AUGMENTING NASA'S EXPLORATION ARCHITECTURE TO ACHIEVE MAJOR SCIENCE GOALS IN SPACE. H. A. Thronson, Exploration, Operations, Communications, and Navigation Systems Division, NASA GSFC, and Chair, Future In-Space Operations (FISO) working group [Harley.A.Thronson@NASA.gov]

Abstract: Future in-space operations (FISO) include assembly, servicing, and maintenance activities in free space, support from space for lunar surface operations, and preparation for long human voyages beyond the Earth-Moon system. NASA's Exploration program has developed an architecture, in particular the *Orion* Crew Exploration Vehicle (CEV), that is capable of being augmented to support a variety of operations, analogous to how the Space Shuttle supports scientific missions such as HST.

The FISO Working Group is made up of engineers, scientists, and technologists from NASA, academia, and industry. Over the past two years, we have assessed a suite of capabilities intended to support future complex systems that cannot be autonomously deployed and high-value systems for which rescue or lifetime extension may be highly desirable. Our work builds upon and extends the investment that the US and other nations have made in achieving major goals in free space.

Here we highlight science (and other) priorities enabled by future in-space operations made possible by adapting the architecture being developed for returning humans to the lunar surface. Notable are *near-term* capabilities that will enable the Exploration Architecture to achieve science goals not long after its first elements are deployed.

Our work to date has favored the Earth-Moon L1 point, because of its flexibility to support *multiple* activities from a single location. However, the general rationale in support of future in-space operations applies to a number of other locations.

FISO multiplies the value of human exploration: Major elements of the Exploration Architecture may be augmented to achieve multiple science, commercial, and national security goals. Augmentations may include advanced space telerobotics, automated rendezvous & docking, non-contaminating propulsion, refueling systems, special-purpose tools, environmental protection, advanced EVA, post-ISS bioastronautics, and critical capabilities for humans to work effectively for long periods in free space.

Notable about the concepts developed by the FISO Working Group are systems that can accomplish *multiple* goals using the same infrastructure in the same location, such as Earth-Moon libration points. For example, facility upgrade, satellite refueling, support for lunar surface operations, and precursor systems for long human voyages beyond the Earth-Moon system may be carried out using the same systems.

National priorities enabled by future in-space operations: The *Vision for Space Exploration (VSE)* highlights building very large optical systems in space to search for Earth-like worlds, which was also noted by the National Research Council in its last decadal review for astronomy and astrophysics. Such a facility (and its precursors) would at the same time constitute perhaps the premier astronomical observatory of the 21st Century, able to carry out multiple science programs. It is certain that such future telescopes would be far larger than can be launched as a single monolith, so some assembly will be required. Moreover, expensive facilities of any kind in space or on the lunar surface are likely to require significant external support – astronauts and/or telerobots – to insure that taxpayer investment will be protected.

Astronomers are not the only scientists interested in large apertures in space: Earth scientists have developed concepts for very large millimeter- and sub-millimeter-wave antennae, perhaps operating at geostationary positions. These too are missions that may be much larger than can be launched fully deployed within a single upper-stage shroud.

There are other uses for very large apertures in space other than for science or commercial enterprise: the national security communities are pursuing options for very large systems operating for very long times in space. Repair, deployment, recovery, and refueling of these systems by means of in-space capabilities should be extremely desirable. Furthermore, the FISO Working Group has opened discussions with other government agencies interested in large, complex missions not possible without in space assembly.

Both the *VSE* and the FY2005 House Authorization bill direct NASA to undertake an extensive program of lunar robotic exploration. There are significant applied and basic surface science programs that can be carried out purely robotically, thus preserving astronauts for those tasks for which humans are most suitable. Given that direct line-of-sight control with very little time delay will be highly desirable, an operations node at the Earth-Moon L1 point, from which an entire lunar hemisphere can be observed, may be enabling.

