THE TRANSITION FROM ISS TO DEEP SPACE EXPLORATION

Michael Raftery
Boeing Defense, Space, & Security, Houston, TX, United States, michael.l.raftery@boeing.com

Kirk Shireman
NASA Johnson Space Center, Houston, TX, United States, kirk.a.shireman@nasa.gov

The assembly of the International Space Station (ISS) was an unprecedented exercise in political cooperation and programmatic discipline. Over the course of a decade, fifteen nations worked together to build a spacecraft that has shattered every significant record for size and capability. While the scale of this project was unprecedented for its time, future missions to the moon, asteroids, or Mars are likely to be similar in scope. Careful management of the transition from ISS to deep space exploration is needed to ensure that the hard won experience gained from ISS is used to win a similar success for exploration.

We will review the history of the ISS assembly missions with an emphasis on lessons applicable to deep space exploration. The Global Exploration Roadmap will be used to illustrate how these lessons can be applied in the new program. A summary of key next steps will be provided so that actions can be taken while ISS is still operational.

I. ISS - A RECORD OF ACHIEVMENT

The International Space Station design and assembly is an epic story of cooperation and commitment. In the early days of its development, many were skeptical whether such an ambitious project could be accomplished. With the benefit of hindsight, we now know that it can, and we also know that the tools that were used to make ISS successful can be applied to future space program objectives. In summary, some of these tools were:

- An international partnership with solid political support ratified in writing at senior levels of the government (a treaty was used to document ISS commitments[1]). This partnership resulted in a long-term commitment to the objective that was strong enough to weather the various political and technical storms that inevitably happen on a program of this magnitude.
- A small, but talented multi-national program office that enforced discipline, programmatic rigor and attention to detail.
- Adequate funding to accomplish the objective. While ISS was not immune to cost growth, performance was relatively stable after the new program office was formed in 1993.
- Agreements on hardware / software interface and construction standards. Agreements on international operations plans, protocols, and procedures.
- Strong coordinated support from associated transportation programs such as Shuttle, Soyuz, Arianne, and H2B which made assembly possible.

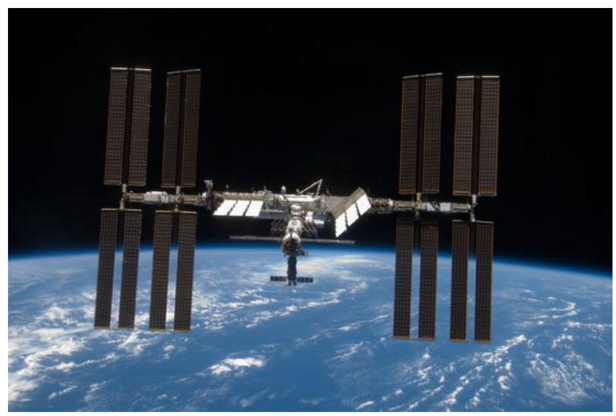


Figure 1 The ISS at Assembly Complete

The recently published update to the Global Exploration Roadmap (GER) has a clear emphasis on the use of ISS to support future exploration missions[2]. The ultimate objective identified in the GER is a human mission to Mars. At a superficial level, ISS can be used as a testbed for technology and a site where experience for human presence in space can be extended. At a much deeper level, however, ISS provides a framework and a template for how the exploration mission should be organized and controlled. While perhaps not as sexy as a focus on technology and space science, these issues of management and organization have far more impact on the probability of program success and thus are worthy of considerable attention. The authors of the GER understand this and the document confirms it.

