

Human Factors Issues in the Design of Ground Systems: **A PATHFINDER ACTIVITY**

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HF Pathfinder Core Team

- Kennedy Space Center
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 - Jeff King
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 - Barbara Kanki
- NASA Engineering and Safety Center
 - Tim Barth
- Outcome Engineering
 - John Westphal



Agenda

- **Introduction**
- **Pathfinder Activities**
 - **Human Factors Overview**
 - **Design Team Sessions**
- **Sample Results and Feedback**
- **Recommendations**
- **Next Steps**



Ground systems represent the largest overall cost for most space programs. However, testing of ground systems does not always get the same visibility as vehicle testing, for example.

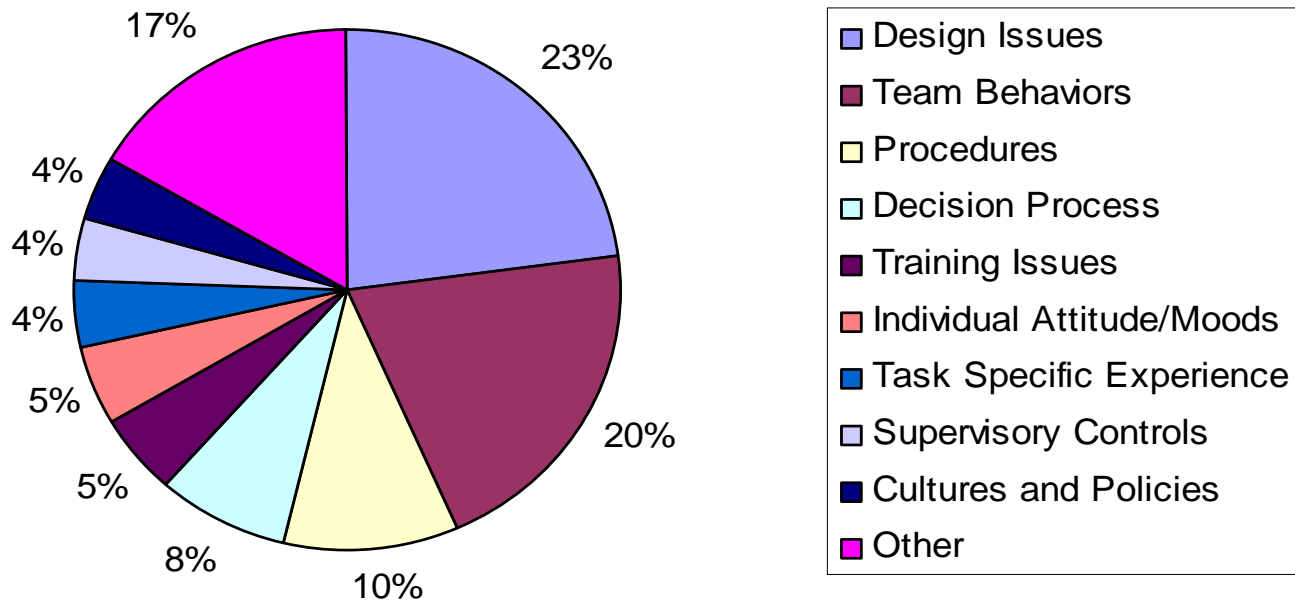
This is a major concern because problems with ground systems are just as likely to cause a mission failure as are vehicle problems. Also, ground systems tests are more prone to human error...”

**Excerpts from “Ground Systems Testing” by Norm Strang,
Aerospace Corporation**



Shuttle Ground Operations Mishap Data

Major Category Comparison
1254 Cause/Contributor Findings in 335 Mishaps
11-08-1996 to 09-30-2007



