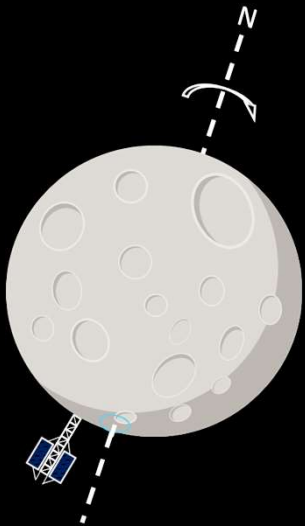


Sizing, Buckling, and Thermal-Structural Analysis of Tall Lunar Tower

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⁴Flight Software Systems Branch

NASA Langley Research Center

Hampton, VA

³National Institute of Aerospace

Hampton, VA

AIAA ASCEND

October 23 - 25, 2023

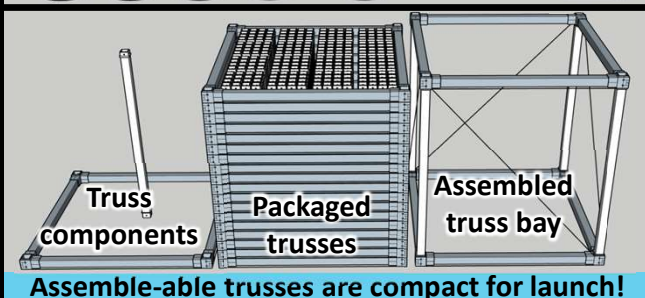
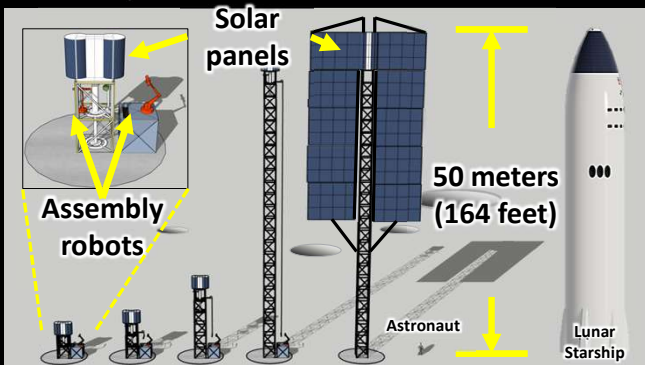
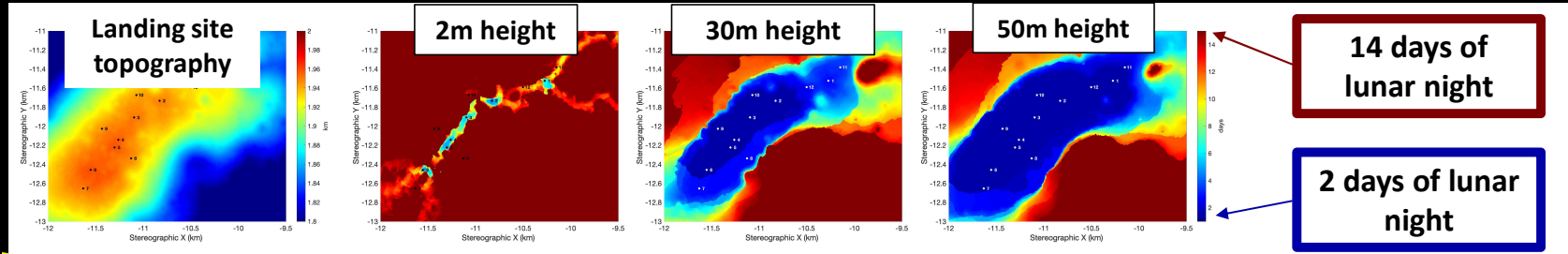
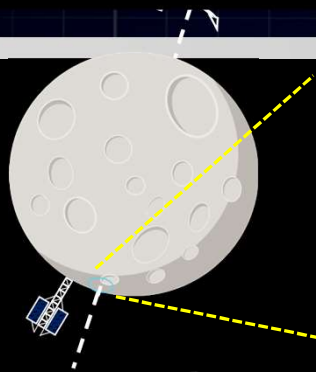
Las Vegas, NV



Outline

- Tall Lunar Tower (TLT) background
- TLT ground engineering development unit (EDU) demonstration
- Analysis process map
- Modeling and analysis of TLT EDU
 - Preliminary tower design sizing (truss configuration utility)
 - Global model analysis
 - Detailed thermal-structural analysis
- Summary

Project Background



Project focus is on structural assembly of a tower structure

- Compact packaging for launch
- Robotic assembly with supervised autonomy
- 50-meter assembled tower height
- High payload capacity (100 kW, communication, science)
- Enabling extreme surface access
- Enabling lunar construction

TLT Ground EDU Demonstration

- Demonstrate functional prototype and assembly process
- Test integrated software and hardware systems with supervised semi-autonomous operation
- Build up to 10 bays of TLT (7.5 m)
Height of EDU was limited by the facility
- NASA Langley Research Center Building 1148 High Bay



