An International Small Cargo Recovery System for the International Space Station

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After the retirement of the Space Shuttle International Space Station (ISS) return-cargo logistics will prove to be a limiting factor for any attempt to increase research utilization. The need to resolve this return-cargo deficiency is urgent, because ISS utilization must be increased as quickly as possible in order to maximize the value of this precious and short lived science and technology development resource. A novel concept for addressing this cargo shortfall is to return EXpediting the PRocessing of Experiments to Space Station (EXPRESS) payloads from the ISS back to Earth by way of a Ballute Cargo Recovery System (BCRS). Benefits of the BCRS are: it can increase the ISS utilization rate by allowing short-duration experiments to be frequently changed out; ensure flexibility for when and where experiments are deorbited; provide a timely solution for addressing some of the down-mass return deficiencies; and, eliminate internal ISS storage problems which may arise from an increase in utilization. Additionally, the BCRS offers the possibility of expanding appeal for ISS use by the broader international community because it can allow non-ISS partner nations to recover any experiments they might sponsor directly to their home territory. Not only could this help create a more diversified set of experiments for the ISS, contributing to its success as a research facility, but it could also make available the opportunity to expand the number of nations on this planet that take part in the quest for knowledge and better international cooperation through the exploration of space.

I. Introduction

The future of the International Space Station has been at the forefront of space policy discussion since the Augustine Committee released its report recommending that its operations be extended beyond 2015. President Obama's National Space Policy, released in June 2010, has now directed the National Aeronautics and Space Administration (NASA) to continue operation of the International Space Station (ISS) until 2020, and possibly beyond, and to expand utilization of the ISS for scientific, technological, commercial, diplomatic and educational purposes.[1] This drive to increase the ISS's utilization rate will be complicated by the now imminent retirement of the Space Shuttle. A number of alternatives are in development to address the expected cargo up-mass shortfall; the Commercial Orbital Transportation Services (COTS) vehicles and the Japanese and European transfer vehicles are some examples. Very few options, however, have materialized for how to solve the impending deficiency in returning cargo back to Earth.

After the Shuttle retires the only vehicles projected to be available for returning cargo from the Station back to Earth are the Russian Space Agency's (RSA) Soyuz and Space Exploration Technologies' (SpaceX) Dragon capsules. The Soyuz is capable of returning only 60 kg,[2] whereas the Dragon will be capable of approximately 3,000 kg.[3] Of the two, only the Soyuz is currently operational. The Dragon is still in development and is not projected to be in service until 2011. At projected flight rates, only between 6,240 to 9,240 kg of the estimated 16,000 kg annual cargo-return need will be able to be met.[4,5] Nearly one-third of that requirement is internal-use utilization cargo; the category of cargo which includes research experiments. This is significant, because the impetus to increase research utilization will only make this shortfall more pronounced. Figure 1 is a chart from the 2005 ISS Panel Report[6] which shows the estimated annual ISS return cargo requirements versus return capability. The red markings have been added to highlight that a shortfall in return cargo capability is still expected to exist even after the Dragon capsule becomes operational.

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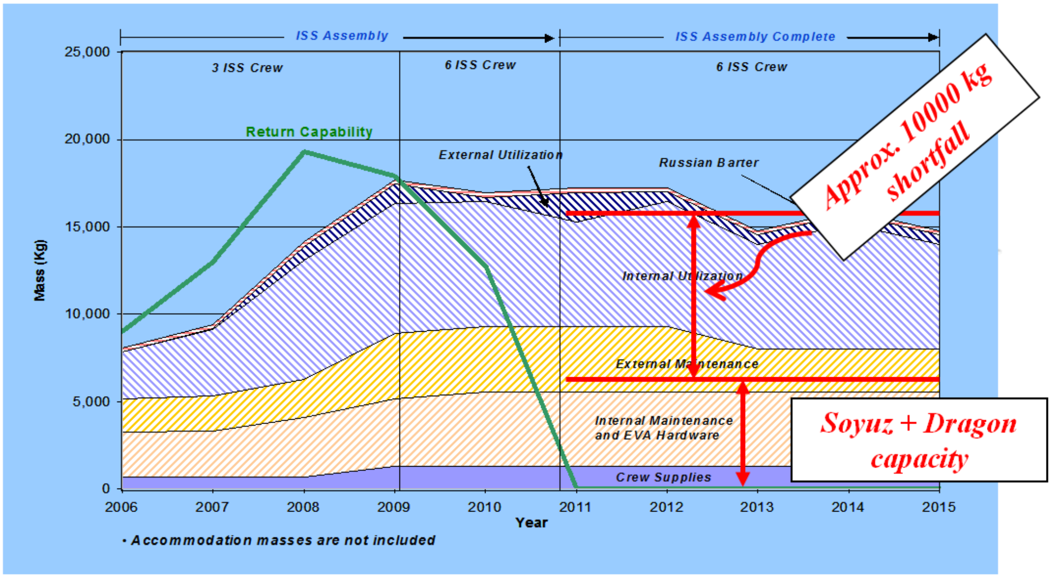