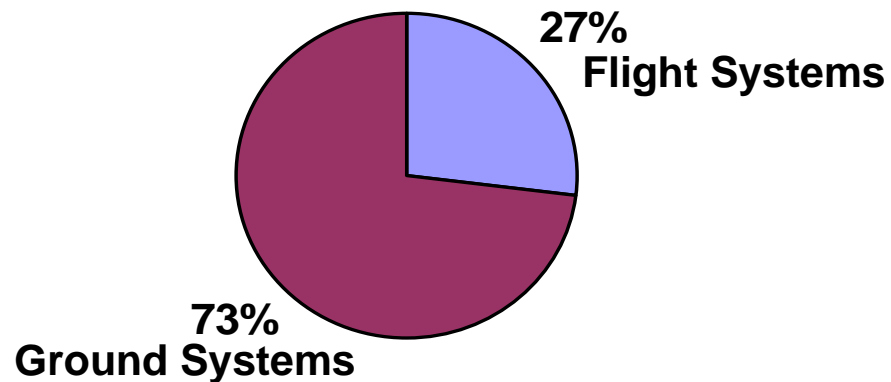
Courtesy of USA Industrial and Human Engineering



Shuttle Ground Operations Mishap Data

Design: Flight vs. Ground Systems

11-08-1996 to 9-30-2007



Courtesy of USA Industrial and Human Engineering



Mishaps in Ground Operations

➤ For 11 NASA/KSC mishap investigation boards in FY06 and FY07:

- \$3.5M 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 investigation boards, corrective actions (new procedures, training, etc.)
- indirect costs
- schedule impacts
- personnel injuries



The Pathfinder Goal

- **The goal was to improve KSC designs by optimizing ground and flight crew interfaces with ground systems and GSE**
 - Tremendous opportunity to influence designs early
 - Applying lessons learned from current ground ops to Constellation
- **The expected outcomes are:**
 - Ground systems/GSE that are safer and easier (and therefore cheaper) for ground crews to operate and maintain during 20+ years of Constellation launch operations
 - Fewer mishaps during ground processing where ground system/GSE designs are cited as contributing factors or causes



Pathfinder Activities

- **During one week in November, 2007:**

- **November 13,**
 - **Two-hour Human Factors Overview for GS/GSE Designers**

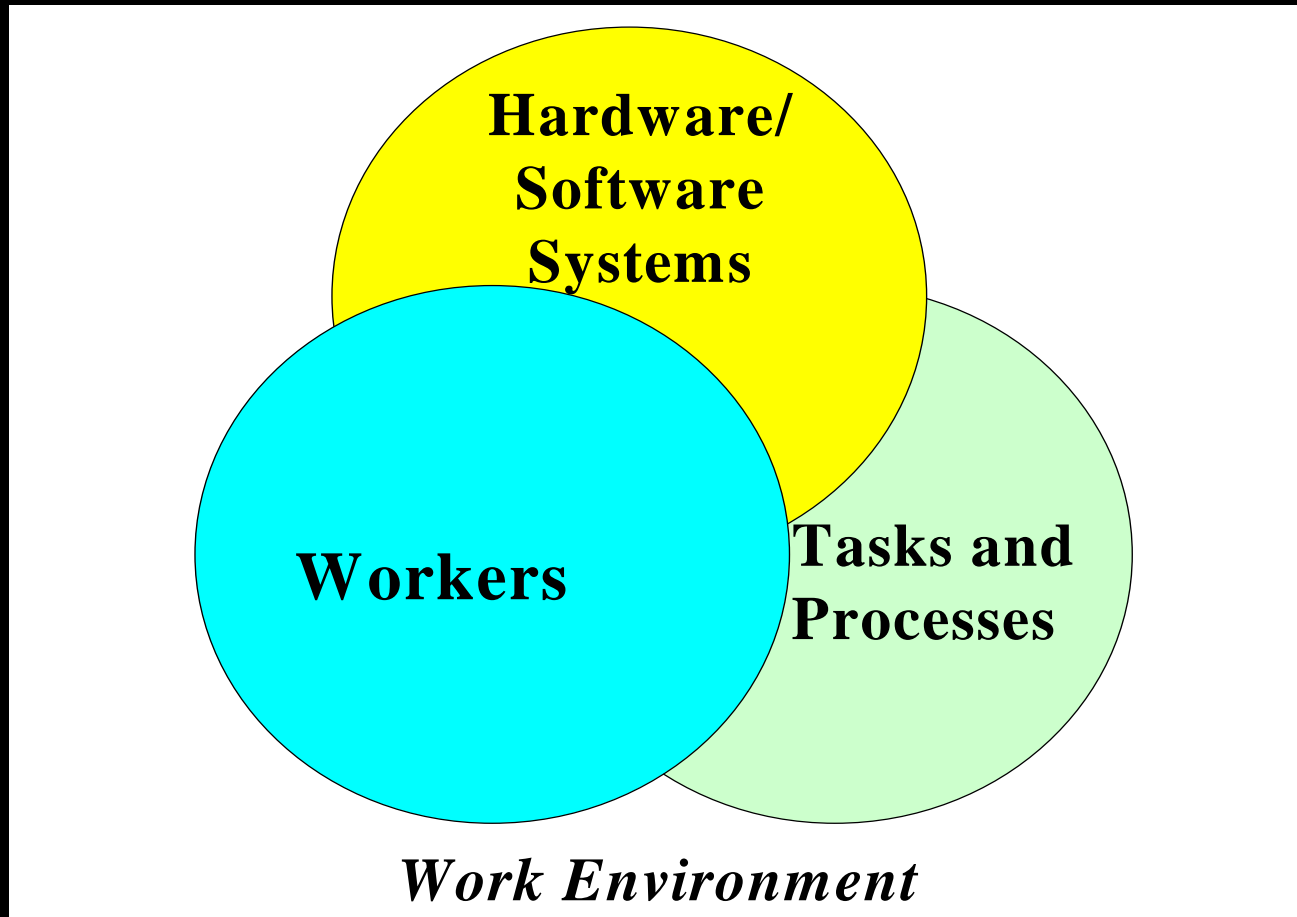
- **November 14 through November 16**
 - **Working Sessions with Design Teams**
 - **Wrap-Up Session with Design Team Leads**



