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NASA-STD-3001, Space Flight Human-System Standard and the Human Integration Design Handbook

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Abstract

NASA-STD-3001 Space Flight Human-System Standard Volume 1, *Crew Health,* Volume 2, *Human Factors, Habitability and Environmental Health,* and the Human Integration Design Handbook (HIDH) have replaced the Man-Systems Integration Standards (MSIS), NASA-STD-3000. For decades, NASA-STD-3000 was a significant contribution to human spaceflight programs and to human-systems integration. However, with research program and project results being realized, advances in technology, and the availability of new information in a variety of topic areas, the time had arrived to update this extensive suite of standards and design information.

NASA-STD-3001, Volume 2 contains the Agency level standards from the human and environmental factors disciplines that ensure human spaceflight operations are performed safely, efficiently, and effectively. The HIDH is organized in the same sequence and serves as the companion document to NASA-STD-3001, Volume 2, providing a compendium of human spaceflight history and knowledge. The HIDH is intended to aid interpretation of NASA-STD-3001, Volume 2 standards and to provide guidance for requirement writers and vehicle and habitat designers.

Keywords
Human Factors, Standards, Environmental Factors, NASA

1. Introduction

In order to ensure that each human is safe and capable of operating in the extreme environment of space, NASA has established human-system integration standards and guidelines. The standards support challenges such as high vibration, microgravity, isolation, high workload, and support the highest levels of safety and effective/efficient human performance. NASA standards provide an established foundation for developing technical requirements across programs or projects. These standards are used by programs (such as the International Space Station and Orion) to write requirements for space vehicle/habitat design, fabrication and assembly, verification and validation, acceptance, operations, and maintenance. Standards are informed from a variety of sources including research, operational experience, and technology development. As advancements are realized they are documented within NASA standards and subsequent guidance documentation such that the information can be made available to programs and projects.

For decades, NASA Space Flight Human-System Standard (NASA-STD-3000), Man-Systems Integration Standards [1] has been considered the premium standard on human-system design for human spaceflight. It has been a significant contribution to human spaceflight programs and to human-systems integration in general. The document has been referenced in numerous design standards both within NASA and by organizations throughout the world (for example see [2]).

With advances in technology, the availability of new information in a variety of topic areas, and emerging new topics, it has been a challenge to keep the information within the NASA-STD-3000 up-to-date. The solution adopted was breaking NASA-STD-3000 into multiple documents; that is, separating the standards from supporting guidelines, lessons learned, and explanatory text. After several years of multi-center collaborative work, NASA-STD-3000 was replaced with a suite of documents reflecting scientific and technicological advances, re-organized to not only ensure that the most current information is available, but that it is in a usable format. The replacement standards consist of the NASA Space Flight Human-System Standards (SFHSS) NASA-STD-3001, Volume 1, *Crew Health* and Volume 2, *Human Factors, Habitability and Environmental Health* [3], and an accompanying Human Integration Design Handbook (NASA/SP-2010-3407, HIDH) [4].

The two-volume set of NASA-STD-3001consists of Agency-level standards, established by the Office of the Chief Health and Medical Officer, that define levels of acceptable risks to crew health and performance resulting from space flight. Volume 1 of the SFHSS sets standards related to crew health. Volume 2 defines the human factors, habitability, and environmental health standards that are related to environmental health and human-system interfaces during human space flight. The HIDH, which is the companion document to Volume 2, provides the background information, design guidance, and research data that support the Volume 2 standards. Splitting the guidance content from the standards provides a more usable product, for less cost. Figure 1 illustrates authority levels and flow-down from NASA Policy Directives (NPD), NASA Procedural Documents (NPR), and Standards to Program and lower-level requirements and specifications. The figure also shows that content of the HIDH interplays with the content of documents at multiple levels. During program level requirements development, the HIDH serves to assist requirements writers in tailoring the Agency standards for the purposes of meeting program specific mission goals and objectives, concurrently with meeting the intent of the standards. The HIDH is also a reference for designers attempting to meet program requirements, offering lessons learned and experience from previous space flight programs.

