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Title: **Enhancing the Human Factors Engineering Role in an Austere Fiscal Environment**

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In response to this concern, planning is ongoing to correct the acting issues. Herein are techniques for ensuring that human interface requirements are integrated into a flight design, from proposal through verification and launch activation. This includes human factors requirements refinement and consolidation across flight programs; keyword phrases in the proposals; closer ties with systems engineering and other classical disciplines; early planning for crew-interface verification; and an Agency integrated human factors verification program, under the "One NASA" theme. Importance is given to communication within the aerospace human factors discipline, and utilizing the strengths of all government, industry, and academic human factors organizations in an unified research and engineering approach.

A list of recommendations and concerns are provided in closing.

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ABSTRACT

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INTRODUCTION

The aerospace community finds itself in a fiscal environment with shrinking funding, even as the space missions and vehicles become ever more advanced and complex. Federal funds and related private contracts require all aspects of the aerospace industry to push for more with less. Addressed herein are human factors engineering concerns and recommendations for a healthy discipline with limited funding in the aerospace industry, based on experience with the various NASA space station programs.

DISCIPLINE NEED

History has established the need for Human Factors Engineering, initiated in the aircraft industry and evolving into spacecraft design. Once NASA was able to define the human operating constraints for spaceflight, it understood the need to apply limitations, requirements, and standards for making the spacecraft design more amenable to crew interaction. In the discipline, the human is considered a subsystem in an integrated spacecraft system. Hence the human provides input to and receives input from all other operating flight sub-systems, thereby guaranteeing a successful flying system.

Through time, NASA has learned the importance of having a human interacting with the spacecraft equipment and software. Programs can utilize the human as a low cost option to expensive automated systems for science research, systems maintenance, and vehicle repair. On-site humans can quickly provide data to response teams and assess realtime the problem or concern. Likewise, the on-orbit human can create innovative repairs for safe return to nominal operations. The option of being directly at the problem source and assessing the problem with all the human senses and cognitive capability provides the mission manager with the most cost effective chance for mission success. Additionally, the on-orbit human can provide mid-term corrections in mission plans and even permit expansion of mission scope (e.g., Comet Kohoutek studies on Skylab). The *cost of placing the human in the spacecraft is insignificant relative to saving an* expensive extended–mission space vehicle via remote sensing and operations.

Human Factors Engineering (HFE) in aerospace design is crucial if the human must participate in any form of the mission, including activation, operation, or maintenance of the space vehicle. It is the objective design approach for validating the human as a spacecraft subsystem or component. Even for missions not transporting flight crew, HFE must be applied to the vehicle design to safely and efficiently prepare it for flight. A cost-effective flight design includes HFE at the planning stage and is utilized throughout the design activity. Otherwise, tradition demonstrates that it will either be applied as only an overhead discipline or left to the operations community to resolve post design and assembly design discrepancies.

In the current International Space Station (ISS) program (and the previous Space Station Freedom program), HFE implements and assesses the crew interface operational and design requirements to accomplish long-term missions. The discipline interfaces with Safety and Mission Assurance, Logistics and Maintenance, and Systems Engineering for safe and maintainable designs. The HFE design requirements, once implemented, provide definable human/equipment interfaces for the mission operations organizations, allowing the flight crew and ground operators to successfully interact with the integrated spacecraft. In summary, HFE is absolutely required for a successful space mission utilizing flight and ground crews.

CONCERN

Early in the human spaceflight programs, when full funding was more readily available, the HFE discipline was adequately embraced. However, in recent years, a more austere fiscal environment in the aerospace community has created pressures to reduce program costs. Often questioned by budget-conscious managers is HFE as possibly an inconsequential or soft discipline. On occasion, management, without a clear understanding of HFE and its benefits, and citing soft HFE requirements, has not utilized qualified HFE personnel and/or research/test facilities. The cost of such decisions has resulted in decreased mission and crew productivity, even to the point of crew impairment; e.g., physiological problems from use of a poorly funded and designed glovebox flown **on USML1/STS 50 mission (1).**

