

# **Using Life-cycle Human Factors Engineering to Avoid \$2.4 Million in Costs: Lessons Learned from NASA's Requirements Verification Process for Space Payloads**

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The Human Factors Implementation Team (HFIT) process has been used to verify human factors requirements for NASA International Space Station (ISS) payloads since 2003, resulting in \$2.4 million in avoided costs. This cost benefit has been realized by greatly reducing the need to process time-consuming formal waivers (exceptions) for individual requirements violations. The HFIT team, which includes astronauts and their technical staff, acts as the single source for human factors requirements integration of payloads. HFIT has the authority to provide inputs during early design phases, thus eliminating many potential requirements violations in a cost-effective manner. In those instances where it is not economically or technically feasible to meet the precise metric of a given requirement, HFIT can work with the payload engineers to develop common sense solutions and formally document that the resulting payload design does not materially affect the astronaut's ability to operate and interact with the payload. The HFIT process is fully ISO 9000 compliant and works concurrently with NASA's formal systems engineering work flow. Due to its success with payloads, the HFIT process is being adapted and extended to ISS systems hardware. Key aspects of this process are also being considered for NASA's Space Shuttle replacement, the Crew Exploration Vehicle.

## **Introduction**

NASA's science payloads account for most of the scientific research accomplished on the International Space Station (ISS), and their relative ease-of-use is critical given limited astronaut crew time available to conduct experiments. NASA's formal system engineering process for development of these space payloads includes formal rigorous tracking of all applicable requirements. The verification plan and verification testing are tracked individually for each requirement, and any requirement violation has to be resolved at a formal NASA payload review board. Although this process is effective in ensuring that all requirements are addressed, it resulted in a relatively large number of human factors requirements violations.

In fact, violations of human factors requirements accounted for about two-thirds of all waivers (exceptions) brought before the NASA payloads control board which formally accepted or rejected these exception requests prior to certification for space flight.

In 2002, managers of NASA's ISS Payloads Office began exploring options with NASA human factors engineering staff to reduce this high volume of human factor requirements exceptions coming before the payload control board. They noted an on-going, successful verification process for labeling, led by NASA human factors engineering. The ISS Payload Label Approval Team (IPLAT) has been in operation since 1998, and has virtually eliminated the need for labeling requirements

exceptions. The IPLAT process is invoked via a single requirement that authorizes the IPLAT team to evaluate and formally verify the entire set of labeling requirements.

The Human Factors Implementation Team (HFIT) process was developed to cover those human factors requirements not directly related to labeling, and was based on IPLAT. Early in this process, along with participation in design reviews, the HFIT team performs a preliminary evaluation of prototype or engineering hardware. Because of this early involvement, any design revisions needed to better accommodate human factors requirements are relatively inexpensive and sometimes cost free. During this preliminary evaluation, all potential requirements violations are formally tracked, and the HFIT team provides specific guidance on how to address each identified issue. As the design matures, HFIT personnel track progress in meeting requirements.

In some cases, it may not be feasible to meet the exact criterion of a given requirement. However, as long as the hardware developer has followed HFIT guidance, HFIT will work with the Astronaut office to do an operational evaluation of the science payload to assess the ease or difficulty of interacting with the payload. If the payload can be operated without significant usability problems, HFIT has the authority to close verification on such requirements without taking it before the NASA payload board.

The HFIT process has been in place since early 2003, and verification has been closed on more than 45 science payloads. Because of the greatly reduced need to prepare and approve payload requirements exceptions at formal NASA board proceedings, it is conservatively estimated that more than \$2.4 million in costs have been avoided. This is estimated by multiplying the number of avoided exceptions (160) by the average cost of preparing, revising, and obtaining approval for a given exception (\$15,000 - \$20,000 each). To date, this cost avoidance is conservatively estimated at  $160 \times \$15,000 = \$2.4 \text{ Million}$ . This cost benefit

is greater than contractor costs for salaries and travel.

### **Practice Innovation and Cost Benefit**

The innovation in human factors requirements integration relates to a process that succeeds in bringing three key aspects together. That is, the formal authority of HFIT team as the primary source for human factors verification that 1) performs preliminary evaluations and provides design guidance to payload developers during early stages of hardware development, 2) can resolve technical requirements violations without going before a formal NASA payload board as long as there is no significant operational impact, and 3) has virtually eliminated human factors requirements exceptions at NASA payload boards, thus avoiding \$2.4 million in cost over 4 years, more than compensating for the labor and travel costs of HFIT personnel.