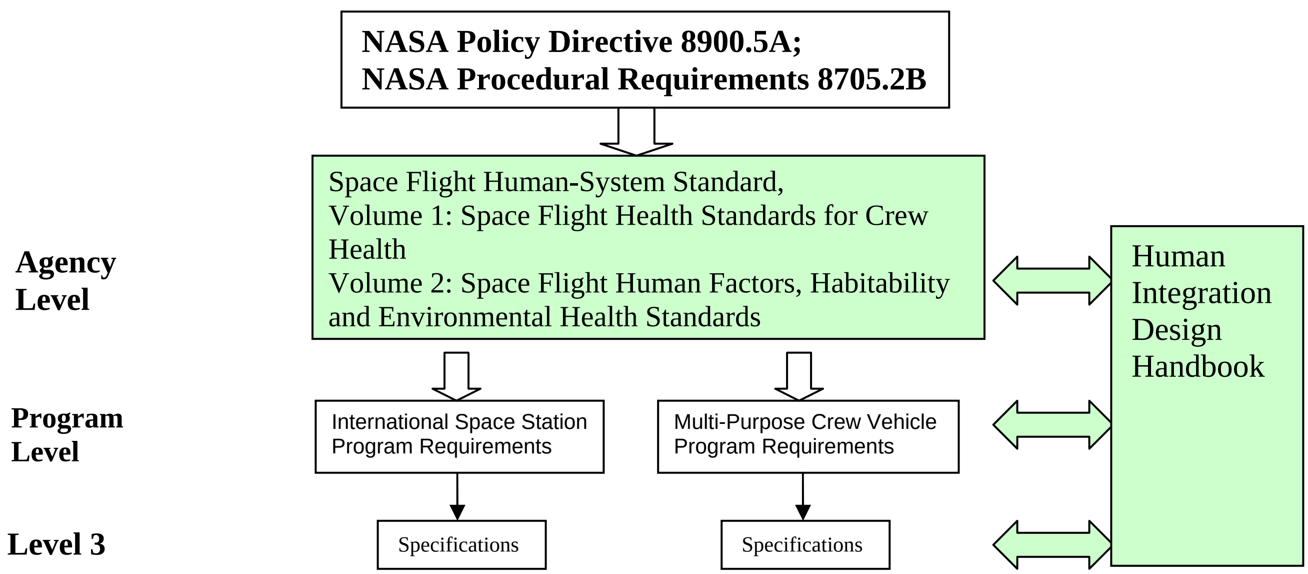

Figure 1. Relationship of NPD 8900.5A *NASA Human Health and Medical Policy for Human Space Exploration,* NPR 8705.2B *Human-Rating Requirements for Space Systems,* the Space Flight Human-System Standard and the Human Integration Design Handbook, and program requirements and specifications.

NASA-STD-3001 Volume 2, and the HIDH which follows the same sequence as Volume 2, is divided into sections for program implementation, physical characteristics (such as body length and range of motion), perception and cognition, natural and induced environments, habitability functions (such as hygiene, sleep and stowage provisions), architecture (such as windows and passage ways), hardware and equipment, crew interfaces, spacesuits, operations, and ground maintenance and assembly (ground processing).

2. NASA-STD-3001 Volume 2 - General and Specific Standards

The standards in NASA-STD-3001 Volume 2 are phrased using *shall* statements to indicate design direction that must be followed (e.g., *Displays and controls shall be grouped according to purpose or function*). These *shall* statements are a collection of both general and very specific criteria. In some cases, research and experience have determined a need for a specific configuration or a specific set of environmental limits to maintain human health and productivity. These specific standards apply to all possible space missions and are not expected to ever change. For example, "*The system shall provide a minimum of 2.0 kg (4.4 lb) of potable water per crewmember per mission day for drinking.*" is designed to ensure that each human on each mission has enough drinking water available to prevent dehydration. In this case, enough is known about the water needs of the human body to allow for a specific standard to be written.