Management, when not fully understanding the cost and performance benefits of a proper HFE design, has minimized or even, in some cases deleted the human interface requirements from the design process. This situation occurred most recently in a Node 3 subsystem experiencing reduced funding, though with proper enlightenment the situation was subsequently corrected. Here, subsystems managers assumed that the Systems Engineer could provide the HFE design, and that the crew would make design input when required. However, no crew reviews were ever planned. The design team has now accepted the HFE design input and they continue to recover with a crew-compatible design. A previous example of reduced funding was the deletion of EVA crew worksite and translation path interfaces to the Skylab Earth Resources Experiment Package, mounted to the Skylab exterior, thereby eliminating the possibility of repairing failed experiment instruments realtime (2). Management, in a cost savings effort, decided that the science instruments were to be robust enough to survive for the life of the mission without crew repair support. Sensors failed without the possibility of crew-provided recovery. With an assumption that the flight crew can recover realtime from a poorly human factored space vehicle design, classical crew interface requirements have either not been included in the design definition, not been properly verified, or not been funded, though still carried as applicable requirements.

Unfortunately, the Human factors discipline has challenged flight programs with some "soft" HFE requirements, difficult to verify relative to other classical discipline requirements. Such requirements are easy targets to be cut early in a program as non-verifiable; e.g., NASA-STD-3000, section 8.2.3.1 *(3).* If they survive the development phase, the requirements are in danger of being ignored in the verification phase. Management then questions the validity of all the HFE discipline requirements.

Even if the requirements are verifiable and applicable, trained, experienced discipline personnel must properly apply these requirements to the spacecraft design for a successful design. However, cost cuts and other factors have affected the quality of retained human factors engineering personnel, as was obvious in the drastically downsizing of the ISS Pressurized Modules prime contractor HFE team prior to design completion of the initial ISS flight elements. Inexpensive engineer "fresh-outs" replaced seasoned, experienced engineers in many facets of the spacecraft design process, including HFE. In other instances, replacements are not provided, and the remaining HFE engineers must assume more responsibilities, thereby seriously hampering their effectiveness. The concern is exacerbated by the pervading belief by some in the industry that "anybody can do HFE; it's just common sense."

Another concern is, even if the qualified HFE personnel remain, the cost of classical HFE design tools is often considered as overhead and not cost effective, resulting in minimum operations funding provisions. Where NASA early in its lifetime, actively performed human-equipment simulations for research and design development, the equipment and operations costs for such simulations now significantly hinder needed efforts. An example is the closure of the Marshall Space Flight Center Neutral Buoyancy Simulator in lieu of the Johnson Space Center Neutral Buoyancy Laboratory (NBL) for cost efficiency [redacted]). The result is a program simulation need much greater than the NBL can support, while there is no longer the opportunity to utilize human subjects in extended neutral buoyancy concept definition and development simulations. Additionally, loss of funding for one-g mockups and multi-degrees-of-freedom (DOF) simulators has driven the HFE community to almost solely rely upon virtual simulators (desktop simulations), which are progressing in reality quality, but are themselves quite expensive and delete kinesthetic experience and assessment. Hence, the HFE flight design suffers due to cost reductions of its tools.

In summary, HFE has become a serious consideration for program management to find cost solutions by reducing or eliminating it from the budget during crunch time. This can often be attributed to uninformed or confused management relative to the HFE role and need.

POSSIBLE SOLUTIONS

In response to the concerns, planning and reorganization is ongoing within the HFE community to correct such issues. Herein are proposed techniques for ensuring that human interface requirements are properly integrated into a spaceflight design, from program proposal through verification. Included are human factors engineering discipline efficiency adjustments, human factors requirements refinements; program definition and proposal preparation considerations; strengthening of the human factors engineering role in program development and verification; including an Agency integrated human factors program, under the “One NASA” theme. Importance is given to communication and language within the aerospace human factors discipline, and utilizing the strengths of all government, industry, and academic human factors organizations, capabilities, and facilities to provide an efficient, unified research and engineering approach.

DISCIPLINE ENHANCEMENT

The following points are proposed for enhancing the human factors engineering discipline within the aerospace community, in order for management and engineering to realize the benefits and recognize HFE as a required discipline for a successful and safe spaceflight mission:

<u>Discipline Awareness</u> – Awareness should be enhanced that HFE is a valuable and needed spacecraft discipline, necessary for mission achievement. Awareness should be accomplished through re-education of aerospace management, budget controllers, and other aerospace design disciplines, as well as Congressional and Administrative lobby organizations, emphasizing that HFE is a prime systems discipline necessary for safe and efficient spaceflight. HFE focused enhancement should be further developed and nurtured in one of the NASA codes, probably within the control of the NASA Chief Engineer. Of note, an Agency integrated human factors verification program has recently been initiated by NASA under the “One NASA” theme. The program is under the Safety and Mission Assurance Office, and addresses human factors issues from a safety perspective.