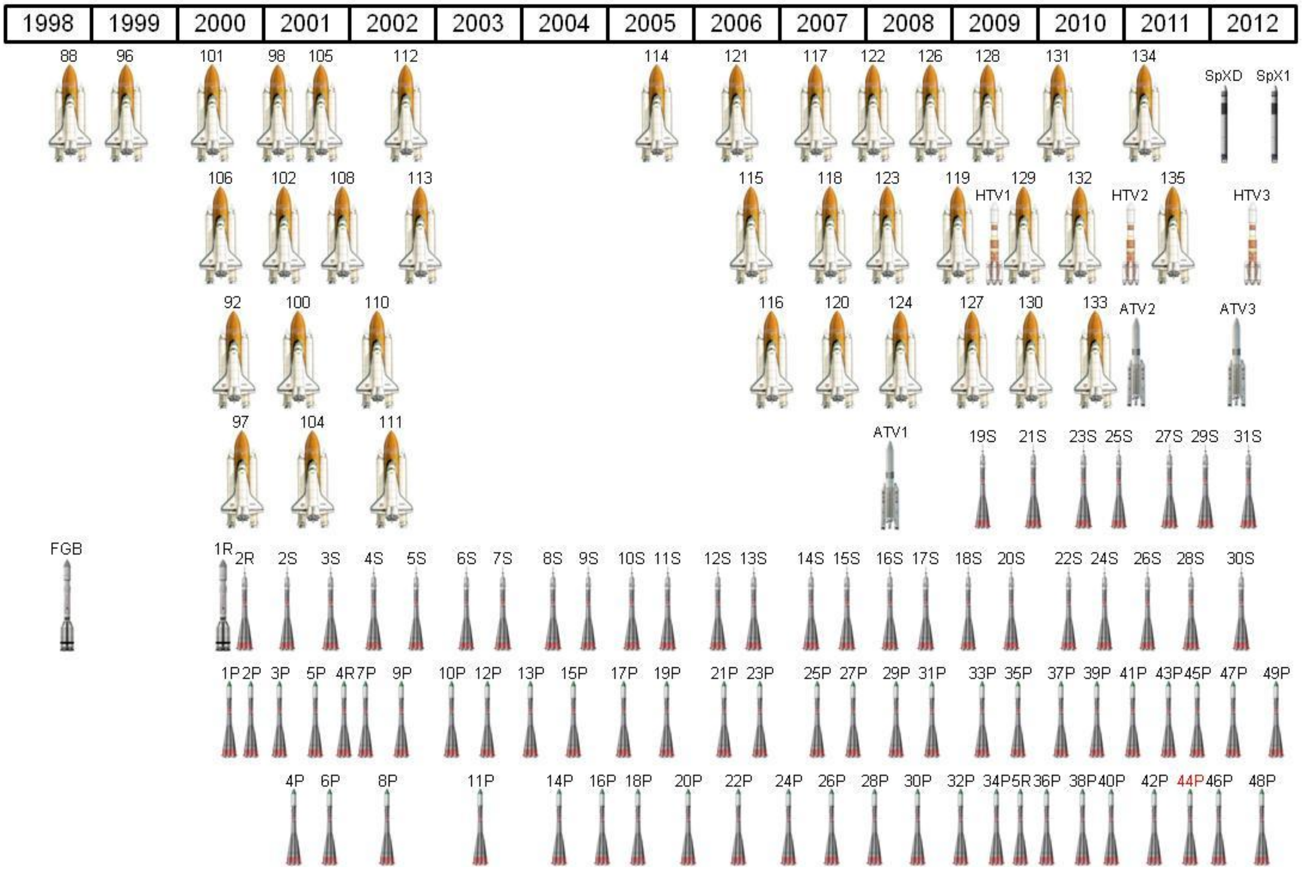


Figure 2 Assembly and operations of the ISS has been a demonstration of substantial international commitment

As figure 2 makes clear, a considerable number of launches have been required to build and operate ISS. This graphic is used to help the reader get a sense for the scale of the program, ultimately so that the scale can be compared to what will be required for a Mars mission. Figure 3 translates the launches into a common metric called "Injected Mass to Low Earth Orbit (IMLEO)." This metric is relevant because it is standard practice for Mars mission planners to use IMLEO to judge the scale, or size of their approach.