For instances where research and experience have not determined a clear limit or solution to a particular problem, standards are expressed in more general terms as design and performance principles. Thus, tailored requirements may vary from program to program, with such factors as crew size, mission duration, and gravity environment. The method for meeting the intent of general standards may vary from one system or mission to another. There is no single, global method of meeting the intent of the general standards, rather a method is specified for each human space flight mission that meets the intent of the general standard

For example, Volume 2 states "*Body length data developed in accordance with section 4.1, Physical Data Sets, in this Standard shall be applied to the design of all elements of system, hardware, and equipment with which the crew interfaces to ensure that crew tasks can be efficiently and effectively performed.*" The program requirement writers will need to assess the data set and determine the requirements to impose based on the program mission duration, and other relevant mission criteria. Another example taken from the crew interfaces section, "*Each program shall define usability acceptance criteria for crew interfaces.*" Efficiency, effectiveness, and satisfaction are the three major components of usability; therefore, acceptance criteria for one or more should be defined and applied by the program. The NASA Constellation Program worked with the Human Research Program to define the usability limits for the crewed vehicle. They decided on a measure of effectiveness, specifically error rates. In contrast, the NASA Commercial Crew Program has decided to include a requirement for effectiveness (error rates) and satisfaction. The standard places the discretion with the program. However, the HIDH provides the supporting material to help make the decision and generate the program requirements.

3. HIDH

The HIDH provides guidance for the crew health, habitability, environmental, and human factors design of all NASA human space flight programs and projects.

The two primary uses for the HIDH are to

- Assist in the preparation of contractual program-specific human interface, habitability and environmental health requirements – Users include program managers and system requirement writers.
- Assist in the development of designs and operations for human interfaces in spacecraft environments – Users include human factors practitioners, environmental health experts, engineers and designers, crews and mission / flight controllers, and training and operations developers.

The HIDH is divided into 13 chapters, the last 9 of which address the range of human operations in space (see Table 1). Each chapter is divided into sections devoted to specific topics.

Table 1: HIDH Tables of Contents

Chapter No	Section/ Paragraph Title	Description
1	Scope	This chapter defines the scope and explains the content and use of the handbook.
2	Applicable Documents	This chapter lists the Government and non-Government documents applicable to the handbook. Each chapter also contains a list of references cited in that chapter.

3	Process and Requirements	This chapter contains general guidance on developing program-specific requirements and developing a human-system integration process throughout system design.
4	Anthropometry, Biomechanics, and Strength	This chapter includes information about the physical size, shape, reach, range of motion, strength, and mass of crewmembers. It explains how to determine the correct data for a project and how this information should be used to create a design that fits the crew.
5	Human Performance Capabilities	This chapter covers the physical, cognitive, and perceptual capabilities and limitations of humans in space flight. Topics covered include physical workload, visual and auditory perception, and cognitive workload.
6	Natural and Induced Environments	This chapter defines the habitable range for environmental factors (air, water, contamination, acceleration, acoustics, vibration, radiation, and temperature) that will ensure that humans can perform safely and effectively.
7	Habitability Functions	This chapter provides design considerations for the daily functions of the crew inside the spacecraft, including eating, sleep, hygiene, waste management, and other activities to ensure a habitable environment.
8	Architecture	This chapter provides guidance for the development and integration of overall spacecraft size and configuration, and layout of location and orientation aids, traffic flow and translation paths, hatches and doors, windows, and lighting.
9	Hardware and Equipment	This chapter provides overall human factors guidelines for the design of hardware and equipment such as tools, drawers and racks, closures, mounting hardware, handles and grasp areas, restraints, mobility aids, fasteners, connectors, visual access, packaging, clothing, and crew personal equipment.
10	Crew Interfaces	This chapter covers the design of interfaces through which information is exchanged between the crew and the systems. Topics include: visual/audio displays, controls, and labels.
11	Extravehicular Activities	This chapter covers the human factors design guidelines for EVA's performed by suited crewmembers outside the pressurized environment of a spaceflight (during space flight or on a destination surface). It also addresses off-nominal operations performed inside unpressurized space craft.
12	Operations	RESERVED
13	Ground Maintenance and Assembly	RESERVED