Engineering Development Unit (EDU)



EDU

Assistant robot system (ARS)

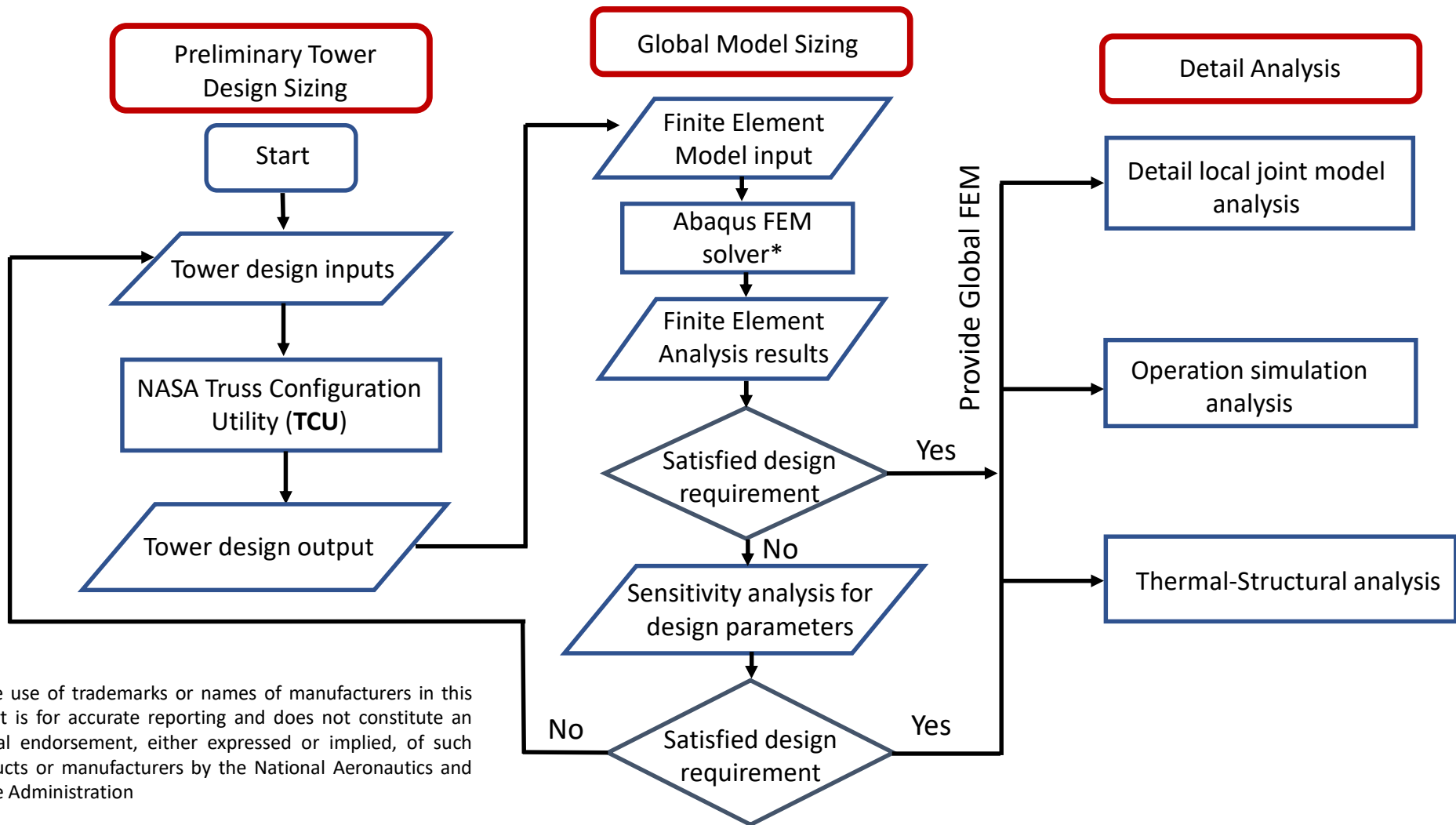
Construction robot system (CRS)

