Sizing and Design Tool for Tall Lunar Tower

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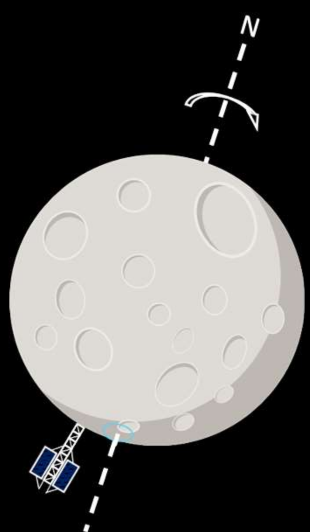

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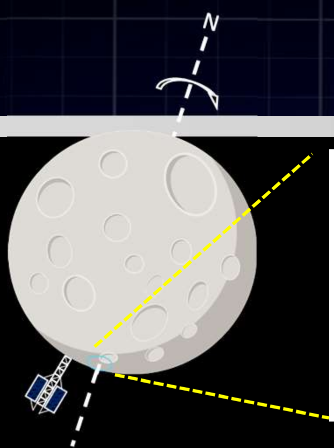
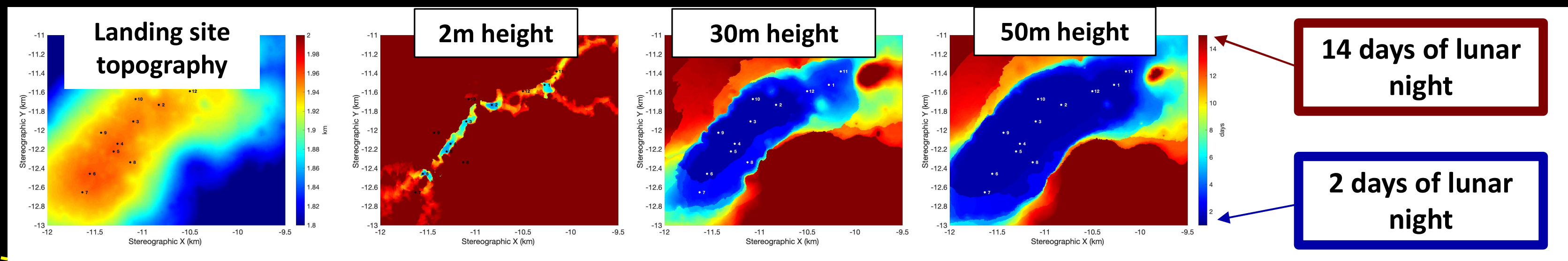
Outline

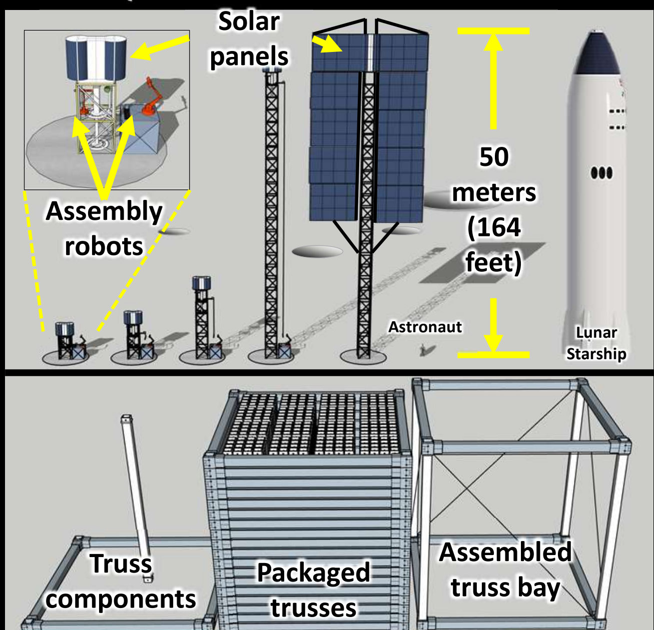
- Tall Lunar Tower (TLT) background
- Analysis process map
- Governing equations of truss tower
- Truss Configuration Utility (TCU) functionality and user interface
- Verification and Validation (V&V) study of TCU
- Summary