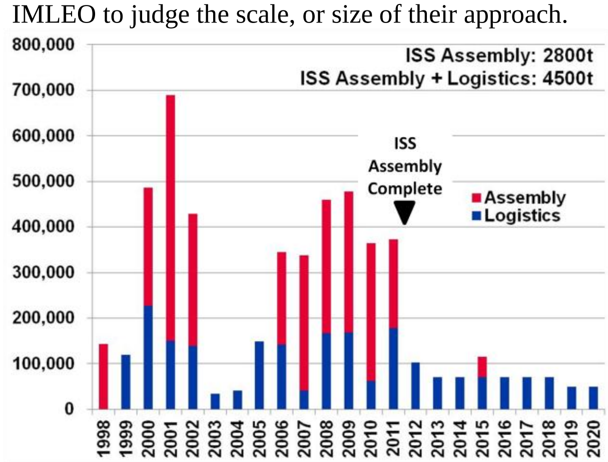


Figure 3 Injected Mass to Low Earth Orbit (IMLEO)

While the space community has been describing a human Mars mission as "really hard," this same space community has already accomplished something that was equally hard: the construction of ISS. It is also important to remember that ISS construction did NOT require an "Apollo-like" surge in funding. When one remembers that the mass of the Orbiter must be included, construction of ISS as an enterprise is somewhere between 3 to 5 times LARGER than a human mission to Mars. When the necessary precursor activities are taken into account, it is certainly on the same basic scale.

The other effect that is clear from figure 3 is the dramatic reduction in IMLEO after ISS assembly complete. Ongoing operations and logistics require far less launch mass, and with continued efforts to commercialize and streamline these operations, cost efficiencies will follow as well.

II. THE GLOBAL EXPLORATION ROADMAP

An update to the Global Exploration Roadmap (GER) has been released which documents the potential for future international collaboration on space exploration objectives[2]. This update contains substantial