Note: Orig. Chart is pre-COTS

Source: ISS Panel Report, 2005

Figure 1. ISS return cargo requirements vs. projected return capability.

A novel concept which could help address this return cargo deficiency is the Ballute Cargo Recovery System (BCRS). The BCRS is used to recover EXpediting the PRocessing of Experiments to Space Station (EXPRESS) payloads. EXPRESS payloads are standardized modular experiments which are integrated into one of several International Standard Payload Racks (ISPR) on board the ISS (see Figure 2). The ISPR provides the EXPRESS payload with the necessary power, data command and control, video, water cooling, air cooling, vacuum exhaust and nitrogen supply. EXPRESS payloads are an ideal candidate for the BCRS because they are representative of a category of cargo which could have a high turnover rate, depending on the duration of the experiment, and one that would benefit dramatically from a low-cost, flexible method for deorbit. Also, unlike other potential cargo options, the EXPRESS payload is small enough to fit through the Quest Airlock; important because the BCRS is designed to be released for reentry from the outside environment.

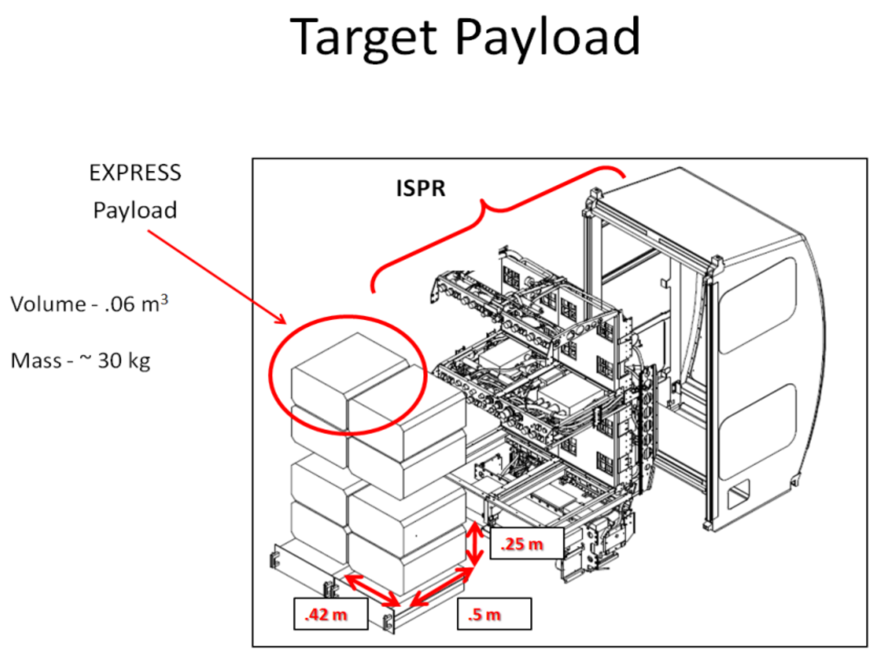

Figure 2. The EXPRESS payload, the target cargo for the BCRS, and its functional position within an ISPR.

Ballutes are inflatable, high drag devices made of thin film materials which are flexible, lightweight and have good thermal protective properties. They are desirable as a reentry device, because they take up relatively little volume when stowed and can be lower in mass than other Thermal Protection Systems (TPS) alternatives. Ballutes rely on their low ballistic coefficient to decelerate spacecraft at higher altitudes where the air density is lower. This results in a lower peak heating profile; low enough that currently available inflatable membrane technology may be sufficient to handle the thermal loads presented by orbital reentry. Additionally, the added surface area serves to distribute the thermal loads of the reentry vehicle, reducing the W/cm^2 heat flux, and to increase radiative heating losses. Finally, the ballute, if sized properly, could serve as a parachute during descent, and as a flotation device for water landings.