ARS



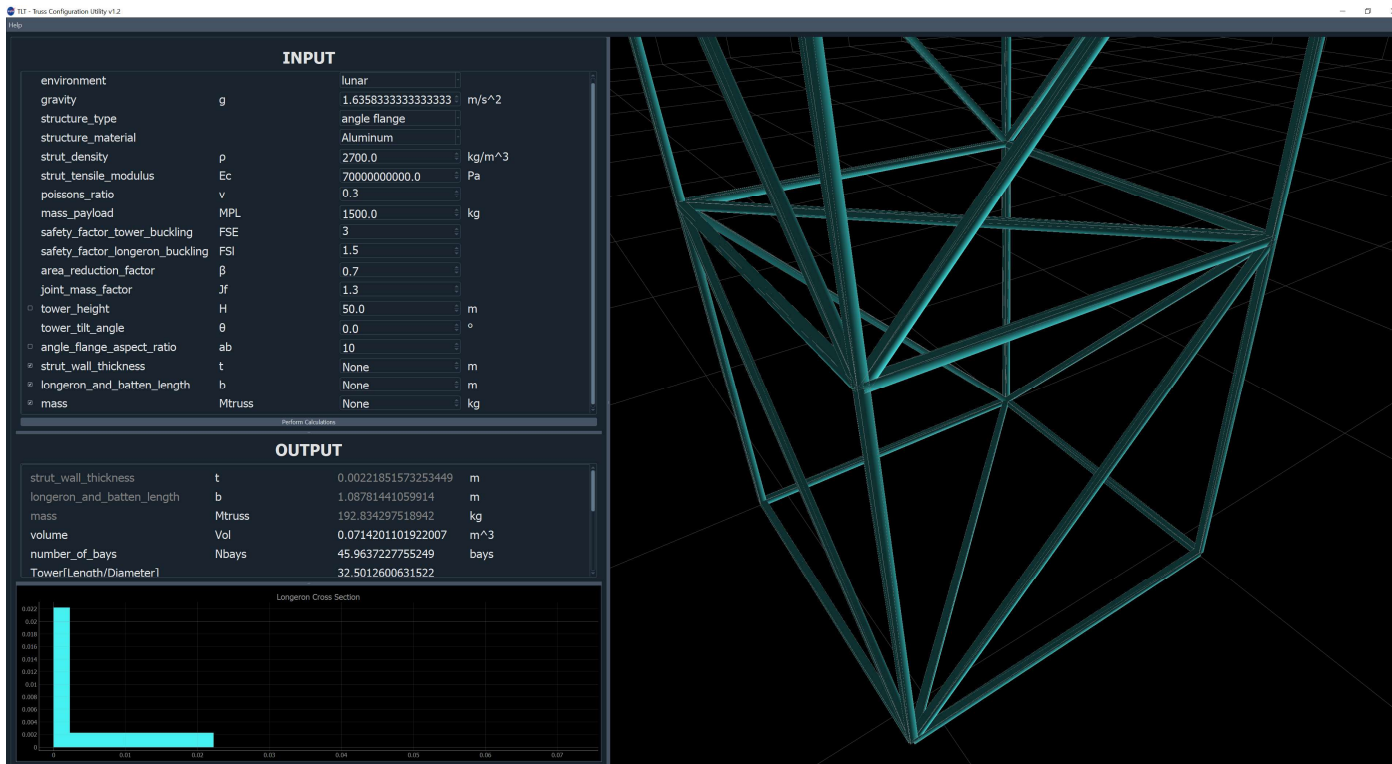
Finite element model

Analysis Process Map



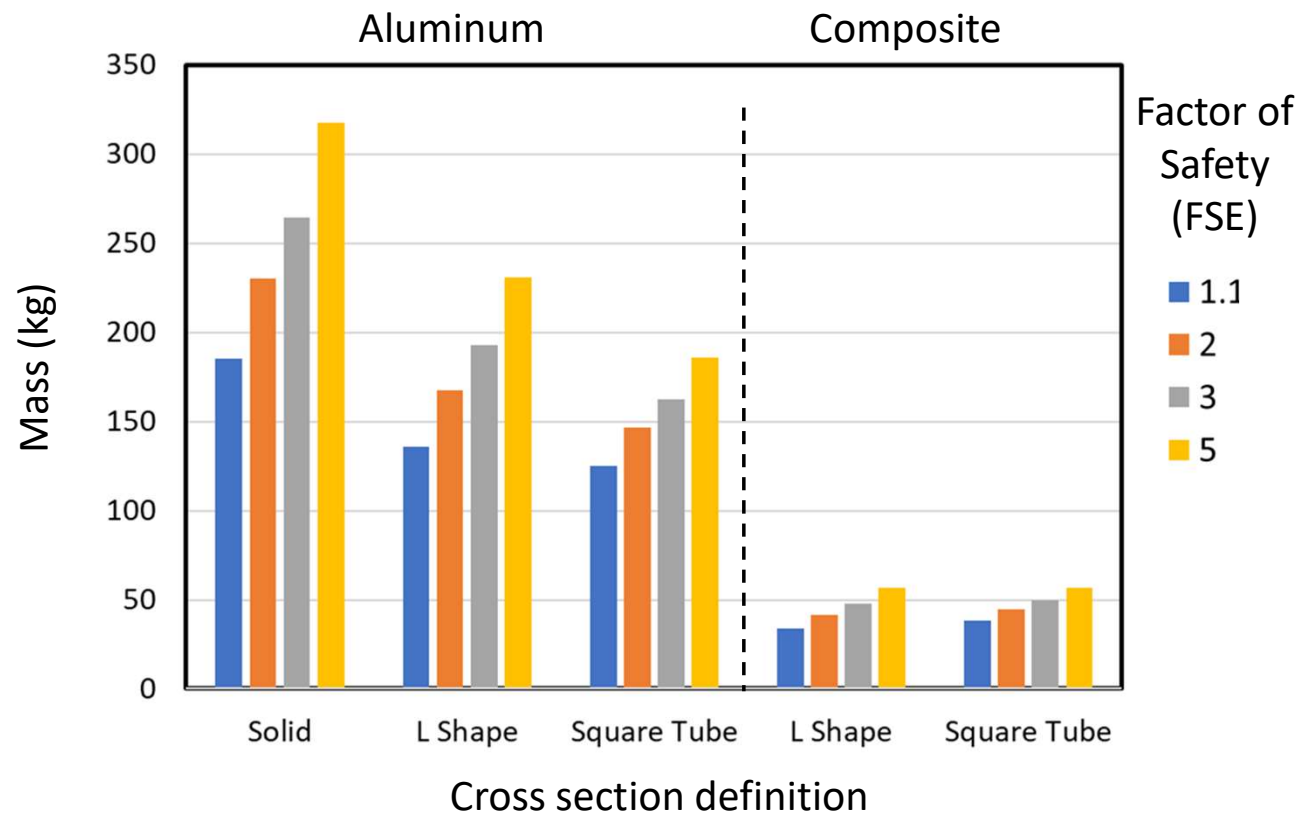
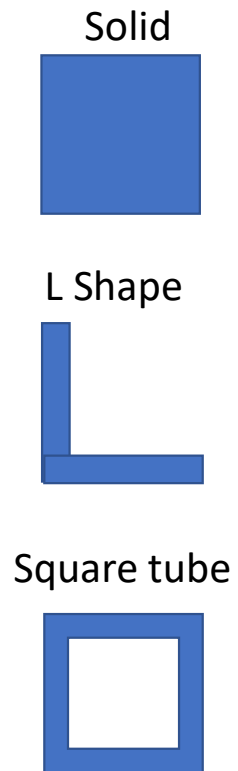
* The use of trademarks or names of manufacturers in this report is for accurate reporting and does not constitute an official endorsement, either expressed or implied, of such products or manufacturers by the National Aeronautics and Space Administration

