in its definition) and the USIS initiative [4] which is the subject of this paper.

It may be reasonably asked, given so many failed past attempts, why the USIS initiative should make yet another attempt at defining an international recognised docking standard. It is argued there are three compelling reasons.

i. It is too important to drop the vision of an international docking standard because of safety and the positive impact on the future of astronautics.
ii. The process of incorporating "lessons learned" from past attempts to establish docking standards have not exhausted.
iii. USIS has new insights into the possibility of a combined launch interface and docking ring to create a truly universal standard.

2. USIS OUTLINE

2.1 Purpose

The purpose of the USIS standard is defined in the draft technical requirement specification [5] as,

> **"to be a standard connection that maximises the interconnectivity between independent systems in both the open space (orbital) and celestial body surface environments."**

To serve this purpose the USIS would need to meet the following objectives:

i. to provide a make and breakable connection between space systems in orbit,
ii. to provide an interface for the connection of payloads to transport systems suitable for both ground to space and in orbit launch systems,
iii. to provide a pressurised access path between systems suitable for a universal human presence in space ,

These objectives were intended to include all space system to space system connections (e.g. docking, berthing and launch system payload interface), for all systems (human or robotic), in all extra-terrestrial locations, for all time.

While it is clearly not possible to meet this ideal objective completely, the USIS studies suggest something very near to it is possible for space systems over a tonne in mass. In particular the two main system to system connections in current use, that is the launch interface for large satellites and docking/berthing ports for human spaceflight, have very similar load and sizing requirements and preliminary studies into the USIS have shown a single standard could under take both roles.

For robotic spacecraft there are two key advantages to using a USIS as the connection for to the launch systems. The first advantage is that it will give access to reusable launch systems when they emerge. A reusable interface is more appropriate if the launch system itself is reusable, so a change of launch system interface maybe a requirement of using such system and thus gaining access to their the cost and reliability advantages.

The second, and probably more attractive, advantage is that using a USIS with a passive docking capability would enable other space systems to connect to the satellite once in orbit. This could be for in orbit servicing, orbital relocating with space tugs, or recovery at the end of life. The USIS would open up the possibility of spacecraft becoming part of a wider support infrastructure of space systems, rather than operating in isolation.

In the case of human spaceflight the advantages of standardisation extend to the possibility of rescue missions, which was seen by the USA Congress as a reason for directing NASA to establish an international standard, [6] which led to the process of defining the International Docking System Standard (IDSS). As the IDSS has not been adopted by neither the Russian nor the US Orion new crew transport developments it seems to have failed to achieve this goal. However the underlying rationale remains, and a workable international docking standard for human spaceflight will still need to be established in the long term, if unrestricted operations between all crewed spacecraft of all nations, including rescue missions, is to be realised

The USIS would meet all the functional requirements of the IDSS, while offering the opportunity to address the mass, cost and hatch size issues are the reason the IDSS has not been taken up more widely.

3. TECHNICAL

3.1 USIS Requirements

The USIS Requirement Specification is currently at draft issue F [5] and its key features are summarised below. It must be emphasised these requirements are provisional and will be subject of a full requirements generation exercise conducted by the USIS Association as its first activity. The draft requirements are seen as a starting point, which demonstrates the feasibility of the concept and illustrating the form a USIS might take.

The very wide range of applications envisaged for the USIS mean that most applications will not need all the functions of the complete USIS offers, so the standard will need to support many versions reflecting the connection required (e.g. docking, berthing, permanent) and whether the system is pressurised or not. An illustration of the range of possible forms is shown in Fig. 2 including versions that are suitable for connection during the integration of the system on the ground for a one off disconnect in space.

A user would select the USIS version that meets their system's requirements. For example, a satellite that wants the provision for a servicing system to attach to it would be fitted with an unpressurised passive docking version. This would be used to mount the satellite on its launch system with a few kilogrammes mass penalty over a currently favoured marmon clamp system (without a docking capability). Once in orbit any system with an active USIS docking system (crewed or robotic) could connect to the satellite for servicing or as a tug to relocate it.

The various levels of connection for the USIS and the key design parameters are defined in Table 1.