Human Factors Overview

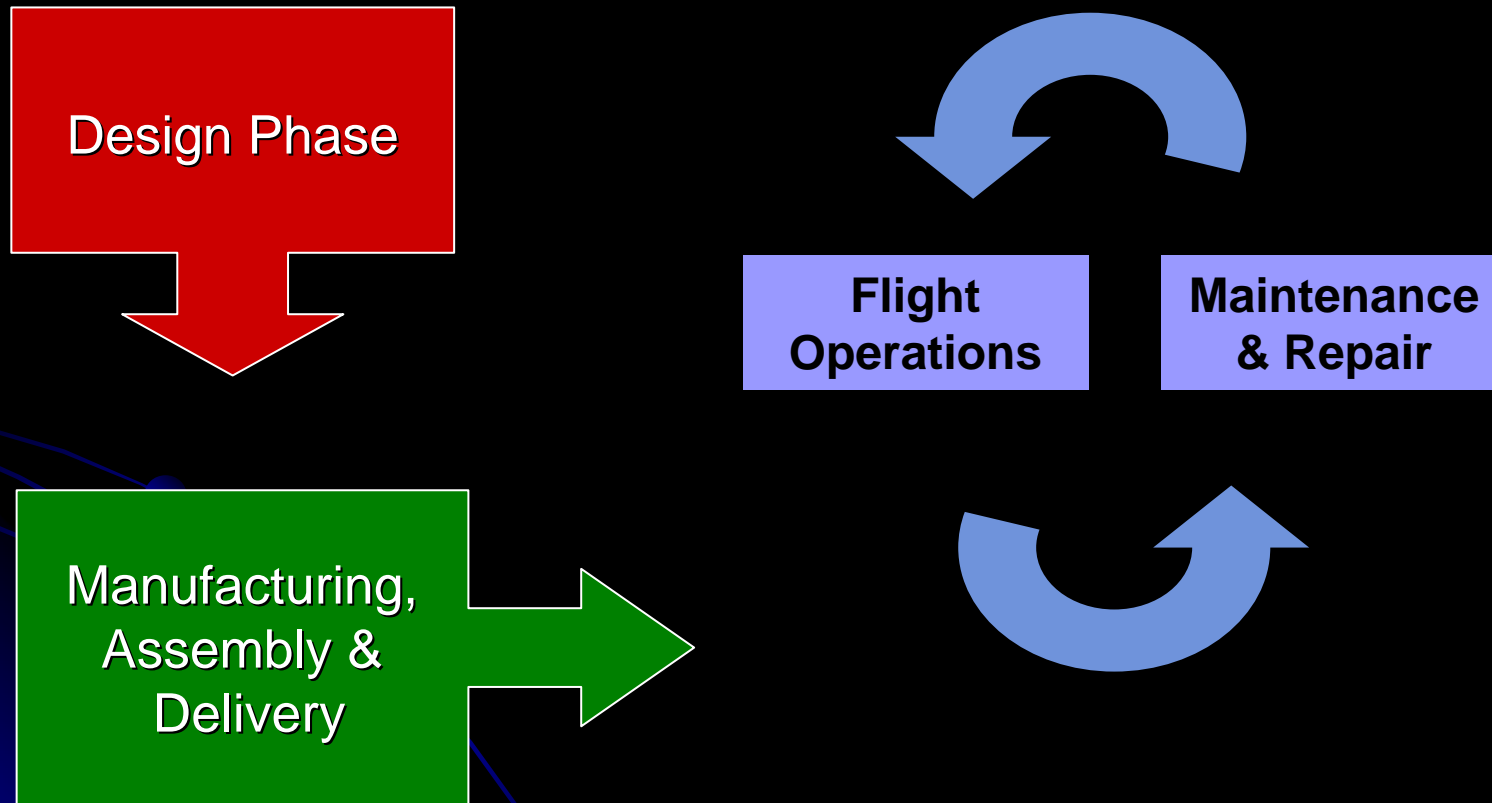
- **Two-hour panel discussion designed to familiarize GS/GSE designers with basic HF principles as a prerequisite for their working sessions**
 - **Topics**
 - ❖ **Goals and Background, Mishap Data**
 - ❖ **Historical Perspective: Aviation Safety**
 - ❖ **Common Design Issues and Examples**
 - ❖ **Shop Floor Perspective**
 - **KSC Engineering Academy support was invaluable**
 - ❖ **Approximately 100 participants**
 - ❖ **Reaching far beyond the Design Teams alone**

