ENABLING LARGE SPACE OPTICS: SAFIR HUMAN AND ROBOTIC DEVELOPMENT. T. M. Espero[1], M. A. Fruhwirth[2], G. L. Bingaman[3], and S. D. Potter[4], [1,2,3,4]The Boeing Company (5301 Bolsa Ave, Huntington Beach, CA 92647) ([1]tracey.m.espero@boeing.com, [2]michael.a.fruhwirth@boeing.com, [3]gary.l.bingaman@boeing.com, [4]seth.d.potter@boeing.com)

Introduction: The Single Aperture Far Infra-Red telescope (SAFIR) represents a complex and very ambitious mission, and has already been identified by the NAS as one of high potential. With a cryogenic aperture of 10 meters and a suite of sophisticated instrumentation, SAFIR will also represent a considerable expense. To compensate for this expense, any and all options for increasing the productivity and life of the mission should be explored. This study was initiated by the Chief Technologist of NASA's Science Mission Directorate (SMD) and encouraged by the Future In-Space Operations working group to investigate the benefits of human and robotic servicing of SAFIR, and to evaluate what architecture elements would enable such operations. This paper highlights the SAFIR Human and Robotic Development (SHRD) study and illustrates results utilizing the architecture being developed to return humans to the vicinity of the Moon.

Study Background: SAFIR has a number of key properties which shape the servicing requirements: operations at Sun Earth L2 (SE L2), 10 meter segmented primary aperture operational over wavelengths from 30 to 800 microns, a combination of active and passive thermal control that results in optics temperatures of near 4 K, and an approximate launch date ~2020. Servicing will occur after the first 5 years of mission life and at each subsequent 5 year interval. SAFIR will be designed for a fully automated deployment, similar to the James Webb Space Telescope. The human and robotic roles will be limited to servicing operations.

Boeing has initiated this study using its experience with in-space operations and methods for identifying new strategies for maintaining space systems. Critical to the development of the results shown in this report were the efforts of the SAFIR Vision Mission team. This team had already produced a complete report [1] describing the properties of the mission, and through the contribution of Boeing on the team, included a top-level discussion of possible servicing options. These were supplemented by features derived from Boeing's experience with space operations. Also ingested were early products from a Johnson Space Center exploratory effort on SHRD under the direction of Brian Derkowski.

Servicing Considerations: Since the observatory is intended to be serviced after being in space for a number of years, the initial design must accommodate the servicing concept. Among the issues to address are structural requirements of the observatory derived from servicing of major elements, such as the sunshades or solar panels. The telescope must also be tolerant to robotic or human operations in its vicinity, including the necessity for warming of the entire system prior to servicing - thermal cycling from near absolute zero to temperatures consistent with the operation of robotic or human servicing agents. This operation will require a careful survey of all components in the spacecraft to assure that their performance and lifetime are not adversely affected by such a thermal cycle.

Key areas in the design for serviceability process include identifying the observatory systems/subsystems/components that will be serviceable, defining appropriate servicing methods, and the degree of servicing activity to be placed on the servicing agent. While the majority of the burden might be assumed by the servicer capabilities, some responsibility for the servicing interfaces is carried by the observatory. The components designated for removal and replacement are known as Orbital Replacement Units (ORUs). Figure 1 illustrates a possible decomposition of the observatory configuration.

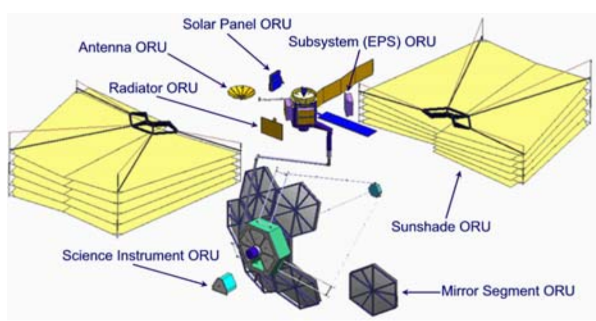

Figure 1 - SAFIR Serviceable Components

Each of the elements shown separately are replaceable items. Accessibility is a basic consideration in designing for servicing, and locations of the servicing worksites must be carefully considered.