<u>Discipline Focus</u> – The HFE discipline scope should be refocused as an aerospace Systems Engineering discipline, which performs research to define specific and verifiable HFE requirements applicable to evolving spacecraft designs, and then implements the requirements throughout the spacecraft design process. The HFE discipline functionally interfaces with the classical aerospace disciplines through the Systems Engineering/Systems Integration discipline.

<u>Discipline Unification</u> - The research and engineering strengths of all government, industry, and academic human factors organizations should be unified for discipline integrity and enhanced capability. Through teamwork, the HFE discipline should be comprehensive, encompassing and efficiently utilizing expertise, resources, and facilities beyond the scope any single local organization. An unified, multi-organizational discipline is significantly stronger and more capable than a localized version. Previously, an unified team of HFE representatives from government, industry, and academia produced the highly successful NASA-STD-3000, which serves today as the human factors engineering design standard for US-involved spacecraft design. It was proven that a HFE inter-community approach produced a product significantly better than what a single organization could produce.

<u>Discipline Communication</u> - A broader-scoped communication link must be re-established within the aerospace HFE discipline for the discipline to compete for funding. The civilian and military HFE community and their private industry counterparts must

exchange HFE design information on a regular basis, in order to grow. Comprehensive networking promotes understanding of creative ideas, design approaches, and evolving aerospace technologies. Intra-discipline and inter-discipline communication is imperative during the development and verification phases of a spacecraft design. Lessons learned from previous missions must be properly assimilated, with requirements and constraints corrected through agreement as necessary for new flight designs.

Discipline Language – The HFE language must be understood by management, in order to know what the HFE discipline can provide to the program. Specific sets of key meaningful HFE terms, independent of the program, define the discipline engineering practices. Care must be taken by the HFE discipline to prohibit organizations from creating, renaming, or redefining key HFE organization terms and icons in order to mold to their program or institutional focuses or biases. Discipline-approved icon terms (e.g., human factors engineering) should be used in lieu of similar lower-level terminology created out of organizational adjustments and divisions (e.g., flight crew integration, extravehicular activity, man-system integration, human-equipment integration, etc.). Such division of terms leads to confusion by program management about what HFE means to them and for what they must budget. And these regional terms may or may not encompass all of the human engineering discipline meaning required for the particular flight program.

Discipline Requirements – The hub of the HFE discipline is the applicable set of human factors requirements. When the HFE requirements are accepted for a program, the discipline comes with them. The requirements must continue to be defined, refined, verified, and consistently applied across flight programs as the relevant technologies evolve. This necessitates continual review and improvements in NASA's HFE standards document, NASA-STD-3000, in order to maintain its strength, usefulness, and recognition by management. It is the job of management to decide where the requirements will be verified, and by whom, but it is the responsibility of the HFE discipline to clearly define how they should be verified.

PROGRAM DEFINITION

The most critical time for HFE in a program is when the program is being defined. Weak HFE acceptance at this point will lead to potentially reduced fiscal support later. Suggestions for enhancing HFE in the beginning of an aerospace program include:

HFE Role in Program – If a human is participating in the mission, HFE must be involved in the program engineering definition. It must be clear to program managers that HFE is a systems engineering/systems integration function, and separate from (though feeds into) flight/mission operations. It is imperative at this juncture that management understands and accepts HFE is a foundation piece of the engineered design. It is required in initial program definition, providing an integral part of the spacecraft engineering design relative to crew efficiency and safety, and if properly implemented, will promote mission success for crew-participating space missions. The human-equipment engineering aspect of the design includes, among others, design definition for crew and equipment safety and for spacecraft on-orbit maintenance. The HFE lead engineer must become actively involved with management in scoping the HFE portion of the program definition. The HFE discipline must demonstrate to management its performance and cost strengths, as well as offer the consequences of a poor, inadequate HFE design. Program cost control managers must understand the cost-effectiveness of HFE from a crew and mission safety and vehicle maintainability aspects of the discipline, which will provide mission success.

Mission-Specific Requirements – Drawing from the HFE discipline requirements base, an established, well-defined, clearly verifiable set of HFE design requirements and standards is tailored to the flight program. The defined requirements set is discipline approved and scrubbed from the generic HFE requirements database. An example is the NASA-STD-3000 requirements, which were reduced to a tailored set of requirements for a space station and released as an ISS HFE requirements specification (5).