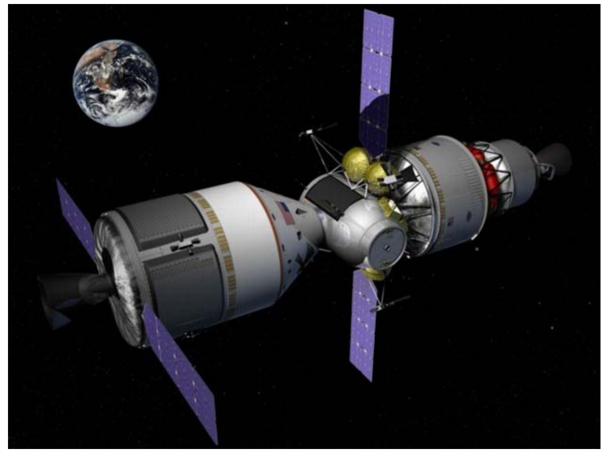
Finally, although not usually appreciated as a science goal, operating with humans and robots at the Earth-Moon L1 point can provide valuable support for contingencies or emergencies on the lunar surface. This could in turn spell the difference between success and failure for major science missions, just as has been the case for terrestrial exploration programs. Support bases for Antarctic missions are excellent models, given the expense of landing on the lunar surface.

Repair equipment, and back-up systems that may not need to be immediately available may more sensibly be "warehoused" in space until needed. Somewhat similarly, serious medical emergencies on the lunar surface appear to be f*ar* better treated on-site, within a gravity well, as opposed to brutalizing transportation back to Earth. Hypothetically, a well-stocked "emergency-room-in-a-can" may be kept on-orbit, perhaps never to be used, but ready to be sent to the lunar surface if required.

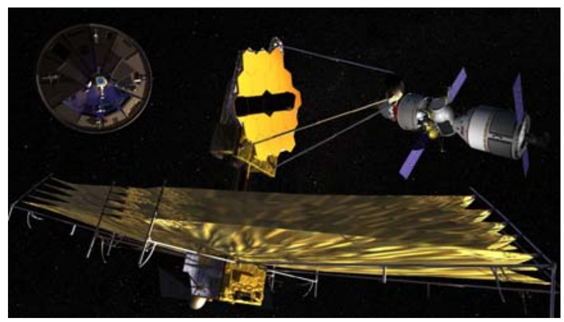
A future in-space architecture: Over the past two years, the FISO Working Group has developed and assessed a series of preliminary concepts to carry out multiple missions to achieve national priorities in science, commerce, and national security. These concepts build upon and augment the Exploration Architecture. The following is presented as *one* plausible sequence of options for extending human capabilities beyond LEO.

Early technology investments could led to a free-flying telerobot capable of an HST deorbit mission (shown here), or as an inspector for simple assistance or intervention for a wide variety of missions.

Subsequent development may include *Orion* mated to a crew module of the LSAM, thus providing additional pressurized volume and an airlock for astronaut EVA. This would significantly extend in-space capabilities, making available astronauts and robotic partners on-site for the most complex activities such as deployment, repair, and upgrade.



Orion mated to a lunar crew module and airlock is shown here delivered to the vicinity of the Moon. This would permit on-orbit support for human and robotic activities on the lunar surface: contingency and emergency supply, line-of-sight communication for a large surface area, and experience for long human voyages beyond the Earth-Moon system.



Farther into the future, more complex and ambitious space operations may be required. Here the augmented *Orion* with a free-flying robot is supporting human-robotic servicing of a post-JWST telescope in orbit about the Earth-Moon L1 libration point. At this location, deployment, assembly, repair, servicing and maintenance of high-value assets is possible. Such an L1 location is energetically convenient to more distant locations where such telescopes will operate. This may constitute experience necessary for longer human voyages in space.

Future work: the FISO Working Group is coordinating more detailed assessments of modest augmentations to the Exploration Architecture (e.g., *Orion*), including how in-space systems may support lunar surface operations (and vice versa) and technology investments applicable both to lunar surface and free-space operations.

The NAC science subcommittees have an opportunity to encourage assessments of how future operations in free space, building upon the Exploration Architecture, may be used to achieve major national goals in science, commerce, and national security.