#### *Early involvement of human factors*

Early involvement by human factors professionals is often cited as desirable in systems engineering of hardware and systems (Chapanis, 1996). This early involvement can identify human factors issues when multiple solutions can be considered, and design changes are not costly to implement, and may result in zero cost. Early involvement can be especially useful when human factors engineers actively suggest design options and design solutions, rather than simply enumerating problems in initial design. When human factors only provide inputs late in the process, identified human factors issues may be very expensive to resolve, and suboptimal designs may be accepted.

In terms of innovation in human factors practice, the key is the combination of multiple elements: 1) early involvement by HFIT, 2) authority HFIT has to resolve technical requirements violations on its own, and 3) demonstrated cost benefit.

Technically, using the HFIT process is an option for payload developers—they can use the “old” process where the payload developer is responsible for tracking and verifying each single requirement.

And if the exact technical metric of a requirement can't be met, the developer is responsible for going before a formal NASA control board before their payload can be certified for flight. However, the HFIT process has a credible track record of saving hassle, time and money for payload developers. Virtually all payload developers which started processing since 2003 have voluntarily chosen the HFIT process. Once the HFIT process is chosen, the early involvement of HFIT engineers is specifically called for—including a preliminary evaluation, enumeration of all potential human factors requirements issues, and specific suggestions for resolving these issues. HFIT also participates in design reviews. Because the HFIT team has extensive experience with requirements verification for multiple payload designs, they are able to provide design suggestions that address the intent of all requirements, and are feasible, cost effective, and practical to implement.

Another aspect of the HFIT process that enhances its credibility with payload developers is the “fairness principle.” This effectively means that if developers provide access to all pertinent design information during the preliminary evaluation, and follow the specific suggestions to resolve all identified requirements issues, there won't be any surprises during subsequent evaluations (HFIT doesn't change the rules on them). That is, no brand new issues will somehow surface later that could impact the cost or schedule for the hardware, except identification of newly discovered safety issues.

#### *Resolution of technical requirements violations*

In some cases, it may not be technically feasible to meet the specific metric of a requirement. For example, there are requirements for minimum spacing between control switches, but the small, fixed size of front panels on some payloads limits the space available to provide separation between controls. In such cases, HFIT has the authority to work with crew astronaut office to evaluate the operational usability of the payload interface with such technical requirements violation(s). If the HFIT team and astronauts office determine there is not a significant degradation of operational

usability, HFIT has the authority to formally resolve this issue on its own without the lengthy and costly process of presenting an exception before a NASA control board.

#### *Cost benefit*

The cost benefit estimate for the HFIT process is based on costs avoided by not having to prepare formal exception documentation and presentation(s) for NASA payload control board. Based on formal records kept for the ISO 9000-compliant HFIT process over the four years from 2003 through 2007, there have been 160 technical requirements violations that have been resolved via HFIT process, thus avoiding the cost of presenting exceptions before a NASA control board. A review of historical cost data revealed that approximately 1.67 – 2.2 person months were required to prepare, revise, process, and present the technical details necessary to successfully receive NASA control board approval for a human requirements exception. The effective hourly rate for technical personnel that do this work is estimated at \$56/hour (in 2005 dollars), including salary, benefits, contract management overhead, etc.

The average cost for processing a single exception is then:

$$(1.67 - 2.2 \text{ person-months}) \times (160 \text{ work hrs./mo.}) \\ \times (\$56/\text{hr.}) = \underline{\$15\text{K} - \$20\text{K per exception}}$$

The total cost benefit over the four year period is then:

$$(\$15\text{K}-\$20\text{K per exception}) \times 160 \text{ exceptions} = \\ \underline{\$2.4 - \$3.2 \text{ million total cost benefit}}$$

This cost benefit is greater than contractor cost for salaries and travel.

It is important to note that this is a conservative estimate of the cost benefit from HFIT. First, the only source of savings considered is from technical requirements violations that are handled by HFIT. The early involvement of HFIT likely leads to complete resolution of many key requirements issues—i.e., a cost-effective design solution is found for a given requirement, and HFIT doesn't

have to do an operation usability assessment because there is no technical requirements violation. Second, another source of savings for payload developers is that HFIT, not the payload developer, performs the actual tracking and verification of human factors requirements. Also, because payloads are better human factored, NASA saves valuable astronaut time on board ISS, leading to more time for scientific research. An example of astronaut research using Microgravity Science Glovebox is shown in Figure 1.