The same requirements apply to the human interface inside or outside the spacecraft, whether the crewmember is in the pressurized volume in "shirtsleeves" or outside wearing a pressure suit. However, verification of such requirements is sometimes confusing, begging the question of duplicate and overlapping, and resulting in management confusion of the HFE discipline. Confused managers do not properly support the discipline. It is recommended that the discipline establish one set HFE requirements on both sides of the spacecraft shell, both intravehicular and extravehicular. Requirements should be imposed, tracked, and verified with an unified set of standards applied. The NASA-STD-3000 attempts to do this, but more effort is necessary to define one set of requirements.

Program WBS – The human factor should be included in the Work Breakdown Structure (WBS) of the new program. A specific HFE heading should be included, probably under Systems Engineering or Systems Integration. If management disagrees with this approach, a standard HFE statement must be included in every WBS callout for hardware, to include HFE design for activation, nominal operations, and on-orbit maintenance.

Program Communication - The HFE language, identified by the HFE discipline, is applied to the new flight program. Included is key HFE terminology, communicable and meaningful to program managers and planners, and utilized within the program context by the HFE engineers. Adjustments in the HFE-approved terminology must be made very carefully, so as not to lose the meaning of each term. Such terminology must provide clearly understood HFE information within the program.

PROPOSALS

Having participated in the program definition process, HFE can then be properly recognized and included during the assembly of a proposal or a request for a proposal. The following considerations for proposal preparation are ventured:

HFE Scope – In the proposal it is important to properly scope mission-specific HFE manpower, resources, and facilities to accomplish a successful HFE design. This can be accomplished since HFE requirements are already established through the NASA-STD-3000 requirements database. The proposal should include sufficient resources to properly integrate the HFE design into the flight vehicle design, remembering that human interface assessments and tests are required to drive the design. The reviewer (or bidder) must recognize that funding must be in place throughout the program to obtain the proper HFE design.

Key HFE Words – Emphasis should be placed on the discipline-honed keyword phrases in the proposals, making these terms easily recognizable and understood within the proposal context as meaningful to HFE. Utilize terms recognizable with other disciplines, providing closer ties with systems engineering and other classical disciplines. The reviewer (or bidder) needs to understand how the HFE discipline is defined for the new program.

Proposal Formatting - There needs to be a stand-alone section defining and scoping the mission HFE design aspect, including EVA if appropriate. Also, appropriate HFE requirements are needed in the Safety and the Logistics & Maintenance sections of the proposal. It is important that HFE be clearly addressed in the verification section of the proposal. Likewise, HFE should be included in the proposal introduction to establish discipline recognition. The thought here is to make the reviewer (or bidder) understand that HFE is a strong and required discipline in the systems engineering and integration of the vehicle.

DESIGN DEVELOPMENT

As the new aerospace program moves through the development phase, HFE design must remain an integral part of the integrated systems design to validate crew-equipment interfaces. Its importance becomes even more obvious near the end of the program, when conflicts arise with the aerospace disciplines and the flight crew organizations as to what is an acceptable design for human performance and safety. Hence, several recommendations are offered for HFE to maintain proper funding and requirements inclusion:

Discipline Relationships - Closer ties with Systems Engineering and other classical disciplines will result in greater HFE discipline recognition by management. The HFE Team must be aggressively active in its involvement, participating in daily engineering design problem solving. It is necessary that HFE design involvement reach a level of integration where other disciplines automatically rely on HFE for a response, even if the question does not have an obvious tie to the HFE discipline. Conditioned disciplines and management will then recognize when a human interface concern has surfaced in the design and how it's to be resolved.

Location, Location, Location - Physical location of the HFE Team relative to the other design disciplines is critical. Close locations to the Systems Engineering and classical engineering leads will remind them to include HFE in the daily design activities. If close location is not possible, it is the responsibility of the HFE engineer to attend as many of the daily activities as possible to stay in the integration process loop. One must be seen to be involved with a problem solution.

Design Participation - It is a HFE responsibility to actively seek out and review any design for which the crew or ground operator will have to operate, utilize, or maintain during the mission lifetime. Management can often pass critical actions and questions off to other less qualified discipline organizations, forgetting that HFE is directly related to crew interfaces in the design. The HFE engineer must be aware of mission design plans for the activation, nominal and contingency operations, and final shutdown phases of the vehicle design.

