National Space Society

Position Paper:

Next Generation Space Stations

April, 2015

Summary

Since November of 2000, people have continuously lived and worked in space on the International Space Station (ISS), and have made significant contributions to improving life on Earth and to enabling future spaceflight activities. However, the ISS is scheduled for destruction in either 2020 or 2024, although there is reason to believe it can last until at least 2028. If that time comes with no replacement, America's and humanity's hard-won foothold in Low Earth Orbit (LEO) will be lost. The National Space Society (NSS) urges that our only continuous habitat in space be expanded and extended, not abandoned. **We propose a program structured much like the successful Commercial Orbital Transportation Services (COTS) and Commercial Crew (CCDev) programs where NASA helps develop multiple, privately owned, commercially operated space stations and then becomes an anchor tenant.**[1]

Current international ISS partners and potential future partners would be invited to join the effort based on a new ISS partnership agreement to be negotiated by NASA[2], thus ensuring the continued international flavor of humanity's LEO outposts. The parts of the existing ISS that currently serve as a U.S. national laboratory would be augmented and eventually replaced by a distributed national facility consisting of leased portions of a number of stations, each optimized for a particular type of research or other activity. The distribution of non-U.S. activities across the various stations would be negotiated by NASA with all parties involved, including international and commercial partners. **Additionally, NSS urges that NASA continue the existing cargo and crew transportation arrangements or something similar for both up and down access to the new stations.** Finally, the U.S. should permit international companies, if they are so inclined and are located in countries that are part of the new partnership agreement, to participate in the development and ownership of the commercial stations that are used by the U.S. Government

Motivation

Without adequate planning, the end of the ISS program will result in the loss of a host of valuable capabilities and activities that promote commerce, science, space operations, and space settlement. These include human-tended materials research, biological research, physics research, robotics, satellite launch, Earth-observation, and astronomy, all conducted by commercial firms, academic institutions and governments from around the world.[3] We will also lose the only space hotel that has ever hosted a paying guest and a valuable example of extensive peaceful international cooperation.

NSS believes that it is in the national interest of the United States for the federal government to take an active role in assuring the continuity of these evolving capabilities. Although the technology base now exists for private companies to develop and operate space stations, we believe that federal support will help assure an appropriate U.S. role in human-operated orbiting facilities. Even the prospect of a significant gap in access to the ISS National Laboratory (which Congress defined in 2005 as the U.S. segment of the ISS)[4] creates a chilling effect on all commercial and scientific efforts targeted toward the exploitation of the microgravity environment on the ISS. An actual gap of years may result in an entire generation of entrepreneurs and scientists moving away from continuing to build on the progress already made on the ISS. Finally, a significant gap will bring to an end the Commercial Resupply Services (CRS) program, which has generated an explosion of technical innovation in terms of reusable resupply of LEO space stations.[5]

Proposal

For these reasons, NSS advocates that capabilities should be migrated off the ISS in a logical and orderly fashion, and that the ISS should not be fully retired until replacements are in orbit and operating, and then only when safety and cost-effectiveness considerations make further operation unwise. Extension of the ISS lifetime beyond 2024 should be strongly considered. Also, when decommissioning time comes, it may be best to recycle the materials and/or reuse equipment in-orbit rather than dump them in the ocean. The possible re-use of ISS parts and experimental equipment in new LEO space stations needs to become part of NASA's planning for the eventual decommissioning of the space station.

However, NSS does not suggest that the ISS be replaced by a single, large, government owned and operated facility. We propose steps leading to a robust in-space commercial economy that can provide space station services to NASA, commercial entities, and international partners. Specifically, we propose that the ISS replacement be modeled on the COTS and CCDev programs, with the goal of a public-private, "commercial" development partnership and private operation of multiple space stations for a variety of purposes. NASA could do this by providing partial development funding to multiple companies and becoming an anchor tenant for the successful competitors. Other customers may include other national governments, international space organizations such as ESA (European Space Agency), commercial firms, non-profits, and private parties. International participants may also purchase shares of the various commercial space stations, although this is not required and would be accomplished via standard business contracts.