Ballutes have been postulated for interplanetary capture and Low-Earth Orbit (LEO) return,[7] but have not yet been used operationally. They have, however, been thoroughly studied and have a long history of use as a decelerator for military munitions. Because ballute technology is a high Technology Readiness Level (TRL) endeavor, it can be an excellent, timely candidate for satisfying some of the near-term cargo return needs created by the Shuttle's impending retirement. This is especially true because the time needed to redesign the Automated Transfer Vehicle (ATV) or H-II Transfer Vehicle (HTV) for a reentry capability might be such that they will not be available to meet the near-term need; which could present itself as early as 2011. Also, as compared to other cargo return alternatives, ballutes offer greater flexibility for when and where experiments can be returned, and can conceivably do so at less cost.

II. System Description

The BCRS has two configurations: stowed (Figure 3) or deployed (Figure 4). In the stowed configuration the BCRS is completely assembled, but the ballute is not inflated. In the deployed configuration the BCRS jettisons the bottom assembly and inflates the ballute. The dimensions depicted are only estimates; more thorough analytical analysis will be required in order to determine the actual size and full component make up.

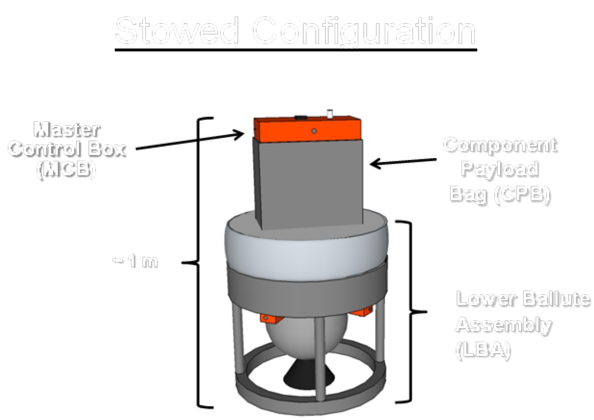

Figure 3. BCRS in stowed configuration.

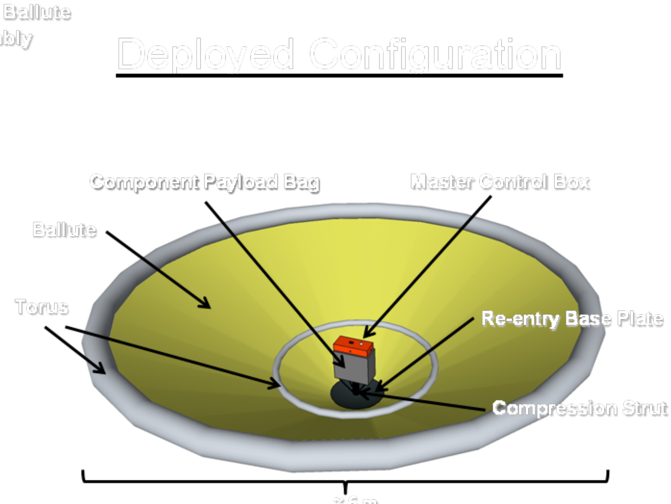

Figure 4. BCRS in deployed configuration.

The BCRS consists of the following components:

Component	Description
Upper Assembly (UA)	
Component Protection Bag (CPB)	A bag made of soft, flexible material similar in construction to the Space Shuttle's Personnel Rescue Enclosure (PRE)[8] in which the EXPRESS payloads are placed. The bag is used to provide protection from space environmental impacts and to keep the payload at the proper pressurization.
Master Control Box (MCB)	Is attached to top of CPB; it provides overall system control, battery power and Attitude Determination and Control System (ADCS) functions. It determines and achieves proper attitude for stabilization spin-up – the vehicle is primarily spin stabilized for reentry until aerodynamic effects take over. The MCB is held securely in place on top of CPB by an assembled interlocking metal frame.
Upper Assembly (UA) Thrusters	Micro-thrusters which are incorporated within the MCB. They provide propulsive force for attitude control and spin-up.
GPS/Iridium Locator Beacon (GLIB)	A GPS device to determine location which is then transmitted via an Iridium transmitter.
Lower Ballute Assembly (LBA)	
Ballute	Composed of Multi-Layer Insulation (MLI) (temperature resistant polymers, metal foils and NEXTEL outer layer). It is stored deflated within the LBA, and is inflated by gas generator prior to atmospheric entry. The inflated interior and outer torus keeps the ballute from collapsing. Additional structural stiffeners are not depicted, but necessary.
Reentry Base Plate	This serves as the foundation to which the UA and LBA are mounted. Made of carbon composite, it serves as not only as a structural base but also as a means to provide thermal protection for areas that exceed the peak heating limit of the ballute material.
Compression Strut* *Derived from a similar design by Andrews Space	This serves as the mount that attaches the CPB to the reentry base plate. It is inflated during the descent by trapping pressure from the ballute's gas generator using a one-way check valve. Upon landing a pressure relief valve ruptures allowing the strut to compress, dampening touchdown shock.
Propulsion Section	Contains a small rocket motor used to perform the minor retrofire necessary to begin vehicle's descent into the atmosphere.
LBA Thrusters	Micro-thrusters which are incorporated within the propulsion section. They provide the propulsive force for attitude control and "spin up."
Associated Components	
Internal BCRS Locker	A storage compartment within the ISS pressurized volume for storage of CPB's.
External BCRS Locker	A storage compartment located externally on a truss for storage of LBA's. Protects LBA's from the space environment. Can store completely assembled BCRS's for later release.

III. Concept of Operations

The Concept of Operations (CONOPS) for the BCRS begins with the removal of the EXPRESS payload from an ISPR. The experiment is then placed in a CPB and pressurized to the required pressure. Next the CPB is removed from the ISS by way of Extra-Vehicular Activity (EVA). Once outside the station, the EVA crewman then assembles the BCRS. Assembly consists of attaching the CPB to the MCB and the LBA (Figure 5). LBA's are stored in the external BCRS Locker located on the ISS truss. The MCB is held securely in place by an assembled, interlocking metal frame which provides the necessary rigidity for the UA. The completed assembly can then be immediately deorbited, or can be attached to a holding place in the BCRS Locker for release at a later time. Timing of the release is dictated by the desired geographic landing point.

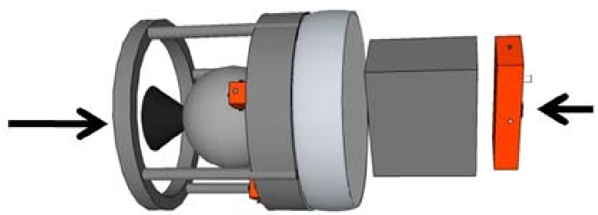

Figure 5. A BCRS being assembled.

The Special Purpose Dexterous Manipulator (SPDM) is used to position the BCRS at the maximum distance below the ISS for launch (Figure 6). Next, the BCRS spins up for stabilization and uses its rocket motor to make a small deorbit retrofire (Figure 7).