Taking a Systems Perspective



*Workers include assemblers, maintainers, operators, inspectors,
and engineers*

Taking a Lifecycle Perspective



Common Design Issues in Ground Crew/Ground System Integration

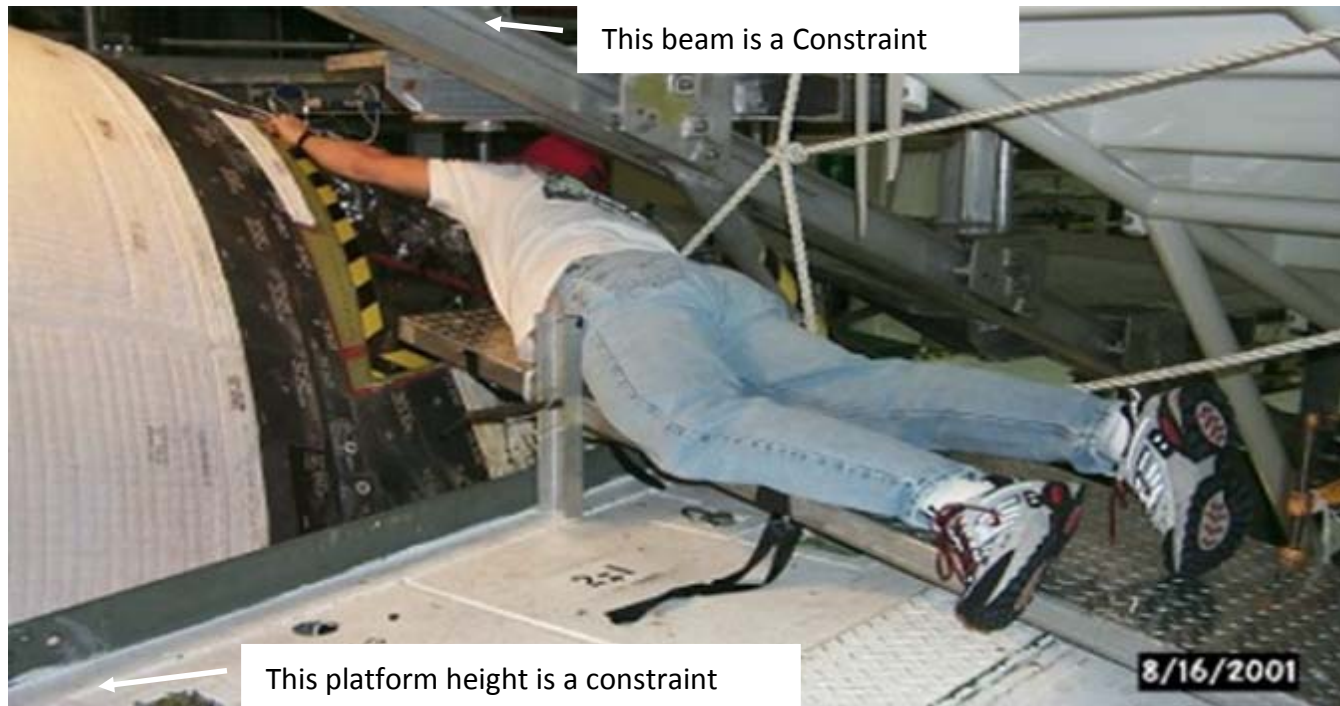


- **Workspace and work envelope**
- **Tool clearances**
- **Functional work areas**
- **Visual access**
- **Displays within field of view**
- **Lifting, pushing, and pulling**
- **Damage/error prevention, detection, and recovery**
- **Connectors**
- **Interface controls and information displays**
- **Labels and communications**
- **Consistent work practices**
- **Personal Protective Equipment (PPE)**
- **Work environment**

Workspace

Some workspace positions may be difficult to reach.

In picture: Forward Reaction Control System (FRCS) work that requires a awkward reach.



Damage/Error Prevention, Detection and Recovery

Orbiter flex hoses and fluid lines may get damaged during ground operations, which can lead to schedule delays and technical issues.

Human Factors Design:

- Protect hardware during inspection and processing
- Location, Design
Temporary Covers





HF Overview Feedback

➤ Things that were most liked:

- ❖ Specific design examples
- ❖ Application of HF principles to GSE designs
- ❖ Varied perspectives of speakers
- ❖ Looking at lifecycle and IPT
- ❖ User input to designs, designing with users in mind
- ❖ HF specialist as part of the design team
- ❖ Worksheet is a good handout to use

➤ Things to improve, additional topics to address:

- ❖ Force these issues to be implemented in design approval/reviews
- ❖ HF specs
- ❖ HF for software



Design Team Sessions

- **9 Design Team sessions conducted**
 - **7 mechanical systems**
 - **1 fluid system**
 - **1 electrical system**
- **All teams completed the evaluation worksheet in advance**
