M^c^Candless

21852 Pleasant Park Road
Conifer, CO 80433-6802
brucemcc@logcabin.com
31 July 2003

Remarks to the HST-JWST Transition Plan Review Panel on 31 July 2003 by Bruce McCandless II, NASA Astronaut crew member on STS-31, the HST Deployment Mission, and previously responsible for crew inputs to the design of the HST for on-orbit serviceability.

Salutation Chairman Bahcall, Nobel Laureate Townes, distinguished committee members: I am honored to be invited to address you today regarding the future of the Hubble Space Telescope. I am here today as an *astronaut emeritus*, as one who has devoted a non-trivial part of his career to ensuring the success of the Hubble Space Telescope, as an unconstrained speaker, and as a sometimes "out-of-the-box" thinker. In these remarks I will briefly address four (4) topics: In-Space Serviceability, End of Life Criteria, Risk, and a Novel Concept for Servicing Mission #5 (SM5).

Terminology Let me start by asserting that the Hubble Space ***Telescope*** should more properly be identified as the Hubble Space ***Observatory*** (HSO), and I will use that appellation throughout the remainder of my remarks. The distinction that I make is that a "telescope" is a static device, defined in the dictionary as "an instrument for making distant objects, as stars, appear nearer and consequently larger," while an observatory is a dynamic facility, "a building equipped for scientific observation, especially for astronomical or meteorological research." In the astronomical sense, an observatory houses and supports a telescope. It accommodates multiple instruments for the execution of diverse scientific protocols, permitting repair as required and replacement when necessary to avoid technological obsolescence or to accommodate temporally evolving lines of scientific inquiry -- "chasing the red-shift," so to speak, towards longer and longer wavelengths.

In-Space Serviceability Over the course of HSO development since 1978 we developed techniques for servicing different categories of subassemblies – ranging from the “custom designed for on-orbit replacement” Scientific Instruments (SI’s) through “already existing” “black boxes” with virtually no flexibility for adaptation to servicing. With a certain amount of hubris we bragged that the only components that could not be replaced on orbit were the main wiring harness, the secondary mirror, and the primary mirror (PM) – which would ***never need*** on-orbit maintenance.

Since launch the HSO has had 4 SI replacements to take advantage of technological progress, principally in the field of larger and higher resolution charge-coupled devices (CCD’s) and in pursuit of longer-wavelength (near IR) observations. Two more SI replacements (Wide Field Camera 3 and the Cosmic Origins Spectrograph) are planned for SM4. Two SI “repairs” have been made in the form of the COSTAR (Corrective Optics Space Telescope Axial Replacement unit) on SM1 which corrected the PM spherical aberration for all of the original axial SI’s and the NICMOS (Near Infrared Camera and Multi-Object Spectrometer) Cryocooler which restored the NICMOS instrument to service following the premature depletion of its solid nitrogen heat sink.
In the “very difficult” category was the replacement of the Power Control Unit (PCU) on SM3B.

This internally redundant box is the main electrical power distribution and control unit. With 36 large “Cannon” style electrical connectors and about a dozen awkwardly-placed fasteners, it was the most dreaded of the prospective tasks. In addition to a design never intended for field replacement, the removal of the original unit required total power-down of the HSO for the first time since its launch in 1990 – with time constraints for task completion in order to reactivate the thermal control systems before incurring physical damage.

Other challenging tasks completed include replacement of the HSO solar arrays – ***twice***. The initial (*i.e.*, those installed at launch) solar array system suffered a failure of one of the pair that became partially deformed, and both that exhibited thermally-induced vibration transients following each orbital sunrise. On the first servicing mission (SM1), these were replaced with a similar set of arrays that incorporated telescoping thermal insulation over the tubular members that drew out the arrays, and that had been the source of the transients. Finally, on SM3B, this second set was replaced with a rigid, smaller array set, fabricated using featuring newer technology gallium-arsenide photovoltaic cells. This finally accomplished the definitive fix for the transient problem, and boosted the available electrical power by about 30%, allowing two or more SI's to be operated simultaneously.