The successful COTS program[6] provided competitively awarded development funds to Orbital Sciences and SpaceX to develop launch vehicles and cargo carriers capable of supplying the ISS. NASA then provided contracts for that resupply through the Commercial Resupply Services (CRS) program.

This approach has also led to ancillary benefits. One of the competitors, SpaceX, has leveraged COTS and CRS, along with support from other customers, to capture about 20% of the international commercial satellite launch market in 2014[7], and is attempting to revolutionize access to space with re-usable launch vehicles.[8]

The CCDev program is applying a similar approach to taking crew members to and from the ISS. This program is currently ongoing and shows every sign of repeating the success of COTS with two companies, Boeing and SpaceX, receiving final development contracts. Although the final verdict isn't yet in on the pros and cons of the COTS and CCDev procurement approaches, NSS believes these kinds of public-private partnerships, properly crafted, can be a sound way to bringing more efficient practices to space procurements.

NSS recommends that at all appropriate points in this process, full commercial and international government participation be encouraged from such partners as may choose to join in this enterprise under a new space station agreement negotiated by NASA.[9]

This not only creates competition, but makes sense from an application point of view because different endeavors have conflicting requirements. For example, biologists need centrifuges or rotating tether-based stations[10] for studies comparing micro-gravity with variable-g or 1-g provided by rotation. Studies comparing lunar and Martian gravity effects on humans require similar but much larger facilities. However, centrifuges cause vibration that degrades the micro-gravity environment required by materials scientists, and rotating tether-based solutions may have difficulty in providing the environment necessary for micro-g materials research. Thus, it would be advantageous to have separate stations for variable gravity research and microgravity research. There are similar issues regarding space operations facilities such as propellant depots and repair facilities. Therefore, we suggest there should be separate stations for at least:

- Variable gravity research, including life support development targeted toward the Moon and Mars, and the effects of lunar and Martian gravity levels on plants and animals.

- Microgravity research, including materials and biological research, with large-scale manufacturing spun off to additional commercial stations as research is productized.

- Space operations (fuel depots, cargo/crew transfer, lunar transit, and repair/refurbishment facilities), perhaps in high orbit.

A significant advantage of having multiple space stations is that each station can have an orbit optimal for its purpose. The ISS is located such that it can be reached by Russian, American, Japanese, and European supply rockets, but it is sub-optimal from the viewpoint of an American launch. However, this orbit makes the ISS a relatively good Earth observation platform. The actual orbit(s) chosen would also be a function of the new international partnership arrangement that is negotiated.

For the initial program it is probably sensible for NASA to help two or three companies to develop one station each, but follow-on activities can be used to support extension to additional stations. Of course, private companies may choose to build stations for their own purposes with or without NASA support, but the public-private cooperative program we propose is much more likely to lead to U.S. leadership, even if non-U.S. companies are involved.

In addition to supplying development and utilization funds, NASA and international partners should support the development of a robust in-space economy with:

- Well-defined standardized mechanical, electrical, optical, software, and other interfaces to enable interoperability of products from different companies. Key standardized technologies include docking/berthing ports, docking control systems, and related interconnection systems. Standards development should be in collaboration with industry and professional societies.

- Testing and analysis facilities, including bringing modules and equipment to the ISS to conduct tests in orbit.

- Research into important technologies such as life support and space robotics.

- Development of new space operations capabilities such as refurbishment, repair, and refueling spacecraft (e. g. fuel depots).

- Development of application hardware such as furnaces, ovens, glove boxes, rodent habitats, centrifuges, etc.

- Development of software of general interest to space station and applications development.

While a careful cost analysis is needed, there are a number of factors that suggest replacing the ISS with a small fleet of commercially operated stations could cost a great deal less to develop and launch than the ISS did.

