NASA PM CHALLENGE
LESSONS LEARNED

KSC Human Factors Lessons Learned

Damon B. Stambolian

NASA Kennedy Space Center (KSC)

Engineering and Technology Directorate

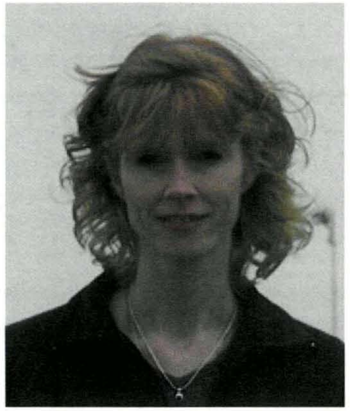
Donald H. Tran

NASA Kennedy Space Center (KSC)

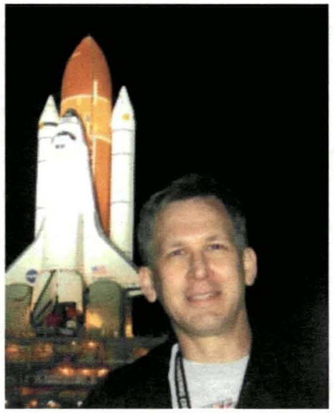
Engineering and Technology Directorate

KSC HF GROUP

Gena Henderson Ph.D.



Darcy Miller



Tim Barth Ph.D.

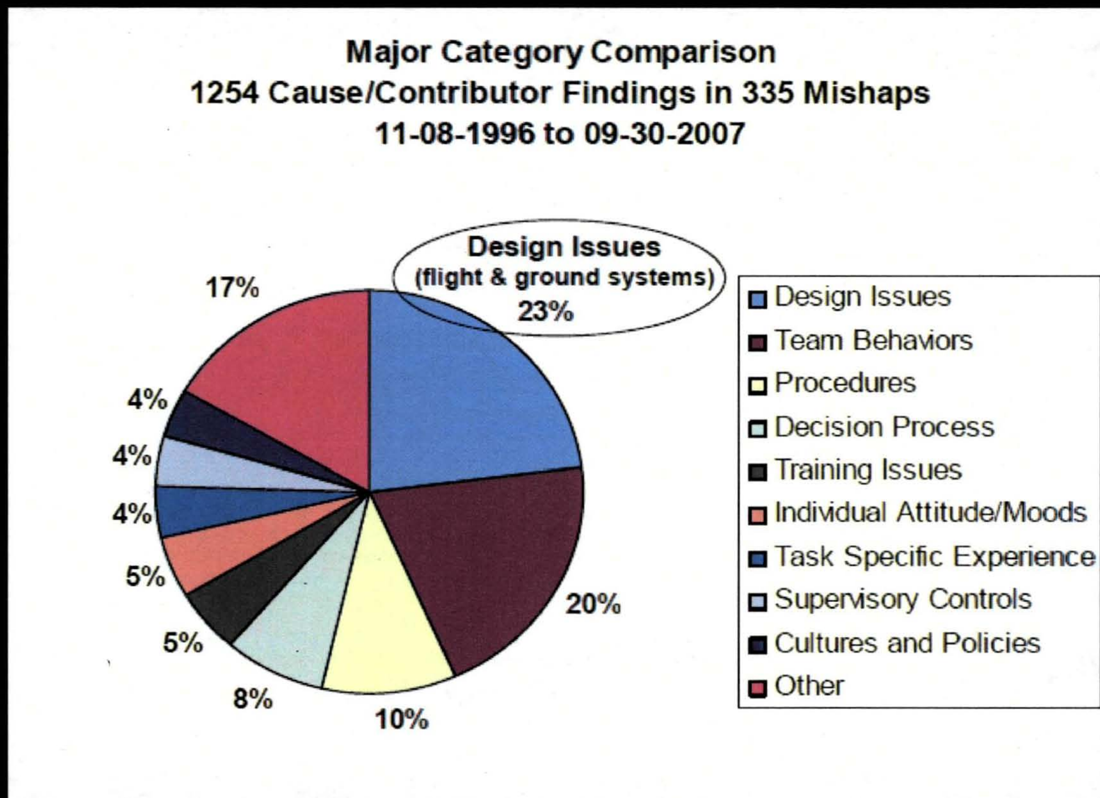
Barbara Kanki Ph.D.

Agenda

- Importance of Human Factors for Ground Processing
- Human Factors Lessons Learned
- Accomplishments from Lessons Learned
- Recommendations

The Importance of Ground Human Factors for Ground Processing

Shuttle Ground Operations Mishap Data



Courtesy of USA Industrial and Human Engineering

Let's Design it Right the First Time!

The Importance of Ground Human Factors for Ground Processing

Mishaps in Ground Operations

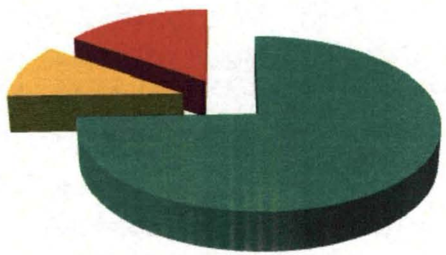
- **For 11 NASA/KSC mishap investigation boards in FY06 and FY07:**
  - Several million dollars in direct costs (includes civil service board member labor and travel, board procurement costs, and estimated hardware damage costs)
  - Plus additional direct costs such as contractor labor for amelioration, contractor labor for investigation boards, corrective actions (new procedures, training, etc.)
  - Plus indirect costs
  - Plus schedule impacts
  - Plus personnel injuries

Human Factors
Lessons Learned

Summary of Lessons Learned Metrics

- Lessons Learned Entry: 1801 Human Factors Engineering; Acceptance, Implementation, and Verification as a System.
- Lessons Learned Entry: 1831 Human Engineering should be considered a Systems Engineering and Integration function
- Lessons Learned Entry: 2136 1-G Human Factors for Optimal Processing and Operability of Constellation Ground Systems
- Lessons Learned Entry 5200: Synchronization of Vehicle Development with Ground Systems Development
- Lessons Learned Entry 5376 No clear communication between the Apollo program and the Shuttle program
- Lessons Learned Entry 5377 The use of human factors and the Space Flight Awareness (SFA) in the Apollo development
- Lessons Learned Entry 5378 Improved Quick Disconnect (QD) Interface Through – Visual Indicators and Labeling Lessons Learned Entry 5416 Kennedy Space Center (KSC) Ground Support Equipment (GSE) Human Factors Engineering Pathfinder
- Lessons Learned Entry 5480 Human Factors Review in the Critical Review Board (CRB)

44 recommendations implemented
6 partially implemented
9 have not been implemented



Human Factors Accomplishments from Lessons Learned

- The Human Factors Engineering Analysis (HFEA) Tool
- Orion Time line HF Analysis
- Mockup Analysis
- Assessing Human Factors using Motion Capture
- Biomechanical Analysis of Installing Avionics Boxes
- Spacecraft Requirements for Ground Processing

A 1

The Human Factors Engineering Analysis (HFEA) Tool

The Human Factors Engineering Analysis (HFEA) Tool

- KSC Design Engineering;
  - Define the human factors Level 5 requirements from the FAA HFDS for each CxP GOP subsystems (Over 40 Subsystems)
  - Develop a process for developing these requirements and improve the design for ground operations

Examples of subsystems:

- Crew Access Arm
- Breathing Air
- Cold Gas Helium
- Crew Module Ammonia
- Environmental Control
- Electrical Ground Support Equipment
- Hypergol
- LO2
- LH2
- GHE
- Ignition Overpressure/Sound
- Vehicle Access Arms
- Umbilicals

HFEA Process

Human factors engineering analysis was required to be performed by qualified human factors engineers

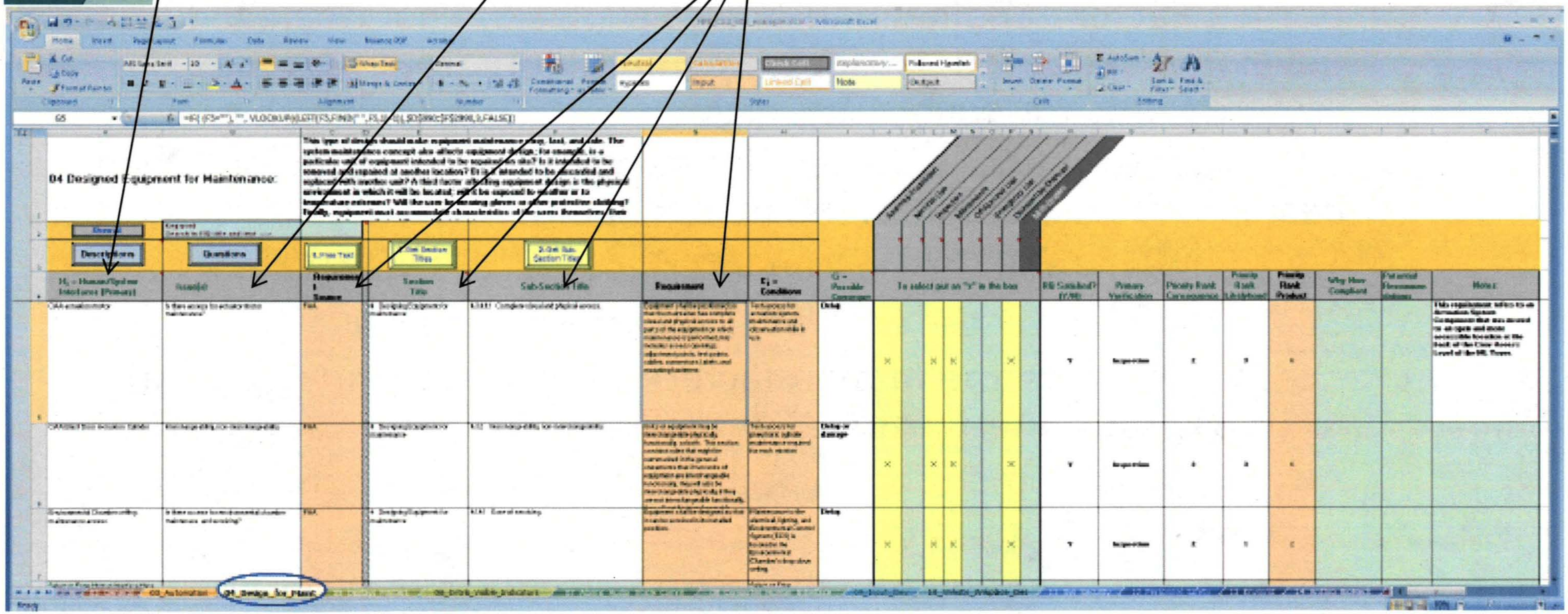
- Human Factors Engineering Analysis (HFEA) Tool was used to develop a dedicated subset of requirements from FAA requirements for each subsystem
- Meetings were held between the human factors engineers, lead design engineers, and systems engineers:
  - To understand the human interfaces of the subsystem
  - To understand the task at these interfaces
  - To determine the human factors considerations/issues with these task interfaces
  - To get agreement on the allocation of requirement on these task interface issues
  - And to derive human engineered design solutions for these requirements

HFEAT

Human/System Interface

Issues

Requirement (Source, Title, Sub Section, and requirement words)

