



Making Space Launch System Safer Through Worksite Design



Human Factors &
Integrated Logistics Engineering

Design of Systems for Safe Launch Operations; the Launch Vehicle

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Concept of rocket design

- ⊕ **First focus is performance**
 - ⊕ Getting it to go as far as planned and to the desired location
 - ⊕ *Without blowing up!*
- ⊕ **So designers worry about**
 - ⊕ **GN&C**
 - ⊕ Avionics
 - ⊕ Electrical power
 - ⊕ Inertial guidance systems
 - ⊕ **Fuels**
 - ⊕ Types
 - ⊕ Amounts
 - ⊕ **Engines**
 - ⊕ Turbines
 - ⊕ Combustion chambers
 - ⊕ Nozzles
 - ⊕ **Plumbing**
 - ⊕ Valves
 - ⊕ Pipes
 - ⊕ **Thermal protection**



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Space Launch System, SLS

- ⊕ **Replacement for the Saturn vehicles**
- ⊕ **Objective: enable Solar System exploration**
 - ⊕ Launch heavy payloads and humans beyond LEO
 - ⊕ Payload to lunar orbit: 26T (initial), growing to 37T by 2024; then 45T
- ⊕ **Configuration; 3 main elements**
 - ⊕ **Strap-on solid boosters**
 - ⊕ **Core Stage**
 - ⊕ Cryogenic
 - ⊕ O₂ and H₂
 - ⊕ Uses four RS-25 engines, derived from SSME
 - ⊕ **Upper stage is derived from Delta Cryogenic Upper Stage, RL-10**
 - ⊕ In advanced configurations, a new stage called Exploration Upper Stage
- ⊕ **Since this vehicle must be human-rated, design for safe ground processing is essential**
 - ⊕ Also note that launch rate of 1/y is driven by costs





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Requirements for human tasks applicability

- ⊕ **The concept is that designers of vehicle structures, components, electrical subsystems, &c. must support the human roles in ground operations, through design features**
- ⊕ **Requirements apply to all human interaction with the vehicle**
 - ⊕ **“Human touch tasks”**
 - ⊕ **These include:**
 - ⊕ **All tasks to be performed each time the stages/components/elements arrive at the Launch Site**
 - Torqueing fasteners, mating connectors, installing pyrotechnics, &c., &c.
 - ⊕ **All tasks associated with Line Replacement Unit removal & replacement**
 - (de-)torqueing fasteners, (de-)mating connectors, testing, &c., &c.
- ⊕ **Requirements apply at the task level**
 - ⊕ **Thus, if task is to mate an electrical connector by hand, tool clearance (envelope) requirements don’t apply**



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Requirements for human tasks; scope

- ⊕ Objective is to protect the flight systems from damage
- ⊕ Requirements do not apply to tasks performed by the designing organization
 - ⊕ These tasks are part of manufacturing
- ⊕ They do apply to work to be done by other organizations, in particular, the Launch Site physical integration teams



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What kinds of requirements?

- ⊕ **Ground Crew Lifting Limits:** System hardware that is required to be handled by one ground crewperson without Ground Support Equipment (GSE) shall not exceed the safe weight limit as determined by the NIOSH lifting equation defined in the National Institute for Occupational Safety and Health (NIOSH) Publication No.94-110, Applications Manual for the Revised NIOSH Lifting Equation or MIL-STD-1472, Section 5.9.11.3, Table XVII.
- ⊕ **Labeling:** The system shall provide labels for ground crew interface controls and indicators that can be seen while in the installed location
- ⊕ **Work Envelope Volumes:** The system shall be designed to provide work envelope volumes needed to perform ground processing tasks.





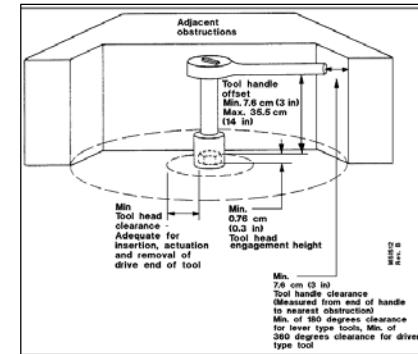
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What kinds of requirements?

- ✚ **LRU Installation:** Line Replaceable Units (LRUs) shall include physical features that prevent incorrect installation.
- ✚ **Tool Clearances:** The system shall provide tool clearances for tool installation and actuation for activities requiring the use of tools during ground processing
- ✚ **Appropriate Clothing and Equipment:** The system shall provide for ground processing by personnel wearing clothing and equipment appropriate to the environment during task





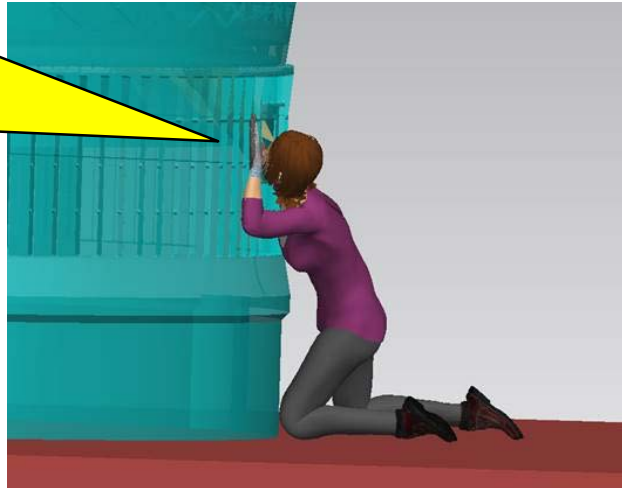
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Current status

- ✦ SLS is in verification phase
- ✦ Components have not yet been delivered to Launch Site (mostly)
- ✦ Large components (elements) have integrated requirements into design;
 - ✦ Assessment of compliance using virtual tools, inspection of drawings (models), and physical mockups





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An example of how we help during design