- The new stations will be able to take full advantage of the engineering knowledge gained during the construction and operation of the ISS. ISS costs included a significant number of development efforts that will not need to be repeated, which include assembly nodes, docking ports, airlocks, external robotic handling equipment, and infrastructure outfitting internal to the modules such as toilets, accommodations, etc.
- There is good reason to believe that it will be possible to launch components of these new stations for significantly less[11] than was the case when the Space Shuttle[12] [13] was used.
- Bigelow Aerospace is currently developing a line of expandable space station modules [14] [15] [16] that are claimed to be less expensive to purchase and assemble in-orbit than the technology used for fixed geometry modules in ISS construction.[17]
- Applying the lessons learned in the construction of the ISS should result in designs that require fewer spacewalks for assembly and on-going maintenance.
- COTS-type programs have been shown to significantly reduce development costs over conventional government procurement (contracting and development) methods.[18]
- The new stations may not seek to replicate all ISS facilities.
- Some existing facilities might be moved in-orbit from the ISS and added to the new stations.
- Costs may be offset by ease of reaching new orbital locations (depending on where they are) compared to the cost of reaching the current ISS orbit.

Of course there is clearly some duplication of equipment that will be needed to maintain multiple stations which may result in higher costs than if a single follow-on facility were created. However, since this duplicated equipment is potentially replicated across multiple stations, the cost of the duplicated equipment for each additional station may be less than the costs associated with the first one.

The efficiency and maintainability of the air and water recycling machinery are major determinants of the on-going expense of lifting water, oxygen, and spare parts to the space station. **For these reasons, NSS recommends that NASA develop and test, as the initial phase of a transition to commercial stations, a new generation of high-efficiency Environmental Control and Life Support Systems (ECLSS) in modules to be attached to the current ISS for testing.** The new ECLSS modules should be sourced competitively from multiple providers with at least two winners. Such modules would support a number of current and potential goals in space:

- Lowering the cost of operating both the ISS and future commercial space stations.
- Potentially expanding the ECLSS capacity of the ISS or allowing for a greater degree of redundancy/reliability.
- Proving, via long-term microgravity testing, ECLSS technologies that might be used on future voyages to Mars, cis-lunar space stations, lunar surface bases, and Mars surface bases.
- Creating a proven set of ECLSS hardware that could be replicated or even re-used in future commercial space stations, thus supporting a post-ISS transition.

Although the optimum architecture for future commercial space stations should be left to a COTS-like competitive process, one idea that might be considered is that the ECLSS modules (or duplicates thereof) might form the core of new commercial space stations. For those competitors who decide to follow the Russian MIR space station architecture[19], where each module provides a variety of services, such modules will also need to provide capabilities similar to those of the core module of the ISS (Zvezda)[20]. These capabilities include, in addition to ECLSS:

- Reboost
- Solar power panels and battery storage
- Habitation space
- Docking adaptor
- Control and communications systems
- Thermal rejection/management

Access to LEO

Regular access to LEO, both to bring new experiments and materials to the ISS or future space stations, and to return experimental outputs and products to the Earth, is essential to both the scientific and commercial utilization of LEO. Since the retirement of the Space Shuttle, it is only with the advent of the Commercial Resupply Services (CRS) program that regular access to and from the ISS on U.S. vehicles is possible, and that is essential for full utilization of the ISS National Laboratory. Hence, when we look toward a post-ISS transition to a number of commercial stations, continued NASA support for routine access to LEO via CRS is a fundamental requirement. The recent announcement that in addition to the two incumbents SpaceX and Orbital Sciences, Boeing, Sierra Nevada, and Lockheed Martin say they will bid on CRS-2[21,22]. This is welcome news, as an increased number of independent suppliers of cargo services will increase overall competitiveness and reliability, and allow maximum utilization of the ISS. Part of NASA's anchor tenant contracts on commercial stations should include both regular up and down access to the station for NASA personnel and experiments/experimental results based on extension of the existing CRS contracts.

