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Paper Session I-A - An Examination of the Human Factors Support of NASA's Safety Directorate on the Space Station Processing Facility

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ABSTRACT

The goal of the Human Factors Engineering (HFE) pilot project undertaken by NASA on the Space Station Processing Facility (SSPF) at Kennedy Space Center, Florida, is to demonstrate the advantages of using Human Factors to support NASA Safety. The primary objective of the project is to demonstrate how Human Factors can assist in decreasing the causes of accidents by reducing error producing situations. The project began with a review of design drawings for the SSPF, in which all Human Factors (HF) concerns were identified especially those that affected personnel safety, payload protection, and operational efficiency. Visits to other KSC facilities produced insights that could be applied to the drawing critiques when the drawings were not sufficient to disclose how the facility's characteristics would fulfill operational needs. Overall, the drawing review revealed a broad range of HF and Safety concerns. When possible, these concerns were discussed with the appropriate engineering personnel to effect workable solutions. To date, some of these HF & **Safety** concerns have been resolved by incorporating HF principles. Thus, this project has reduced potential problems that can contribute to accidents and costly delays, such as the **Magellan Spacecraft incident in October of 1988.** This incident typifies payload processing problems that can develop unexpectedly within any processing facility when Human Factors issues are either ignored or overlooked in the initial design of the spacecraft or in developing appropriate service and checkout procedures. Although the problem occurred on a spacecraft, this type of problem also could easily occur within a processing facility, on payloads that are being processed, or on the ground support equipment being used to process the payloads. In addition, this project has led to the evaluation of candidate methods for the implementation of HF. Among these, a means of conducting HF evaluations during Engineering Prototyping in a Computer Aided Design environment. This innovative technique is expected to demonstrate the Safety advantage and substantial cost savings of incorporating HF principles.

Acknowledgments

I am indebted to **Brad Lydle,** Facility Engineering, Mechanical Section (DF-FED-33) who (1) provided constructive feedback in his critique of the Human Factors Evaluation on the SSPF Crane Accommodations, (2) arranged for interviews of crane operators and maintenance personnel to obtain essential operational details when they were not in the SSPF drawing package; (3) assisted in providing access to various crane sites where similar operations were being conducted at other KSC facilities to gain additional information for the Human Factors assessment of the SSPF Drawing Package, and (4) allowed HF to test the effectiveness of one of its findings by making accessible various crane purchasing specifications. We then demonstrated the value-added benefits in tailoring HF requirements to selected crane purchasing specifications to avoid the need to modify new equipment items shortly after they were purchased.

Recognition should also be given to **Faith T. Chandler,** Human Factors Consultant in Brevard County, Fl., for her assistance in suggesting alternative formats and new ways to organize this material for publication.

Human Factors Engineering applied to NASA's Space Station Processing Facility

Although many of the systems being developed for NASA embrace leading edge technologies, some of those developed for ground based facilities do not. Currently, systems found in ground based facilities lack documented policy guides that ensure the application of Human Factors (HF) or the use of ergonomically designed equipment. These systems should benefit from the application of HF standards because the standards can reduce the likelihood of accidents and injuries. These deficiencies were recognized by KSC personnel as far back as the early 1970s when Design Engineering tried to alleviate this concern by establishing its own documentation guidelines, in a **Guide for Design Engineering of Ground Support Equipment and Facilities for Use at Kennedy Space Center (KSC-DE-512-SM)** (1). This document attempts to address some of the Human Engineering issues of concern. The few HF paragraphs in this document may be contrasted with the comprehensive treatment found in MIL-STD-1472D (9). Compounding this problem is the lack of skilled Human Factors personnel at KSC to implement the standards of either KSC-DE-512-SM (1) or MIL-STD-1472D (9).

To determine how Human Factors standards can augment safety in ground-based facilities, NASA KSC began a Human Factors Engineering (HFE) pilot project in the Space Station Processing Facility (SSPF). This project, which began in 1991, demonstrates the supportive role of HF in reducing accidents caused by human error.

To reduce human error and make systems more effective, Human Factors principles can be applied to system design by using features such as ergonomically designed displays, controls, and environments; performance aids, appropriate labels, and fail-safe characteristics. These features accommodate human limitations and enhance human abilities thereby increasing the overall system safety. When HF is applied to design, it assists Safety in achieving objectives such as: eliminating potential hazards, reducing risks, increasing operational safety, and eliminating personnel injuries. Through this supportive role, Human Factors enhances operational efficiency by reducing accidents that are due to human error.