TCU Functionality and User Interface



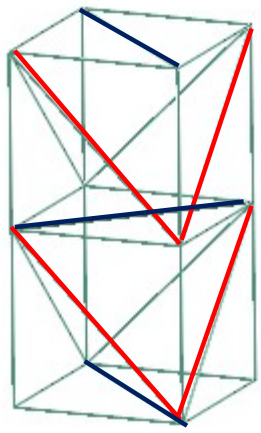
- Developed to rapidly explore the preliminary design space and structural requirements in the lunar environment
- The mass of tower, length of strut of each bay, and other modeling parameters are obtained

The Mass of TLT Based on Material Selection, Cross-sectional Geometry, and Factor of Safety

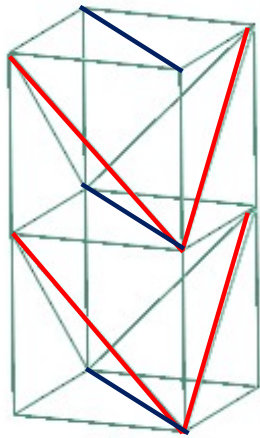


Finite Element Model with Different Tower Design

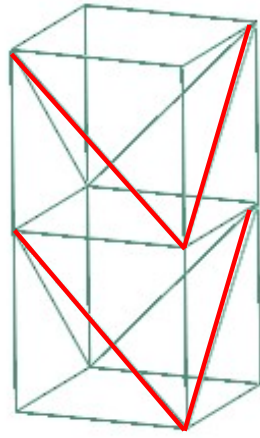
Type A



(a)
with cross
In-plane members



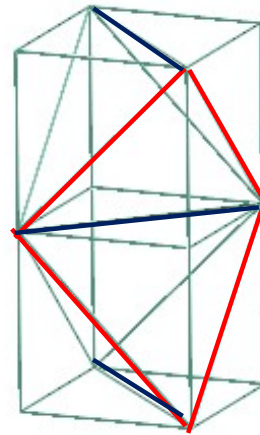
(b)
with parallel
In-plane members



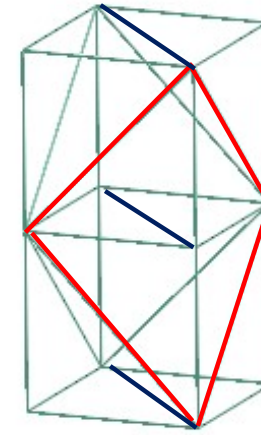
(c)
without
In-plane members

Type B

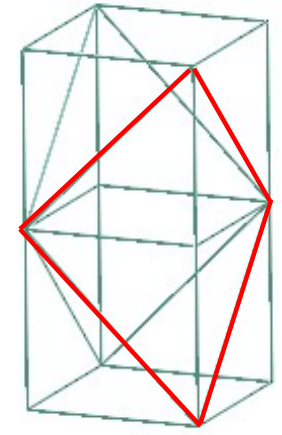
Selected



(a)
with cross
In-plane members



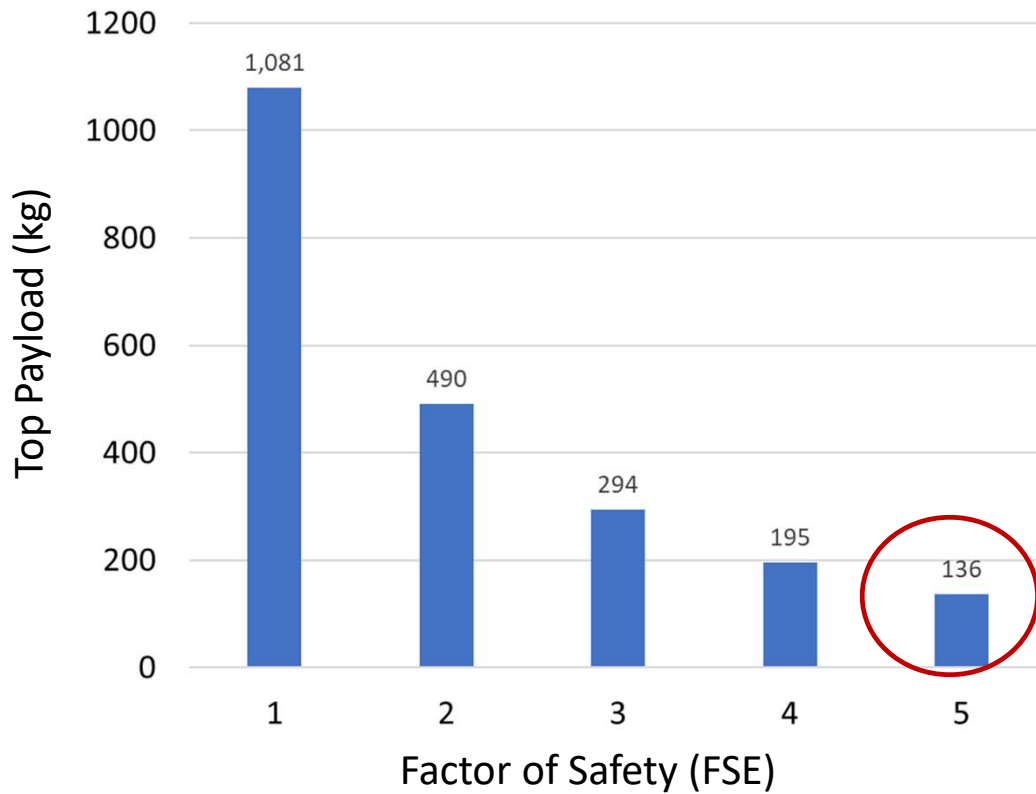
(b)
with parallel
In-plane members



(c)
without
In-plane members

Analysis of EDU and Joint Test

Top Payload Capability (50-meter tower)



