Evolving A <u>Responsible</u> Human Space Flight Architecture

As the United States seeks to extend its human space flight (HSF) exploration capability beyond low Earth orbit (LEO), there is much concern about the evolving space architecture's *sustainability*. Gone are the fleeting Cold War political motives for deep space exploration in the Apollo Era. Now we are in this business for the long haul. As Jeff Greason eloquently opined at the 2011 International Space Development Conference (http://www.youtube.com/watch?v=mD-S25RRW10), our *de facto* end game is to <u>settle</u> space. For that, we need an architecture that is politically and economically sustainable.

To achieve this sustainability, we should also be prepared to evolve an architecture that is *responsible*. At its inception, the heavy lift Space Launch System (SLS) appears to be conceptually responsible. Its crew and payload are not subject to a potential supersonic debris stream during routine launch. In the event of serious SLS malfunction, the crew can call upon independent propulsion to be pulled free of the launch vehicle with a reasonable chance at safe return to Earth. There is hope SLS will evolve exclusively toward fail safe propulsive systems whose thrust can be terminated at will without issuing a destruct command.

Another aspect of responsible beyond-LEO HSF architecture relates to SLS performance as measured by initial mass in LEO (IMLEO). At http://www.nasa.gov/exploration/systems/sls/sls1.html, posted on 14 September 2011, we read SLS will evolve from IMLEO near 70 mt to 130 mt when mature. These numbers currently defy rigorous comparison because they must first be qualified by the assumed height and inclination of the LEO to which they relate. This pedigree is currently unknown to the general public and should be clarified at NASA's earliest opportunity.

Nevertheless, there is a scenario dictating what minimal IMLEO should be provided by a mature SLS in support of responsible beyond-LEO HSF architecture. Consider a time-critical crew rescue or resupply to be conducted somewhere between LEO and the Moon's vicinity. We know from historic examples there will be compelling pressure to address this scenario in a timely fashion, particularly if crew self-rescue is not possible as it was after Apollo 13's trans-lunar abort. During *Skylab* and post-*Columbia* Space Shuttle Program operations, a strategy known as launch on need (LON) was developed to address crew rescue. It entailed processing a potential rescue vehicle for launch virtually in parallel with the primary vehicle that might become disabled. Such LON processing capability has existed at the Kennedy Space Center's Launch Complex 39 (LC-39) at least as early as *Skylab*, and it should be in place when SLS begins launching astronauts. Unfortunately, not one of NASA's recent beyond-LEO architecture studies has considered the LON scenario.

Schedule and resources associated with a LON mission will heavily depend on the anticipated rescue/resupply scenario. For example, a strategy called Contingency Shuttle Crew Support (CSCS) evolved post-*Columbia* using the International Space Station (ISS) as a safe haven for the crew of a disabled Shuttle unable to safely perform Earth return. With ISS as a refuge, weeks to months were available in which to prepare a rescue Shuttle mission, eliminating need for dedicated contingency Shuttle processing until after a CSCS scenario was declared. In the case of STS-125's Hubble Space Telescope repair mission, however, no such crew refuge capability existed. Prior to STS-125 departure from LC-39 Pad A, the Shuttle to be processed for STS-127 was instead prepared as the STS-400 LON mission at Pad B.

Whenever safe haven infrastructure and cached resources are marginal, as is typically the case early in a specific HSF exploration effort, LON capability is most desirable. But it is precisely at such times that a higher flight rate is also desirable. A parallel vehicle flow capability conferred by LON rationale will certainly help enable more frequent launches. By considering the LON "surge" scenario, ground infrastructure (such as cryogenic propellant generation and storage facilities) is sized with supplemental capacity and redundancy. Launch crews can similarly benefit from surge tasking to support more launch attempts and achieve greater proficiency.

Even with IMLEO capability well over 100 mt from a single launch, interplanetary missions requiring multi-launch campaigns will take on LON-like surge aspects if a limited Earth departure season develops a slim schedule margin. Tight launch schedules are particularly likely for near-Earth asteroid destinations, the vast majority of which have yet to be discovered. The most compelling of these destinations may not become known and sufficiently characterized for HSF until shortly before a viable mission opportunity arises.

The LON strategy in a time-critical deep space rescue/resupply context demands sufficient trans-lunar injection (TLI) capability from a single launch. To require otherwise would not be responsible, given the delays imposed by multiple launches, rendezvous, docking, assembly, and propellant transfer operations. Even if all these operations occur as planned, they introduce a delay of days or weeks compared with a single launch leading to TLI. Because multi-launch operations are inherently serial in nature, a single schedule delay at any point only tends to compound TLI delays. Furthermore, TLI time is fixed by the first launch in a campaign, and another opportunity will not arise for ~10 days if the first is missed.

We know from the Apollo Era that TLI can indeed be achieved for HSF with a single launch. The Apollo 8 mission even provides us with a quantitative example of the minimal IMLEO necessary to mount the contemplated minimal rescue/resupply in cis-lunar space. Data with which to compute as-flown Apollo 8 IMLEO have been published by Orloff and Harland in *Apollo: The Definitive Sourcebook*. Summing Saturn IV-B structure and propellant, together with a 28.8 mt Command-Service Module (CSM) and 9.0 mt of ballast replacing a Lunar Module, results in 127.5 mt IMLEO at a circular orbit height of 185 km and inclination of 32.5°. This mission carried a crew of 3 safely into low lunar orbit and back to Earth. By Apollo 15, Saturn V performance and flight profile improvements were achieving IMLEO of 140.4 mt at a circular orbit height of 167 km and inclination of 29.7°.

As budget cycles, Congresses, and Presidential administrations come and go, NASA should stay mindful of the LON scenario and the responsibility it will impart to a sustainable beyond-LEO HSF architecture. We appear to have an initial plan addressing this scenario with a fully evolved SLS, but with very little performance margin to spare. In our desire to begin exploring beyond LEO with HSF missions again, we should be prepared to incur delays and expense until we can do so responsibly. We owe future astronauts and "settlers" nothing less.