- **Most teams were able to access current design packages/files during their working session**
- **Human factors workbook and reference guide provided**
- **Worked with team leads to identify the most significant HF issues that need to be addressed by the design teams**
- **Potential HF issues were documented**
- **Observation: different/overlapping perspectives valuable**
 - **SMA Professional**
 - **Technician (current end users)**
 - **Systems Engineer**
 - **Human Factors Specialist**

Ground System/GSE Design Evaluation Worksheet for Human Factors Engineering

Ground System/GSE: Please briefly describe the ground system/ground support equipment (GSE) your team is designing.

For each human factor consideration listed below, please check a box for applicability and briefly describe potential human factor challenges related to the ground system/GSE your team is designing.

Work Envelope Volume (e.g. design is limited in granting minimum access needed to remove, relocate, and replace flight and ground hardware)	Human Factors Challenge	Applicable Yes <input type="checkbox"/> No <input type="checkbox"/>
Tool Clearances (e.g. design does not allow enough space to use required tools for removal of components during maintenance tasks)	Human Factors Challenge	Applicable Yes <input type="checkbox"/> No <input type="checkbox"/>
Functional Work Areas (e.g. design does not separate functions or activities that could conflict with each other during processing, maintenance, or inspection tasks)	Human Factors Challenge	Applicable Yes <input type="checkbox"/> No <input type="checkbox"/>
Visual Access (e.g. design has visual access openings located beneath or behind components that restrict visibility)	Human Factors Challenge	Applicable Yes <input type="checkbox"/> No <input type="checkbox"/>



