Integrating Human Factors into Crew Exploration Vehicle (CEV) Design

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Background/ Purpose

• NASA’s new Vision for Exploration
  – Send humans beyond Earth orbit

• It is critical to consider the human as a system
  – Demand early and continuous user involvement
  – Iterative “prototype/test/redesign” process
  – Cost savings since human/system issues identified early

• NASA/Prime Contractor human engineering (HE) team formed for Crew Exploration Vehicle (CEV)
  – Apply HE requirements and guidelines to hardware/software
  – Provide HE design, analysis and evaluation of crew interfaces
HE Activities

- Requirements development
- Mission-level task analysis
- Many practice-orientated evaluations using low-fidelity CEV mock-ups:
  - Crew module internal layout in terms of seats, display and control panel and other systems/ sub-systems
  - Window size and location
  - Validation of HE requirement on Net Habitable Volume (NHV)
• Definition of Net Habitable Volume (NHV):
  “Total remaining pressurized volume available to on-orbit crew after accounting for the loss of volume due to deployed hardware and structural inefficiencies which decrease functional volume.”

• Purpose of the Study:
  – Develop and validate requirements providing sufficient CEV NHV for crewmembers to live and perform tasks in support of mission goals
    • Develop a standard NHV calculation method using computer models and physical mockups
    • Measure and validate sufficiency of NHV for the current design concepts via computer modeling and crew/stakeholder evaluations
• Crew of 2, 4 and 6
  – Worst case: all 99\textsuperscript{th} percentile male astronauts
• Selected critical on-orbit tasks such as:
  – Ascent/descent
  – Post insertion activities
    • Seat egress
    • Suit doff and stow
    • Waste hygiene usage
    • Sleeping/ eating
    • Cargo transfer
  – Docking/rendezvous
CASE STUDY: Human Modeling Results

**Ascent / Descent** – Crew is suited and seats are in the full upright position.

**Rendezvous/ Docking** – It is assumed that a crew member will adjust their position to allow for visibility through the hatch window to assist rendezvous and docking operations.
**Post Insertion** – All crew members have stowed their respective seats and suits. Access to waste and hygiene is now possible and the crew is ready to perform in-flight tasks.

**Post Sleep** – Potential activities include food preparation, review flight plan/execute pack, housekeeping/filter cleaning, and personal hygiene.
• Computer modeling analysis confirmed that there was adequate volume for unsuited scenarios and suit donning/doffing activity
  – Seats, suit design stowage and waste hygiene activities noted to be critical volume drivers
CASE STUDY: Human-in-the-Loop Evaluation Approach

• Participants:
  – Nine stakeholders and ten crewmembers participated in the unsuited evaluations
  – Six crewmembers also participated in a suited evaluation

• A physical mock-up was outfitted with volumetric representations of systems such as seats, and stowage bags
  – Design for suits, seats and other key systems do not yet exist for CEV
  – Notional placeholders such as existing space suit and seat prototype concepts were used in the mock-up

• Thirteen scenarios were developed to represent mission/crew tasks and considered to be primary volume drivers for the CEV
  – Unsuited evaluations included a structured walkthrough of these tasks such as suit stowage, waste hygiene activity, trash stowage, sleep, and 36-hour rescue (land/water)
  – Suited evaluations included timed donning of the existing launch and entry suit to simulate a contingency scenario followed by doffing/stowing of the suits

• All mockup evaluations were videotaped

• Structured questionnaires were used to document user interface issues and impacts of layout configuration on volume
• Initial evaluation showed that NHV would support crew of 6
• NHV of the current design accommodated task-based scenarios evaluated
• Current design NHV accommodated space suit donning for a crew of 6
  – One should plan for volume of a minimum 2 crew helpers and 1 crewmember being donned in one volume area
  – Doffing → Only limitation was that a crewmember needed his/her full body length to doff the suit
• Human-in-the-loop evaluations also confirmed that there was adequate volume for unsuited scenarios and suit donning/doffing activity

• Additional comments from crew and stakeholders on internal cabin layout:
  – Seats → provide stowage volume for gloves, personal items & possibly the suit
  – Suit Stowage → stow individually and possibly integrate it into seat
  – Consumables → Multiple means of access to consumable stowage volume (e.g., access from side and below stowage volume)
  – Sleep → Simplified (shuttle) bag with less volume/weight; need to access to toilet
  – Restraints → Egress/Ingress handholds/footholds by hatch/tunnel, mobility aids for crewmember during seat egress in 1g, flexible straps for temporary stowage and mobility aids
  – Rescue-water landing → Sick bags/water should be handy
• In 2007, NASA and Lockheed Martin will conduct additional NHV studies of the most recent CEV design configuration(s) as the design matures
  – Computer modeling and analyses
  – Physical measurements of mockup hardware
  – Human in the loop task evaluations

• Based on these studies, verification methods for the NHV requirement will be planned and documented
  – Master Verification Plan
  – Verification Information Sheets
In Conclusion…

• HE System team has been key to ensuring
  – Human is treated as a “system” with key functions, requirements, and interfaces to vehicle systems
  – HE is involved early in the design process

• The low-fidelity mock-up evaluations along with human modeling analysis generated discussions that:
  – led to high-level systems requirements and human-centered design decisions
    • Habitable volume is a key enabler of the human system’s ability to meet its requirements safely, and effectively accomplish mission goals
  – allowed HE requirements and operational concepts to evolve in parallel with engineering system concepts and design requirements
    • Habitable volume should be managed as an integrated system (considering stowage, equipment, and fixed and reconfigurable vehicle structures)
    • Translation corridors within the habitable volume must be established to reduce crew risk during a contingency such as pad egress, fire or off-nominal landing

BOTTOM LINE: Continued HE involvement will ensure a structured approach to human-centered CEV design.
THANK YOU!