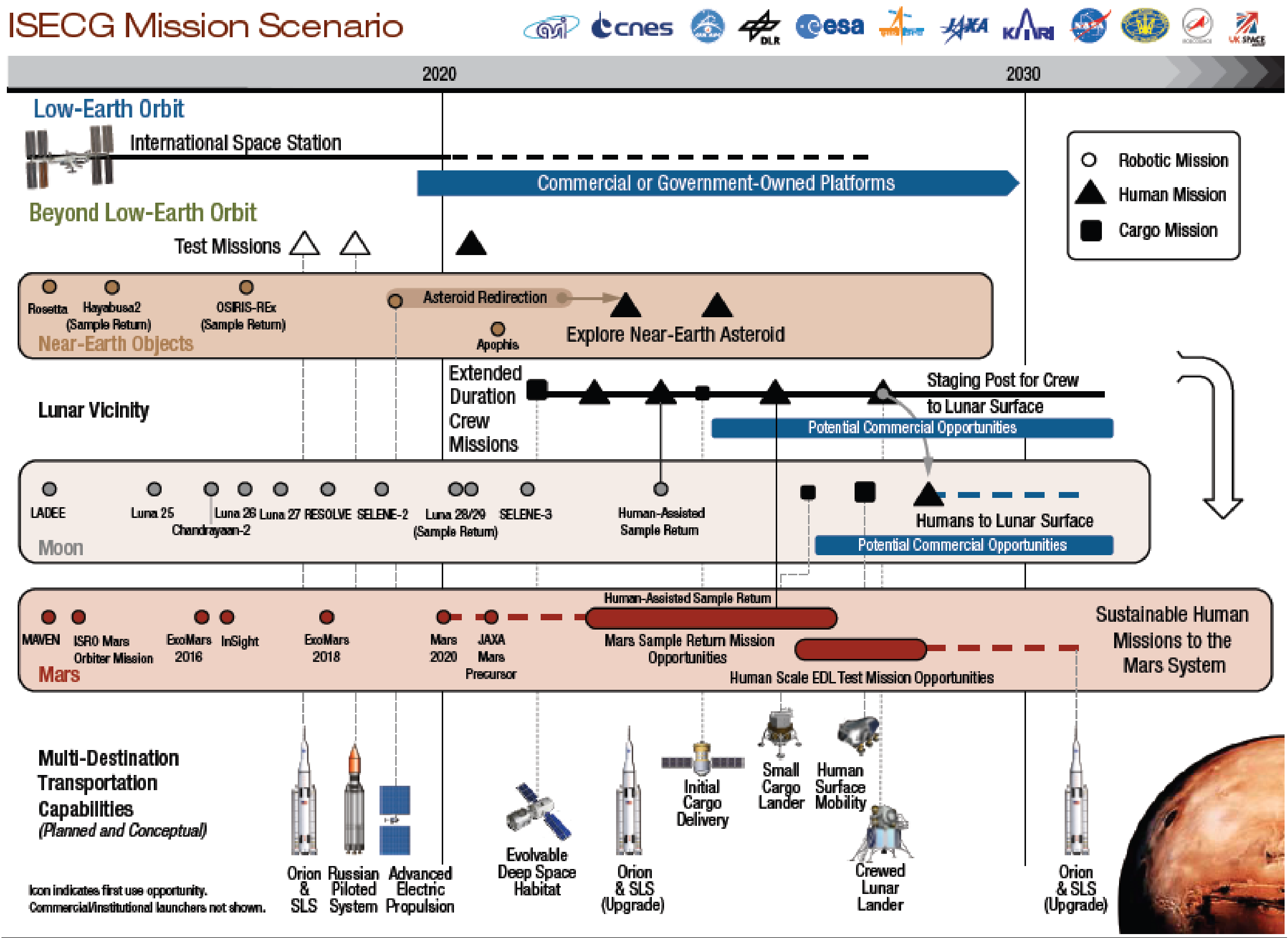


Figure 4 Global Exploration Roadmap

revisions which clearly indicate the probable direction of future international efforts. Figure 4 presents a top-level summary of the roadmap and several noteworthy points are clearly evident:

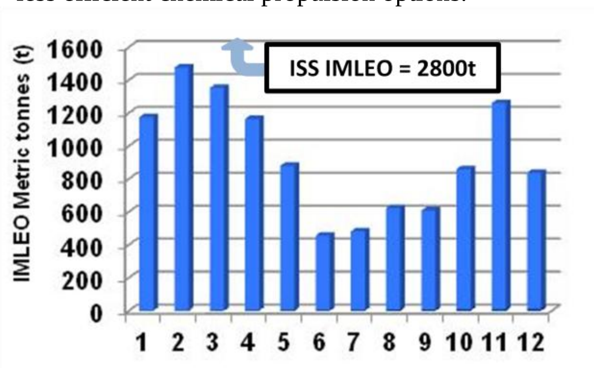
- The ultimate objective is Mars.
- Significant precursor activities will be necessary to prepare the systems needed to achieve this objective. The roadmap does not contend that all of the activities shown in the diagram are necessary but instead makes clear that these are examples of the types of activities that will be necessary.
- Several interim destinations are possible. All of these destinations offer potential to reduce risk for the Mars objective and system studies must be performed to validate their return on investment toward that objective.
- ISS will play a strong role in shaping both the technical basis for the exploration program as well as the managerial model used for execution and operations.
- A strong partnership between human and robotic exploration programs will clearly be required. These programs have run largely independently in the past but it seems clear that both programs benefit substantially from improved integration as human exploration moves out beyond LEO.
- International partners are prepared for and require key, mission critical roles in the program. ISS has proven that partners can rely on each other for mission critical elements and this model allows contributing agencies to match their industrial skill base with program needs in a way that balances risk and shares program cost.

The update to the GER demonstrates that international space agencies are coordinating their efforts in a productive and mutually beneficial way. As program planning for Mars matures, the GER will likely see future updates that help to guide partner agencies in collaboration and coordinated execution.

III. MISSION PLANNING FOR MARS

Planning studies for Mars are as old as the space program. Initial studies were wildly ambitions, grand in their visionary scale and largely impractical from a funding perspective. Studies done within the past two decades, however, have better incorporated lessons learned from ongoing spaceflight activities and fiscal realities.

