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"Gateway" Architectures: a Major "Flexible Path" Step to the Moon and Mars after the International Space Station?

A 2006 concept developed from earlier designs for post-ISS "Gateway" human operations at an Earth-Moon $L_{1,2}$ venue. This was proposed as a single integrated facility to support lunar surface operations, upgrade or prepare major on-orbit science and depot missions, and develop essential capabilities for future human missions to Mars. (credit: The Future In-Space Operations (FISO) working group and John Frassanito & Associates)

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With NASA's commitment to the International Space Station (ISS) now all but certain for at least through the coming decade, serious consideration may be given to extended US in-space operations in the 2020s, when presumably the ISS will exceed its "sell by" date. Indeed, both ESA and Roscosmos, in addition to their unambiguous current commitment to ISS, have published early concept studies for extended post-ISS habitation (e.g., http://www.esa.int/esaHS/index.html, http://www.russianspaceweb.com/opsek.html and references therein). In the US, engineers and scientists have for a decade been working both within and outside NASA to assess one consistent candidate for long-term post-ISS habitation and operations, although interrupted by changing priorities for human space flight, Congressional direction, and constrained budgets. The evolving work of these groups is described here, which may have renewed relevance with the recent completion of a major review of the nation's human space flight program.

The "Gateway" architecture has been evaluated since 2000 as a single, large-volume, multi-purpose, free-space habitat. It was from the start proposed to be simultaneously the next major on-orbit facility after the ISS, operating as a key human space flight "stepping stone" on the way to Mars, supporting lunar surface operations, including space depots, while serving as a "work site" for major satellite repair and upgrade; that is, achieving multiple priority NASA goals via a single facility. The "Gateway" was first studied in depth by NASA's Decade Planning Team (DPT) and its successor, the NASA Exploration Team (NEXT) (http://history.nasa.gov/DPT/DPT.htm see "Lunar L_1 Gateway Conceptual Design Report," EX15-01-001, hereafter referred to as "Gateway Design Report"). Produced by the NASA JSC Advanced Development Office, this extensive architecture study was developed in response to requirements in coordination with the DPT and NEXT. Briefly, these were

1. Simultaneously support human and robotic lunar surface operations, upgrade and construct major in-orbit science facilities, oversee resource depot systems, and demonstrate key capabilities necessary for long-duration human spaceflight.
2. Have a design lifetime of 15 years.
3. Support a crew of four for mission durations of up to a few weeks.
4. Use existing or near-future launch vehicle infrastructure.
5. After autonomous transfer from LEO, operate at Earth-Moon L_1 or L_2.
6. Operate without human attendance for up to several weeks at a time.

From the start, it was obvious to the JSC/DPT/NEXT team that the same technological solutions adopted to make ISS successful would not in all cases work for a candidate follow-on system. In particular, maximizing living volume while minimizing total launch mass (and cost) drove the designers of the Gateway to an inflatable solution, which not coincidentally had been developed a few years earlier at JSC.

The TransHab – a contraction of *Transit Habitation* – was a concept begun in the late-1990s under the leadership of William Schneider (2006 interview in http://www.thespacereview.com/article/686/1) with the goal of developing for demonstration on ISS a lighter-weight candidate for eventual human missions to Mars. Proposed habitation volumes for such missions would require, if using the aluminum shell structure of the ISS design, a total mass likely to be prohibitively heavy. Schneider and his team instead applied high-strength fibers, which permitted a structure that could be collapsed around a rigid core for launch, but expand to an impressive usable volume when on orbit (see also http://en.wikipedia.org/wiki/TransHab and references therein).

According to histories of the program and later interviews (e.g., Kennedy [AIAA 2002-6105]), TransHab suffered the controversies and increased costs of ISS to the point where the US House of Representatives banned NASA from conducting further research and development of the concept. This would not be the last time that post-ISS habitation concepts in the US would be mired in controversy. It is, therefore, ironic that the TransHab patents and designs were purchased by Bigelow Aerospace for the purpose of building "hotels" in orbit for a variety of purposes (http://www.bigelowaerospace.com/), which have had a pair of successful one-third scale model demonstrations. And perhaps doubly ironic, almost simultaneously with the termination of TransHab design work at JSC, NASA Administrator Dan Goldin's DPT began a much more ambitious assessment of TransHab-based designs to extend human presence beyond LEO and eventually to Mars . . . using an engineering design team from JSC.

The resulting DPT/NEXT Gateway (hereafter, Gateway 2001, which refers to the date that the final design report was completed) was presented as "the cornerstone in a series of elements that comprise the Gateway Architecture, as it serves as the primary mission staging platform through which [multiple priority activities] will be performed" (Executive Summary, Gateway Design Report). As with the earlier TransHab team and learning the lessons from the ISS design experience, the JSC/DPT/NEXT team recognized the importance of minimizing the necessary in-space infrastructure, including numbers of required launches. The final Gateway 2001 design used a single Delta IV EELV vehicle to place the hybrid inflatable/rigid shell structure into a low-Earth orbit. The rigid shell portion offered load-bearing support and the inflatable portion offered increased volume-per-mass: in a single launch of a 23 mT payload, a pressurized volume of 275 m^3 was available for four astronauts for a few weeks. In comparison, the Skylab volume was 361 m^3 for three people for about three months, the Bigelow Aerospace *BA330* space habitat is proposed to have 330 m^3, and upon completion ISS will have somewhat less than 1000 m^3 for up to six astronauts. The Constellation Orion crew exploration vehicle is designed to have an interior volume of roughly15 m^3.