4. Example 3001 Standard and Corresponding HIDH Material

NASA-STD-3001 is most often used to generate program requirements (it also can be used as a design reference). To do this, the writer must first have a full understanding of proposed program mission goals and objectives. The writer will then refer to NASA-STD-3001 (Volume 1 and 2) and determine which of the standards are applicable to the specific program mission goals and objectives. The review proceeds to the corresponding content in the HIDH, and then a program level requirement is generated from that content. For the limit specific standards in NASA-STD-3001 that are applicable to a specific program mission goals and objectives, the standards can be used in the program document as stated. However, the general standards in NASA-STD-3001 (Volume 1 and 2) may need to be tailored to fit the mission environment. The process of generating program requirements is depicted below (Figure 2 and text below).

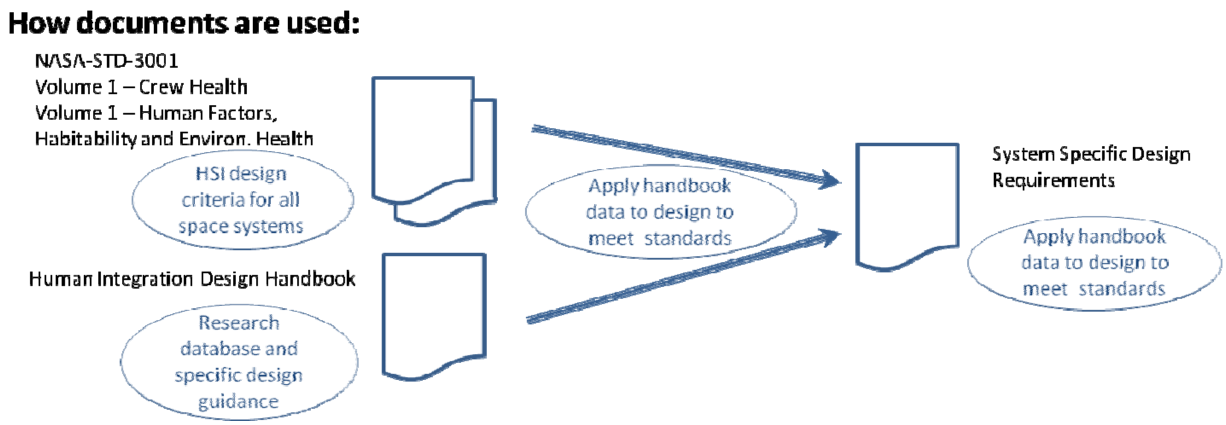

Figure 2. Process for generating system specific requirements (program requirements) from NASA-STD-3001 and the HIDH.

1. The Standard

NASA-STD-3001 Volume 2 contains the following standard:

7.4.1 Physiological Countermeasures Capability [V2 7038]
The system shall provide countermeasures to meet crew bone, muscle, sensory-motor, and cardiovascular standards defined in NASA-STD-3001, Volume 1.
Rationale: Exercise is used to maintain crew cardiovascular fitness (to aid in ambulation during gravity transitions and to minimize fatigue), to maintain muscle mass and strength/endurance, for recovery from strenuous tasks and confined postures, and to rehabilitate minor muscle injuries. Exercise is to commence as early as possible during the mission and continue throughout all mission phases in accordance with results from the Apollo crew's participation in the June 2006 Apollo Medical Summit (NASA/TM-2007-214755, The Apollo Medical Operations Project: Recommendations to Improve Crew Health and Performance for Future Exploration Missions and Lunar Surface Operations), and recommendation from the 2005 Musculoskeletal Summit. See Appendix A, Reference Documents, for complete citations.