Figure 5 provides a summary of the Mars design reference missions done since 1988. As discussed earlier, IMLEO is used as a metric to describe the magnitude of the proposed approach. A quick examination of the chart shows that recent (more realistic) planning for Mars puts IMLEO somewhere between 600 and 1200 tons; less than half of the IMLEO for ISS assembly. The variability in this estimate is largely tied to the technology used for the in-space propulsion approach. Generally, the lower IMLEO estimates are tied to higher efficiency nuclear or solar electric options and the higher estimate is tied to less efficient chemical propulsion options.



1 – 1988 Mars Expedition (Chem A/B)
2 – 1989 Mars Evolution (Chem A/B)
3 – 1990 90-day Study (NTR)
4 – 1991 Synthesis Group (NTR)
5 – 1995 DRM 1 Long Stay (NTR)
6 – 1997 DRM 3 Refinement (NTR)
7 – 1998 DRM 4 Refinement (NTR or SEP)
8 – 1999 Dual Landers (SEP)
9 – 2000 DPT/NEXT (NTR or SEP)
10 – 2009 DRA 5 (NTR Option)
11 – 2009 DRA 5 (Chem Option)
12 – 2013 DRA 5 Addendum (SEP Hybrid)

Figure 5 IMLEO estimates for Mars missions

Naturally, Mars mission planners are seeking to produce the best IMLEO metric possible and smaller is better. What this means is that few mission architects include the precursor activities that will be required to get ready for the Mars mission in their metric. Using Apollo as an example, it is unlikely that the program would have been as successful without Mercury and Gemini. If one takes a careful look at the GER roadmap in figure 4, one will quickly realize that ALL of the activities shown in that roadmap are precursor activities for Mars. So continuing with the Apollo analogy, the entire Mercury program had an IMLEO of about 11t; Gemini about 47t. The pre-landing Apollo missions (4 thru 10) had a combined IMLEO of 720t and the first landing (Apollo 11) had an IMLEO of 136t. Figure 6 provides a summary of the Apollo IMLEO.

	Mission IMLEO	Orbital Missions	Total IMLEO
Mercury	1.4	7	9.8
Gemini	3.8	11	41.8
Apollo Test	103	7	721
Apollo Operations	137	7	959
	Apollo Era Total IMLEO		1732

Figure 6 IMLEO actuals for Apollo

One can see from these numbers that considerable precursor activities were required in order to ensure a successful first landing mission. The same premise will likely be true for Mars and responsible planning will take this into account.

Much of the controversy that surrounds the next steps for human exploration revolves around the selection of the Mars precursors. Again, going back to the GER roadmap in figure 4, one can see that a very broad selection of precursor mission options are accommodated by the roadmap. We will not attempt to adjudicate this controversy in this paper nor is it necessary to make our points. Most readers will recognize that SOME of the precursor activities identified by the roadmap will be necessary.

To simplify the discussion, the Mars planning data would suggest that something in the neighborhood of 6 SLS launches will be needed to accomplish the Mars mission. In the evolved configuration assumed to be available in the early 2030's, six SLS launches provides an IMLEO of ~780t which is a reasonable estimate given the data. Unlike Apollo, Mars will offer the potential for re-use of some of the in-space elements of the system. This means that subsequent landings would require fewer launches; perhaps four. Naturally, all of these numbers are adjusted if international or commercial heavy lift capabilities are added.

Mars precursor missions will also likely require from 6 to 10 SLS launches. The first two, which are already on the books, will be used to qualify the launch system and the Orion capsule. More will be needed to qualify the other elements of the Mars mission system and to provide much-needed experience for human spaceflight beyond earth's radiation belts. The controversy we face now if how to use those launches to best prepare for the Mars mission. The only way to solve this controversy is to provide more focused attention on the details of how the Mars mission should be accomplished. The Apollo designers didn't know how much they needed Gemini until they got started on the Apollo design. Once we have a better understanding of what the Mars system will look like, we will have a clearer picture of how those precursor SLS launches should be used.