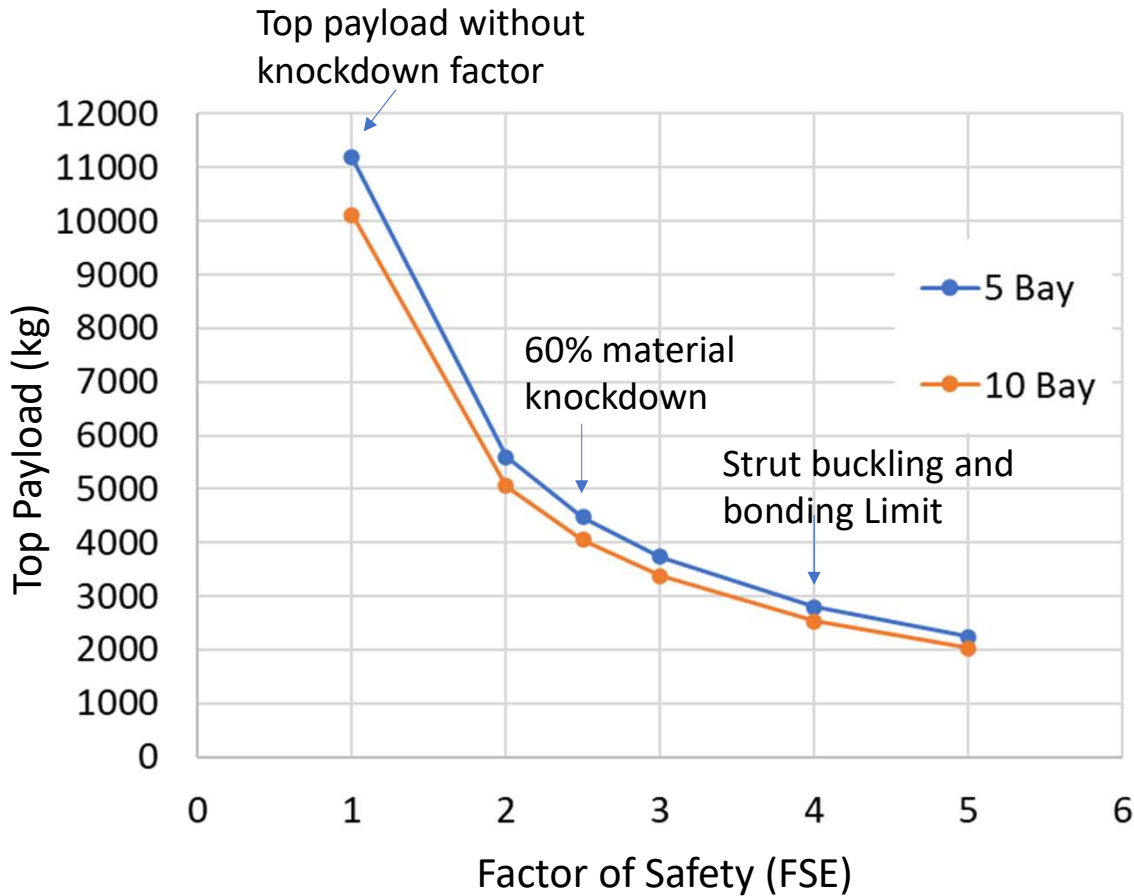
Joint under loading

Joint Test



Joint under loading

Capability of EDU (5 Bay and 10 Bay)



Compression Test

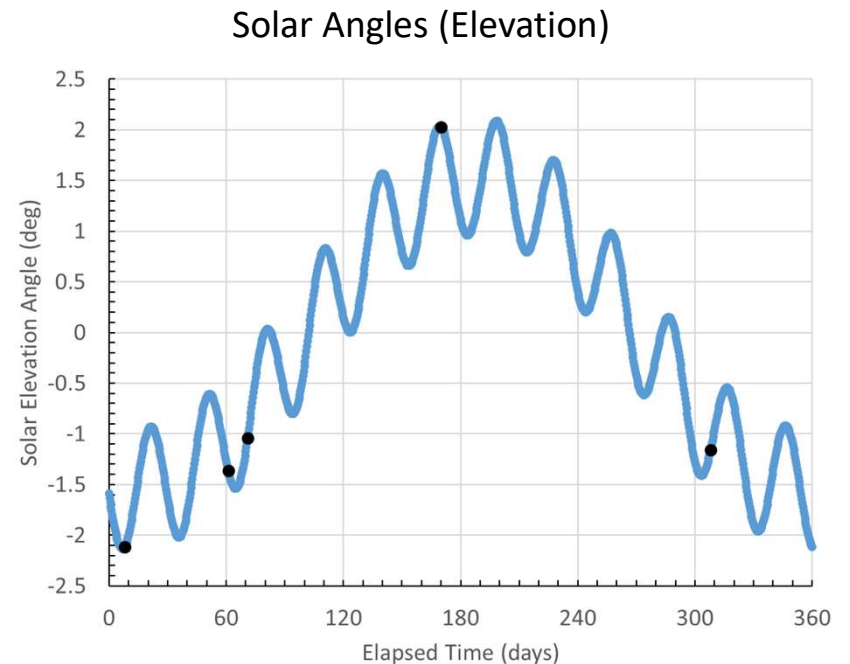


Tension Test



Thermal Analysis: TLT Thermal Model

- 50.25 m tower, 0.75 m bays
- Geometry maps to structural model
- Design for truss and joints (square tube)
 - Truss 20 mm x 20 mm, 1 mm thick
 - Diagonal truss 20 mm x 20 mm, 1 mm thick
 - Joint 35 x 50.8 mm, 2 mm thick
 - Diagonal joint 20x20 mm, 2 mm thick
- Material Properties
 - Truss elements: Graphite-epoxy M55J
 - Emissivity: 0.78
 - Solar Absorptivity: 0.825
 - Density: 1650 kg/m³
 - Thermal conductivity and specific heat anisotropic and temperature dependent
 - Joints: Aluminum 6061-T6
 - Emissivity: 0.8
 - Solar Absorptivity: 0.31
 - Density: 2705 kg/m³
 - Thermal conductivity and specific heat temperature dependent
- Temperature values are obtained from heat flux analysis



