# Design for Maintainability

## SLS case study and long-duration habitation relevance

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# History of Design for Maintainability in launch vehicles

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- **Saturn had none**
- **Shuttle had none**
- **Commercial ???**
- **Military**
  - **ICBMs**
  - **Other rockets**
- **Constellation**
  - **Requirements development**
- **Space Launch System/SLS**

# Design process in SLS

- **Requirements-driven**
- **Examples:**
  - **Worksites for ground processing tasks shall be sized for the 5th female to 95th male percentiles ground crew population based on 1988 U.S. Army Anthropometry Survey (ANSUR) database (NATICK/TR-89/044)**
  - **The system shall provide for ground processing by personnel wearing clothing and equipment appropriate to the environment during tasks**
  - **LRUs of a weight that exceeds the ground crew lifting limits in Section 3.1.2 shall accommodate assisted mechanical lifting devices that support the weight of the component without operator assistance**
  - **Protrusions that could be inadvertently used as handles, steps, handrails, or mobility aids shall be designed to either support the weight of the ground crew or be clearly labeled as keep-out zones**
- **Since these are *design* requirements, verification is required before the hardware is built**

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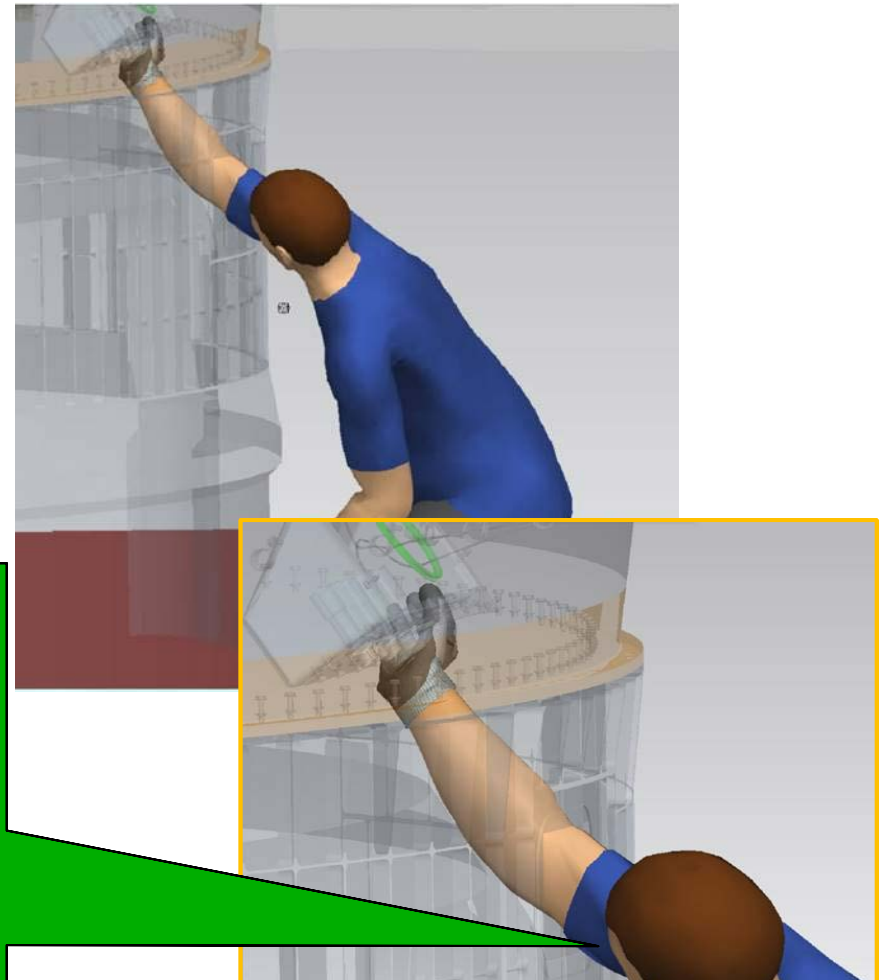
- **Verification is by analysis**
  - **Allocate requirements to task**
  - **Perform assessment to determine compliance**
- **Verification report identifies noncompliance and identifies possible mitigations**
  - **(operational workarounds)**



# Transition: DfM in long duration missions

- **Mars/Venus transit**
- **Mars surface/Venus atmospheric**

# Unverifiable (by me) but credible

## A Surprising Space Fact...

***Fact:*** *All of the equipment launched in the 55 year history of the space program equates to less than 1 day of worldwide auto production.*

***Conclusion:*** *At a fundamental level, statistical process control principles associated with mass production do not apply to the space business.*

***Lesson:*** *The space workforce is fundamentally a craft-based "guild" where key knowledge is passed from generation to generation.*

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# Relationship between reliability and mission success/crew survival

- **In deep space missions, mission success is largely survival and return**
- **Humans central to system reliability**
- **Gap is integration of this into design decisions (models)**

# System resilience

- **Resilience: The ability of a system to sustain required operations under both expected and unexpected conditions by adjusting its functioning prior to, during, or following changes, disturbances, and opportunities – Erik Hollnagel**
- **Gap is integration of this into design decisions (models). Resilient systems:**
  - ***Anticipate*: Knowing what to expect, *e.g.*, potential disruptions, novel demands or constraints, new opportunities, changing operating conditions**
  - ***Monitor*: Knowing what to look for, and being able to monitor states which could seriously affect the system's performance in the near term , especially negatively**
  - ***Respond*: Knowing what to do; being able to respond to changes, disturbances, and opportunities by activating prepared actions or by adjusting current mode of functioning**
  - ***Learn*: Knowing what has happened, and learning from experience, in particular to learn the right lessons from the right experience**
- **System reliability and maintainability are key to resilience, and these must be designed-in**

From Jon Holbrook, LaRC