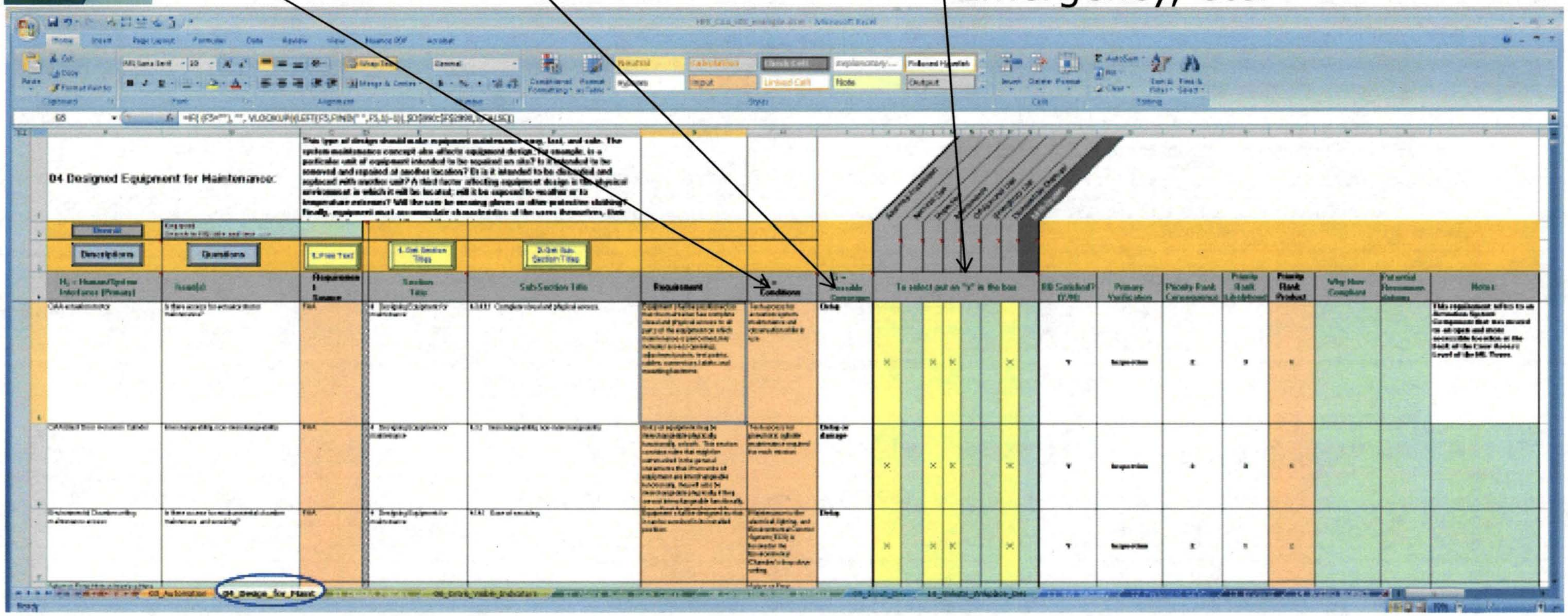


HFEAT

Conditions

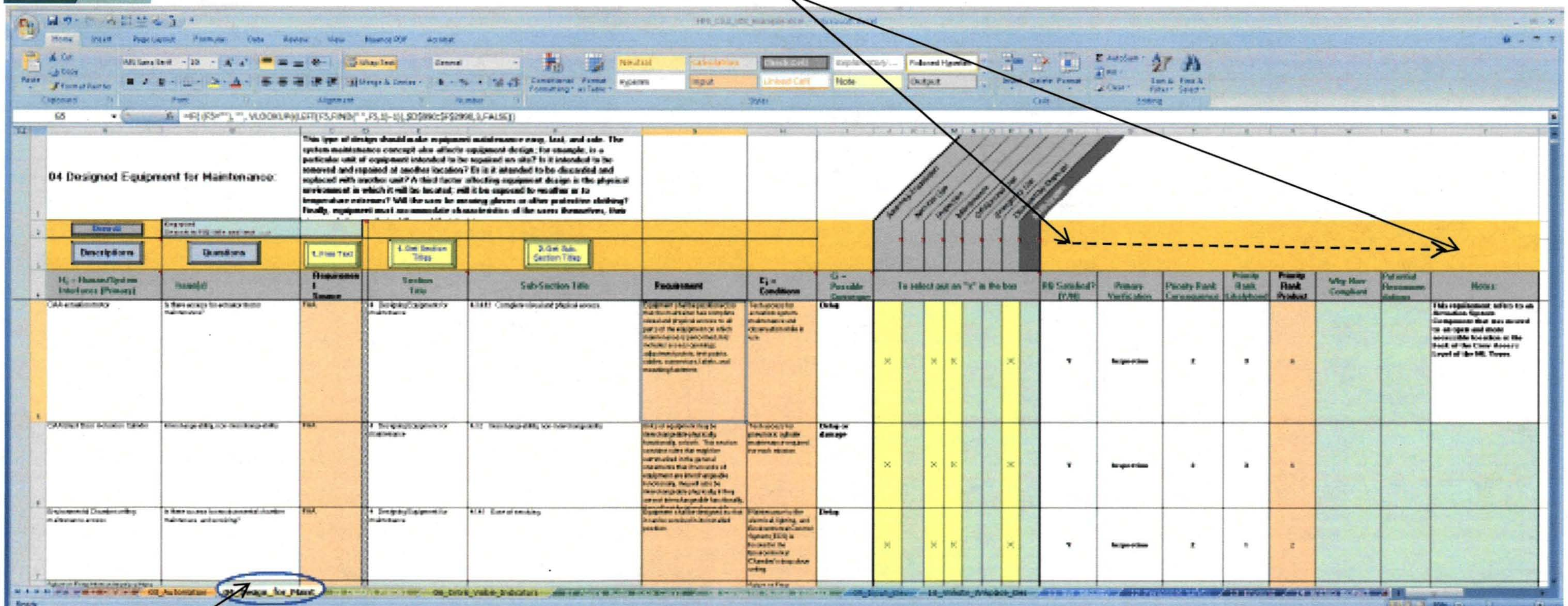
Consequences

Type of processing, Assembly, Nominal, inspection, Emergency, etc.



HFEAT

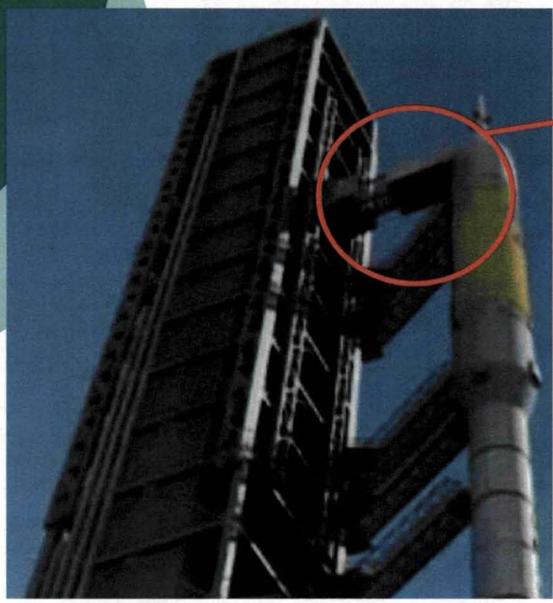
Requirement Satisfied, Verification, Consequence, Likelihood, Priority Rank, Why Non-Compliant, Recommendation, Notes.



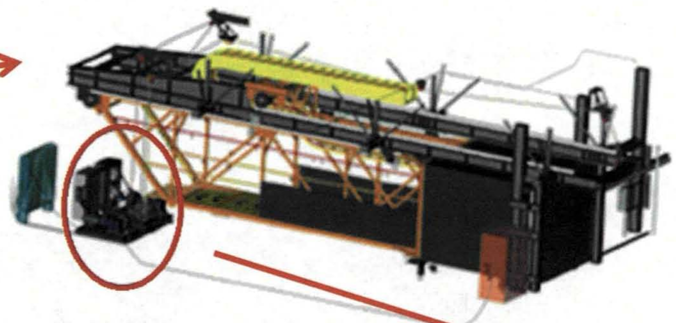
Each Tab is a FAA Chapter: Design equipment for maintenance, Controls and visual indicators, etc.

Example Actuator Motor

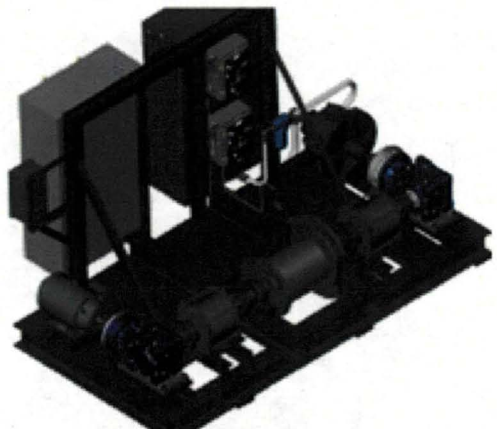
Mobile Launcher



Crew Access Arm



Actuator Motor

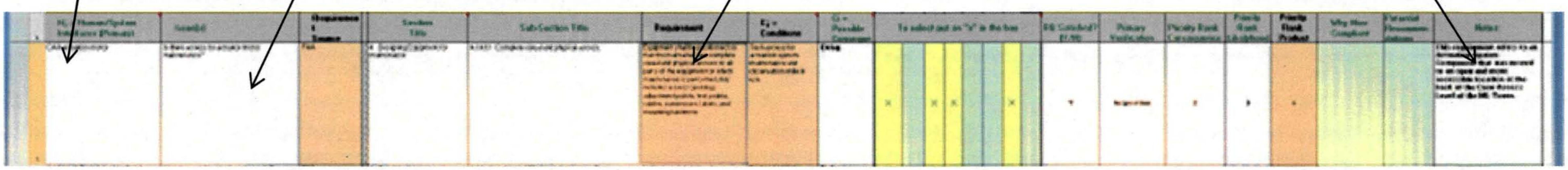


Actuator Motor

Complete visual and physical access

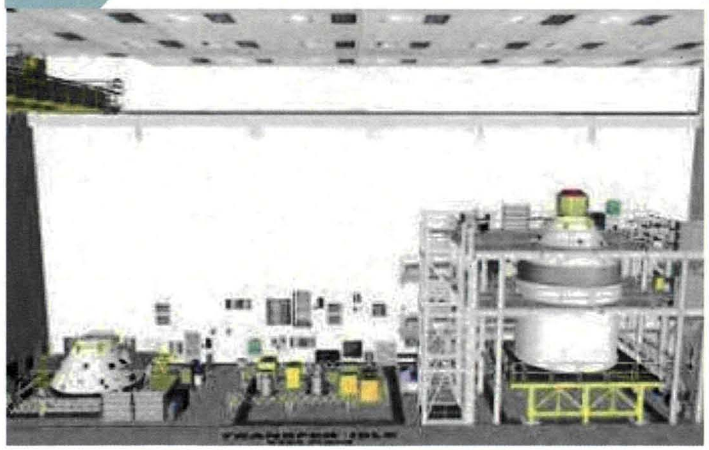
Access for maintenance

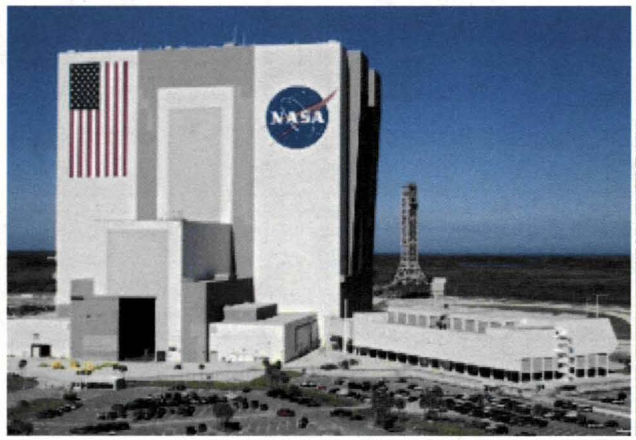
Move the motor



A 2

Orion Time line HF Analysis





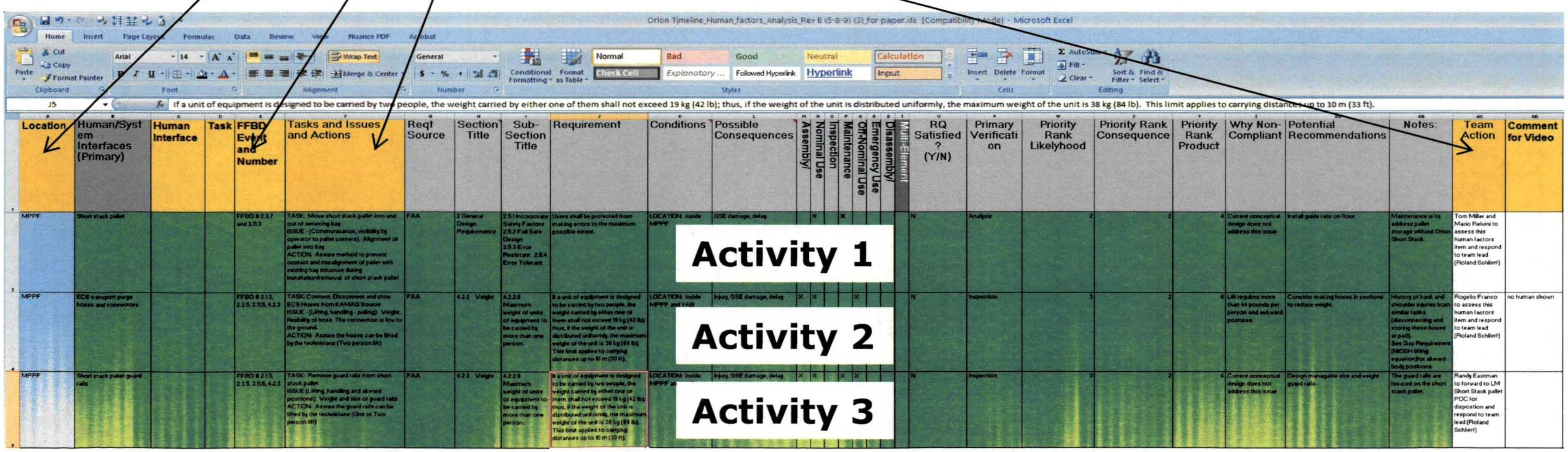
Orion Time line HF Analysis

- Orion vehicle goes through several areas and stages of processing before its launched at the Kennedy Space Center
  - In order to have efficient and effective processing, all of the activities need have a human factors engineering analysis
  - Corresponding Human factors requirements and design solutions needed to be defined

- Areas of Processing
  - MPPF (Crew module and Service module)
  - Vehicle Integration Building (VAB) (Crew module/Service module to Launch Vehicle and Ground Support Equipment
  - Launch Pad

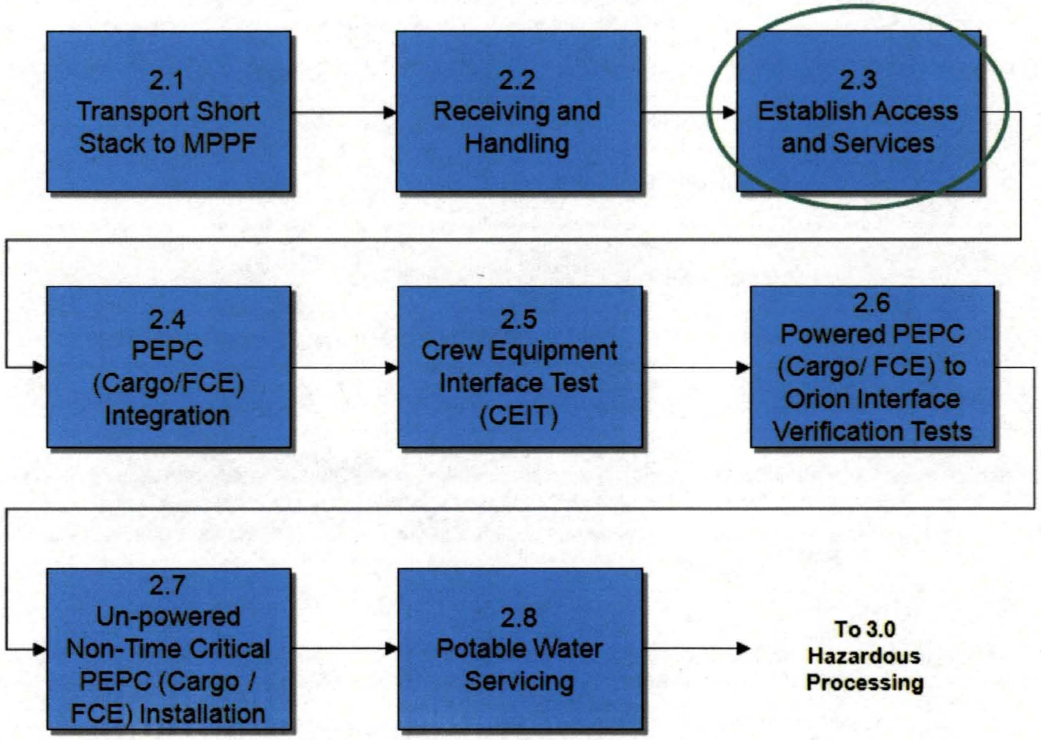
Modification of HFEAT for Timeline Analysis