Day considered

Day 8: cold case

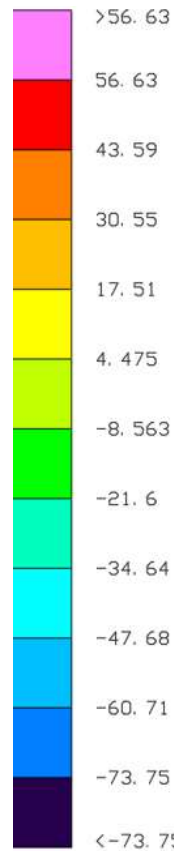
Day 170: hot case

Days 61, 71, and 308: max gradients

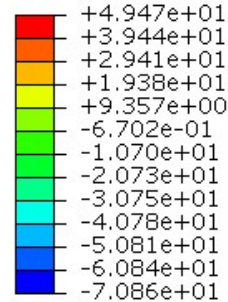
Day 170 days, Temperature Distribution

Thermal Model Temperature Map

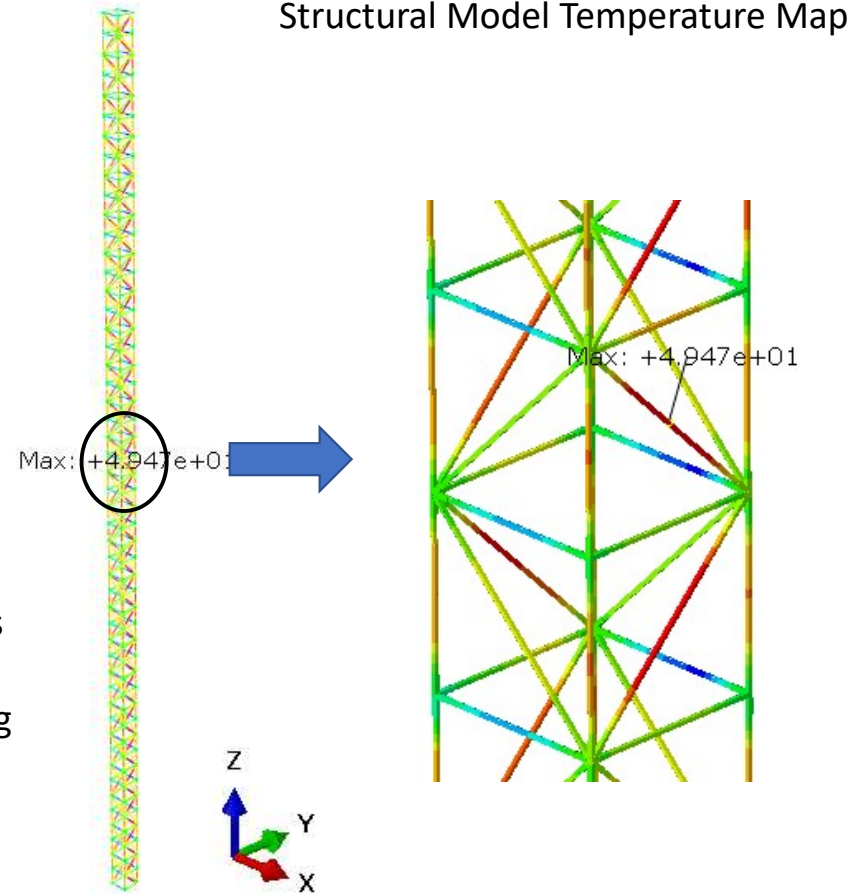
Temperature °C



Temperature °C



- Max Temperature is observed along the diagonal strut facing the sun



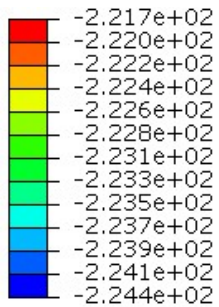
Thermal-Structural Analysis (Temperature Map)

Day 8: cold case

Day 170: hot case

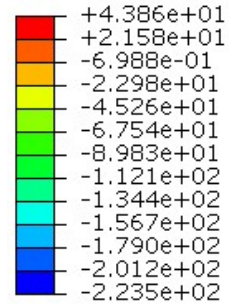
Days 61, 71, and 308: max gradients

Temperature °C



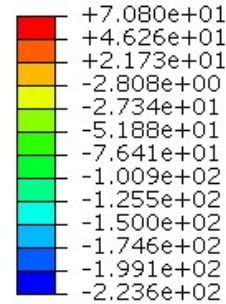
Day 8 (Cold)

Temperature °C



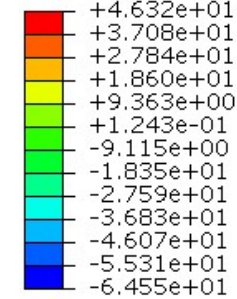
Day 61

Temperature °C



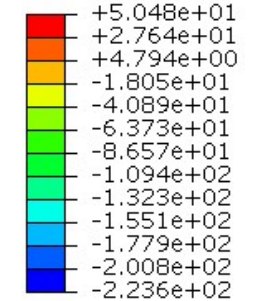
Day 71

Temperature °C



Day 170 (Hot)