IV. ISS ROLE IN EXPLORATION

The experience of the ISS team is unique. We have already made the case that ISS is on the same scale is the Mission to Mars. When one considers the in-space elements of the Mars architecture, one sees great similarities to ISS: long duration habitats and large solar arrays for in-space propulsion. As an example, figure 7 shows the ISS next to a solar electric propulsion (SEP) tug in the class needed for a human Mars mission and the similarities are striking.

It is well-known in the space community that the life support systems needed for Mars are being tested today on ISS. We have also acknowledged that an International collaboration similar to that used on ISS is just what is needed for Mars as well. Why not task that same International team to evaluate ISS methods for the Mars mission? Using the ISECG Global Exploration Roadmap as a reference, the International ISS team could define design reference missions for Mars and proposals for the precursor missions in the Lunar vicinity that would precede it. This approach would have several benefits:

- As an operational spaceflight organization, ISS will bring programmatic rigor and an attention to detail that will result in achievable concepts.
- The experience and lessons learned from construction of ISS can be directly applied to inform these concepts again improving achievability[3,4].
- Clause 14 of the ISS agreement which considers evolution of the ISS could be used to provide a legal and political framework for the cooperative effort.
- Use of residual assets from ISS and the Space Shuttle program could be evaluated for use with the potential to reduce costs[5].
- ISS methods for engagement of commercial logistics services could be evaluated to support the exploration mission.
- Systems needed for these precursor missions could be prototyped and tested at the ISS, thus improving their reliability and prospects for mission success.

IV. CONCLUSION

The release of the Global Exploration Roadmap (GER) has made clear that our unified long term goal is for a human mission to Mars. ISS systems, management techniques, and experience could all be brought to bear toward making this goal a reality.

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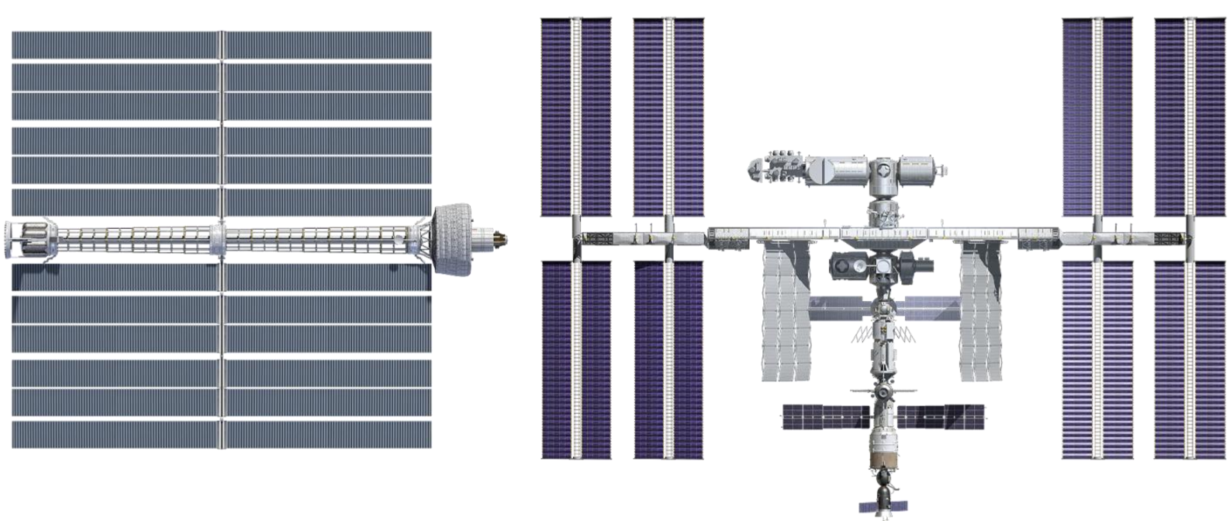

Figure 7 Mars SEP tug compared to ISS

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