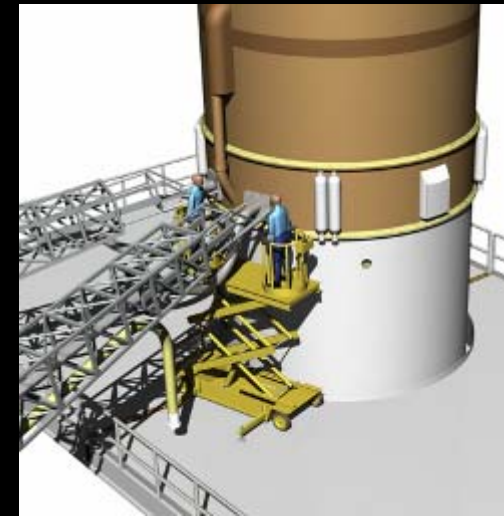
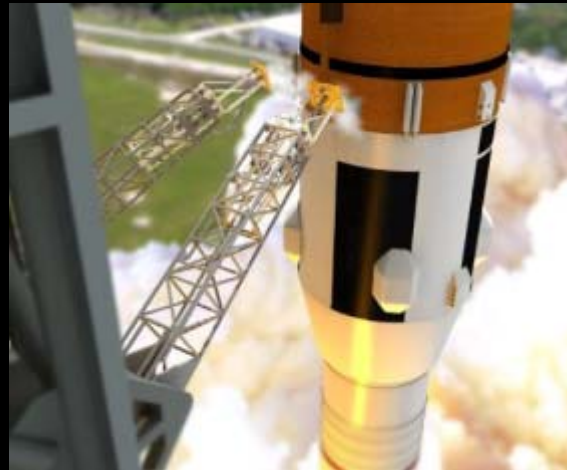
GSE Design Teams

- **Upper Stage T-0 Tilt-Up Umbilical Arms**
- **Upper Stage Umbilical Plates**
- **Mobile Launcher Physical Data Interface (E)**
- **Emergency Egress System**
- **Crew Access Arm**
- **Mobile Launcher Hypergol Servicing System (F)**
- **Mobile Launcher Access Platforms**
- **SRB Forward Skirt Umbilical**
- **First Stage Aft Skirt Umbilical**

Upper Stage T-0 Tilt-Up Umbilical Arms (TUUA)



(Includes updates after 30% design review on 2/29/08)

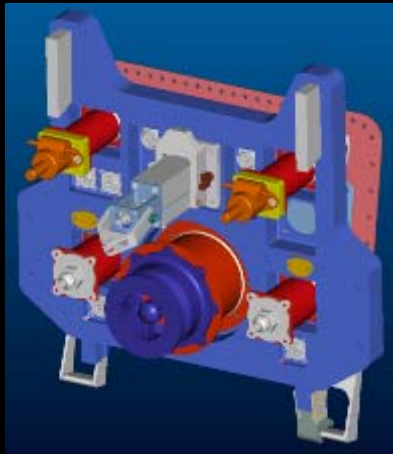


Human Factor Challenges (Examples)	Recommendations & Potential Design Solutions
<p>Damage/error prevention – need reliable system feedback when technician lowers arm and mates the umbilicals.</p> <p>Umbilical placement and mating are precision operations requiring two technicians; a mistake during the mating operation could cause incapacitating damage to the vehicle.</p>	<p>Have one technician run the motor to lower umbilical to a marked position. Use lock- out pins so umbilical can't go below horizontal position and so the umbilical end does not over-extend and damage the vehicle.</p> <p>Include a systematic analysis of VAB processing tasks for potential process escapes/catches (using HF-PFMEA or a similar method) and usability evaluations using the prototype to satisfy the requirement for a human factors assessment in the 60% design review package.</p>
<p>Work envelope – ground plate to flight plate interface is only accessible by platforms in VAB (no on-pad access). Potentially limited platform area during mating operation.</p>	<p>Coordinate platforms used for vehicle access so they can also be used for maintenance and inspection of umbilical components and subsystem replacement items in nominal and vertical positions. Consider designing custom access platforms.</p>