Procedure

We have completed or will complete the following activities to identify Human Engineering (HE) design deficiencies and/or safety concerns:

1. Review the System Design Drawings of the Space Station Processing Facility (SSPF) to Identify Man-System Interfaces or Relationships that pose potential hazards
2. Identify potential Safety problems and or areas of concern
3. Identify potential Human Errors in Operational Procedures
4. Visit other facilities at KSC to observe similar operations and to obtain **Lessons Learned** insights
5. Participate in an Operating and Support Hazard Analysis
6. Participate in a Preliminary Hazard Analysis
7. Conduct a Critical Task Analysis
8. Conduct an Engineering System Analysis

Once Safety issues were documented, we identified applicable Human Factors issues and findings using MIL-STD-1472D (9), NASA-STD-3000 (2), the Human Engineering Handbook for Safety Assurance, [NSS1740.XX] (4), and other applicable HF Resources. Then, we reassessed the beneficial aspects of applying HF to specific concerns of Safety within the SSPF. Following this, we reexamined the guidelines in the Human Engineering Handbook for Safety Assurance (4) to see if the requested HF data is effectively supplementing the ongoing safety analyses in a timely manner. This is a rare opportunity to test the guidelines of the policies being stated in this Handbook **prior** to its official publication.

Results

The initial phase of our endeavor consisted of a review of design drawings for the SSPF. In this review we identified all human factors concerns with special emphasis on those that affected personnel safety, payload pretection, and operational efficiency. When drawings did not completely disclose how the facility's characteristics would fulfill the intended operational needs, we then visited other facilities at KSC to obtain insights that could be applied to the drawing critique.

Although our objective was to identify HF and Safety oversights in the SSPF, we did identify some very effective HE and Safety features. For example, Figure 1 shows the positive design features of the vertical access ladders within the facility to the crane walkways. This design incorporates Human Engineering design principles as stated in MIL-STD-1472D (9) and the Safety guidelines in the OSHA section of the Federal Register. These ladders were designed to incorporate two

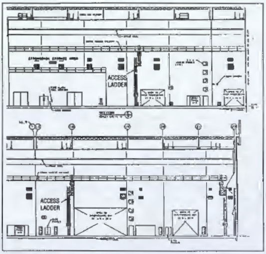

Figure 1 Crane Access

safety features: the cage, and a rest platform at the prescribed height.

The original Human Factors' charter was to identify both positive and negative examples of the application of Human Factors. Later, the emphasis was shifted to concentrate on the lack of Human Factors or the Human Factors oversights. Other positive examples of good Human Engineering practices were uncovered, but our charter as restated was to focus on the discovery and identification of the HF and Safety oversights, and many of the positive examples remain undocumented.

However, our review of the System Design Drawings has revealed a variety of Safety/ Human Factors problems relating to both operability and maintainability issues in the SSPF. To date, the most serious problem discovered originates from the design of the SSPF module processing layout and service area (Figures 2A & B and Figures 3A & B). The service area was designed with a CAD system, in which one "footprint" was created and then flipped repeatedly, to produce eight "footprints". Identical foot prints are depicted by similar shading (Figure 2A). These footprints have mirror image symmetry, so **identical** gaseous stub-ups to the right side as personnel face the foot print (service area) are to the left side in reverse order when they face a different service area (Figure 2B). Because all stub-ups have similar fittings which appear identical, they are easy to confuse and could pose serious high pressure line mismating problems and hazards. For example, potential high pressure line mating

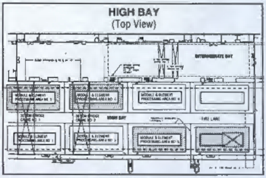

Figure 2A SSPF Highbay Showing Two Types of Footprints (Identical Footprints Depicted by Shading)

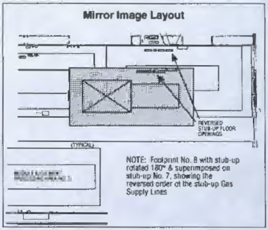

Figure 2B Mirror Image Layout Illustrating Stub-up Reversal

mistakes could be made when a technician works on one "footprint" and then moves to another "footprint" where stub-up layouts are reversed. Since at each of the gaseous stub-ups locations, high pressure hoses are connected to lines supplying gaseous nitrogen or helium at 6000, 3000 or 750 PSIG, attaching a line to the incorrect source at the wrong delivery pressure could be disastrous (Figure 3A).