NASA-STD-3001 Volume 1 contains related standards:
- 4.2.3 Fitness-for-Duty Aerobic Capacity Standards
- 4.2.4 Fitness-for-Duty Sensorimotor Standards
- 4.2.8 Permissible Outcome Limit for Muscle Strength Standards
- 4.2.9 Permissible Outcome Limit for Microgravity-Induced Bone Mineral Loss Performance Standards (Baseline with Measured T-score)

2. The Handbook

The corresponding section in the handbook shows different methods for meeting the standard and discusses when they are applicable. For our example, HIDH Chapter 7 Habitability Functions provides design considerations for the daily functions of the crew inside the spacecraft, including dining, sleep, hygiene, waste management, and other activities to ensure a habitable environment. Specifically, HIDH Section 7.5 discusses countermeasures, providing general considerations (see Figure 3), types of countermeasures, volume and dimension considerations, location considerations, interfaces, and stowage needs. In order to meet the Volume 2 standard, one must consider the physiological countermeasure appropriate for the mission duration, but also stowage of the equipment, deployment operations and volume, restraints for operation in microgravity, etc. The HIDH content addresses all of those topics, offering the information along with historical space flight experiences and lessons learned. For example, in the context of aerobic devices, the HIDH offers this historical information, "*The first spaceflight treadmill was developed for Skylab 4 to mitigate aerobic deconditioning and fluid volume loss. The treadmill design was a Teflon®-coated aluminum walking surface attached to the iso-grid floor with a bungee-harness system capable of applying an external load of 80 kg. Locomotion was similar to walking up a slippery hill, which caused premature muscle fatigue and thus could not be practiced for a significant duration. The next-generation treadmill was* *nonmotorized (a crewmember was required to actively move the belt) and crewmembers were tethered to the treadmill with a bungee-harness system. This treadmill was used only for experimental purposes on Space Shuttle missions. The treadmill with vibration isolation system (TVIS) aboard the ISS is mounted to a vibration isolation system and is motorized; therefore, it can be used in either the active or passive mode. At this time, because the TVIS has been in use for only a short time, it is not possible to draw conclusions about its physiological effectiveness*."

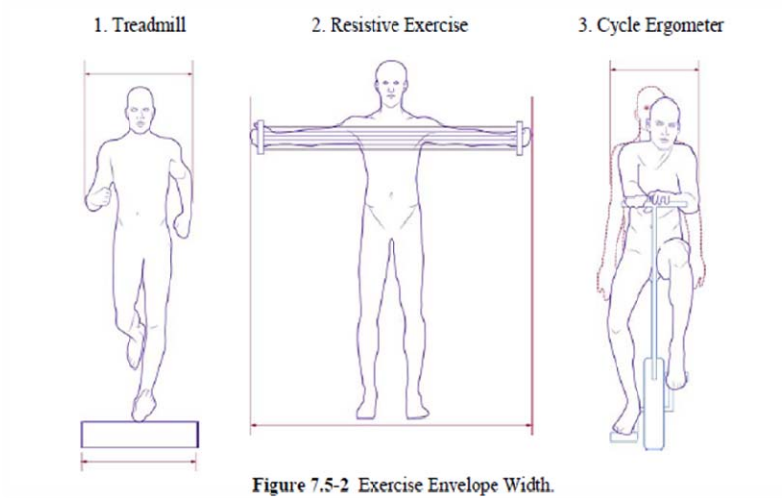

Figure 3. A figure from NASA-STD-3001 Volume 2 showing the exercise envelope width of three possible physiological countermeasure devices.

3. The Program

Individual programs will use the information in the handbook to develop a system-specific requirement for meeting the standards in NASA-STD-3001. For example, the MPCV program (Orion, formerly part of the Constellation Program) has all of its human-systems requirements in the Human Systems Integration Requirements (HSIR) document. The HSIR contains the following requirement related to physiological countermeasures, based on a design reference mission entailing a Lunar landing.