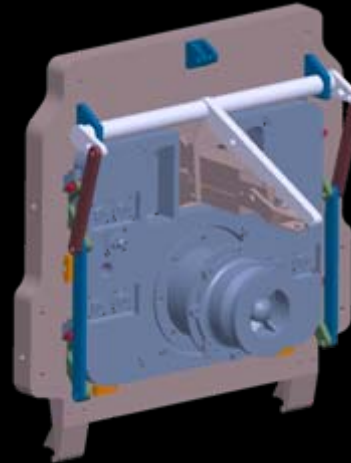
Upper Stage Umbilical Plates



Nov 07
baseline

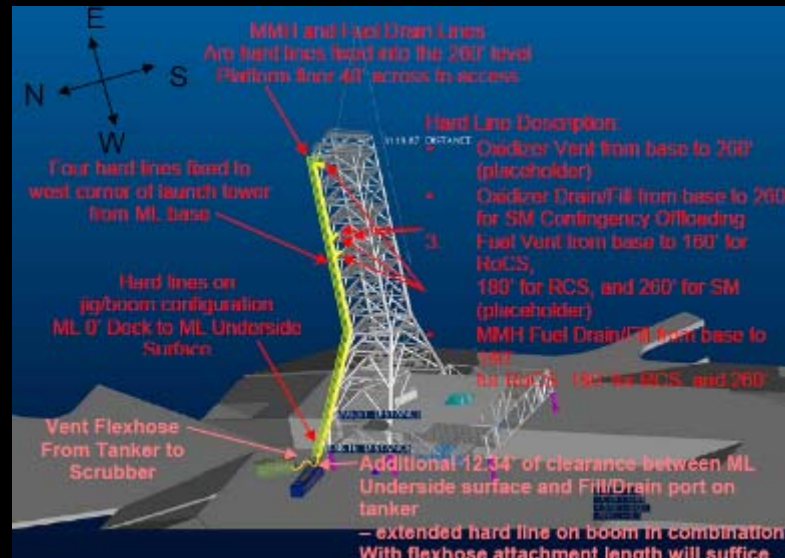
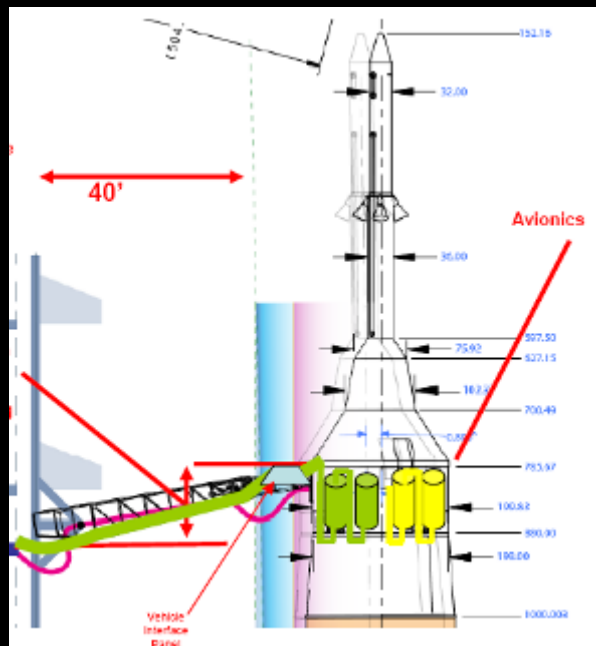


Feb 08
baseline



Human Factor Challenges (Examples)	Recommendations & Potential Design Solutions
<p>Connectors – if not connected properly, requires roll-back to VAB. Limited space is available on the plate to access connectors.</p> <p><i>Note: in the Feb 08 baseline, a “linear engagement after angular mate” design with centering feet is used. The alignment pins were eliminated.</i></p>	<p><i>Consider a trade study on number of guide pins or a custom alignment tool. Extend crows feet to reduce the mating angle and use a centering feature. Consider self-alignment approaches, a laser alignment system, and/or a linear mating system (vs angled mating system).</i></p> <p>Consider a full design mockup and thorough usability testing to predict/demonstrate human reliability of aligning the plates and ensuring a correct mate.</p>
<p>Damage/error prevention and detection.</p>	<p>Provide a visual indication on the collet engagement to aid full connection and prevent overrun. Need verification that feet are properly seated. 21</p>

Hypergol Servicing Systems



Human Factor Challenges (Examples)

Work envelope – access arm at vehicle interface needs to accommodate at least two SCAPE personnel and control panel.

Connectors – quick disconnects vs. B-nuts.