<u>HSO End of Life Criteria</u> In searching for a rational criterion to use for establishing the end of the HSO’s useful life, I initially considered degradation of the Primary and Secondary Mirrors since these are not on-orbit serviceable and would not appear to be cost effective to return the HSO to the ground, clean and recoat the mirrors, and relaunch the original unit. Both mirrors, however, are holding up very nicely, and it does not appear legitimate to try to project from this point in time a mirror degradation threshold. A much better indicator could be based on the oversubscription ratio by the professional astronomers who comprise the first tier customer base of the HSO. This ratio has run as high as 8:1 (*i.e.,* eight times as much observing time demanded as available) and is currently about 6:1. This indicator of its scientific viability could be used as the “switch” for discontinuing further support. I would suggest that when it falls into the 2:1 range, it would show that the premier astronomers have found a newer, more capable facility for making their observations, or that the HSO can no longer deliver the quality of data sought irregardless of the availability of other facilities. I would also observe that the HSO still commands front page space in popular news media, to a degree that no other astronomical observational system has ever done previously – the public interest ***is alive here***, even if it has become jaded with regard to other space endeavors.

<u>Risk</u>

{1} National Asset Risks. The HSO (*nee* Large Space Telescope) came into the world with a budget of \$500 M (1978\$) and a 10% (\$50 M) reserve. By the time that is was actually launched in April, 1990, it was reported to have cost approximately \$1600 M (\$1.6 B, in mixed year dollars). The "CHALLENGER-replacement-orbiter," ENDEAVOR, procured in the late ‘80’s time frame was reported to have cost about \$ 2.1 – 2.2 B – the same order of magnitude as the HSO. Consequently, it is reasonable to assert that the HSO and the Shuttle Orbiters taken individually, all National Assets, are comparably valued, and the use of one (Orbiter) to extend the service life of the other (HSO) is a rational proposition.

{2} Personnel Risks. There are certainly human risks associated with the conduct of HSO Servicing Missions. However, four have been conducted to date (SM1, SM2, SM3A, SM3B), with 100% success on each and no personnel casualties or even "near misses." In the conduct of these missions 18 two-person extravehicular activities (EVA's or "spacewalks") have been conducted. HSO Servicing Missions are regarded by members of the astronaut cadre as "plum" or prize assignments. They offer the opportunity to undertake a challenging, ever different, assignment and to contribute to the ongoing success of a publicly revered National Asset. Set amidst the manifest of generally repetitious International Space Station (ISS) support and resupply missions, the HSO Servicing Missions are truly the gleaming stars of human space flight today.

In this post-COLUMBIA period of investigation, introspection, and recovery (Note that the Columbia Accident Investigation Board (CAIB) Report has not yet been released as I write this), it is true that each mission must be scrutinized under a more powerful glass. However, I believe that is safe to say that just as the loss of CHALLENGER drove such massive redesign that we have never subsequently had an SRB "O-ring" problem, the release of and reaction to the CAIB Report will insure that we never again lose an Orbiter as a result of any sort of insulation shedding or debris impact event. As I, who am not an astronomer, have refrained from attempting to evaluate one discipline relative to another, or one instrument *vs*. another, I implore This Committee to deliberate within your area of expertise and to leave the assessment and acceptance of Servicing Mission risks to those with both the experience and the vested interests in doing so. Specifically, This Committee should assess the value of an SM5 on the basis of its scientific merits (and demerits), and leave the decisions on risk to NASA Headquarters Codes M (Office of Space Flight) and Q (Office of Safety & Mission Assurance) and the NASA Johnson Space Center Codes CA (Flight Crew Operations Directorate), CB (Astronaut Office), and DA (Mission Operations Directorate).

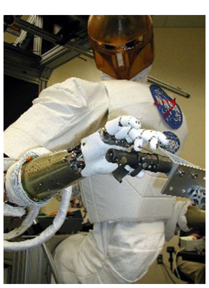
Allied with this “Personnel Risk” category is that of sunken personnel investment – by which I mean the non-trivial investments of time and career in bring the HSO to fruition. It is never possible to recognize all contributors, but I would like to mention Dr. Lyman Spitzer’s inspirational and guiding influences on the project – from 1946 onwards! In the later years of his life travel was such a burden upon him that he refused to leave Princeton – except for HSO Program Reviews at the NASA Marshall Space Flight Center!