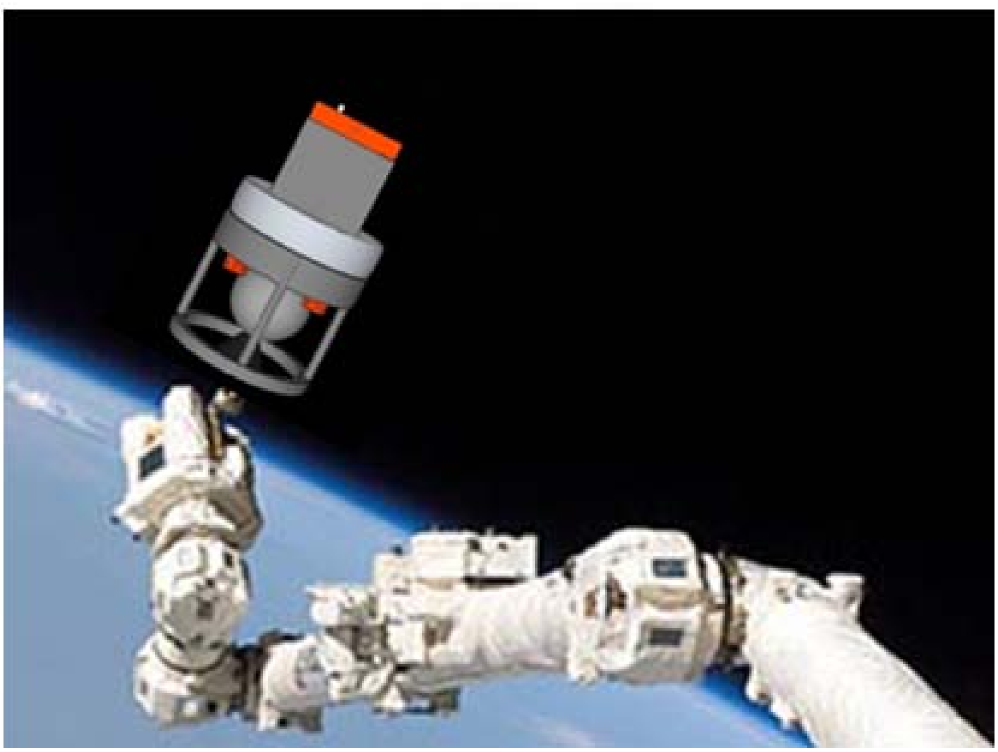

Figure 6. The SPDM releasing a BCRS.

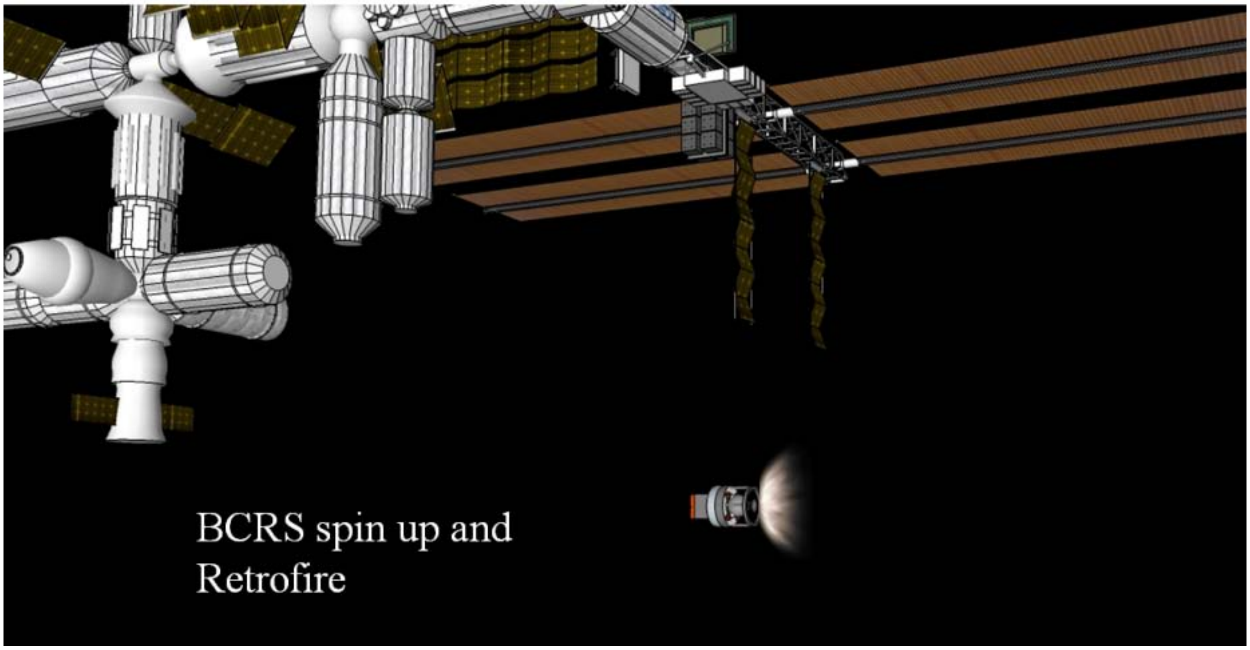

Figure 7. A BCRS departing the ISS.

After the retrofire is completed the LBA assembly is jettisoned and the ballute is deployed (Figure 8). The BCRS remains primarily spin stabilized until aerodynamic forces become prevalent, where it then uses its inherent neutral dynamic stability to remain in proper attitude.