The DPT/NEXT team's challenge was to design a single-launch habitation module that would serve as a "stepping stone" – a key DPT/NEXT concept – for subsequent science and human spaceflight goals in the era following the ISS. With this as a requirement, the Gateway Architecture study identified the Earth-Moon (E-M) L_1 (or, about equivalently, L_2) venue as the single site in the Earth-Moon system where multiple NASA goals could be achieved, while enabling future growth potential for one day sending humans to Mars. However, sending Gateway 2001 beyond LEO required additional outfitting and propulsion systems. In the Gateway Architecture, two additional launches to LEO are required to support operations at E-M $L_{1,2}$: a Space Shuttle-based supply and outfitting mission and an EELV launch of a solar electric propulsion (SEP) unit to dock with the outfitted and inflated Gateway. The combined Gateway-SEP system would then spiral outward over several months to its final location, about 60,000 km from the Moon; the SEP module would then return to LEO for re-use. [Multiple-use or re-use was another priority for DPT/NEXT architectures.] Astronauts would be sent to the Gateway via chemical propulsion and a dedicated, re-usable transfer stage. In the JSC/DPT/NEXT design, Gateway 2001 over its 15-year lifetime could support per year, for example, two Apollo-like short-stay sortie missions with astronauts to the lunar surface and two upgrade/support missions with major science facilities and/or depots. Furthermore, operations would also be carried out to build upon experience and technologies learned from ISS, guaranteeing that they would not be lost when the ISS program ended. Although the DPT/NEXT estimated that Gateway 2001 could be deployed within about a decade with sustained investment, there was not at that time either a national commitment to human missions beyond LEO or plans for complex science missions or space depots that required human servicing.

In late 2001, Dan Goldin departed NASA and much of the DPT/NEXT work was taken over by the new Space Architect office at NASA HQ, although Gateway design work was not pursued in greater depth at that time. Moreover, the Space Architect position was terminated by Goldin’s successor, so concepts, options, technology priorities, and combined science/human space flight goals developed by the DPT/NEXT languished. A few years later in 2004, the *Vision for Space Exploration* (VSE) was announced by the Bush White House and in mid-2005, new NASA Administrator Michael Griffin established the Exploration Systems Architecture Study (ESAS) to develop the implementation strategy for the VSE. An option for sustained human libration-point operations was considered, but rejected, by the ESAS team, which used significantly different human space flight requirements and goals from that of DPT/NEXT. Consequently, the resultant Constellation architecture had long-stay human lunar surface occupation as the overriding major human spaceflight goal.

About the time that the ESAS activity was beginning, the *ad hoc* Future In-Space Operations (FISO) working group was established to assess how the facilities recommended by ESAS could <u>also</u> be adapted to additional purposes. That is, the FISO working group deliberately duplicated the Apollo Applications Program of four decades earlier: evaluating how human space flight hardware intended for the Moon might be more broadly applicable. In the event, a core element of the Constellation architecture – the Ares V heavy-lift vehicle – was identified by the FISO working group as permitting a major advancement in capabilities for a future post-ISS Gateway facility.

Working in 2006 with John Frassanito & Associates (JF&A) and a small engineering team, members of the FISO working group resurrected the TransHab/Gateway 2001 designs and adapted them to take advantage of the capabilities offered by elements of

NASA's new Constellation architecture. At the time, the particular version of heavy lift design could place about 95 mT into LEO, so from the start this new design (hereafter "Gateway 2006") was both much larger and used a single launch to put into orbit a combined habitation/propulsion system that did not require subsequent outfitting launches. To propel the system to its final operations site at E-M $L_{1,2}$, this Gateway design used both chemical and SEP systems.

An artist's concept of Gateway 2006 opens this article. Its usable volume is about 575 m^3 or approaching 60% of the final pressurized volume of ISS when completed, which is made possible by the assumed availability of the heavy-lift vehicle and, of course, the inflatable technology originally developed for the TransHab system at JSC almost a decade earlier. The figure shows the team's concept for a lunar lander and an Earth-to-Gateway human transfer stage on the far side of the habitation system, and a servicing site on the near side. As with the earlier Gateway 2001 design, the updated version was sized to support a crew of four for up to a few weeks at a time, two lunar surface sortie missions and two satellite upgrade/construction missions annually, along with extended development and testing of capabilities in support of future human missions to Mars. The libration-point venue of Gateway 2006 also offers a site for tending depot systems.

This updated Gateway architecture and concept for adapting Constellation systems was proposed to the NASA HQ Exploration Systems Mission Directorate (ESMD) in spring 2006. However, ESMD declined to support further design work, concerned that evaluating concepts for free-space human space flight would be excessively distracting from work on NASA's priority lunar south pole "outpost." This ended another Gateway effort, and once again, post-ISS free-space human habitation design work within NASA ceased.

However, three years later in 2009, the concept of a broadly capable, inflatable post-ISS long-duration human habitation system beyond LEO was yet again resurrected, this time as part of last year's OSTP-directed Review of Human Space Flight Plans Committee, chaired by Norman Augustine (http://www.nasa.gov/offices/hsf/home/index.html). One of the scenarios considered in some depth by the Augustine Committee was the so-called "Flexible Path," which proposed a multi-faceted program to develop the capabilities for human space flight to multiple destinations in preparation for missions to Mars. [The similarity with the architecture developed several years earlier by the DPT/NEXT activity has been widely noted.]

Within the Flexible Path is an option for, once again, a post-ISS Gateway-like system. As Augustine Committee member, Prof. Edward Crawley was to remark during a recent colloquium, "I guess our committee re-discovered this for the first time."

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