HFE Reporting – The HFE lead must ensure that HFE information and status data, prepared by the HFE organization, is expected by management as standard inputs to all program status presentations and discussions. Emphasis in the charts must include technical justification and benefits for HFE participation in requirements implementation. The goal is to assure the HFE benefits are obvious and consistent throughout the vehicle development process.

HFE Team - The HFE Team Lead should give specific design responsibilities to each of the HFE team members based on individual capabilities and expertise, letting each respond to management as often as possible, in order build credible team interaction and recognition. Cross-training among team members in the team responsibilities is needed to back up the primary person in a critical moment. The HFE Team Lead should respect and fully utilize each team member. That said, the Team Lead must remain as the single point of contact for inquiries and criticisms from outside the team. The Team Lead must carefully recruit team members, accepting only productive persons with mission task skills. The Lead must educate each team member with design and mission nuances relative to HFE. A solid cross-trained team of experts in HFE will reflect on the discipline, making it a productive and required design discipline for the flight program.

VERIFICATION

Having imposed HFE requirements on the design, and implemented the requirements into the flight design, the HFE Team must then verify that the requirements were properly applied to the design. Management will be aware of how successfully verification was accomplished. Considerations are offered for HFE verification:

Verification Application - The time to plan for requirements verification is when the HFE requirements are imposed on the design, early in the concept definition period. A clear understanding of the requirement and its verification technique must be understood by the HFE engineer and by management. Since verification techniques can often be soft for some crew-interface requirements, it is important to carefully define with management early in the design process clear verification techniques that will withstand independent audit throughout the program. Clear responsibilities for verification definition and implementation are necessary at this time.

Verification Methodology - An understanding of HFE verification methodology within the flight program scope is key. Each program has its own interpretation and technique of what is proof of a properly integrated requirement in the design. This interpretation is bounded by factors such as funding, development time, mission criticality, mission length, etc. An acceptable verification technique in one program may or may not be appropriate for another. However, the requirement verification lineage should be obvious, with the deviations documented and understood. The HFE verification methodology must provide clear requirement verification techniques within the program scope, to prevent requirements from being scrubbed as superfluous in the fiscally challenging part of the program development.

Verification Standards - As a goal, the recently initiated Agency-integrated human factors program should provide for all spaceflight programs standardized verification definition for each of the standard HFE requirements, based on test data and lessons learned from previous programs. The results should be coordinated with all NASA and DOD spaceflight offices as acceptable for any mission. Armed with a set of standards, verification definition will be much easier in the beginning of the program. Note that this was a key purpose of NASA-STD-3000, and needs to be re-emphasized.

Verification Testing - Initially planned tests to verify requirements are often reduced to paper or computer analysis as cost savings are applied in fiscally challenged times. This may be acceptable for classical disciplines where science and engineering methodology serve as true predictors. However, with the human involved, testing and demonstrations are required and must be maintained as absolutely necessary, especially if the human is required to perform repetitive, critical, and/or long-term operations. Human performance capabilities change over time, and temporal options must be considered. Budgetary controls must recognize the need to keep such test activities in program scope. It is important to know very early in the program what the verification test should accomplish and exactly what resources will be adequate to verify the design requirement. Once established the program management must respect the decision for testing.

Lessons Learned - Knowledge of how well a requirement was implemented and verified in an integrated human-machine system is important to follow-on programs, and must be tracked in the HFE discipline and in the mission program as a "lesson learned," to be shared with the next program. Improvement within the aerospace community to accept and utilize "lessons-learned" data is imperative in the current cost-restrictive world. The HFE discipline must accept previously learned verification data, while understanding how it was obtained. A benefit is a direct HFE input into the follow-on program. On-orbit verification of the HFE requirements during the flight mission is also important, while providing lessons learned for HFE requirements definition and refinement activity,

CONCLUSION

The purpose of this treatise is to assist the current and future managers and engineers in the field of human factors engineering in providing a product so valuable as to warrant an uncompromised need in the aerospace design. With careful planning and well defined systems engineering and integration principles, HFE will be a key discipline in any aerospace endeavor which utilizes the human as a mission participant, whether in spaceflight or on the ground. The HFE product will result in cost savings for the flight program. The discipline is key in the success of a spaceflight mission. So recognized, proper funding support should be equivalent to any other classical aerospace discipline.

REFERENCES

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