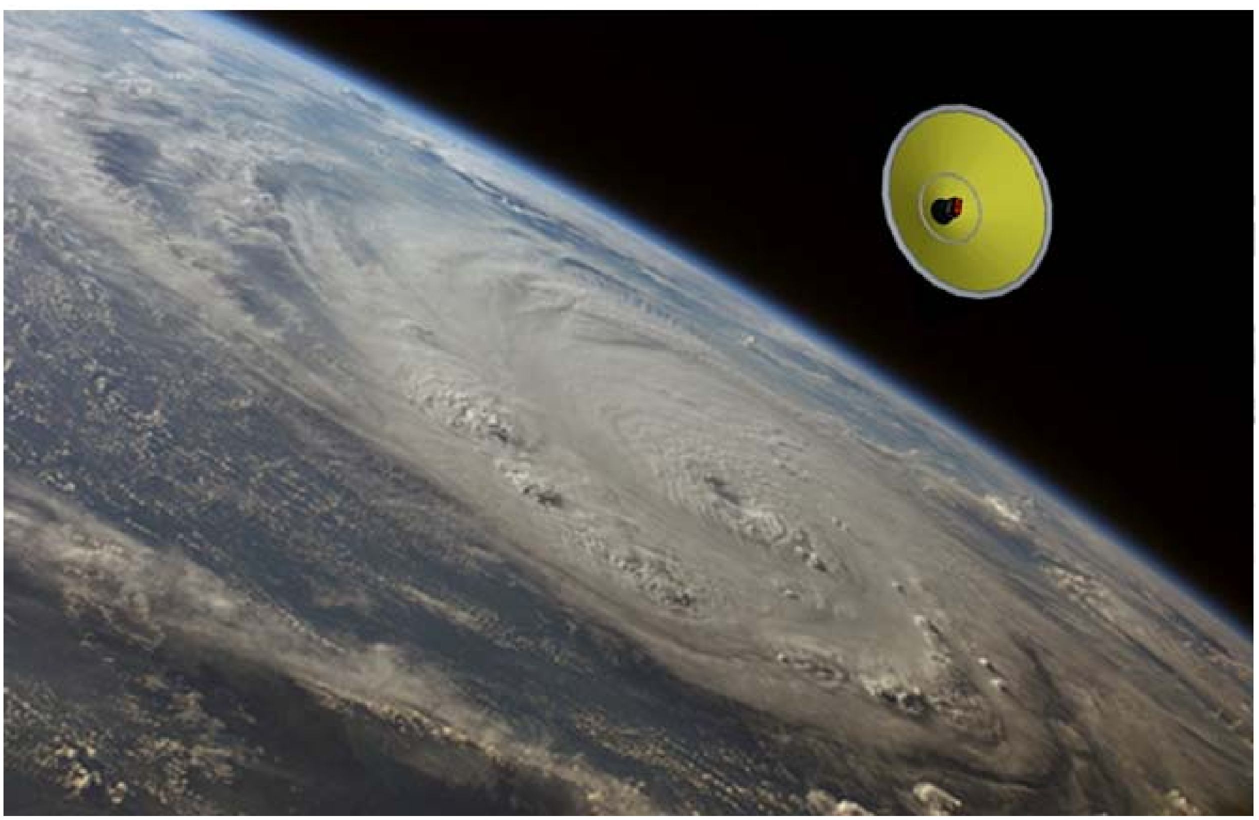

Figure 8. A BCRS reentering the atmosphere.

Once safely inside the atmosphere the BCRS flight path naturally becomes a vertical decent, using its low ballistic coefficient to keep its terminal velocity slow enough to land without a parachute. If the reentry takes the BCRS to a water landing the ballute will also serve as floatation device. The GPS/Iridium Locator Beacon (GILB) then alerts recovery crews to the vehicle's location. Because the BCRS can land anywhere and does not require sophisticated methods for geo-locating it can be recovered by virtually anyone. Figure 9 highlights this attribute by showing how the BCRS can land on water, to be recovered by a local fishing vessel, or set down on land, where the CPB has been removed from the ballute and recovered from a jungle by way of elephant.