In addition to the connection requirements the USIS will have a disconnect and separation system which provides a maximum force of 10 kN

Table 2 gives the required load carrying capability both when unpressurised and when pressurised to 200 kPa. The unpressurised case corresponds to carrying a 10 tonne payload with a centre of mass 2.5m above the interface ring. The pressured connection corresponds to a 100 tonne system as part of an orbital complex.

The size of the free passage between the two space systems, once the connection has been made, has been the key limitation of all docking systems to date. On current systems typically have an 80 cm diameter circular hatch, which creates several restrictions such as:

- an astronaut in EVA spacesuit cannot get through it,
- standard ISPR racks cannot get through it,
- it is unsuitable for use in a gravity field (i.e. Moon or Mars surface),
- it is not suitable for public access spaceflight.

A comparison can be made between the current 80 cm diameter circular passageway and the passage way from one from the Reaction Engines USIS study concepts can be seen in Fig. 3 showing the marked difference between them.

The USIS is required to be able to have a pressurised passageway through the pressurised connection as shown in Fig. 4. This enables astronauts in EVA suits to pass through, and also enables the transfer of International Standard Payload Racks (ISPR) used on the ISS.

3.2 The Requirement Generation Process

The USIS requirement generation process followed the logic

Fig. 2 USIS variants.

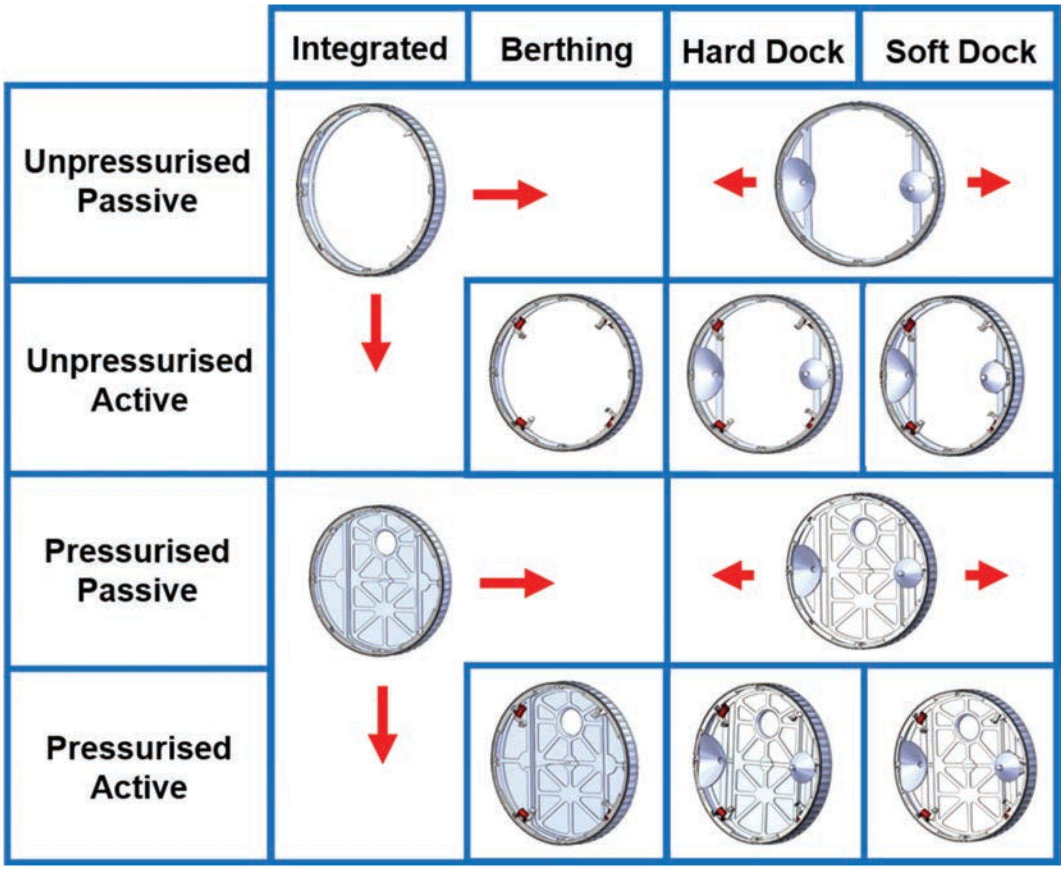

TABLE 1: *USIS Functional Levels.*

	Description	Maximum Contact Velocity	Maximum Contact Forces	Maximum Misalignment
Level I - Integrated	Permanent or breakable connection	Negligible	Ground handling	Integration tolerences
Level II - Berthing	In orbit connection with a manipulator	Nominally zero Below .01 m/s	Maximum150 N	30 mm
Level III - Hard Docking	In orbit connection between two free flying spacecraft	Linear axial 0.1 m/sec all other 0.04 m/sec Angular axial 0.4 deg./sec all other 0.15 deg./sec	Compression 10 kN Linear 4 kN all other Moment 3 kN m	110 mm + 5 degrees
Level IV- Soft Docking	As hard docking with active control to reduce impact loads			