After presentation of these findings to NASA, it was discovered that corrective steps had already been taken to eliminate the potential mismating errors.

In addition, our investigation of the design drawings revealed a variety of other Safety and Maintenance problems in the SSPF that could have been/be corrected with the application of relevant HF guidelines (Figure 4). Figures 5 & 6 illustrate examples of safety problems. Figure 5 shows an access walkway

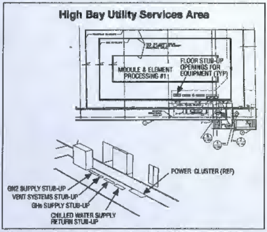

Figure 3A Module Processing Layout & Utility Service Area

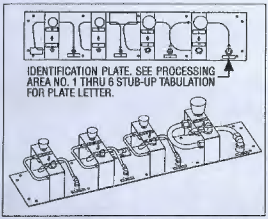

Figure 3B Stub-up Hardware and Layout, Depicting the 750, 3000, and 6000 PSIG GN2/GHe Feed Line Gas Supply Outlet Ports

where the incline angle of the ramp exceeds the incline allowable (using acceptable HF guidelines) by ten degrees. Figure 6 illustrates sharp corners on a stair handrail. Both of these figures show hazards that can cause an accident or injury.

Human Factors applied to design results in efficient and easily maintained equipment and environments. However, the failure to apply HF principles can lead to overlooking a number of problems. Maintenance problems of both old and new equipment were discovered in the System Drawings Review (Figure 7-9). For example, a thirty-year-old overhead crane that resides in a clean-room environment poses several maintenance problems (Figure 7).This crane had no room for an oil drip pan under the oil drain plug, making oil removal very difficult. Before design modifications were incorporated, five to eight gallons of oil were drained into Glad plastic trash bags, transferred to buckets, and lowered to the ground 100 feet below. During this procedure, maintenance personnel were required to adhere to strict clean room requirements.

1. Dwg A-076 featuring the Overhead Crane placement depicts a Generic crane with limited access.
2. Tunnel Dwg A-129 identifies the locations for Fire extinguishers as the only Life Safety feature included on the drawing.
3. Dwg S-163 shows the Ramp to the Visitors Viewing Gallery without a rest platform for the handicapped.
4. Visitors Viewing Gallery has wheelchair and rail limitations (Dwg A-025).
5. Height of Outside Vertical Ladder has reached the upper limit without a caged or guard protection (Dwg A-072 shows a requirement for a Maintenance Man to reach outboard to the left of the ladder to turn a valve creating a safety hazard).
6. Dwgs A-020, A-021, and A-023 show raised areas or ramp down areas on catwalk which exceed walkway incline requirements (Ref. Dwg A-094 shows Ramp details).
7. Door access is restricted to catwalk for normal maintenance requirements (Dwg A-109, MIL-STD 1472D, Para. 5.7.8.3, specifies an Access Opening should be at least 29" x 34").
8. Crane head room clearance for maintenance is restricted (Dwg A-073).
9. Limited provisions for performing Crane maintenance in a clean room environment (Dwgs A-073, A-074, A-075, A-076, and A-077).
10. Warning, "Possible Air Contamination in Event of Tunnel Leaks" (Dwg A-109) are posted only at entrance to First Floor Stairwell Connected to Tunnel area.
11. High Bay Light Servicing Dwg A-073 (Dwg A-093 shows possible back injury situation).
12. Dwg A-071 denotes removable section of exterior wall for Future Crane Access.
13. Chiller Plant Handrail (Dwg A-139) shows sharp corners creating a safety hazard.
14. Tunnel Alarm Controller and Monitoring System with modified Human Engineering panel design featuring functional or separate groupings of Alarms and Failure Panels. Easy referenced Alarm Locator Panel

Figure 4 Selected Examples of HFE Drawing Review on the SSPF Indicating Human Factors and Safety Concerns

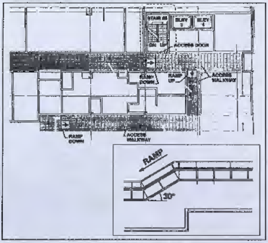

Figure 5 Access Walkway Ramp Hazards

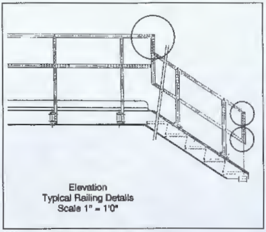

Figure 6 Stair Handrail Hazards

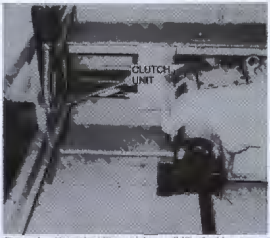

Figure 7 Maintainability and Accessibility Problems

Similar Human Engineering deficiencies have been encountered in recently purchased equipment.