3.5.4.1.1 Exercise Capability [HS6032]
The system shall provide the capability for aerobic and resistive exercise training for 30 continuous minutes each day per crewmember for missions greater than 8 days.
Rationale: An exercise capability is not required on Orion missions to the ISS or for missions with total durations of less than 8 days. Exercise is required on Lunar missions greater than 8 total days to maintain crew cardiovascular fitness (to aid in ambulation during g- transitions and to minimize fatigue), to maintain muscle mass and strength/endurance (to complete mission tasks such as EVA walk-back and contingency response capability,) and for recovery from strenuous tasks, confined postures, and to rehabilitate minor muscle injuries. Per the Apollo crew participating in the June 2006 Apollo Medical Summit (Houston, TX) and recommendation from the 2005 Musculoskeletal Summit, exercise should be commenced as early as possible during the mission and continue throughout all mission phases. Exercise will not be required on launch day, landing day, days that include ascent to and descent from the lunar surface, and on contingency, non-wave off days. Given these exclusions, it is expected that exercise will be performed in the Orion on up to 11 days of a maximum 18-day Orion stay. Expected CO2, heat, and water output can be found in Appendix E, table Crew Induced Metabolic Loads for a Standard Mission Day With Exercise.

The use of the information in the handbook allows the program requirements writers to tailor the Volume 2 standard to meet programs mission needs, while still meeting the intent of the standard.

5. Document Maintenance

Document maintenance is an on-going process aimed at ensuring that programs are informed with the most recent information. This means that advances in research and technology and lessons learned from current and past space flight programs must be continually documented or updated. Advances in research are particularly important in that the findings may directly impact how the intent of a standard is met, changing a standard from general to specific (or vice versa), or updating specific criteria to a more sensitive value. As an example, the cognitive workload standard within Volume 2*"Cognitive workload shall be accommodated (to avoid overload or underload) in the design of all system elements that interface with the crew for all levels of crew capability and all levels of task demands."* is general and allows for flexibility in interpretation for each implementation of the requirement. Research aimed at determining a method for measuring cognitive workload could alter this standard such that a limit is provided. However, should the research determine that there is no single method for measuring cognitive workload but that several methods are applicable to different scenarios then these should be captured within the HIDH and provided as guidance information.

Each Standard is updated every five years, while the HIDH is updated every two years. The HIDH needs to be updated more frequently to ensure that it contains the most recent information available. The document updates involve collaboration across multiple centers at NASA, as well as engagement of subject matter experts in industry and academia.

6. Inputs to NASA-STD-3001 and the HIDH

In addition to the importance of structuring the documents for ease of updating, the mechanism for developing new technical content is also an important consideration. Content for these documents frequently comes from 1) lessons learned from developmental and operational programs and projects and 2) NASA-funded research through the Human Research Program (HRP). The HRP has two main responsibilities regarding these standards. In some cases, a NASA-STD-3001 standard is written in generic terms to ensure its applicability to a wide range of mission environments (such as microgravity in orbit, lunar surface habitation, or transit to Mars). HRP research can serve to inform the standard, refine the standard, and help define processes or methods to meet the standard (cutting edge or state of the art). Where emerging evidence or knowledge may indicate that the standards are not written in a way that captures a complete set of relevant considerations, additional research may be conducted to facilitate an update.

The HRP approach is Evidence → Risk → Gap → Task → Deliverable (e.g., a standard). Reviews of the accumulated evidence from medical records, spaceflight operations and research findings are compiled into the HRP Evidence Book, providing the basis for identifying the highest priority human risks in space exploration. In order to maintain NASA-STD-3001, Volumes 1 and 2, all instances where standards cannot be met by a space flight program and the plan to mitigate the risks associated with unmet standards are documented. All instances where standards are not met can be categorized as risks to the human system. Other risks may include gaps in standards stemming from new mission needs (such as travel to a near Earth asteroid). For each risk requiring research, HRP identifies gaps in knowledge about the risk and the ability to mitigate the risk and lists them in the Integrated Research Plan (IRP). The IRP defines the tasks that will provide the deliverables required to fill the gaps. Research tasks are targeted at better defining a risk, or developing mitigation strategies to reduce the risk to an acceptable level. Common deliverables include recommended standards (such as Permissible Exposure Limits), flight rules (such as avoiding certain exposure levels), processes, countermeasures and technology. [5]