TABLE 2: *USIS Load Carrying Requirements.*

Load	Unpressurised	Pressurised
Axial Compressive	590 kN	100 kN
Axial Tension	300 kN	100 kN
Shear	200 kN	120 kN
Moment	500 kN m	300 kN m
Torque	80 kN m	80 kN m

of functional requirement generation (as opposed to mission requirement generation) [7]. This process requires the generation of feasibility designs tested in validation exercises from which the requirements are captured. There have been three such USIS feasibility designs the first from Reaction Engines (Fig. 5) was based on earlier University of Bristol work [8] but was little more than an illustration of USIS functionality.

The USIS requirements generation process has included the creation of feasibility designs to demonstrate feasibility and perform validation analysis. In 2013-2014 this work was part of the Skylon Based European Launch Service Operator (S-ELSO) study conducted for ESA and lead by Reaction Engines. The USIS component of the study was conducted by QinetiQ Space and reported in Reference 9.

The QinetiQ Space concept design (Fig. 6) was based on IDSS technology that was repackaged to accommodate the large hatch requirements. The IBDM technologies incorporated include the dual hook mating connection and the Stewart Platform mounted capture ring as a fundamental part of the standard. The QinetiQ USIS concept exploits the IDSS's Stewart Platform mounted capture ring technology, not only to match and reduce the loads during the capture process, but also to play a part in meeting the misalignment requirements. Thus the capture system operates as an active platform that is steered with the supporting linear actuators. The platform actively aligns during capture of the mating vehicle. To do so, the relative position and orientation of the vehicles would be obtained from the vehicles' guidance and navigation control system. This reduces the size of the capture guide vanes, helping to meet the passageway requirements while keeping the ring diameter down to 1800 mm.

The QinetiQ USIS uses 12 active hook mechanisms to make the structural connection. This concept is inherited from the IBDM and has a heritage in several Russian docking system. If both sudes are active then it provides separation redundancy as the hook on either side can initiate the release. However this redundancy is lost if one side is a passive ring.

The loads on the mechanism were found to be very similar when carrying 10 tonnes unpressurised and when carrying the pressurised loads, confirming the close match between these two cases (which was the fundamental insight that led to the

Fig. 3 USIS Passage Way (left) Compared with an 80 cm Passage Way (right).

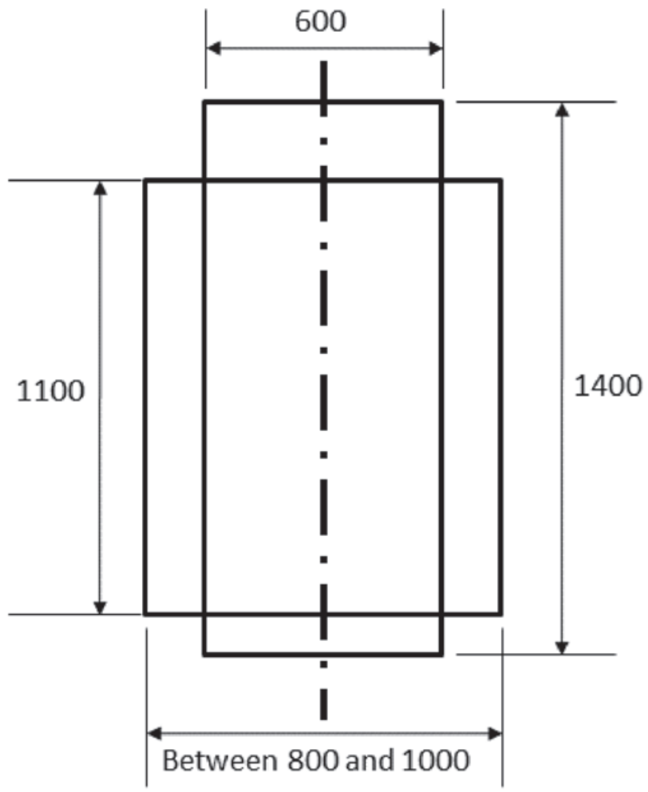

Fig. 4 USIS pressurised hatch clear passage requirements.