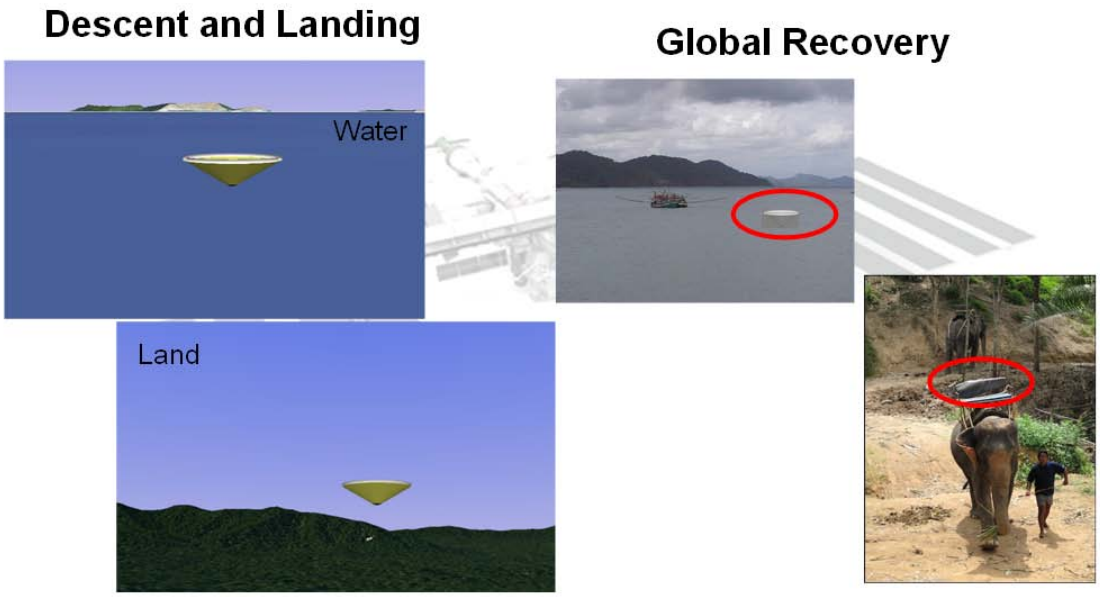

Figure 9. Landing and recovery options for the BCRS.

Since BCRS's are meant to be a low-cost alternative for cargo return, they are not equipped with sophisticated methods for achieving highly precise touchdown accuracy; therefore, touchdown locations can only be approximated. BCRS touchdown location is highly sensitive to trajectory errors due to timing of release, changes in the ballute's shape from high aerodynamic pressures and the affect of high winds aloft during its atmospheric descent. Although the touchdown velocity of the BCRS is projected to be low, it is imperative that they be targeted for touchdown in a remote, cleared area where there is low probability of damage to people or structures from impact.

BCRS's are continually resupplied to the station by Earth-to-Orbit Transfer Vehicles (EOTV), such as the HTV, Dragon, etc (Figure 10). The CPB's are transported in the pressurized cargo section of the transfer vehicles, because they are meant to be stored inside the Station. The LBA's are shipped in the unpressurized section and, correspondingly, are stored externally in a locker on the truss.

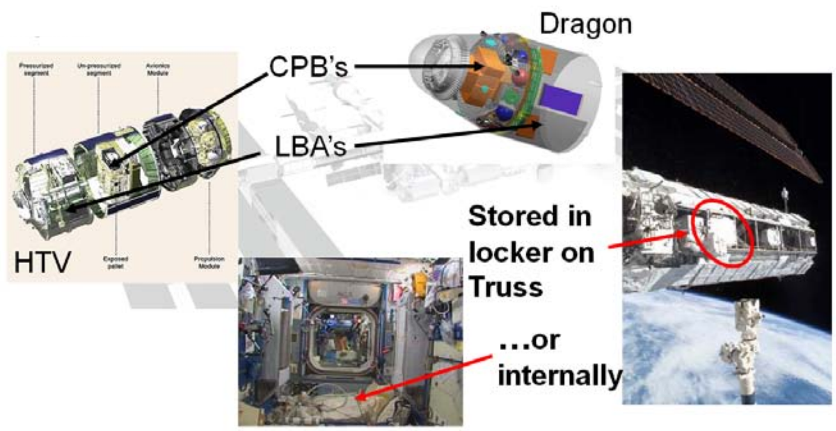

Figure 10. Examples of resupply options for the BCRS.

IV. Future Enhancements

Future increases in capability can be realized by scaling the BCRS up in size. Then, possibly, BCRS's could be used to deorbit larger cargo like an entire ISPR; however, the size of the Quest airlock will continue to be a limiting factor. Eventually the ballutes could be increased in size so as to provide an alternative to a traditional TPS for an ATV, HTV, etc. Another area for future effort is the improvement of touchdown accuracy by allowing for active guidance control, or by enhancing the fidelity of reentry trajectory modeling to better determine orbital release points.

V. Benefits

The BCRS offers many benefits:

1) The ability to frequently change out short-duration experiments; thus allowing for increased ISS research utilization.

2) Flexibility for when experiments can be deorbited. Experiments can be deorbited immediately after completion, or can be stored externally for return at a later date. Also, experiments can be returned to any geographic location within the ISS's ground track, allowing for targeted touchdown directly to an experimenter's home nation.