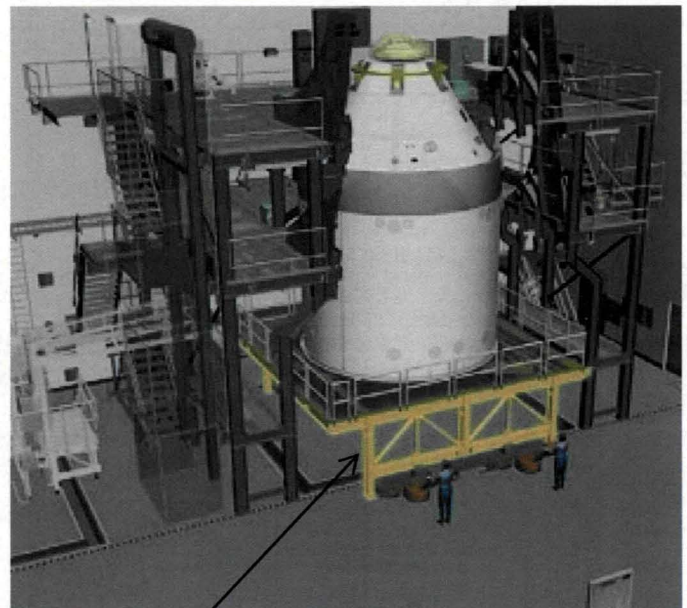
- The HFEAT was modified to analyze the task in a timeline, and additional input columns were added.
  - Location
  - FFBD Event and Number
  - Tasks, Issues and Actions
  - Team Actions



Example of Establishing Access in MPPF

Functional flow block diagram at MPPF

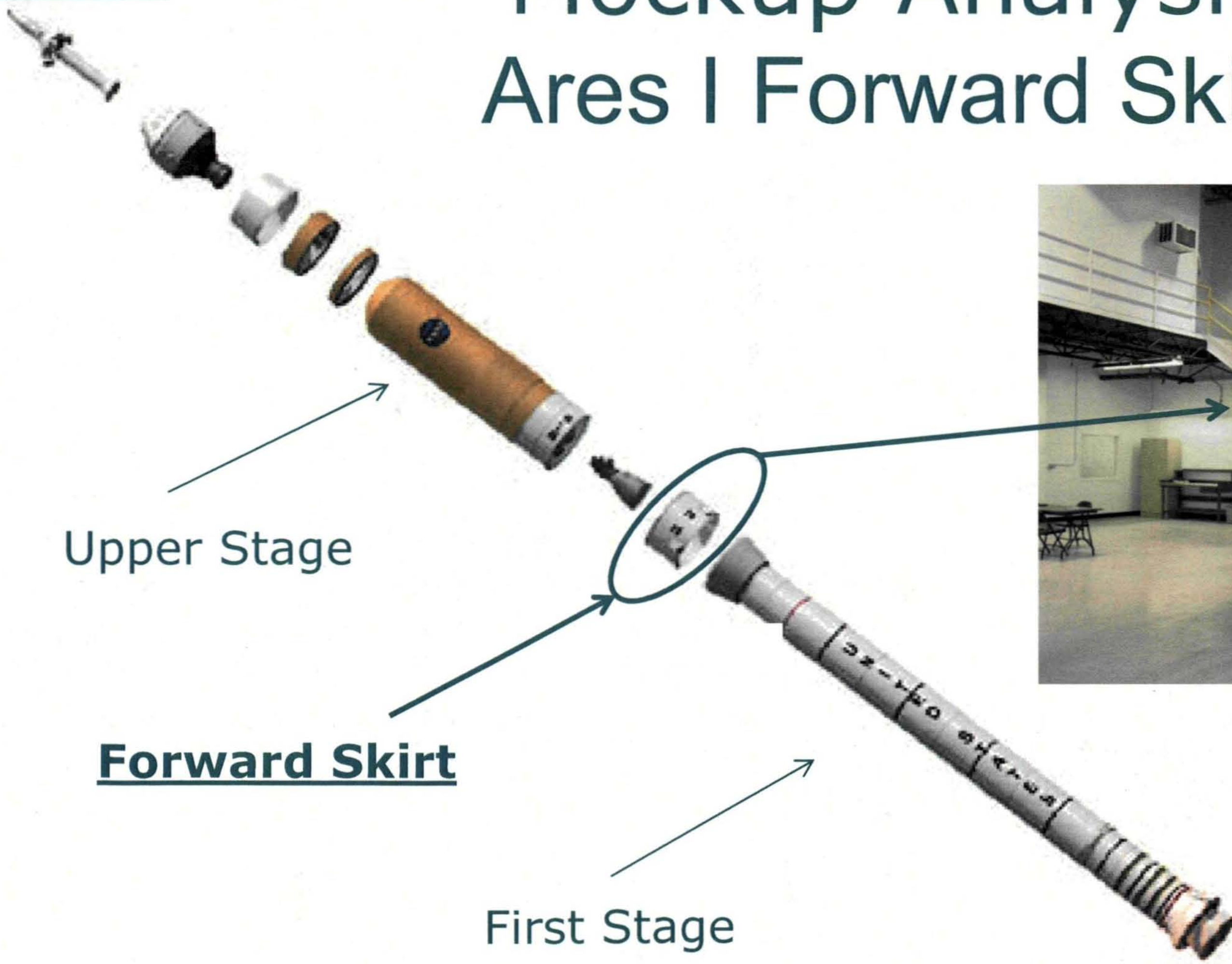


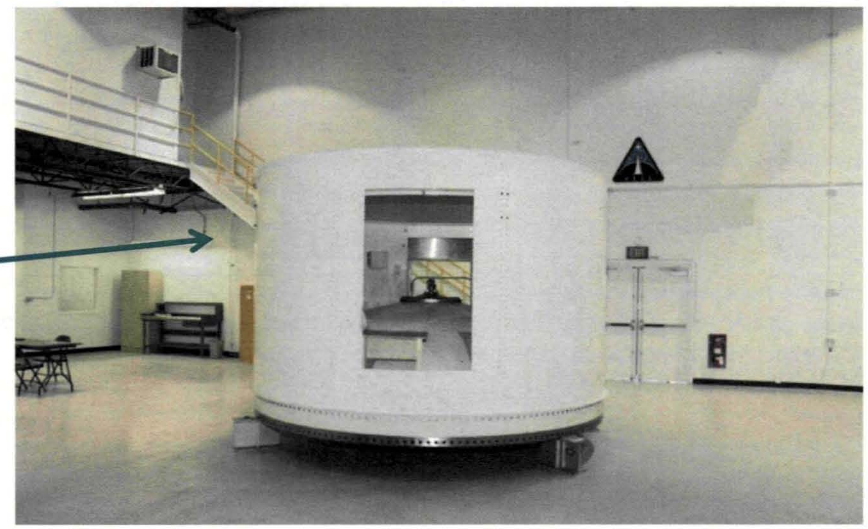


Short stack pallet

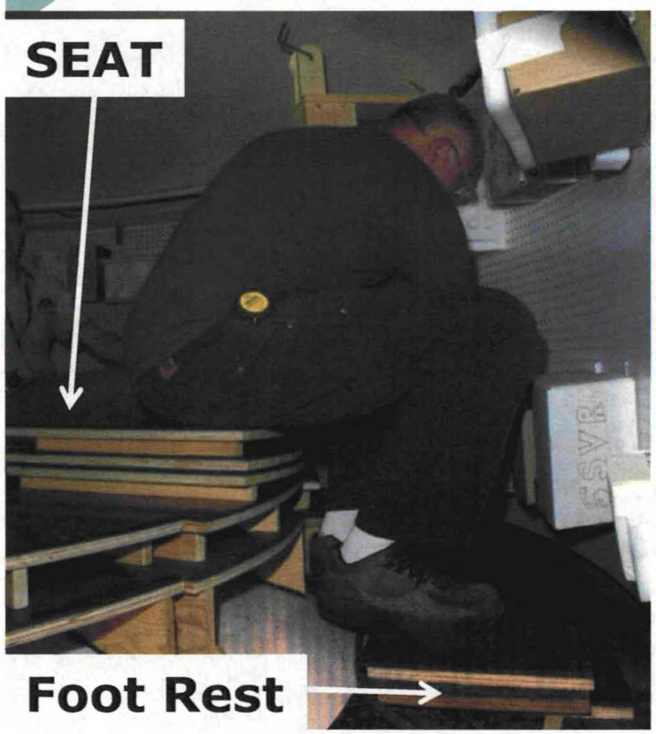
A 3

Mockup Analysis
Ares I Forward Skirt





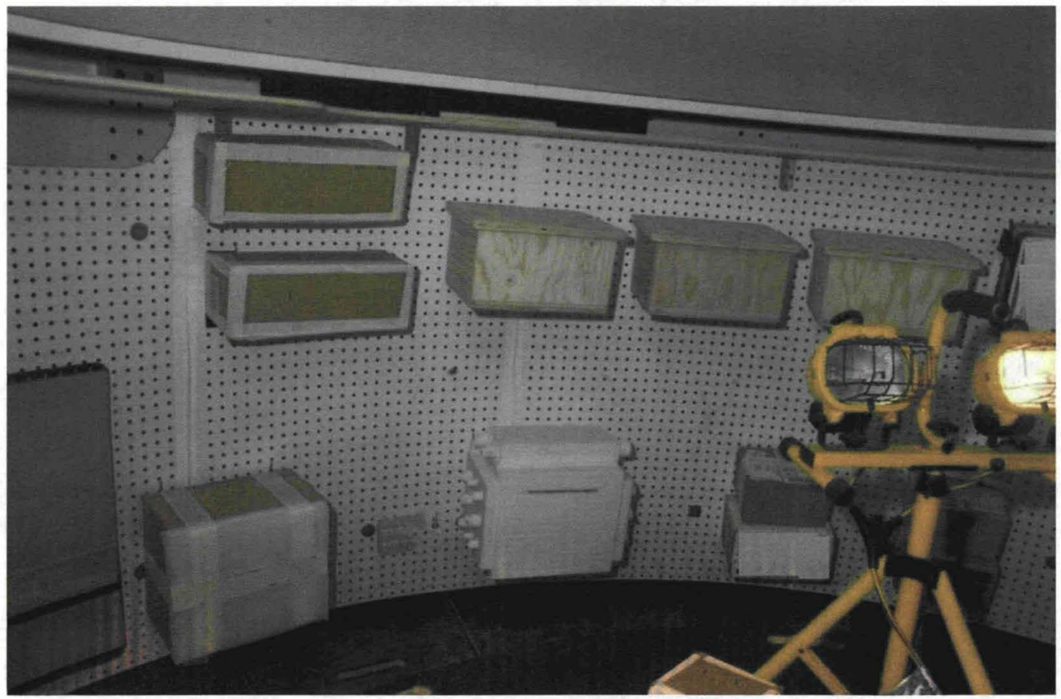
Example Ground Support Equipment



- There is little that can be done to change these cramped dimensions in rocket design, so adjustments were made to:
  - the ground support equipment
  - box placement locations and heights
- The ground support equipment acts as a seat, and foot rest.
- Ground support equipment installed to:
  - protect the technician from injury
  - protect the flight hardware from damage

Avionics Boxes

- The analysis determined the best locations of avionics boxes based on the technicians location capabilities and:
  - Box weight
  - Tool access
  - Hand volumes
  - Cable routes

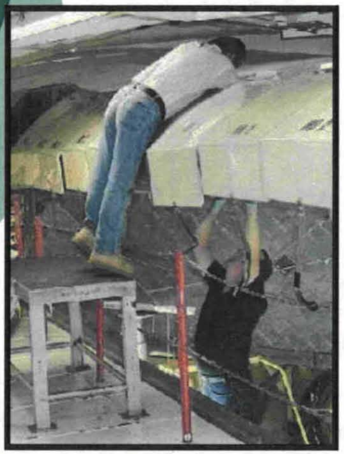


Hatch

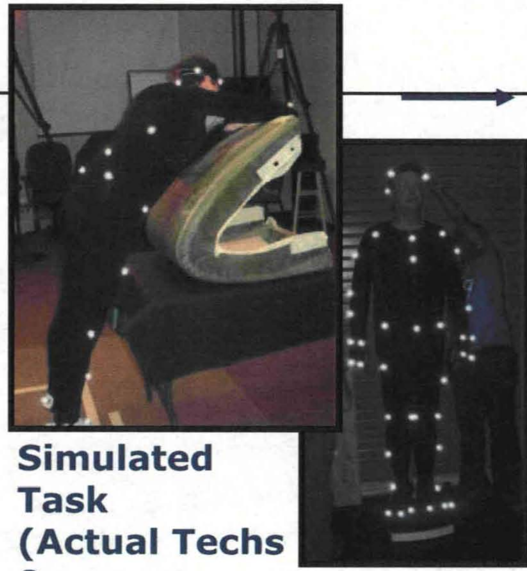
A 4

Assessing Human Factors using Motion Capture

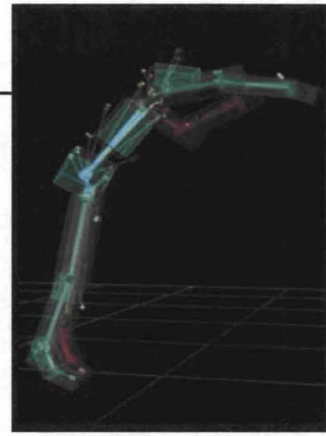
KSC Human Engineering Modeling and Performance Laboratory (HEMAP) Motion Capture to CAD to HF Analysis Process