As Figure 8 and 9 illustrate, the equipment custom designed and purchased recently also poses operational maintenance problems. This crane provides operators an **inch and a half** of clearance between the bottom of the gear case and the hardware protective oil drip pan. This clearance is inadequate for routine oil drainage. However, without major design modifications, this equipment could have provided maintenance crews with more clearance. For example, the relocation of an electrical connector to the other side of the electrical case would have allowed the oil drip pan to be lowered 3 to 4 inches, providing the needed clearance.

Figure 8 Restricted Clearance Problems

Figure 9 A Correctable Problem

From Figure 9, another clearance deficiency is apparent. A motor support cross member that has been positioned under the gear case near the oil drain plug further restricts the clearance making it difficult for maintenance to perform essential oil changes.

Discussion

To date, our investigation of the SSPF has revealed a number of Safety & Maintenance Problems. These problems are a product of limited human factors input and NASA's preferred policy of purchasing commercial off-the-shelf items (COTS).

1. Currently, there is no definitive NASA policy guidance documentation for the broad application of HF standards and specifications to support the development of new systems and facilities. Thus, ground based facilities have minimum ergonomic design.

In an effort to standardize the application of Human Factors and/or Human Engineering within organizations under DOD the following were developed: various DOD directives, [e.g., 5000.1, 5000.2, 5000.3 (6, 7, & 8)], along with a definitive Military Specification, [e.g., MIL-H-46855B (5)], and a definitive Military Standard, [e.g., MIL-STD-1472D (9)]. These directives should be applied to achieve an effective integration of man into the development of military systems, equipment, and facilities. With all these documents governing its policies, DOD has the upper hand in applying HF in most areas throughout the entire research and development process.

The application of HF at NASA on the Space Station Freedom Program is governed by Revision A of NASA-STD-3000 (3) primarily developed for flight hardware, and the basic Man-Systems Integration Standards (MSIS) (2). However, this documentation does not cover all HF applications. A supplement, Human Engineering Handbook for Safety Assurance NSS 1740.XX (Preliminary) (4), is being evaluated to determine its potential to bridge the gap between Safety and Human Factors. This handbook would provide Safety with the added benefits of Human Factors analytical techniques that can assist in identifying error-producing situations, thus helping to reduce the potential for accidents. By evaluating suggested applications prior to the official release of the handbook, an opportunity is presented to evaluate the effectiveness of the suggested procedures and to provide timely feedback in the form of recommendations for improving the handbook.

2. In developing ground based facilities, NASA is trying to utilize existing components and hardware available as off-the-shelf items because these items are less expensive. Only when it is absolutely essential does NASA develop and underwrite new items for ground based facilities. From this desire to minimize cost, NASA is prevented from totally adopting and implementing the Human Factors application system developed and enacted by DOD.

If Human Factors principles are not applied to facilities, such as the SSPF, and to equipment, such as the heavy-lift crane, resulting safety problems can contribute to serious accidents and/or costly delays. This point can be illustrated by the mishap on the Magellan Spacecraft that occurred while it was being prepared for launch. In October of 1988 in a Flight Hardware Processing Facility at KSC, maintenance personnel performed a service operation on a piece of flight hardware. During this operation, a technician was required to make three very difficult blind connections. **These circumstances combined with other factors contributed to an incident** causing a fire that consumed all the combustible wire harness material from the connector back to the battery. This resulted in a costly delay.

A summary of the Magellan Mishap Investigation (Figure 10) identifies some of the major incident contributors and categorizes each incident contributor as to its problem type, and specific area of responsibility by discipline. Although this is flight hardware and we are dealing exclusively with ground support hardware, the same type of accident with the same causes can occur on either type of hardware. From Figure 10, it is apparent that some of the factors were **design induced,** while others resulted from the **use of incor-**

– Mishap Investigation Team Commissioned to pinpoint causes
– Team identified multiple causes which contributed to the incident

Listed below are some of the Team's Findings (Underlying Causes):

Incident Contributors	Type of Problems	Area Responsibility
Technician required to make blind connections	Maintainability and Access	Mechanical Design & Procedural Design
Connectors were not fool proof	When mismate occurred, neither Master nor Slave Keys would prevent a partial mating when a scooping mating technique was used	Electrical Design
Electrical power was on during connector mating	Safety/Procedural Design	Electrical & Procedural Design
Power was supplied to male connector pins	Safety	Electrical Design

The **bottom line** announced by the Magellan Mishap Chief Investigator, Jon R. Busse, (NASA/Goddard Space Flight Center), was ***"We must consider Human Factors in both the Design & Procedural Development Process"***.