Study Approach: To provide an integrated assessment of the servicing operations, a Quality Functional Deployment study was conducted. SAFIR servicing can be globally defined by a set of servicing requirements, which list the main servicing operations that are desired by the observatory managers. Specific requirements may include maintenance, repair or replacement of the science instruments, sunshade, solar panels, propellant, and the cryocooler. These services will need to be provided by a set of servicing functions, which are the methodology, hardware, and process options that could be employed by the servicing vehicle/observatory combination. This will fulfill the desired servicing operations, such as access to the "cold side" of the observatory to enable instrument replacement. The overall space architecture will need to provide the elements and architectural structure to support the defined servicing operations, and define their location. Servicing requirements are related to servicing functions, and the functions related to architecture.

Study Results: The study revealed that servicing of SAFIR is enabled by a suite of capabilities. Two of the highest-ranking architectures are CEV plus telerobotics servicing in a cis-Lunar orbit with a tug transport, and servicing at SE L2 by a resident robotic servicing vehicle; both including a cargo transport vehicle.

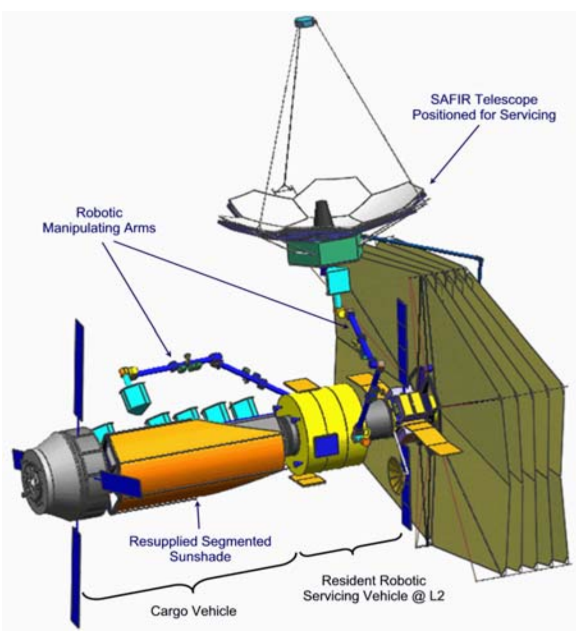

Figure 2 - Servicing of SAFIR by a Robotic Servicer

Figure 2 illustrates a concept for the servicing of SAFIR by a resident robotic servicing vehicle. This concept includes a manipulating arm which places the science instruments on the "warm side" of the observatory, aiding in access for the servicer. The robotic servicing vehicle performs the instrument removal and replacement, supported by a cargo vehicle that has brought the replacement ORUs. With the current architecture in development, robotic systems are a focus area of development and will likely result in servicing systems that can be adapted for free-space use.

The resident robotic servicer could easily be replaced by a CEV with telerobotic capability as shown in Figure 3. This concept also utilizes a cargo vehicle to house replacement ORUs and performs servicing on SAFIR by advanced robotics. Additional control is available in this scenario with human in the loop decision making, possible with telerobotic control from the CEV.

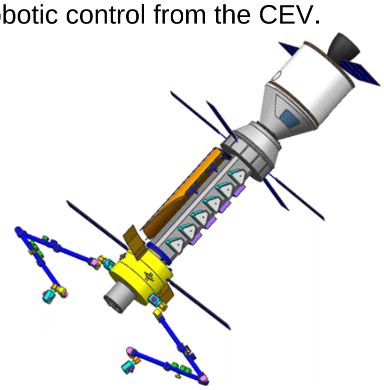

Figure 3 - CEV with Telerobotics Servicing Vehicle

Conclusion: SAFIR and missions of its type will likely be too expensive to be used for only one design lifetime and then replaced. Indeed, HST has demonstrated the value of employing serviceability to add new features, overcome failures, and assure that key science systems are using the latest technologies. The architecture being developed to return humans to the vicinity of the Moon provides capabilities that should be augmented to allow new observatories, including SAFIR, to enjoy life extension and enhanced science productivity via servicing.

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References:

[1] D. L. (2005) *Science Promise and Conceptual Mission Design Study for SAFIR-the Single Aperture Far Infrared Observatory*