Real-time Task

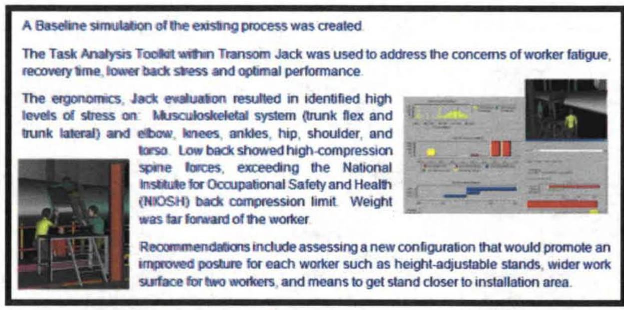


Simulated Task (Actual Techs & Biomechanical Data)



Motion Capture

Simulations



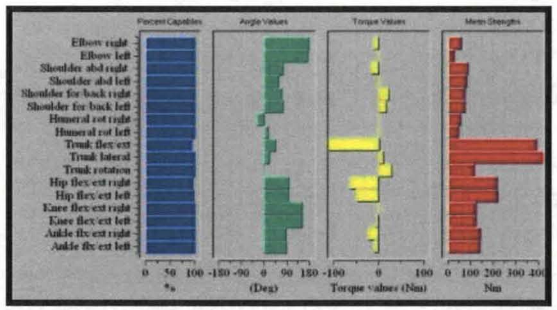
A Baseline simulation of the existing process was created.

The Task Analysis Toolkit within Transom Jack was used to address the concerns of worker fatigue, recovery time, lower back stress and optimal performance.

The ergonomics, Jack evaluation resulted in identified high levels of stress on: Musculoskeletal system (trunk flex and trunk lateral) and elbow, knees, ankles, hip, shoulder, and torso. Low back showed high-compression spine forces, exceeding the National Institute for Occupational Safety and Health (NIOSH) back compression limit. Weight was far forward of the worker.

Recommendations include assessing a new configuration that would promote an improved posture for each worker such as height-adjustable stands, wider work surface for two workers, and means to get stand closer to installation area.

Human Factors Analyses/Recommendations

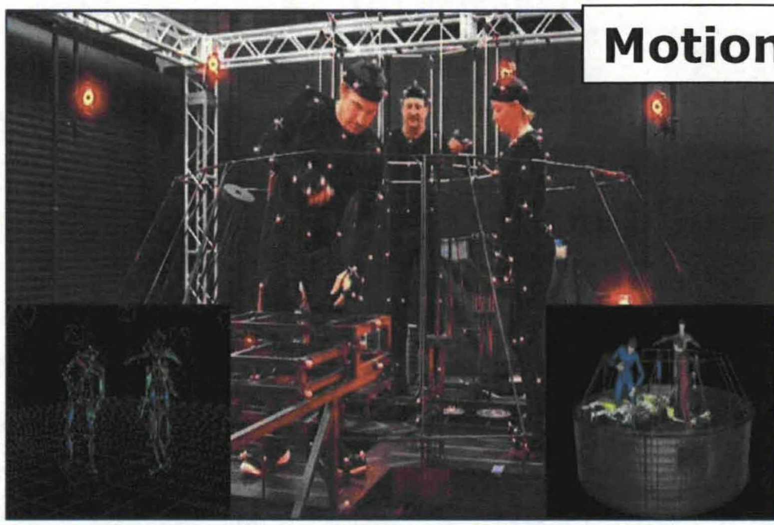


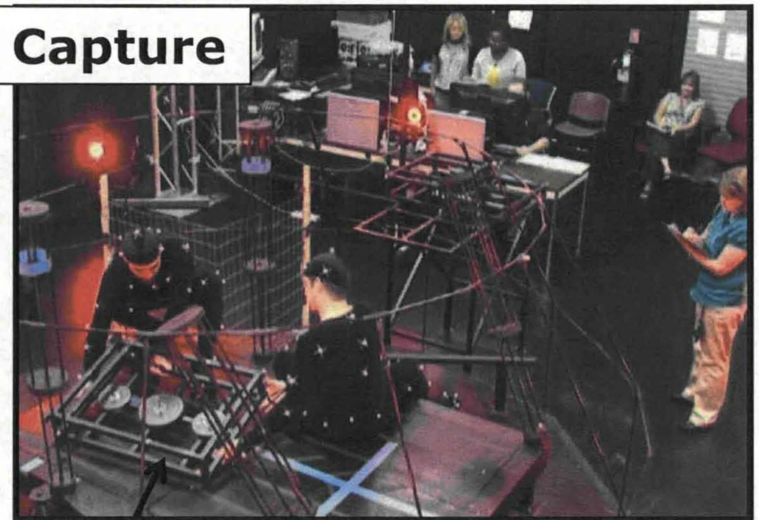
Ergonomic Analysis Output/Indicators

HEMAP supports multiple person/object tracking plus live ergonomic analyses

Orion Seat R&R

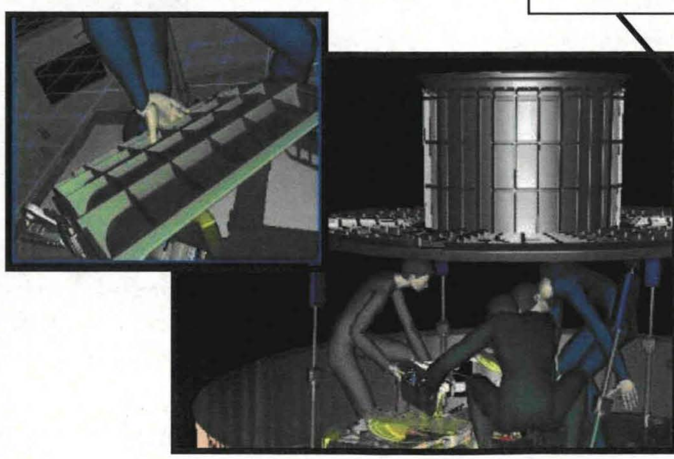
Motion Capture

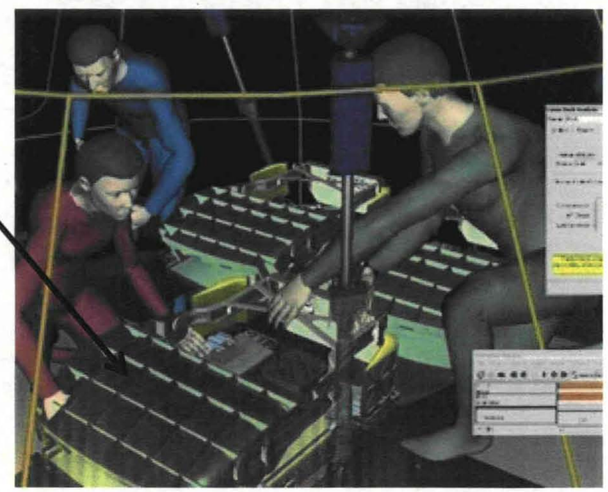




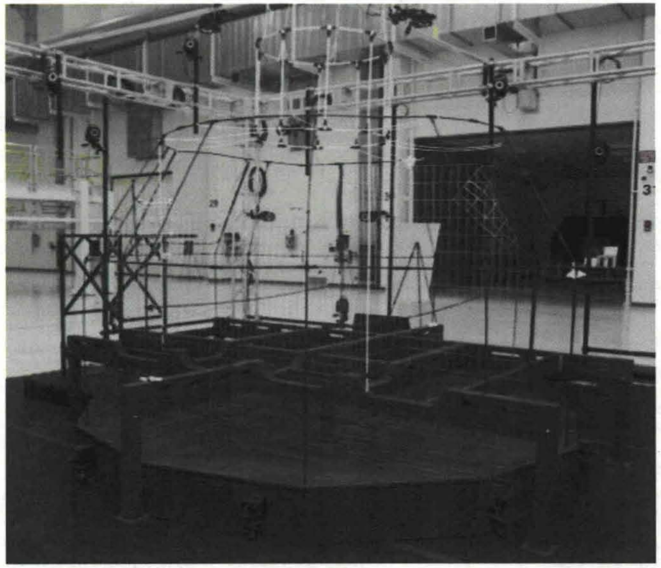
CAD Models with Human Models

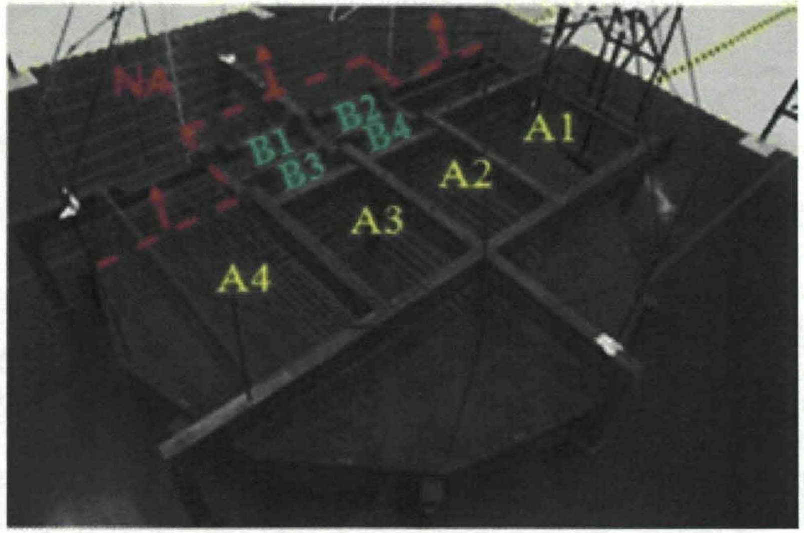
SEAT

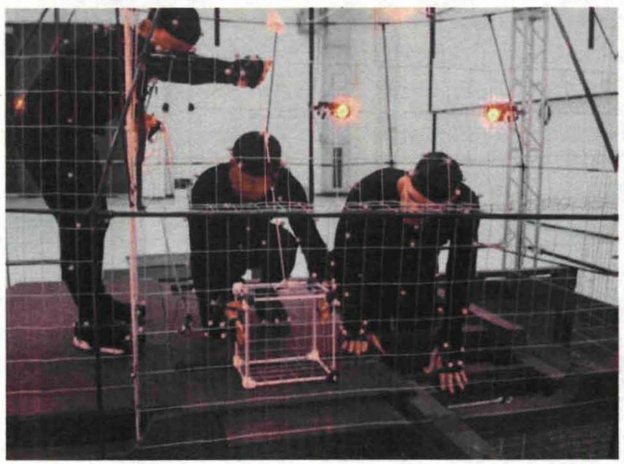


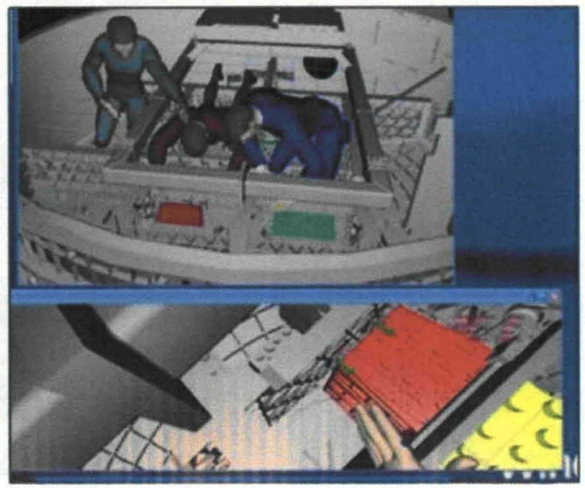


Orion Avionics Box Installation









Self-Contained Atmospheric Protective Ensemble SCAPE Suit

Markers placed on SCAPE suits to create actual life size and motion of suits

HEMAP Most Recent Accomplishments

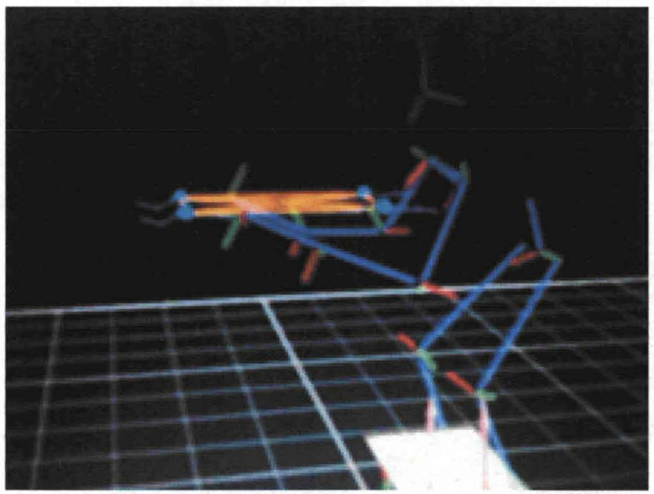
- Interactive virtual collaboration of motion capture data among KSC and MSFC
  - The web sharing of motion capture tasks within the shared virtual environment provides real-time ability to update designs based on actual human-system interfaces being evaluated.