Figure 10 An Analytical Summary of the Magellan Spacecraft Mishap

rect hardware, and others from the **use of incorrect procedures**. This accident **should not have happened** and could have been prevented through the application of Human Factors.

At the conclusion of the mishap investigation, one of the predominant findings stated by Jon Busse, the Chairman of the Magellan Mishap Board, was: *the lack of Human Factors principles being applied during the design of the space craft was a significant factor and more specifically. . .*

The lack of Human Factors being applied during the development of the operational procedures and during the evaluation of essential provisions which are utilized during both operational servicing and the performance of routine maintenance operations also were major contributors to this incident.

Conclusion

Maintenance & Safety problems, such as those we encountered in the SSPF, can be prevented or rectified with the application of Human Factors principles. To overcome obstacles, such as NASA'a cost effective approach, HF specialists must develop creative new approaches to implement HF at NASA. These approaches must identify the ways and means to provide HF in a timely manner and on a cost effective basis. Presently, several candidate methods are under consideration for implementation.

1) Develop a Designer's Application Guide of Human Factors Design Principles and incorporate it into NASA's requirements to ensure consideration of Human Factors. This is essential, because the complexity of many new systems make it impractical or exceedingly costly to incorporate changes after items are produced.

2) Develop effective Human Factors purchasing specifications, stressing maintainability, operability, accessibility, and other important HF principles to augment KSC-DE-512-SM (1). These specifications would help to eliminate maintenance problems such as the restricted clearance found in the new crane (Figure 7 & 8).

3) Develop and utilize a systematic means to apply Human Factors in the preparation of Operational Precedures.

4) Develop a Human Factors modeling technique for conducting Human Engineering evaluations in conjunction with Engineering Prototyping in a Computer Aided Design (CAD) environment. Currently, a 3-D Animated Design Visualization Modeling Program is used as an aid for facility design. A shortcoming of this model is that the software's mannequins can not effectively demonstrate the man-machine interface because they can not be animated to perform selected tasks. The mannequins are static and act only as scaled props. Therefore, the influence of a 3-D Animated Model has great potential for enhancing the Design Visualization and Human Factors Engineering design capability.

Presently, HF prototyping can be accomplished in a Computer Aided Design (CAD) environment, through the use of an anthropometric modeling software called JACK. This software can be used to evaluate a variety of human factors concerns, ergonomic issues, biomechanical issues, and specific man-machine interfaces. This can be accomplished by using an animated mannequin to demonstrate the following:

(1) Reach and space relationships

(2) Man-machine visual links

(3) Performance of selected operational and maintenance tasks

(4) Workspace requirements and operational tolerance, and

(5) Body sizing constraints

Currently, it is feasible to conduct electronic HF simulations of specific workspaces by utilizing scaled mannequins to perform selected activities. Activities that are te be evaluated would be chosen on a criticality and/or high risk basis. The electronic "run through" of the activities is an **inexpensive** way to identify design problems and potential hazards.

The anthropometric modeling software would take advantage of the computer resources presently available at KSC, such as Space Station Freedom's facility details stored in electronic data bases on NASA's Intergraph CAD system. Through the application of HF in the design and development of systems and facilities, this software could reduce accident situations due to human error.

This modeling capability is currently under development in an early prototype stage. The initial effort will allow engineering designs and models to be moved from the KSC

Intergraph Workstations to a Silicon Graphics Onyx/2RE[2] Workstation.

We have demonstrated that Operability, Maintainability and Safety problems can be identified by a Human Factors Specialist and that these problems can be rectified through the development of creative new approaches to implementing Human Factors principles. Possible approaches include the development of Human Factors purchasing specifications, designer application guides, systematic means to apply Human Factors to operations and the use of a 3-D animated design visualization modeling program. Failure to improve or apply sound Human Factors principles to ground based facilities and equipment at KSC can be costly and dangerous, such as the fire on Magellan. Although our pilot program is not complete, to date it demonstrates that Human Factors in a supportive role can assist NASA Safety in the reduction and/or elimination of accident situations due to human error.

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