Temperature °C



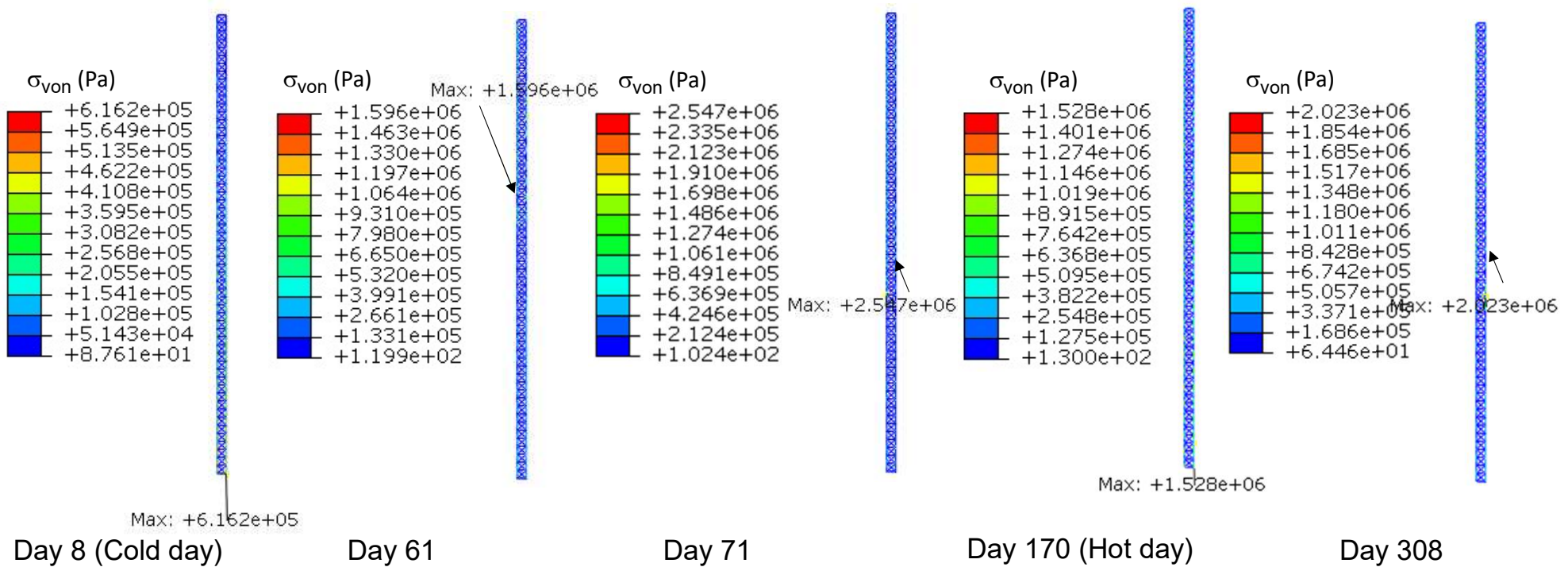
Day 308

von Mises Stress Results

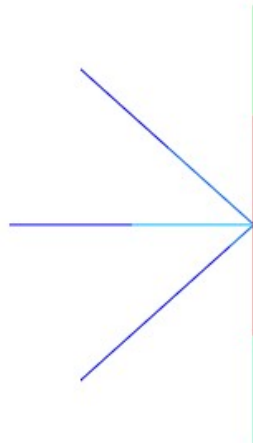
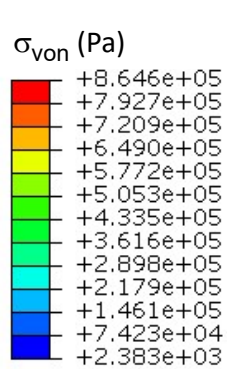
Day 8: cold case

Day 170: hot case

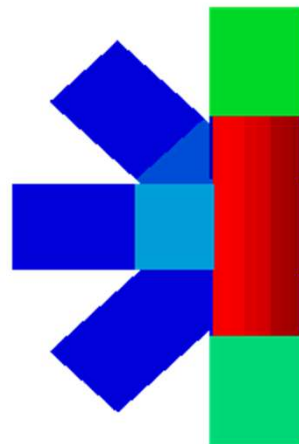
Days 61, 71, and 308: max gradients



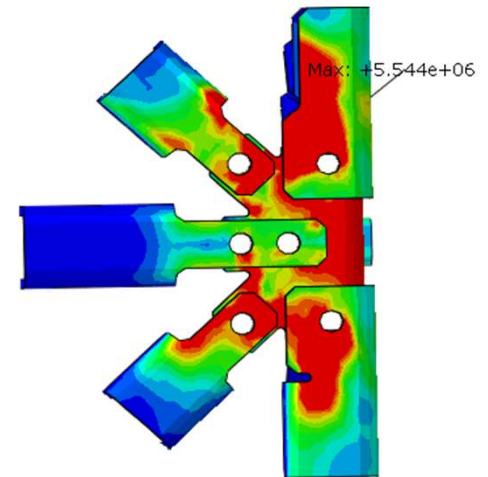
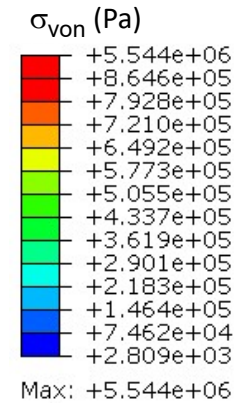
von Mises Stress Results of the Rivet Joint of Bay 23 on Day 61



Beam model



Beam model with
cross section definition



Solid element model

Summary

- Three-step modeling and analysis plan for the TLT EDU was developed and presented
 - In preliminary tower design sizing step, the structural requirements of the TLT EDU were reviewed and the modeling parameters, including material selection, the cross-section definition, and the length of longeron, of the TLT EDU were obtained from TCU
 - In the global analysis step, the FEM of the TLT EDU was developed based on the outputs of TCU. Buckling analysis was performed to investigate the structural response of the TLT EDU for a given top payload and FSE
 - In the detailed analysis step, thermal structural analysis was performed for key days during operation of the TLT at a lunar polar location