HEMAP Most Recent Accomplishments

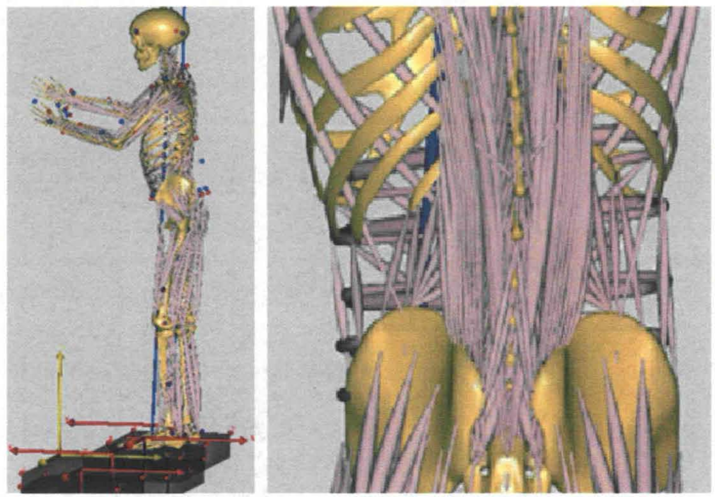
- Incorporation of wearable Head-Mounted Displays (HMDs):
  - Negates need for physical mockups.
  - Familiarization/training benefits
  - Collaborative web sharing of models and live motion tracking among NASA centers
  - Immersing the HMD wearers in simple physical mockups

A 5

Biomechanical Analysis of Installing Avionics Boxes

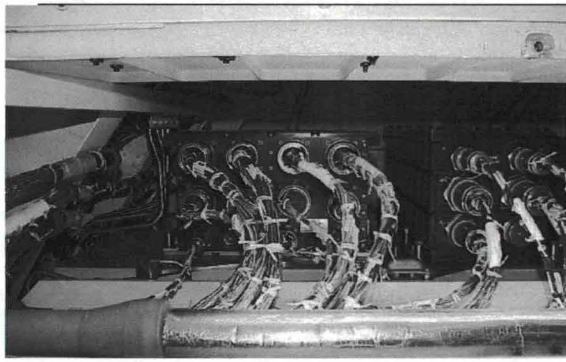


Placing Box Accurately

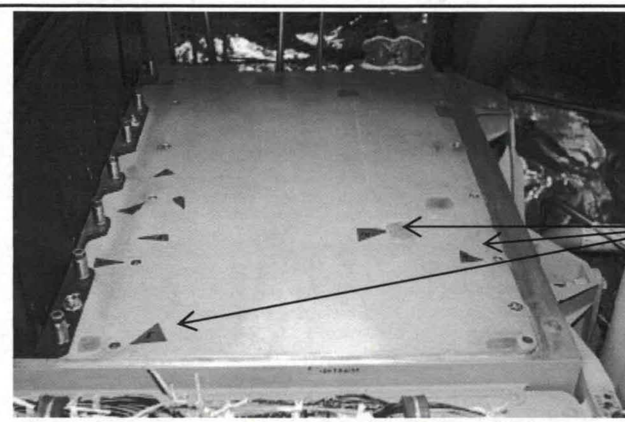


L5/S1 spinal stress

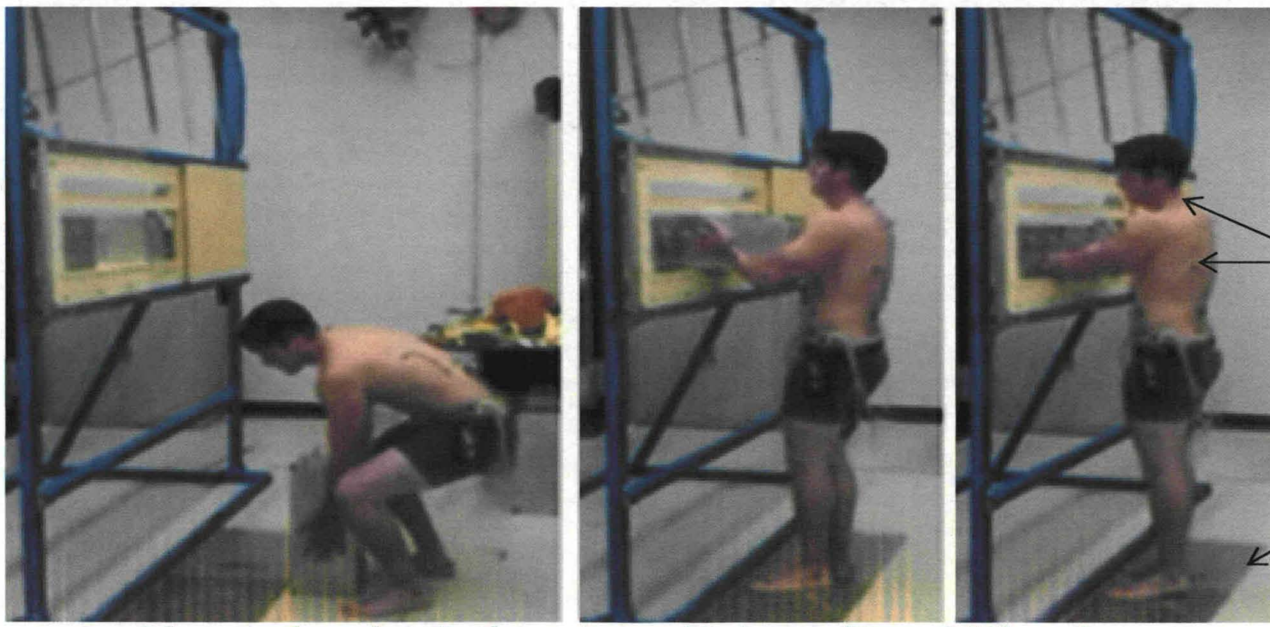
Biomechanical Analysis of Avionics Box Installation



Box in restricted space



Cold plate damage



EMG and reflective markers

Force Plate

Biomechanics Laboratory University of Miami

A 6

Development of Human Factors Engineering Requirements for Ground Task Design for a NASA Flight Program

Janis Connolly
Charles, Jr. H. Dischinger
Keith V. Holubec
Barry Tillman

Development of Human Factors Engineering Requirements for Application to Ground Task Design for a NASA Flight Program

- The National Aeronautics and Space Administration (NASA) has long employed human factors requirements for development of flight systems.

- NASA-STD-3000 does not include human factors design requirements for ground tasks, and therefore, programs have not been required to develop human factors requirements for ground crew tasks.

- The result has been that ground crews have had to develop complicated strategies for accomplishment of ground assembly and maintenance of flight systems.

- The Constellation Program (the execution program for the Exploration Vision) has accepted the responsibility, imposed by the NASA Administrator, to find ways to reduce ground operations costs. One of the ways the Program is doing this is through the application of human factors design requirements for the ground processing to flight systems.

Human Systems Integration Requirements (HSIR)

1.2 SCOPE AND PRECEDENCE

The requirements in this document are applicable to the Constellation Systems, including but not limited to Orion, Ares I, Ares V, Altair, Mission Systems (MS), Ground Operations (GO), Extravehicular Activity (EVA), and Flight Crew Equipment (FCE)

The requirements in this document address the needs of the flight crew during all phases of flight. These requirements also address the needs of ground personnel during pre-flight preparation, maintenance, and post-flight activities on the flight vehicles where there is a common interface with the flight crew

Human Systems Integration Requirements (HSIR)

3.9 GROUND MAINTENANCE AND ASSEMBLY

This section addresses tasks to be performed by NASA and its launch site contractors in accomplishment of launch site processing and ground maintenance. Launch site processing includes vehicle assembly (e.g., Ares I + Orion) activities that occur within the Outer Mold Line of the Launch Stack, Launch Stack physical integration (e.g., umbilical integration), and launch preparation (e.g., propellant loading). Ground maintenance includes corrective and preventive maintenance activities associated with Line Replaceable Unit (LRU) removal and replacement. These requirements do not apply to unplanned repair at the launch site, build activities at the manufacturing site, or potential build up at the launch site prior to system integration (for example, build up of the Orion). The requirements in this section apply only to those aspects of design that are under direct control of the vehicle developers, but not to the design of external Ground Support Equipment (GSE) and test systems. These requirements do not apply to any powered portable equipment that is intended for flight.

NASA-STD-3001, VOLUME 2

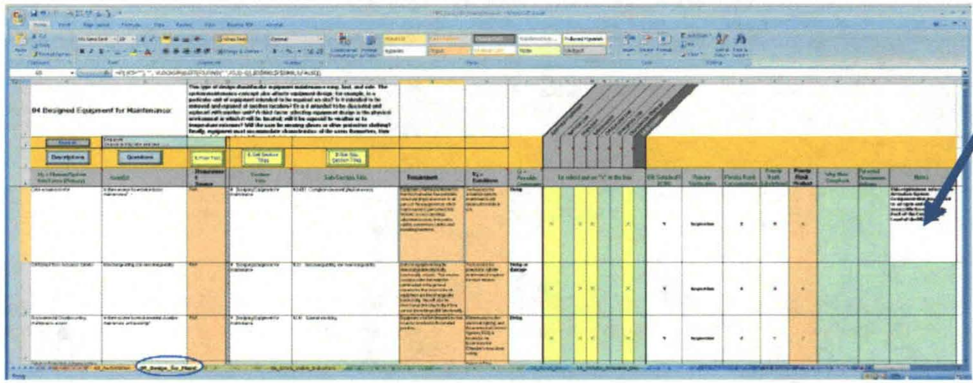
Section 13, Ground Maintenance and Assembly, will address the requirements for the configuration of interfaces that are common to both flight crew and ground personnel. This section is currently marked reserved and will be developed during Fiscal Year 2010.

https://standards.nasa.gov/documents/viewdoc/3315785/3315785

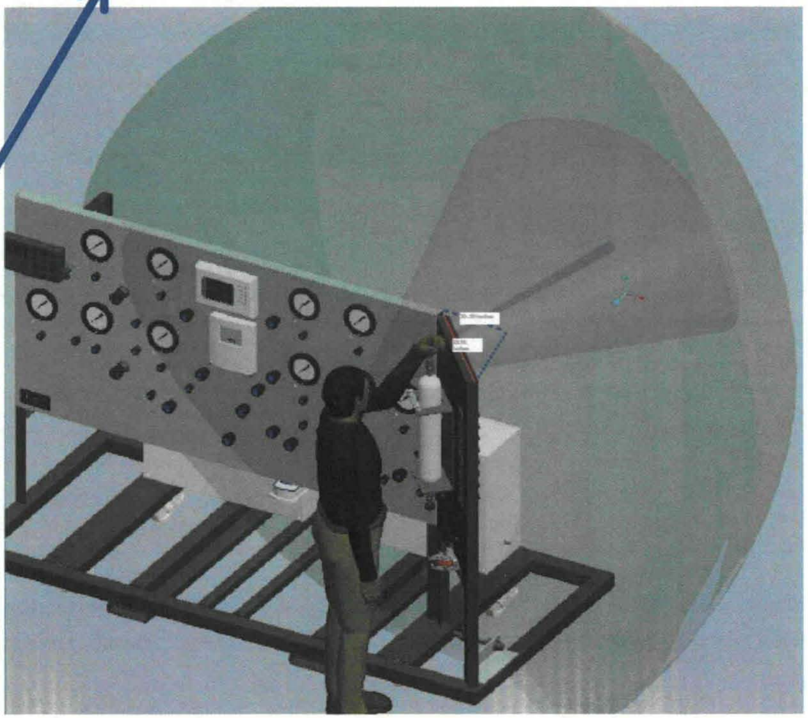
- Pro E Manikin
- KSC Design Visualization
- KSC Display/Control Screens