Benefits to National Prestige and Foreign Policy

The United States has enjoyed a long period during which its position in managing the ISS and the lack of any rival LEO space stations has enabled a considerable extension of "soft power" on behalf of the United States. Both Russia[23,24] and China[25] have said they will build stations of their own in the relatively near future. It seems self-evident that the USA will suffer a considerable blow in terms of prestige when the Russians and Chinese can offer stays on their LEO space stations to other nations while the U.S. offers nothing, or perhaps only a supporting role in a long term Mars program. The U.S. would be ceding all benefits from leading crewed LEO research and economic development to Russia and China, as well as providing an impetus for current ISS partners to work with China and Russian in LEO.

Benefits to Moon, Mars, and Free-Space Settlement

In addition to furthering human space activities in Earth orbit, the program proposed by NSS could bring us significantly closer to settling the solar system: in free-space, on the Moon and/or on Mars. For the Moon and Mars, developing adequate life support (particularly plant growth since permanent settlement requires in situ food production) requires experimentation at the relevant g-level, which can be provided by the proposed stations within a few hundred kilometers of Earth. In addition, new stations that acted as transportation hubs, repair centers, and fuel depots would facilitate a large number of Beyond Earth Orbit endeavors as well as enhancing operations in Earth orbit.

Conclusion

In conclusion, NSS proposes the creation and operation of a number of next-generation human space facilities based on public-private partnerships such as those demonstrated in the very successful COTS and CCDev programs. NASA would then become an anchor tenant for the successful competitors along with international partners operating under a new space station agreement. Available space on the new commercial space stations could then be rented, leased or purchased by companies, research institutions, non-profits, and even individuals. Such a program could be considerably less expensive than current activities and lead to the expansion of the economy, civilization, humanity and life itself into space.

Footnotes and References

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[1] Items in **bold** text indicate the primary NSS recommendations in the position paper.

[2] There is no implication that this partner list would be exactly the same as the current ISS partner list. New countries such as India or even China might join. Russia might drop out of the agreement.

[3] "International Space Station | NASA." http://www.nasa.gov/mission_pages/station. Accessed 3/7/15.

[4] "What is the ISS National Lab? | NASA." http://www.nasa.gov/content/what-is-the-iss-national-lab/. Accessed 3/30/15.

[5] Foust, Jeff. "For commercial cargo, ideas old and new." The Space Review, March 23, 2015. http://www.thespacereview.com/article/2717/1.

[6] "Commercial Cargo: NASA's Management of Commercial Orbital Transportation Services and ISS Commercial Resupply Contracts," Audit Report, Office of Inspector General, NASA, Report IG-13-016, June 13, 2013.

[7] "Commercial Space Transportation 2013 Year in Review," Federal Aviation Administration, Fig. 3 and Table 1. For example, in 2013, SpaceX captured 13% of the global commercial launch business. According to a SpaceX representative, the 2014 percentage is 20% of the global commercial satellite launch market.

[8] Wikipedia, "SpaceX reusable launch system development program." http://en.wikipedia.org/wiki/SpaceX_reusable_launch_system_development_program. Accessed 3/7/15.

[9] The international partners in this new enterprise may or may not be the same as those currently participating in the current ISS agreement.

[10] Personal communication, Joe Carroll. Different g-levels can be generated by long, tether-based, rotating space stations such as those proposed by Joe Carroll. These systems appear to be excellent platforms for variable-g research.

[11] SpaceX, "Capabilities & Services." http://www.spacex.com/about/capabilities. Accessed 12/21/14. We note here that the $/lb to LEO for the Falcon 9 is $2,110, and for the proposed Falcon Heavy $727, with both figures not including payload integration services which often adds 10% or more to the base price.