concept of a common universal connection standard). The QinetiQ study explored three unpressurised USIS variations as shown in Fig. 6, a fully active docking system using the hook mechanism, a passive docking ring and a "light" version which had a one shot marmon clamp connection combined with a passive docking ring.

The QinetiQ Space work provided significant new insights into the USIS requirements however the feasibility design did not at the end of the study meet the emerging cost and mass constraints. To take the process beyond the S-ELSO study Hempsell Astronautics produced another concept design that fully met the requirements laid out in the Draft F issue of "USIS Technical Requirement Specification" [5]. This was not intended to be the definitive design for the USIS only a focus to progress the functional requirement generation process.

3.3 Hempsell Astronautics USIS Concept

The Hempsell Astronautics concept design (Fig. 7) has a berthing ring which can operate as a hard connection using berthing operations, and a docking ring which can be added to allow the USIS to perform docking operations. Both rings have an androgynous design so the USIS can berth or dock to an identical replica of itself as required.

3.3.1 The Berthing Ring

The Berthing Ring has an inner diameter of 1600 mm and an outer diameter of 1624 mm with two seals each with a 2 mm circular cross section and with centre line diameters of 1608 mm and 1616 mm. The outer edge is 3 mm thick with a 15 degree slope on the back face, suitable for a Marmon clamp connection along the same lines as the QinetiQ "light" described above.

Twelve 60 mm diameter half cone pins provide alignment during the hard mating and take the rotational and shear forces once connected. The hard connection is made by twelve fork clamps forcing the two berthing rings together. These mechanisms have redundant electrical drives and a weak link that will break on separation if both drives fail to open the clamp. Twelve other locations on the ring, between the clamps, provide the space for the twelve fork clamps on the other USIS. If both sides of the interface engage their clamps the carry load is almost doubled.