Figure 1. Astronaut Jeff Williams conducting science experiment using Microgravity Science Glovebox (MSG).

#### *NASA space payload context*

When considering how this process innovation may relate to other systems engineering processes, it is important to understand the NASA context, and how it is similar to and different from other situations. There are basically two key areas to consider—1) payload will be launched into space and used aboard the ISS, and 2) the unique systems engineering and administrative context for NASA payloads processing.

First, the hardware items being developed are space payloads—they will be used by astronauts in microgravity and must withstand increased gravity and vibrations during launch. Because of the space context, there are also severe limits on weight and power usage. It costs approximately \$10,000 a pound to launch space cargo, and there is limited electrical power available to power equipment. Another constraint is limited astronaut time available to conduct science experiments, and thus the consistency of crew interfaces helps to conserve valuable astronaut crew time.

Second, the NASA payload process includes about 125 human factors requirements (not including labeling requirements) that are formally documented (NASA, 2006). All of these requirements are directly assessable via inspection or straight forward measurement. Some requirements examples include maximum force needed to actuate a control, minimum spacing between controls, and the color and reflectivity of paint or decals on the front panels of payload hardware. Another aspect of these requirements is that the criterion measurements are repeatable. Different human factors engineers can measure the same criterion and get the same answer. No complex usability evaluations are necessary to verify these requirements.

In terms of the formal systems engineering methods, the NASA system is similar to other military and governmental systems. The multi-stage process includes familiar milestones such as preliminary design review, critical design review, etc. The HFIT team is cognizant of these design process milestones, and HFIT evaluations are coordinated to coincide with design reviews.

#### **Findings**

The HFIT process at NASA is now in its fifth year of successful human factors verification for space payloads, and has virtually eliminated human factors requirements exceptions being presented at the NASA control board. This has resulted in conservative cost benefit estimate of \$2.4 million over four years, or \$0.6 million per year.

Even though the use of HFIT is a voluntary choice for payload developers, virtually all developers have chosen HFIT to save time and money. This has been especially beneficial to some of the smaller payload developers who have limited or no experience developing NASA payloads, such as small university laboratories who want to develop science experiments that require micro gravity. HFIT helps developers from early design stages through final bench reviews when payloads are formally certified for a specific space flight to ISS.

In every case, the HFIT team has been involved at early design stages, and has provided specific guidance on how to address potential human factors requirements issues identified during the preliminary evaluation. Later, requirements verification has been conducted by inspection and measurement of actual flight hardware.

Finally, it's important to note that the success of HFIT has led to its adoption beyond payloads—the HFIT process is now being adapted to apply to all new systems hardware being developed for ISS, including a new exercise treadmill and new waste and hygiene compartment. Key aspects of this process are also being considered for NASA's Space Shuttle replacement, the Crew Exploration Vehicle.

### **Discussion and Lessons Learned**

Even though the successful HFIT process is used for unique domain of space payloads, the benefits of using this process should be able to be generalized to other systems engineering contexts. The considerations and limits to generalization are discussed below, along with selected lessons learned.

The previous success of NASA's labeling verification process, IPLAT, was a key reason that HFIT was even considered, and IPLAT also served as a model for the development of HFIT process. IPLAT had been developed and successfully implemented for the relatively narrow domain of labeling requirements. Although somewhat broader in scope, HFIT requirements are similarly focused on directly assessable requirements that can be verified by direct inspection or straightforward measurement. The criterion measurements for HFIT verification are also highly repeatable. Additionally, the face validity of HFIT requirements is readily discernable and easy to communicate to payload developers.

The successful track record of IPLAT also led to acceptance of voluntary HFIT process by payload developers. The successful use of HFIT process has

led to further credibility of HFIT, and Payload Integration Managers (PIMs), who are responsible for shepherding payloads through the entire NASA systems engineering process, all recognize HFIT at the focal point for human factors requirements integration.

The early involvement of HFIT, combined with HFIT's authority to resolve technical requirements violations without NASA board approval is perhaps the key generalizable finding, and directly contributed to the \$2.4 million cost benefit.

### **References**

Chapanis, A. (1996). Human factors in systems engineering. New York, NY: Wiley:

NASA (2006). Pressurized payloads interface requirements document (IRD). Houston, TX: NASA Johnson Space Center. (NASA No. SSP57000, Rev. F)