[12] Hsu, Jeremy. "Total Cost of NASA's Space Shuttle Program: Nearly $200 Billion," April 11, 2011. http://www.space.com/11358-nasa-space-shuttle-program-cost-30-years.html. According to this source, the total cost of the Space Shuttle per flight was $1.6 Billion. Based on a payload of up to 50,000 lbs to LEO, which is the relevant metric for comparing space station construction, this would result in a cost per lb to LEO for the Space Shuttle of $50,000.

[13] "Current and Near-Future Space Launch Vehicles for Manned Trans-Planetary Space Exploration: Phobos-Deimos mission architecture case study." http://www.uh.edu/sicsa/library/media/publications/AIAA_2013. Accessed 3/10/15. This 2013 paper surveys modern launch vehicles and reviews the costs involved in the context of selecting a vehicle for a future Phobos/Deimos mission. Figure 7 compares past and future launch vehicles, including the Space Shuttle. It is readily apparent from Figure 7 that the Falcon 9 provides a significantly lower cost

to LEO that the Space Shuttle or other competing systems. Further, the analysis suggests that next generation vehicles such as the Falcon Heavy will provide a still lower cost to LEO, but for significantly larger payloads.

[14] http://www.bigelowaerospace.com/

[15] Higginbotham, Adam. "Robert Bigelow Plans a Real Estate Empire in Space," May 2, 2013. http://www.bloomberg.com/bw/articles/2013-05-02/robert-bigelow-plans-a-real-estate-empire-in-space. Accessed 3/7/15.

[16] Howell, Elizabeth. "Bigelow Aerospace: Inflatable Modules for ISS," January 17, 2013. http://www.space.com/19311-bigelow-aerospace.html. Accessed 3/7/15.

[17] Bigelow Aerospace has published prices for their service: a minimum of $26.25 million per seat to fly astronauts to the station; in addition, there is a charge of $25 million for 60 days exclusive use of 110 cubic meters of the station (1/3 of a module) [http://bigelowaerospace.com/about/opportunities-pricing-services/. Accessed 4/5/15]. Compare this to about $70 million to the ISS using Russian vehicles starting in 2017 [Wall, Mike. "NASA to Pay $70 Million a Seat to Fly Astronauts on Russian Spacecraft," April 30, 2013. http://www.space.com/20897-nasa-russia-astronaut-launches-2017.html. Accessed 3/7/15].

[18] "Commercial Cargo: NASA's Management of Commercial Orbital Transportation Services and ISS Commercial Resupply Contracts," Audit Report, Office of Inspector General, NASA, Report IG-13-016, June 13, 2013.

[19] The ISS was started with the Mir II core section which provided a wide variety of services. It was only later that specialized non-Russian modules were added.

[20] Wikipedia, "Zvezda (ISS module)." http://en.wikipedia.org/wiki/Zvezda_%28ISS_module%29. Accessed 3/23/15.

[21] Klotz, Irene. "ISS Cargo Shippers Face Competition from Space Taxis." http://spacenews.com/40903iss-cargo-shippers-face-competition-from-space-taxis/. Accessed 3/7/15.

[22] Foust, Jeff. "For commercial cargo, ideas old and new." The Space Review, March 23, 2015. http://www.thespacereview.com/article/2717/1. Accessed 3/23/15.

[23] "Uninternational Space Station." http://www.russianspaceweb.com/vshos.html. Accessed 3/7/15.

[24] Klotz, Irene. "Russia Will Spin-Off ISS Parts for New Space Station." http://news.discovery.com/space/russia-will-detach-iss-parts-for-new-space-station-150226.htm. Accessed 3/7/15.

[25] "Countdown to China's new space programs begins." http://news.xinhuanet.com/english/china/2014-12/07/c_133838367.htm. Accessed 3/7/15.

About the National Space Society (NSS): NSS is an independent non-profit educational membership organization dedicated to the creation of a spacefaring civilization. NSS is widely acknowledged as the preeminent citizen's voice on space, with over 50 chapters in the United States and around the world. The Society publishes *Ad Astra* magazine, an award-winning periodical chronicling the most important developments in space. To learn more, visit www.nss.org.