Fig. 5 Reaction Engines USIS Concept. **(Reaction Engines)**

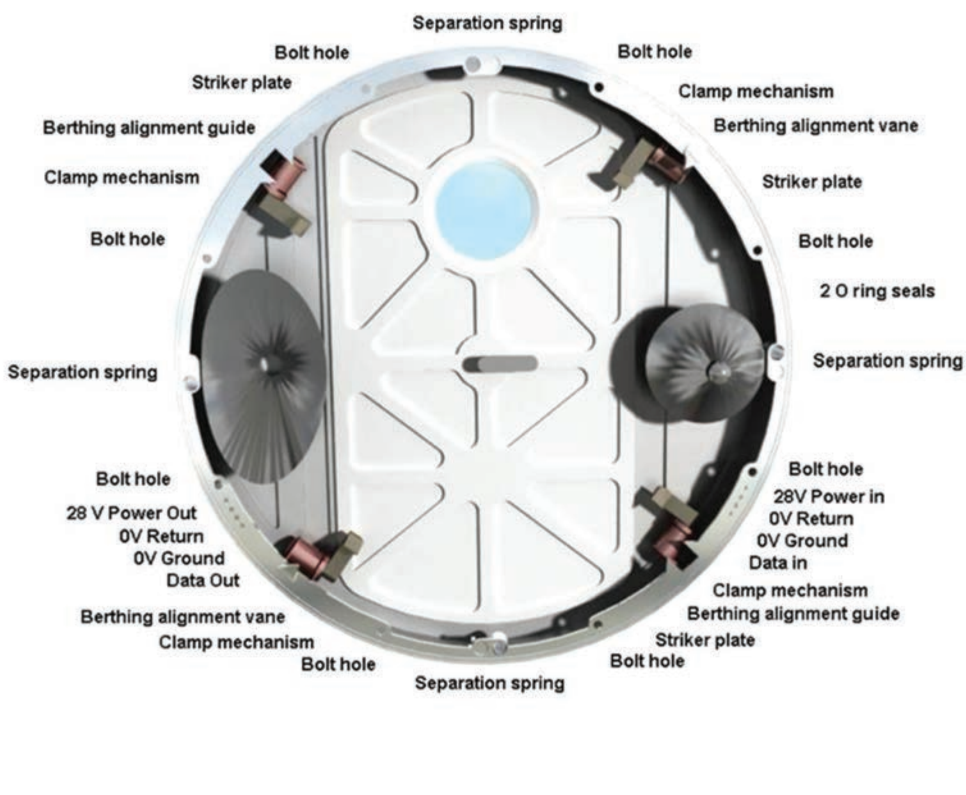

Fig. 6 Three unpressurised USIS variations. **(QinetiQ)**

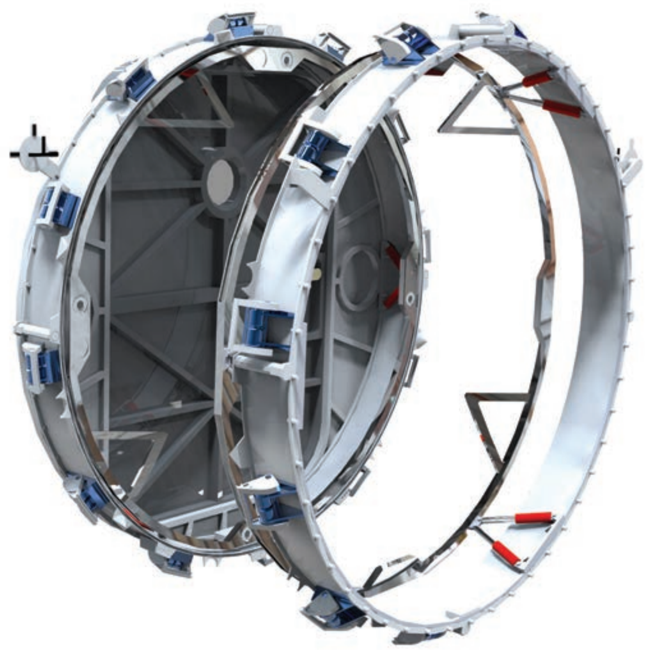

Fig. 7 Two Hempsell Astronautics USIS. (Left) A pressurised version in passive mode. (Right) An unpressurised version in active mode with capture ring extended.

Four push devices at 90 degrees to each other provide the separation force after decoupling.

There are two electrical connection locations each carrying 28 volt power, earth, neutral and emergency disconnect lines and also data connections. On the right are the male connectors for inward power and signals, on the left female connectors for outward power and signals.

3.3.2 The Capture Ring

The Capture Ring is located inside the berthing ring when a docking capability is required. It provides the guidance and alignment during docking operations and soft capture using 4 electromagnets mounted at 90 degrees to each other. Alignment is achieved by four guide vanes that protrude 140 mm above the ring's connecting surface. The main structural ring has an inner diameter of 1525 mm and an outer diameter of 1575 mm.

When docking the active USIS extends its capture ring by 65 mm using a mechanism that can range from a simple of pistons with shock absorbers to a full Stewart Platform depending upon the mass properties and other characteristics of the active vehicle. Once the electromagnetic capture is achieved the mechanism draws the two USIS together for the mating connectors on the berthing ring to operate.

If a capture ring is included then a docking target is also added to the right side, 30 degrees along from the horizontal axis, to aid human controlled docking procedures

3.3.3 Mass Estimate

Table 3 gives the mass estimates including margins for four variations of the USIS in unpressurised form, that is without a pressure bulkhead or hatch. These are specification values that included margins on the raw estimate and were judge suitable for inclusion in later version of the USIS specification and are the values that were used in the validation studies such as the Post ISS Architecture (PIA) Study [10].

TABLE 3: *USIS Specification Masses*.

	Spec
Passive Berthing	13.5 kg
Passive Docking	24.2 kg
Active Berthing	48.6 kg
Active Docking	75.1 kg

4. THE USIS ASSOCIATION

In order to develop and control the USIS so that it could become an open standard that could be used by the space industry with confidence it was proposed to found an independent association with the legal structure of a limited equity private company that would be owned by stakeholders such as satellite manufacturers, launch system providers and government agencies. Its working name was The USIS Association (Fig. 8).