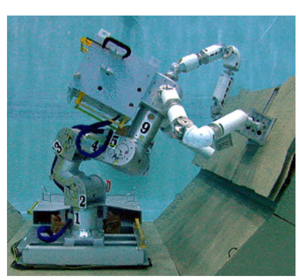
{3} Statistical Risks. From a *statistical* point of view, the James Webb Space Telescope (JWST) must be viewed as somewhat less than a certainty. I say this with no malice. Current launch vehicle expectations of success are in the 95 – 98% range, depending upon the detailed configuration. The JWST configuration is novel, and requires considerable post-launch reconfiguration to become fully operational. (Note for historical reference the “Galileo” space craft high gain antenna deployment jam; the failure of one Mars Global Surveyor solar array to latch in the fully extended position). Without presuming to pinpoint a specific (sub)system, it is likely that the JWST may have similar deployment or subsystem anomalies impacting its design-reference performance. Taking both of these (launch and system performance) probabilities of success at an arbitrary value of 95% yields an overall probability of total mission success of 90.25% – not bad, but not a total certainty either. Transition planning must protect a “fall back” position to indefinitely extend HSO operations in the event of a JWST contingency – after two decades of high quality space based optical astronomy, it would be truly regrettable if there materialized an avoidable disruption of significant duration.

Costs The NASA Space Transportation Architecture Study, Phase 3A, (STAS 3A) in the fall of 1999, provided as a study guideline the figure of a flat $2.4 Billion/year in operational costs for 5 – 8 Shuttle missions per year. Fewer than 5 flights/year was construed to be unsafe due to a loss of proficiency, and would result in greatly increased training exercises (and expenses) for the affected personnel. Greater than 8 per year incurred an incremental additional cost/ mission. These figures did not include crew training, mission operations, or payload related costs. The message, however, is that declining an SM5 from a cost savings perspective may reduce a line item in the Code S budget, but will provide an almost imperceptible saving to the U.S. Treasury or to us as taxpayers.

<u>Novel Concept for SM5</u> Following the highly successful Solar Maximum Repair Mission, I had the opportunity at the Goddard Space Flight Center to utilize a set of telemanipulators in a laboratory environment to carry out on a training mockup the task of replacing the main electronics box (MEB) of the Coronagraph-Polarimeter instrument. In the design and construction of the spacecraft there had been absolutely no provisions made for on-orbit servicing. In brief, it was necessary to remove a blanket of multi-layer insulation, install a piece of support equipment in the form of a hinge, remove about a dozen non-captive bolts, swing open the panel on which the MEB was located, install a "keep open" stay, disconnect 14 subminiature "D" connectors (each secured with two #4-40 fillister head screws), cut several cable ties, remove the panel carrying the MEB, and then reverse the entire process using a new MEB-panel assembly. In the nearly 20 years since this test took place the technology of space compatible telemanipulators has progressed substantially, but the devices themselves have had no real use.

Recognizing both that the JWST is not being designed for in-space serviceability nor repair (but I have cited several examples of difficult in-space repairs above) and that there are no plans in the foreseeable future that would support human access to the Earth-Sun L2 Libration Point where the JWST will be stationed, I propose the following approach to SM5 for the HSO. Baseline a "normal" servicing mission approach, refurbishing all systems requiring it, and exchanging SI's as appropriate. Train and fly a fully qualified EVA crew, but plan for total accomplishment of the servicing activities by means of (dexterous) telemanipulators. Such manipulators could be controlled from onboard the Shuttle, but would ideally permit ground-based operators to work "around the clock," relieving the "man-hours on-orbit" limitation and gathering experience in this mode of operations. In this manner we could get a realistic evaluation of the capabilities and flight experience with the relevant devices in a "can't fail" situation – with 100% on-scene EVA backup. There are at least three candidate systems for this task, and I have no personal involvement with any of them. They are (with small images included below, from left to right): the NASA JSC "Robonaut"; the University of Maryland, College Park, "Ranger"; and the Canadian "Special Purpose Dexterous Manipulator," bound for the International Space Station.





This approach to SM5 would get some genuine flight experience in telerobotic servicing under our collective belts, and possibly spread the cost over a broader base than just Code S. Having gained such flight experience, NASA would in my opinion be much more likely to undertake an expendable telerobotic assistance mission to the JWST should the need arise.

Closing In this first-person address to This Committee I would like to close by stating that I am immensely proud to have been in some small way involved in bringing the HSO to its current position as one of the premier astronomical observatories in the world. I am committed to working to insure that it is not prematurely allowed to deteriorate, and to insure the development of a telerobotic servicing capability potentially applicable to the JWST. Thank you for your consideration of these remarks.