A 7

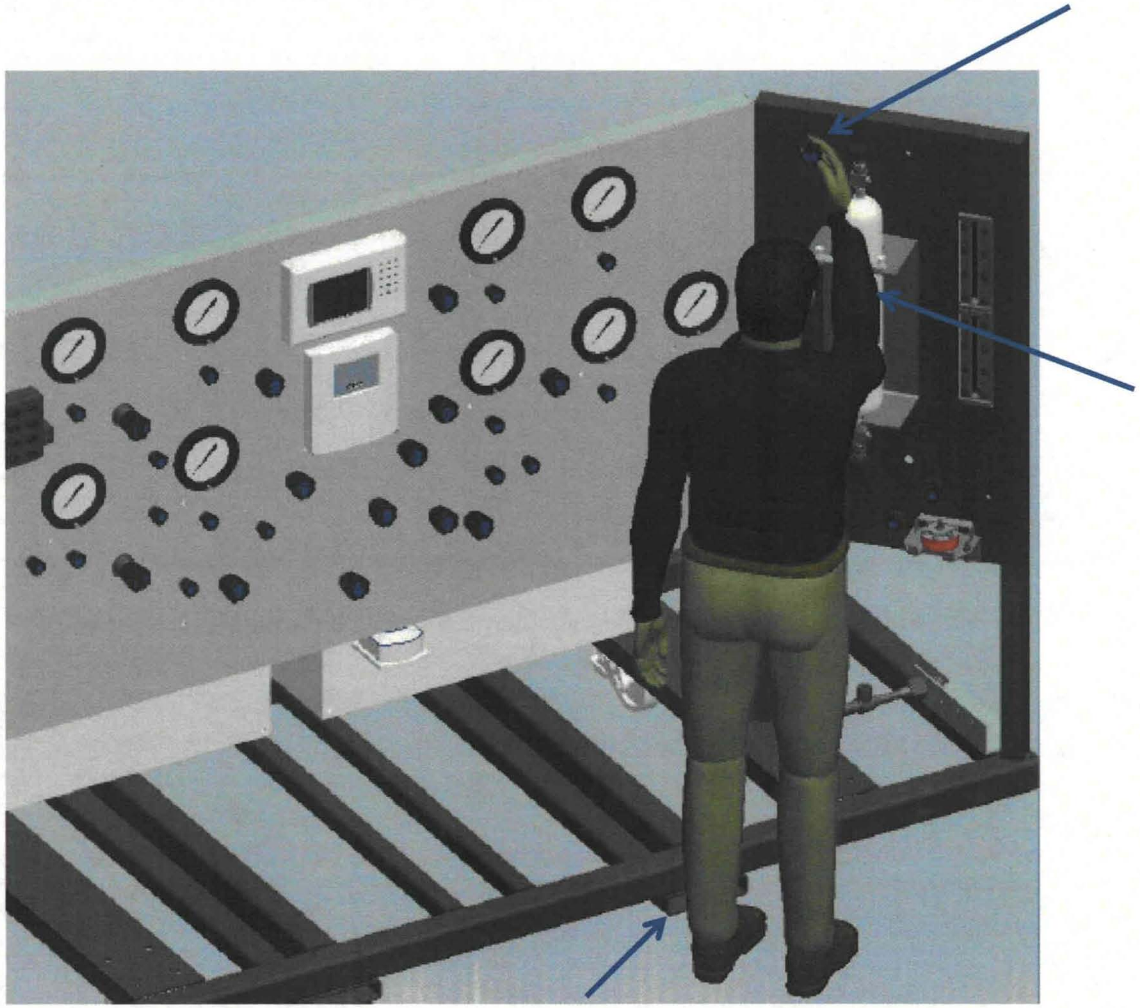
Pro E Manikin



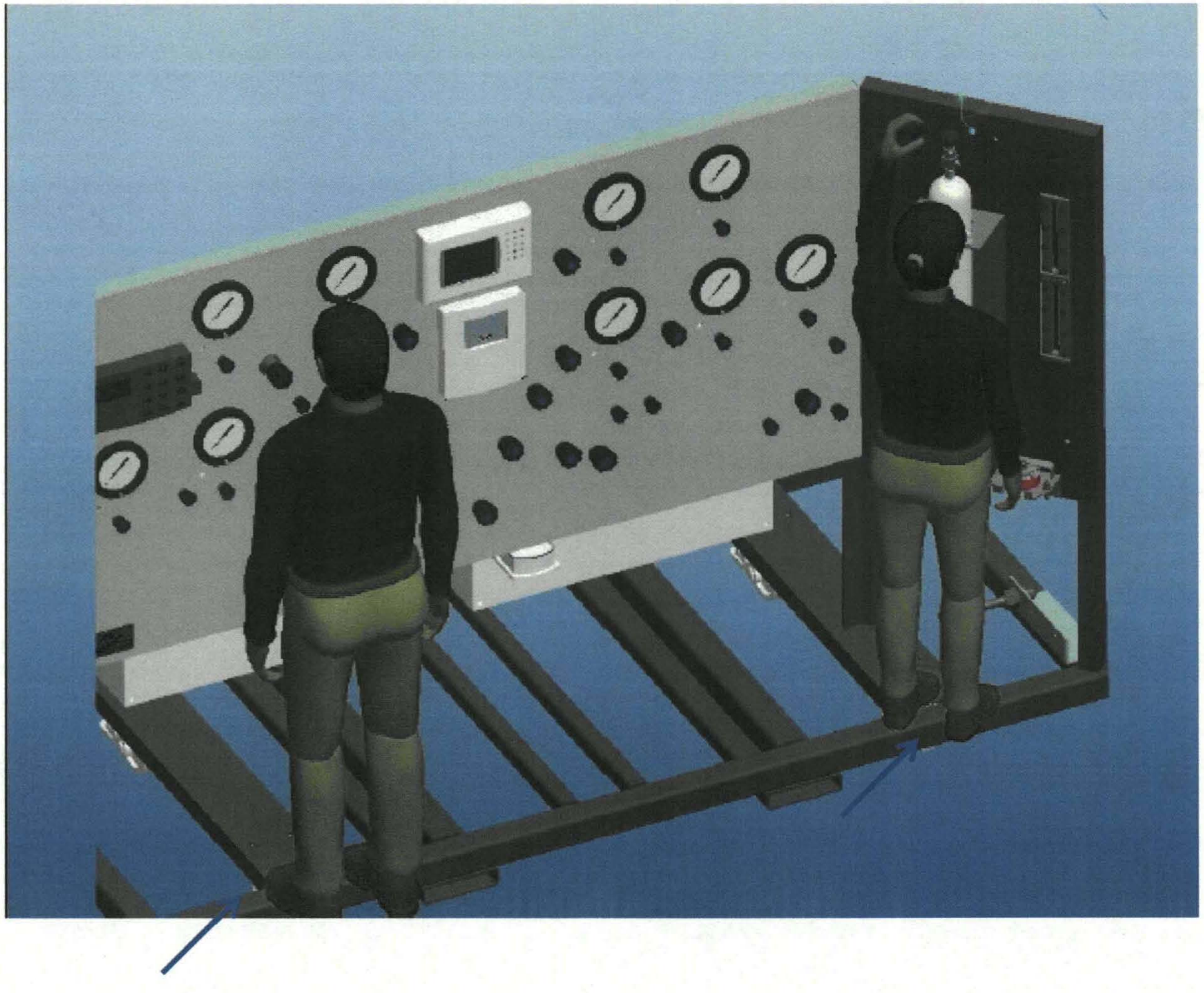
PRO E MANIKIN for Verification



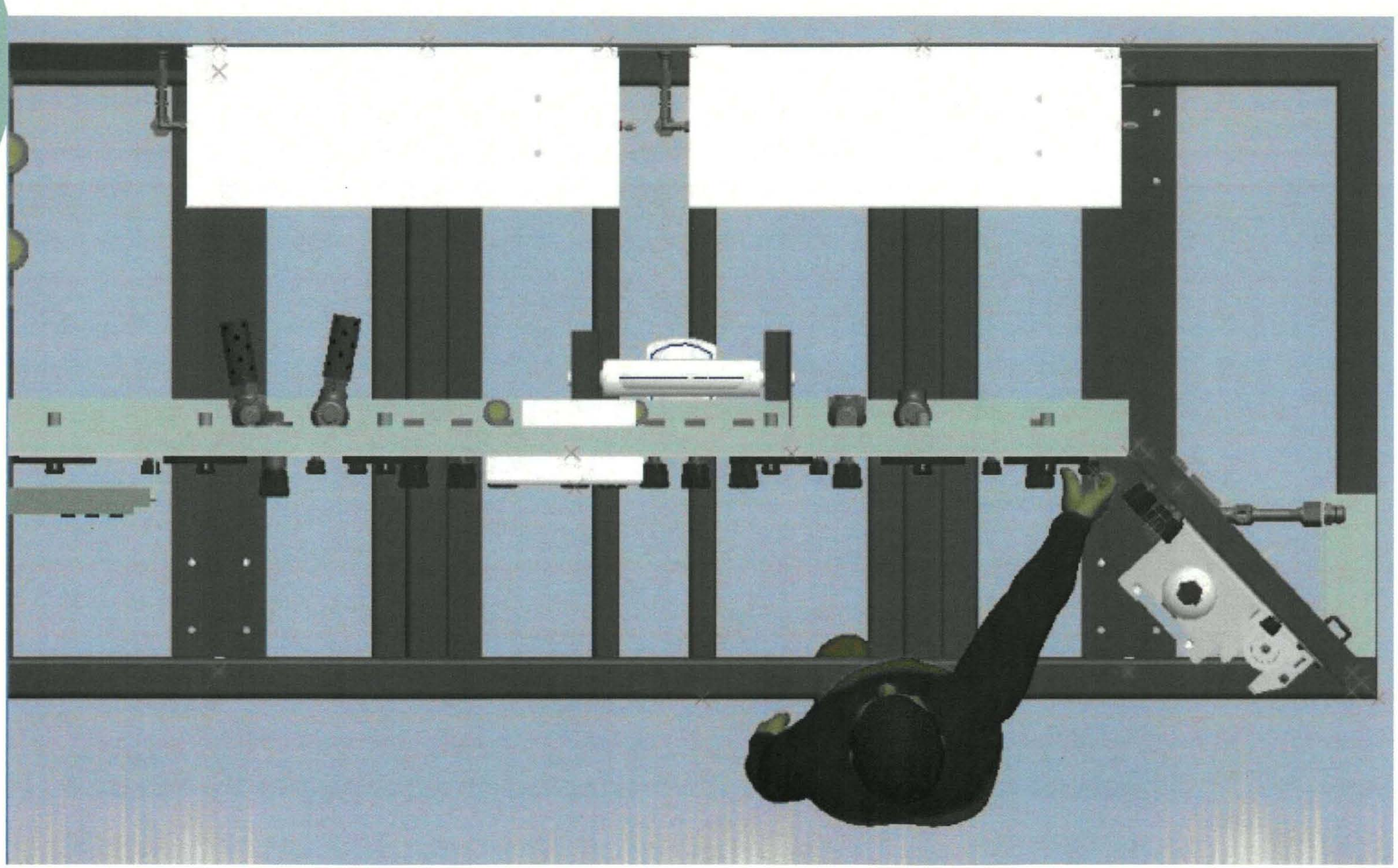
Pro E Manikin



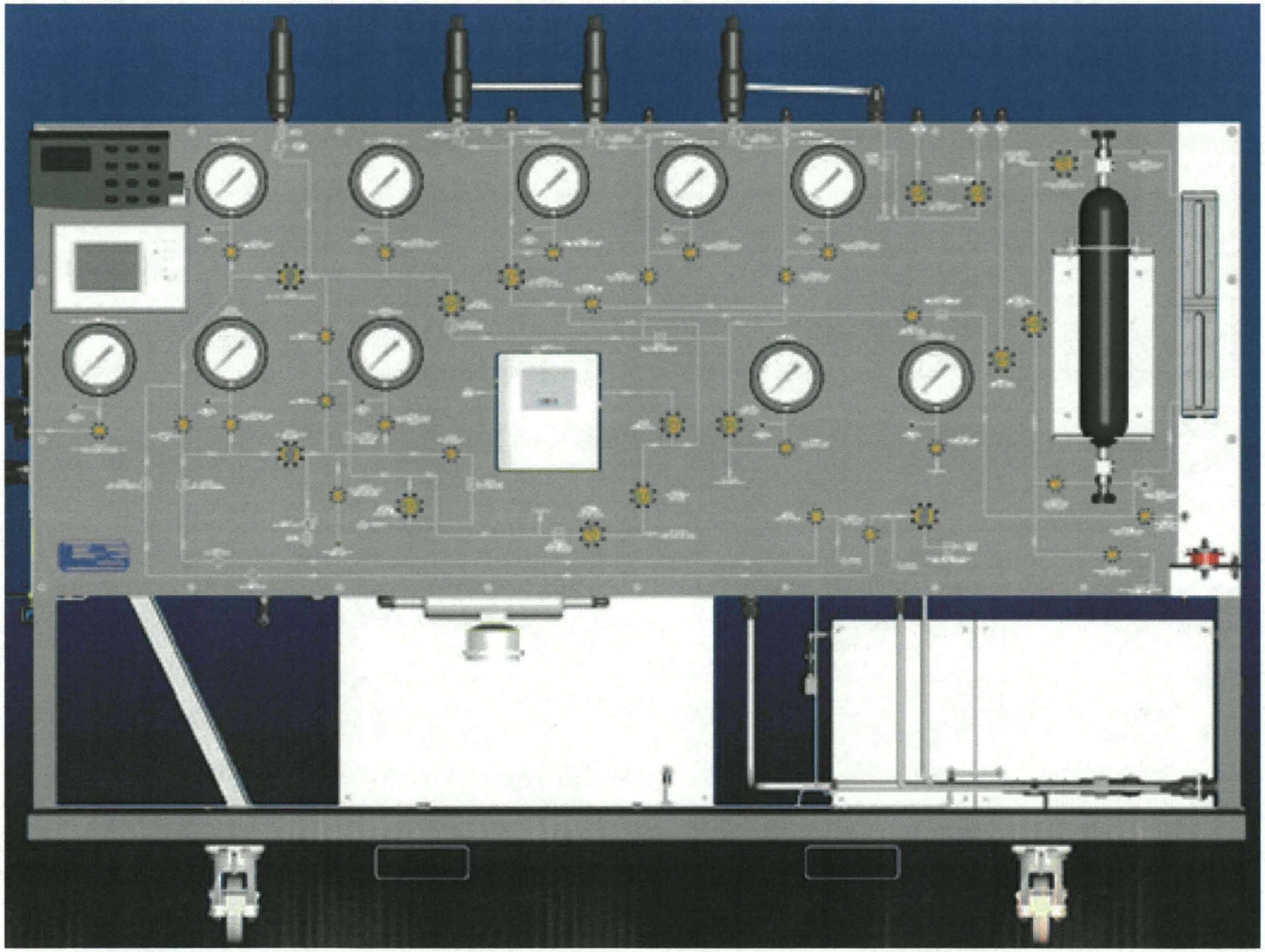
Pro E Manikin



Pro E Manikin



Solution



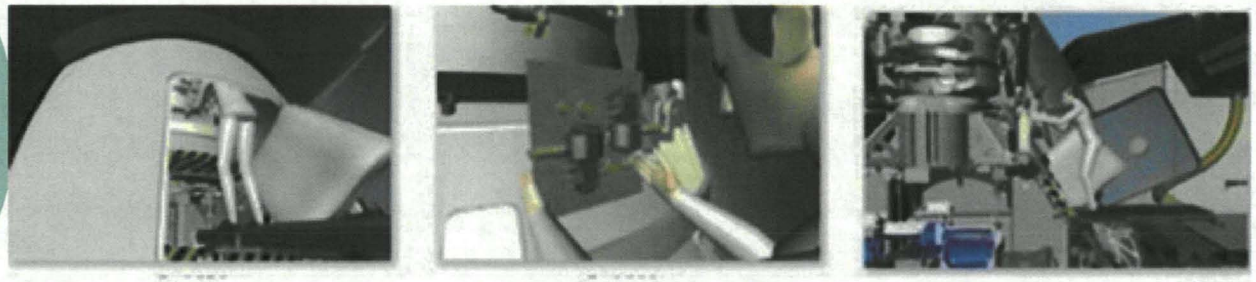
A 8

KSC Design Visualization

Simulation-Based Human Factors Kennedy Space Center has the capability to analyze human factors.