To be a truly universal interface; the USIS would need to be universally accepted, and given the history of docking standards this is clearly a difficult issue. This model was proposed in part due to the failure of repeated space agency lead attempts to create a viable standard even within the limited remit of a human spaceflight docking system. It was felt a fundamentally new organisational structure was required, with different internal constraints and dynamics, to produce a viable result.

The model for the development organisation was taken from

Fig. 8 The USIS Association logo.

those used by past successful standards, particularly in the information technology industry such as USB and MIDI. These are independent bodies set up as companies that are owned by the producers and users of the standard. These are normally set as “not for profit” companies but given that the development of the USIS may require significant investment it is proposed to set up the USIS Association so that it can levy licencing fees to recover the development costs if the Members wish it. However it constituted so that should members wish to turn it not a “not for profit” charity that could be easily accomplished.

The most common structure is an Executive Board that determines the business aspects of the Association and a Technical Board who determine the technical aspects of the standard. Proposed. A draft set of articles has been proposed drawing from the constitutions of these electronics industry organisations (particularly the USB Implementers Forum, Inc) but with a special arrangement to allow non-profit organisations like many space agencies that are prevented from receiving a commercial return with commercial companies that by definition are to mix with equal voting rights in the Association.

The proposed Articles of Association outline a company founded under English law that would be in the control of the Members. These Members would be restricted to corporate bodies with an interest in the USIS as part of their purpose. Members would pay a subscription which entitled them to shares in the Association but they would not have to take up this share entitlement; it was membership rather than shareholding that would confer the right to participate and vote in the Association’s affairs. If a Member with shares left the Association, it would retain the shareholding and the right to receive any dividends that were paid out but lose the right to participate in the Association.

A three stage development programme had been designed for the USIS Association to reach the point of a defined standard on which royalties could be paid for its uses. The stages were Requirement Generation, Technical Definition, and Implementation. This was only a starting point as the actual definition and progress of the USIS development would be in the control of the Association’s Board of Directors and Technical Board once they are established.

5. CONCLUSIONS

Spacecraft to spacecraft interfaces are the most critical way space systems interact physically with the infrastructure that supports them. The greater the degree of standardisation that can be applied to them the greater the degree of interaction can take place within that infrastructure. There are three areas where great improvement can be made.

In launch systems area, while the current approach of essentially launch vehicles copying each other’s interfaces could be argued to be working, however there are three drivers for change:

i. There is no controlling authority for any of these de facto standards.
ii. There is a concern about the shock loads induced by these standard marmon clamp interfaces (SpaceX is currently developing a low shock tension band separation system for the Falcon 9, which uses a non-pyrotechnic release mechanism to address this issue [11]).
iii. The Skylon studies have found conventional payload attachments suitable for expendable launch system do not work well with the operations of a reusable vehicle [9].

In the area of human spaceflight there are four strong and urgent drivers for change:

i. The lack of any effective standards is an outstanding safety issue
ii. The lack of standards will restrict markets for commercial human spaceflight systems
iii. The 80 cm hatch size used by current docking systems is too small for many applications
iv. The lack of commonality between berthing and docking system requires additional ports which would not otherwise be required

In the field of robotic spaceflight the launch system is the only current physical interface however if a docking attachment could be incorporated it would open up the potential of satellite servicing. This raises a classic “chicken and egg” debate as to whether the servicing systems need to exist before the satellites will include the attachment or whether the satellites should first incorporate the attachment creating a real and identifiable market for the services. Given the relative up front investments involved it is suggest that satellites should first incorporate the attachment.

So there is a need for standardisation of system to system interfaces in all aspects of spaceflight and if separate solutions for each of these three areas was established it would be a considerable advance over the current state of affairs. However the USIS studies have found that a common standard to address all of the issues is technical feasible and offers considerable advantages.

The key insight that makes USIS different from past attempts to create standards is the insight that that the size and load carrying requirements of human docking/berthing ports and launch systems (on particular launchers in the geostationary market) are very close. Thus there is very little impact on efficiency if they were made a common interface.

The key issue with extending the interface capabilities of satellites is the cost and mass implications of adding an attachment, given at the moment there are no services on offer to make it worthwhile. However if the USIS were to be used as the launch system interface then the attachment would be a passive capture ring with a mass of around 10 kg and no integrational issues.