Damage/error prevention – fundamentally different hyper servicing approach without the level of redundancy and controls used by the Shuttle system.

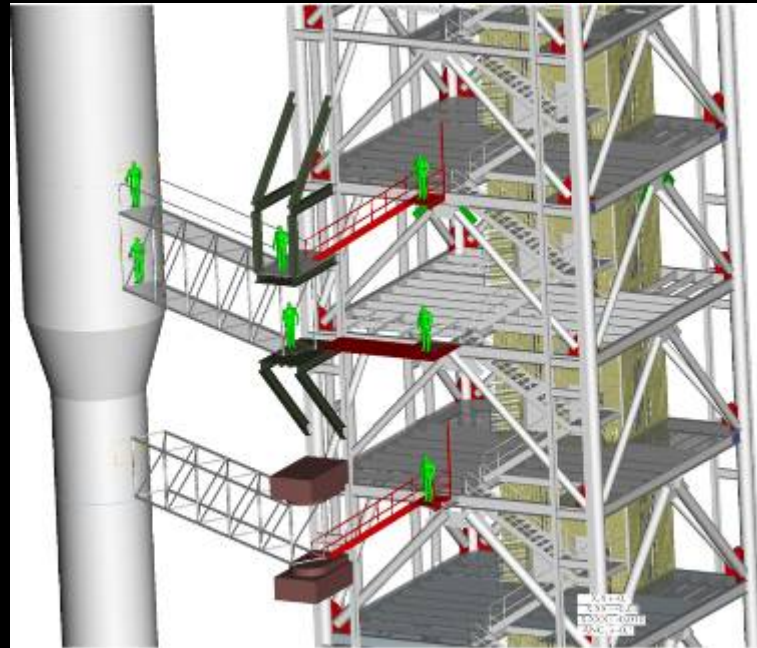
Recommendations & Potential Design Solutions

Provide adequate space on access arm to allow SCAPE personnel maneuverability. Include SCAPE technicians on the design team.

Perform a formal usability analysis in the SCAPE lab as part of the connector trade study.

Perform an in-depth task analysis of hyper servicing (HF-PFMEA, socio-technical PRA, or other method). Proactively identify and mitigate potential process escapes, process catches, and human errors.

Mobile Launcher Access Platforms



Human Factor Challenges (Examples)

Work envelope and access – suited personnel have limited access, mobility, peripheral vision, etc.

Visual access – lighting (covered by OSHA requirements).

Recommendations & Potential Design Solutions

Use mezzanine elevator stops and/or ramps to limit number of stairs required for personnel in SCAPE suits. Allow 44" minimum width for walkways. Consider suited personnel in the design and placement of the control panel, hypergol lines, signs, displays, equipment labels. Enlarge work platform at vehicle interface to provide space to set tools down. Provide OIS box at the end of the arm for communication.

Provide lights on the access platforms.



Feedback

- **5 of 8 design team leads participated**
- **Primary issue: team leads wanted HF experts embedded on their design teams, continued HF support**
- **Other shared issues:**
 - **Adequate integration/communication of requirements and design trades with other design teams**
 - **Increased technician participation in design teams**
 - **Design team activities to increase understanding of the hands-on user perspective**

Recommendations



- Utilize technician experience and expertise, as appropriate
- Continue soliciting design inputs from SMA and Ops Engineers
- Integrate human factors engineering into the systems engineering process
 - Establish Human Factors POCs
 - Lead development of the HF guidance and resources
 - Determine criteria for human factors assessment requirements
 - Acquire additional HF expertise to provide embedded support to design teams
- Address need for adequate consideration/evaluation of human factors in software and computer system designs
- Increase use of KSC modeling and simulation capabilities for evaluating designs from a HF perspective

Next Steps



- **Attend selected design reviews (limited availability) for each design team in the pathfinder activity and provide comments and recommendations**
- **Assist with (not perform) formal HF assessments and requirement validations**
- **If requested, support another round of working sessions with additional GSE design teams**
- **Develop resource materials**
 - **Support updates to NASA STDs where appropriate**
 - **Develop a KSC Human Factors Handbook**
- **Expand applications beyond KSC GS/GSE Teams for Constellation**



Thank you!

QUESTIONS?