3) It provides a timely solution for addressing some of the down-mass requirement deficiencies. Because BCRS's represent a relatively low technological risk (a high TRL), they can be commissioned quickly; much sooner than redesigning the Automated Transfer Vehicle (ATV) or H-II Transfer Vehicle (HTV) with a reentry capability.

4) Alleviation of concerns about storage space for completed experiments, because, again, it allows for immediate deorbit, or the possibility of storage external to the ISS pressurized volume.

5) Reduction of cargo-return demand for those reentry capable Transfer Vehicles

VI. Broad International Collaboration for ISS

In addition to the other benefits, the BCRS also offers the unique possibility of expanding the appeal of ISS participation to the broader international community, helping to expand the ISS's mission of facilitating greater world cooperation. There are 63 countries with national space agencies,[9] only thirteen of which are ISS partners. This means there is tremendous growth opportunity for international participation in the Station. The BCRS will give non-ISS partner nations the capability to recover any experiments they might sponsor directly to their home territory. Now countries, which might not otherwise be inclined, will be able to experience the national pride that comes with being an ISS partner; manifested visually for their citizens to see through the recovery, by themselves, of their own space experiments. This will also allow them to, perhaps, realize some of the benefits that an active space program can have on the well-being of a nation's scientific, technological and

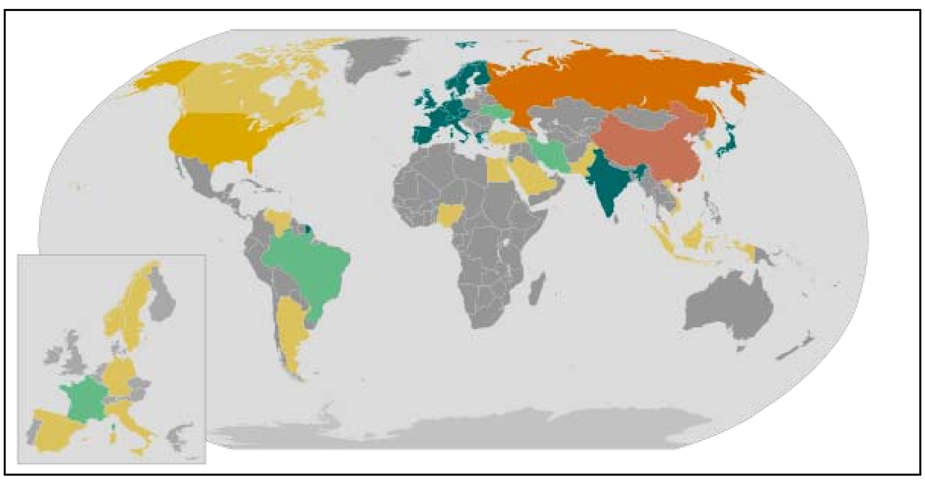

Figure 11. Countries with national space programs

educational progress. Not only could this help to create a more diversified set of experiments for the ISS, thereby contributing to its success as a research facility, but it could also make available the opportunity to expand the number of nations on this planet who take part in the quest for knowledge and international cooperation through the exploration of space.

VII. Conclusion

The BCRS can be very important to the future of space research, because it could help the ISS to achieve its full potential. The ISS is truly a world treasure, and was recognized accordingly by the Congress of the United States in the 2005 NASA Authorization Bill which gave it status as the first National Laboratory beyond Earth.[10] It has demonstrated so many benefits, many of which go beyond just scientific research or engineering. Perhaps one of the most valuable contributions of the ISS is its impact on cooperation among world partners. It is reinforcing working relationships and shown the ability for diverse nations to come together for a single, and challenging, purpose. It has also served as an outlet for the U.S. to demonstrate its leadership in an immensely important and peaceful manner. Now, after 25 years in the making, the ISS is nearing completion of construction, marking the beginning of its next phase of operations: full research utilization. This represents an extremely fruitful and fleeting opportunity to unlock all that space research has to offer. In addition to the many advances in science which can be beneficial for life here are on Earth, the ISS remains the best hope for preparing for a future of space exploration beyond Low Earth Orbit (LEO). In light of the sacrifices in terms of wealth and effort amongst the ISS partner nations, it is difficult to see resolve for building a replacement for the ISS. This means that any efforts to maximize the use of today's space station, such the BCRS, must be welcomed, because there may not be another chance to realize opportunities lost.

Acknowledgements

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