When implemented; the USIS will maximise the interconnectivity of the space infrastructure as any space system could connect to any other whether robotic or crewed space system, removing the distinction between the two regimes operationally. This will remove restriction on the utilisation of any space system whether it be a launch system, an in-orbit propulsion stage, a servicing vehicle, a logistics supply vehicle or a crew transportation system. In commercial terms it maximises the market for these systems.

The technical viability of the USIS has been established by a series of studies and the resulting requirement specification [5], while far from finalised, represents a coherent picture of what a USIS could do.

Given the very diverse range of potential users of the USIS both geographically and by application, and what is more users do not normally have working relations, perhaps creating the organisation to enact the USIS represents a bigger challenge than the technical realisation. To ensure all potential stakeholders in the USIS can influence its development it is proposed to establish a USIS Association modelled on the standard definition and control bodies common in the commercial electronics industry which would be owned and controlled by these stakeholders.

If nothing is done to consciously implement interface standards based on well conducted requirement generation processes, then in areas where standards are essential some de facto standards will emerge (like already exist with launch system interfaces). History has shown such standards are never as good or as comprehensive as they could be as they end up being the minimum needed for the moment and constrain future developments. Where standards are only desirable and not essential, they will never form and their potential benefit is never realised.

There is also a considerable danger that national groups will continue to use and invest in national standards and the interaction of spacecraft of different nations will be technically impractical without special adaptors and years of preparation. Certainly the intention expressed by the US Congress [6] to enable any nation to rescue crew from any other nation will never happen.

We are at a critical time in the history of astronautics. The expansion of human spaceflight activity by several nations and the introduction of reusable launch system will create a powerful drive to rapidly establish the essential interface standards that, like the railway gauge, once in place will never be able to be altered regardless of any later realisation of the problems created by an established but inadequate standard. The USIS initiative is a way out of this scenario by establishing a standard that is thought out and will not later be a matter of regret. It will be a key facilitator in the growth of existing space services and enable new service to be created.

USIS would lead to an open standard available to all mankind on an equal basis enabling any space system to connect with any other from any national background. The physical Space interface standards we establish will be the key legacy our generation of astronautical engineers leaves to posterity, whether intended or not. The USIS would try to ensure we will be thanked not cursed for it by future generations.

REFERENCES

1. E.C.Ezell, and L.N. Ezell, "*The Partnership: A History of the Apollo Soyuz Test Project*", NASA History Series, NASA SP-4209, 1978
2. Mark Hempsell, "Standardisation of Interfaces within the Space Infrastructure", *JBIS,* **39**, pp.92-98, 1986.
3. International Docking System Standard (IDSS) Interface Definition Document (IDD) Revision C, 20 November 2013.
4. Mark Hempsell, "The Requirement for a Docking Standard Within a Systems of System Infrastructure", *59th International Astronautical Congress*, Glasgow, Scotland, 29 September - 3 October 2008. Paper No. IAC-08-D3.3.4.
5. "USIS Technical Requirement Specification", presently unnumbered pending the establishing of a USIS controlling body, Draft F (this can be downloaded from www.hempsellastro.com or www.usisassociation.org).
6. Section 406 of "National Aeronautics and Space Administration Authorization Act of 2008", 110th Congress of the United States HR6063 passed 18th June 2008.
7. Mark Hempsell, "Requirement Generation for Space Infrastructure Systems", *JBIS*, **60**, pp.350-357, 2007.
8. Mark Hempsell "The Requirement for a Docking Standard Within a System of Systems Infrastructure", *59th International Astronautical Congress,* Glasgow, Scotland, 29 September - 3 October 2008. Paper No.IAC-08-D3.3.4
9. Mark Hempsell, Julio Aprea, Roger Longstaff, Giorgio Ferrari, Steven Hens, Sebastian Soller, Roger Dewell, Dan Ahearn and Catriona Francis, "A Technical Overview of a Skylon Based European Launch Service Operator", *65th International Astronautical Congress.* Toronto, Canada, 29 September - 3 October 2014. Paper No. IAC-14.D2.4.5.
10. Mark Hempsell, "A Concept Study into a Post ISS Architecture", *JBIS*, **69**, pp.163-174, 2016.
11. "Falcon 9 Launch Vehicle Payload User's Guide", SCM2008-010 Rev.1, 2009.

(Received 23 April 2016; Revision & Accepted 19 August 2016)

* * *