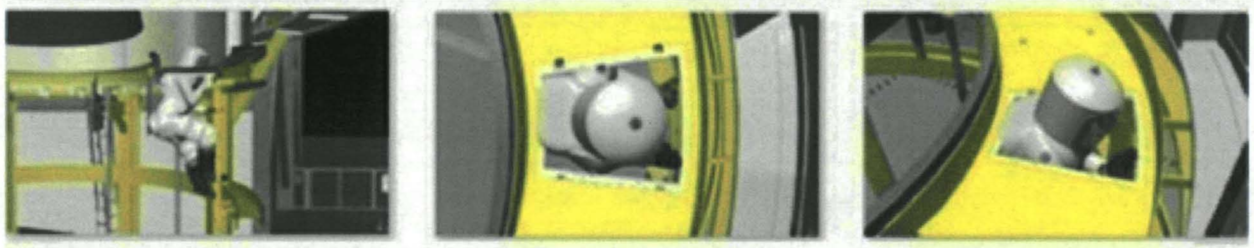
These factors include sight lines, visibility, reach, motion, joint loading, repetition, calories and any additional impediments caused by safety or life support systems.

KSC Design Visualization



LAS safe and arm access at PAD

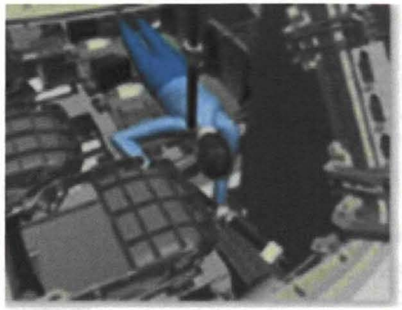
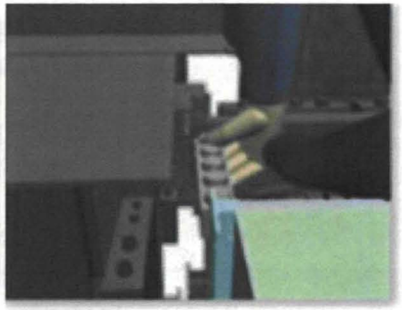
SCAPE fueling



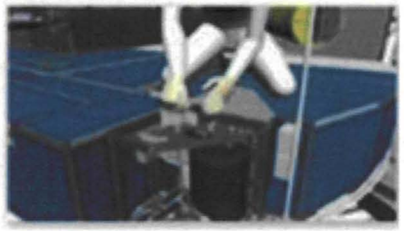
SCAPE access

Astronaut emergency egress

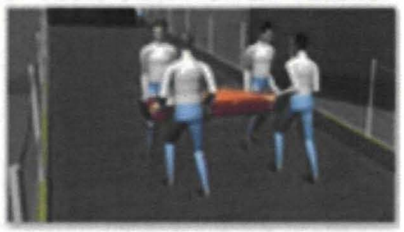
KSC Design Visualization

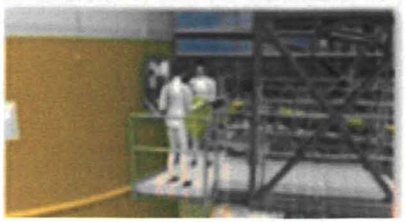
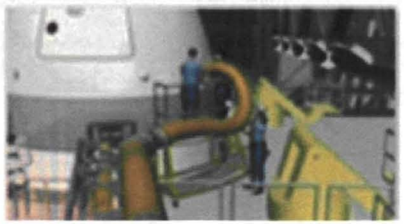
Pryo access

Water filter access

Astronaut egress post flight

Access arm assessment

A 9

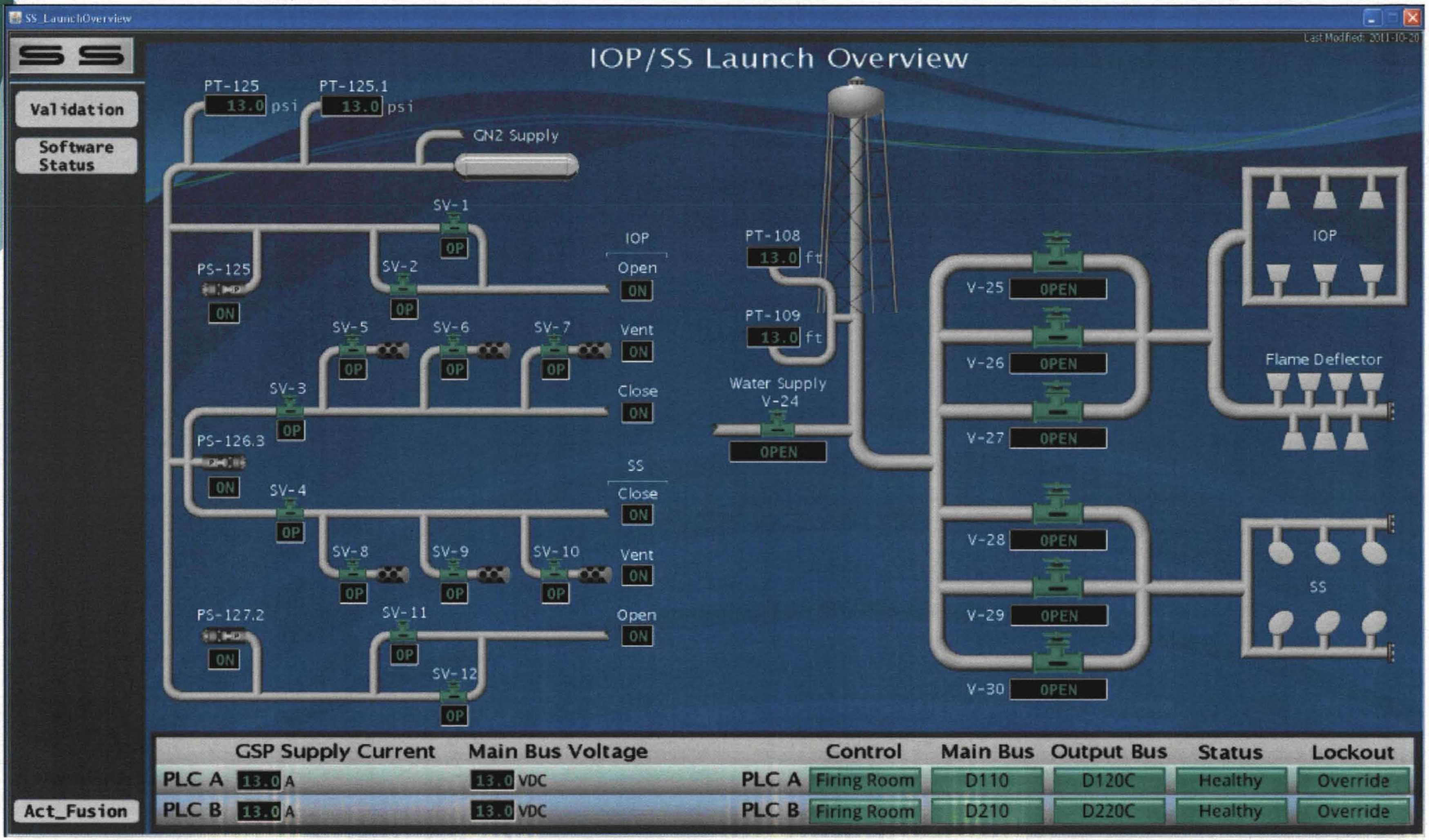
KSC Display/Control Screens

A 9

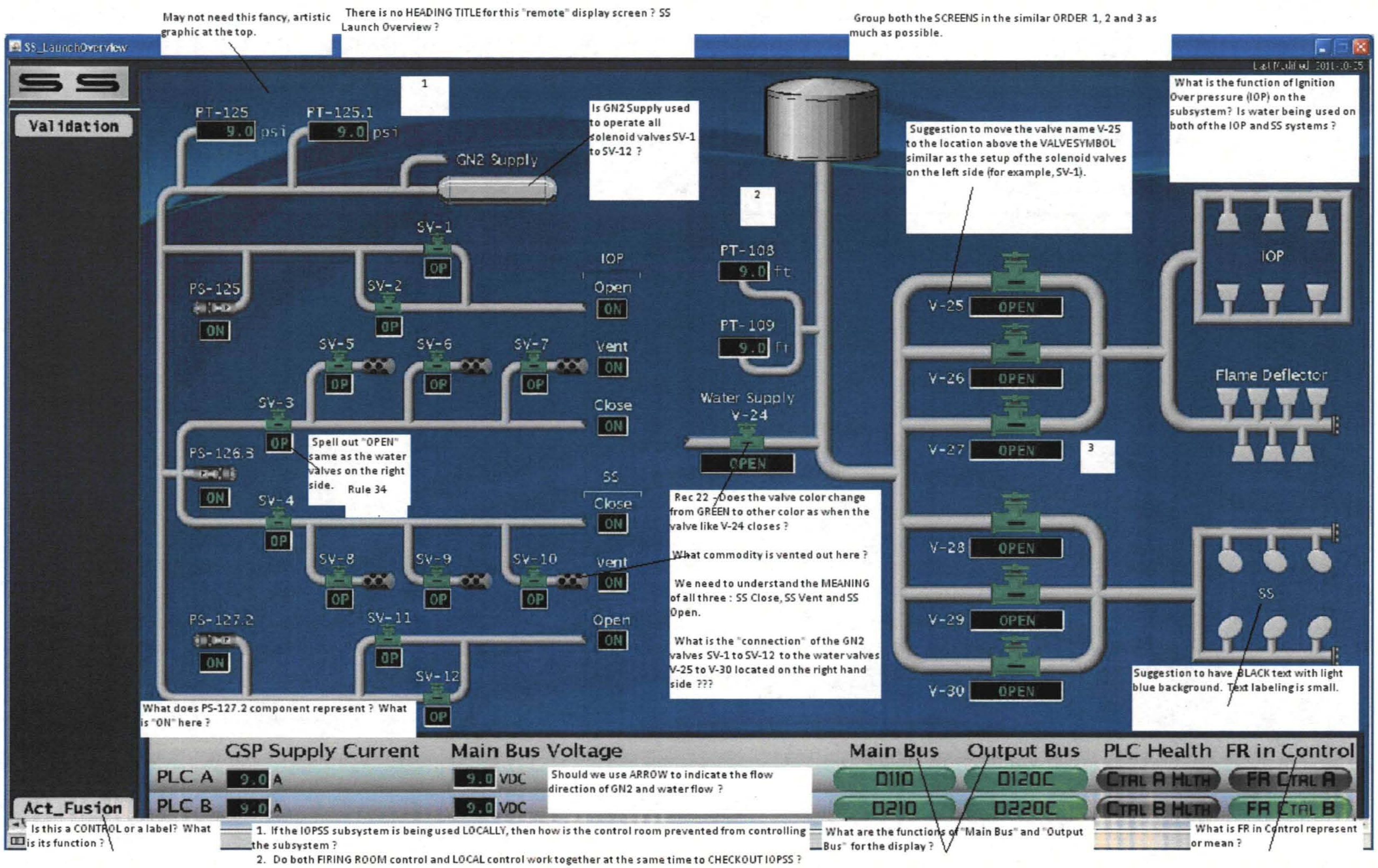
Local and Remote(LCS)

- Human Machine Interface (HMI) Programming Guidelines, (KGCS) local screen guidelines document
- Ground Elements Integrated Launch Operations Application Software Implementation Standards (ILOA) human factors section for local and remote screen design.
- Screens currently under development
  - GSP (Ground Special Power)
  - ECS (Environmental Control System)
  - CMASS (Crew Module Ammonia Servicing System)
  - FLDS (Fire Detection)
  - LH2/LO2
  - IOPSS (Ignition Overpressure Sound Suppression)