7. Future Developments

7.1 Expansion of Topics

When NASA-STD-3001 Volume 2 was baselined in 2010 Sections 12 and 13 were marked reserved. These sections address operations and ground processing, respectively. Over the next few years NASA will work to develop and baseline the appropriate crew operations and system design for support operations (i.e., ground processing) standards for Volume 2 and the supporting information for the HIDH. The design for crew operations focuses on incorporation of human factors and habitability considerations into mission activities to ensure the crew can effectively and safely execute the mission objectives. The crew operations content is related to the scheduling of crew activities, crew training, and crew procedures, that occur prior to and during a mission. The information on system design for support operations pertains to flight systems, hardware, and equipment that are accessed, used, or interfaced in some way by personnel other than the space flight crews. This includes such topics as hatches, passageways, inspection points, and emergency equipment, as well as pre-flight and post-flight activities. The content also addresses "common" systems for the two user populations, emphasizing that space flight crew and ground personnel are to be accommodated in system design.

7.2 Documentation of Processes

NASA is currently working to develop a Human-Systems Integration Processes (HSIP) document as a companion to NASA-STD-3001 and the HIDH. As part of NASA's critical documents development such as standards, regulations, guidelines, etc, dealing with human-systems integration, there is a need to document the processes and tools for integrating humans with space systems. The goal of the HSIP is to document processes that will aid in vehicle/habitat design and verification, and/or improve HSI at NASA. The HSIP will be a compendium of human-systems design "how-to's," describing the processes, methodologies, and best practices used by NASA as a result of lessons learned and legacy space system standards. The key is to include humans throughout the design lifecycle no matter what type of vehicle or habitat is being designed.

Some of the topic areas may include:

- User task analysis
- Usability evaluation
- Design for crewmember physical characteristics and capabilities
- Acoustic noise control design
- Functional volume design
- Radiation shielding design
- Display format design
- Occupant protection design
- How to plan a human-in-the-loop (HITL) type verification event, verifying multiple requirements in one event.
- Accounting for deconditioned crew, including post-landing operations.
- How to write a requirement from a standard.
- How to verify the legibility requirement.
- Accounting for vibration in crew performance.

7.3 Interactive Web Development

The concept of providing the information in NASA-STD -3001, Volume 2 and the HIDH in an interactive website is a necessary next step in informing the community of NASA standards and lessons learned as well as providing current users a sophisticated, interactive format for accessing the data. An added benefit to the standard and handbook team is the capability for users to provide feedback related to usage and updates that need be made to the information.

The features and capabilities of such a website include:

- A system that allows users of the standard and handbook simple data location, access, storage, retrieval, application, and comment.
- Simple access to supporting materials such as a glossary, abbreviation index, and measurement units and conversions.
- Ability to filter, flag, and store interested portions of the standard and handbook.
- A means to search standard and handbook contents.
- Ability to provide comments and suggested revisions to materials.
- Ability for caretakers of the standard and handbook to retrieve, store, and review user comments.
- Ability for the standard and handbook caretakers to revise and supplement the content and to track and maintain a record of the changes.

8. Conclusions

HSI standards and supporting guidance documents are important tools for ensuring that human capabilities and limitations are considered and accommodated during space vehicle design. At NASA the suit of NASA-STD-3001 Volume 1 and 2, and the HIDH provide the technical standards and guidance for the design, selection, and application of hardware, software, processes, procedures, practices, and methods for human-rated systems. The inputs to these documents come from the HRP evaluation of human space flight gaps and from lessons learned from developmental and operational space flight programs (such as ISS). The documents benefit from expert inputs from within and outside of the NASA community, which makes the content first-rate. NASA-STD-3001, Volumes 1 and 2, and the HIDH can be found at the following link:

http://www.nasa.gov/centers/johnson/slsd/about/divisions/hefd/standards/index.html

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