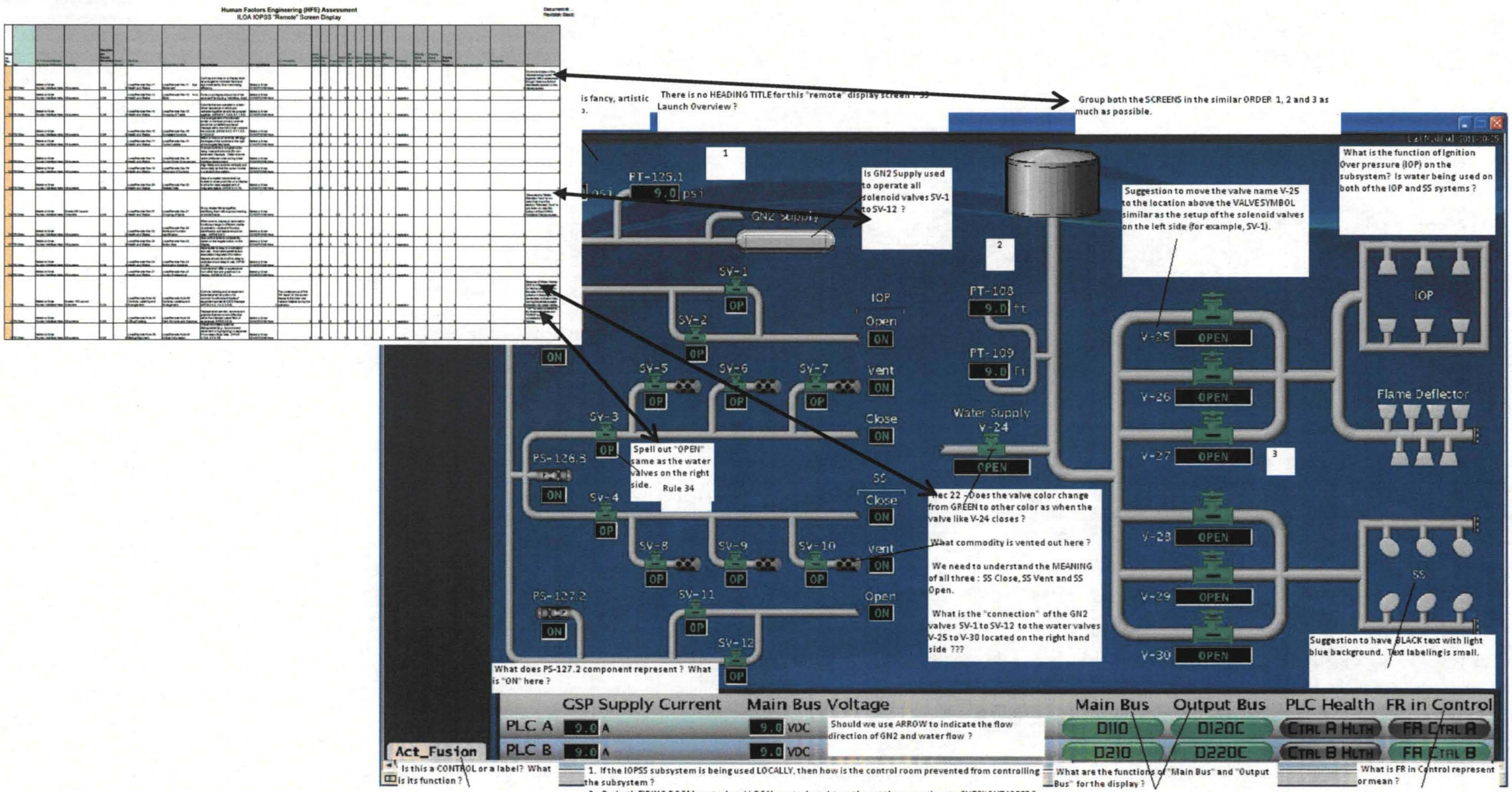
IOPSS Screen Shot



Screen Shot With HFEA Notes



Screen Shot With HFEA Notes



HFEA Report

Human Factors Engineering (HFE) Assessment
ILOA IOPSS "Remote" Screen Display

Document #: ...
Revision: Basic

Relative Req #	Tab	HI = Human/System Interface (Primary)	Impact(s)	Requirement Source Document	Shall/Should	Section Title	Sub-Section Title	Requirement	CI = Condition	CI = Possible Consequences	[illegible]	[illegible]	Inspection	Maintenance	Off-Nominal Use	Emergency Use	[illegible]	[illegible]	RD Satisfied? (Y/N)	Primary Verification	Priority Rank Consequence	Priority Rank Likelihood	Priority Rank Product	Why Non-Compliant	Potential Recommendations	Notes
19	18 Other	Select or Enter Human Interface Here	All screens	ILOA	0	Local/Remote-Rec-11 Health and Status	Local/Remote-Rec-11 Eye Movement	Controls and data on a Display shall be arranged to minimize hand and eye movements, thus maximizing efficiency.	Select or Enter CONDITION Here	0	0	X	X	0	X	X	0	0	Y	Inspection	0	0	0	0	0	Control and data on the displays are grouped together within areas even though there is a limit of real estate (space) on the display screen.
20	18 Other	Select or Enter Human Interface Here	All screens	ILOA	0	Local/Remote-Rec-12 Health and Status	Local/Remote-Rec-12 Font Style	Fonts on a Display should be of the sans-serif family (e.g. Helvetica, Arial).	Select or Enter CONDITION Here	0	0	X	X	0	X	X	0	0	Y	Inspection	0	0	0	0	0	0
23	18 Other	Select or Enter Human Interface Here	All screens	ILOA	0	Local/Remote-Rec-15 Health and Status	Local/Remote-Rec-15 Grouping of Tasks	Controls that are operated in a task-driven sequence or which are operated together should be grouped together. (HFDS 6.1.1.3.3, 6.1.1.3.5)	Select or Enter CONDITION Here	0	0	X	X	0	X	X	0	0	Y	Inspection	0	0	0	0	0	0
24	18 Other	Select or Enter Human Interface Here	All screens	ILOA	0	Local/Remote-Rec-16 Health and Status	Local/Remote-Rec-16 Consistent Controls	The arrangement of functionally similar or identical primary controls should be consistent across all Displays within the CSCI that contains the controls. (HFDS 3.4.2, 6.1.1.3.8, 6.14.2.8.3)	Select or Enter CONDITION Here	0	0	X	X	0	X	X	0	0	Y	Inspection	0	0	0	0	0	0
25	18 Other	Select or Enter Human Interface Here	All screens	ILOA	0	Local/Remote-Rec-17 Health and Status	Local/Remote-Rec-17 Control Labels	Within a column of controls, left-align the edges of the controls to the right of the longest field label.	Select or Enter CONDITION Here	0	0	X	X	0	X	X	0	0	Y	Inspection	0	0	0	0	0	0
26	18 Other	Select or Enter Human Interface Here	All screens	ILOA	0	Local/Remote-Rec-18 Health and Status	Local/Remote-Rec-18 Control Order Arrangement	Arrange controls in a logical order, using rows and columns (for non-schematic Displays). Determine the users' preferred order during initial interface development.	Select or Enter CONDITION Here	0	0	X	X	0	X	X	0	0	Y	Inspection	0	0	0	0	0	0
27	18 Other	Select or Enter Human Interface Here	All screens	ILOA	0	Local/Remote-Rec-19 Health and Status	Local/Remote-Rec-19 Alignment of Controls	Align fields and controls vertically and horizontally so that the cursor moves in a straight-line pattern.	Select or Enter CONDITION Here	0	0	X	X	0	X	X	0	0	Y	Inspection	0	0	0	0	0	0
28	18 Other	Select or Enter Human Interface Here	All screens	ILOA	0	Local/Remote-Rec-20 Health and Status	Local/Remote-Rec-20 Related Data	Data of a related nature shall be located in close proximity on a Display to allow for easy assessment of integrated status. (HFDS 3.12.18)	Select or Enter CONDITION Here	0	0	X	X	0	X	X	0	0	Y	Inspection	0	0	0	0	0	0
29	18 Other	Select or Enter Human Interface Here	Screen XX Launch Overview	ILOA	0	Local/Remote-Rec-21 Health and Status	Local/Remote-Rec-21 Grouping of Items	Group related items together, identifying them with a group heading, or border/frame.	Select or Enter CONDITION Here	0	0	X	0	X	0	0	0	0	Y	Inspection	0	0	0	0	0	Because the "Water Elevated Tank" is not used that much the section "Elevated Tank" is put down on near the bottom of the IOPSS Validation Display screen.
30	18 Other	Select or Enter Human Interface Here	All screens	ILOA	0	Local/Remote-Rec-22 Health and Status	Local/Remote-Rec-22 Mode and Function Identification	When control, display or automation functions change in different modes of operation, mode and function identification and status should be clear. (HFDS 3.6.1)	Select or Enter CONDITION Here	0	0	X	X	0	X	X	0	0	Y	Inspection	0	0	0	0	0	0
31	18 Other	Select or Enter Human Interface Here	All screens	ILOA	0	Local/Remote-Rec-23 Health and Status	Local/Remote-Rec-23 Button Size	Size control buttons consistently, based on the largest button on the Display.	Select or Enter CONDITION Here	0	0	X	X	0	X	X	0	0	Y	Inspection	0	0	0	0	0	0
32	18 Other	Select or Enter Human Interface Here	All screens	ILOA	0	Local/Remote-Rec-24 Health and Status	Local/Remote-Rec-24 Automation Systems	Make systems easy to understand and use. Automated systems and associated integrated information displays should be intuitive, easy to understand and easy to use. (HFDS 9.1.29)	Select or Enter CONDITION Here	0	0	X	X	0	X	X	0	0	Y	Inspection	0	0	0	0	0	0
34	18 Other	Select or Enter Human Interface Here	All screens	ILOA	0	Local/Remote-Rec-27 Health and Status	Local/Remote-Rec-27 Control Appearance	Controls shall differ in appearance from other text and graphics in a Display. (HFDS 6.13.1.2)	Select or Enter CONDITION Here	0	0	X	X	0	X	X	0	0	Y	Inspection	0	0	0	0	0	0
1	18 Other	Select or Enter Human Interface Here	Screen XX Launch Overview	ILOA	0	Local/Remote-Rule-33 Controls, Labeling and Arrangement	Local/Remote-Rule-33 Controls, Labeling and Arrangement	Controls, labeling and arrangement schemes shall be uniform for common functions and types of equipment across all CSCI Displays. (HFDS 2.4.2, 2.4.3, 3.6.8)	0	The consequence of this "HF issue" of the screen display is the User may make a mistake during the Operation.	0	X	X	0	X	X	0	0	Y	Inspection	0	0	0	0	0	Because of Water Valves (V20 to V30) are stacked by having valve labels to the side of the valve position indicator this will cause less confusion than having the labels located between the water valves.
2	18 Other	Select or Enter Human Interface Here	All screens	ILOA	0	Local/Remote-Rule-34 Lifting/Twisting	Local/Remote-Rule-34 Text, Symbols and Graphics	Displays shall use text, symbols and graphics that are common/familiar within the intended users' field of experience. (HFDS 2.8.3)	Select or Enter CONDITION Here	0	0	X	X	0	X	X	0	0	Y	Inspection	0	0	0	0	0	"OP" is used consistently for Solenoid Valves and "OPEN" is used consistently for Water Valves.
3	18 Other	Select or Enter Human Interface Here	All screens	ILOA	0	Local/Remote-Rule-35 Marking/Alignment	Local/Remote-Rule-35 Critical Information	Critical information shall be distinguished (e.g., by prominent placement or highlighting) to separate it from less-critical data. (HFDS 8.12.9, 8.1.3.13)	Select or Enter CONDITION Here	0	0	X	X	0	X	X	0	0	Y	Inspection	0	0	0	0	0	0

RECOMMENDATIONS

Recommendations to Agency

- Continue to develop Human Factors requirements and processes at All levels.
- Continue to develop human factors tools, motion capture and other mockups and human modeling.
- Continue the Human factors collaborations between centers for our missions and programs, tools, requirements, and processes.
- Continue to revisit and improve upon these lessons from the past. And develop new lessons as we go through these incremental developments.

Thanks to all the folks at KSC and across the NASA Agency for their efforts towards the human factors achievements for spacecraft ground processing.

References

- Dr., Kanki, B,; Dr., Barth, T,; Ms, Miller, D,; Mr, King, J,; Mr., Stambolian, D,; Ms, Hawkins, J,; Mr, Westphal, J,; Ms, Dippolito, P; Mr, Dinally, J,; Ms, Blunt, M. " Human Factors Issues in the Design of Ground Systems: A Pathfinder Activity" http://www.congrex.nl/08a11/programme.asp
- Jeffrey S. Osterlund & Brad A. Lawrence. 61st Virtual Reality: Avatars in Human Spaceflight Training. International Astronautical Congress, Prague, CZ. Copyright ©2010 by the International Astronautical Federation. http://kave.ksc.nasa.gov/HEMAP/HEMAP2010/HEMAP2010.mp4
- Damon B. Stambolian, Dr. Gena Henderson, Ms. Darcy Miller, Mr. Gary Prevost, Mr. Donald Tran, and Dr. Tim Barth."1-G Human Factors for Optimal Processing and Operability of Ground Systems up to CxP PDR" 2011 IEEEAC paper#1007
- Gregory M. Dippolito & Damon B. Stambolian. Co-authors; Bao Nguyen, Charles Dischinger, Donald Tran, Gena Henderson, Dr. Tim Barth. Human Factors Analysis to Improve the Processing of Ares-1 Launch Vehicle. 2011 IEEEACpaper#1022
- Roland Schlierf & Damon B. Stambolian; co-authors Darcy Miller, Juan Posada, Mike Haddock, Mike Haddad, Mr. Donald Tran, Dr. Gena Henderson, and Dr. Tim Barth, Human Factors Operability Timeline Analysis to Improve the Processing Flow of the Orion Spacecraft. 2011 IEEEACpaper#1021
- Damon B. Stambolian, Shihab S. Asfour, Moataz Eltoukhy, and Stephanie Bonin. Avionics Box Precision Placement in Restricted Space. XXIIIrd Annual International Occupational Ergonomics and Safety Conference. June 9-10, 2011
- United Space Alliance Human Engineering Modeling and Performance (HEMAP) Laboratory. OFT-1 Backbone Avionics Installation/Removal Assessment. Baseline Report (Overall Access, Gross Motor Tasks
- Damon B. Stambolian., Marie-Jeanne O. Steady Ndiaye., Brad A. Lawrence., Katrine S Stelges., Lora C. Ridgwell., Mary K. Osterhout., Robert E. Mills., Gena Henderson., Donald Tran., and Tim Barth. Human Modeling for Ground Processing Human Factors Engineering Analysis. 2012 IEEEACpaper#0175
- NASA Lesson Learned Entry: 3696. 2010. Avionics Cooling. https://nen.nasa.gov/web/ll/home/llis-doc-viwer?url=https://nen.nasa.gov/llis_content/imported_content/lesson_3696.html
- Damon B. Stambolian., Steven W. Larcher., Gena Henderson., Donald Tran., and Tim Barth. Avionics Box Cold Plate Damage Prevention. 2012 IEEEACpaper#1074
- Stambolian, D., Eltoukhy, M., Asfour, S., & Bonin, S. (2011, July). Investigation of avionics box precision placement using motion capturing and thermal imaging techniques. International Journal of Scientific & Engineering Research, 2(7)