Project Background

Powering exploration at the Lunar South Pole



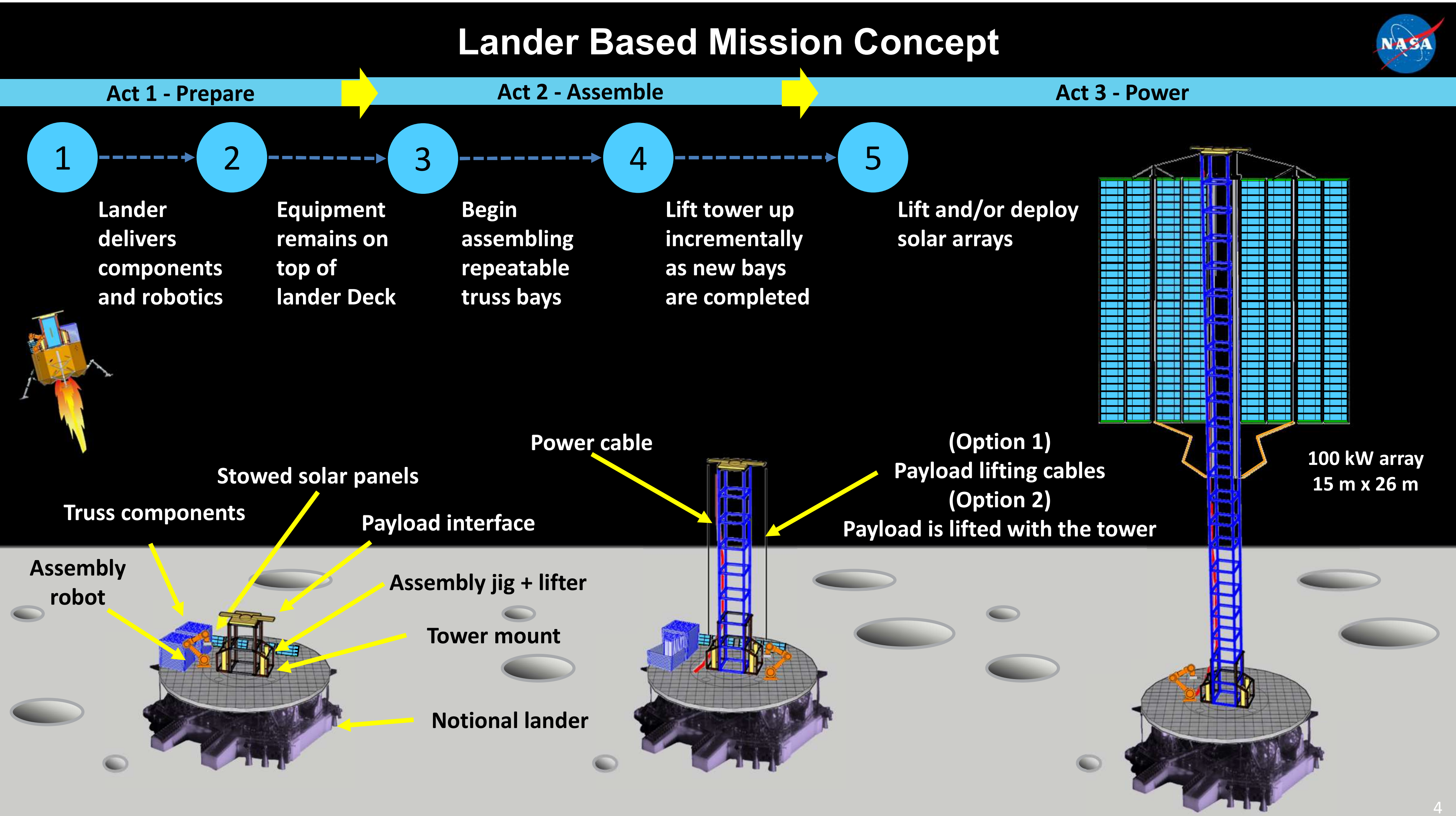




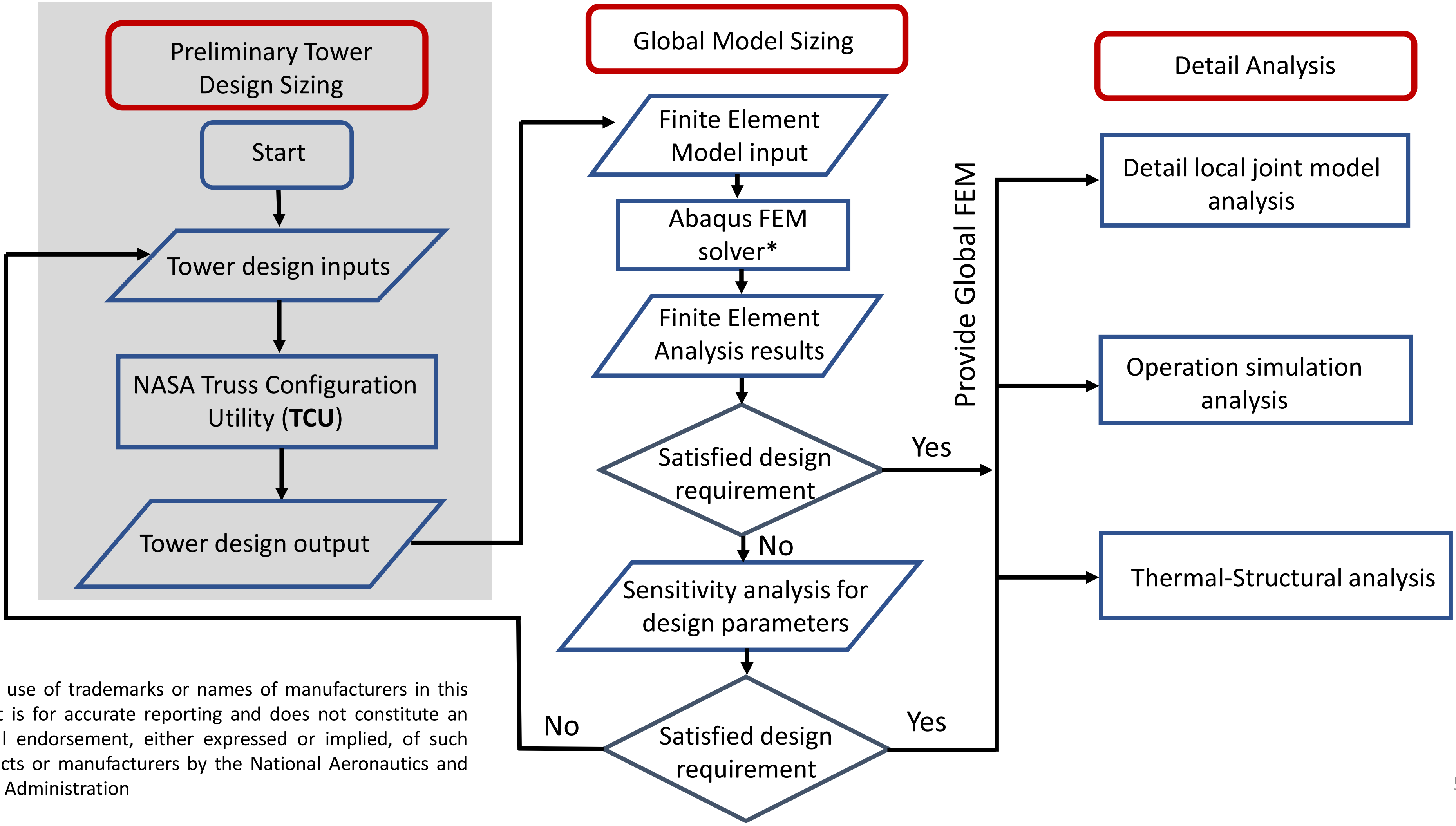
Assemble-able trusses are compact for launch!

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


Lander Based Mission Concept
NASA
Act 1 - Prepare
Act 2 - Assemble
Act 3 - Power
1
Lander delivers components and robotics
2
Equipment remains on top of lander Deck
3
Begin assembling repeatable truss bays
4
Lift tower up incrementally as new bays are completed
5
Lift and/or deploy solar arrays
Stowed solar panels
Truss components
Payload interface
Assembly robot
Assembly jig + lifter
Tower mount
Notional lander
Power cable
(Option 1)
Payload lifting cables
(Option 2)
Payload is lifted with the tower
100 kW array
15 m x 26 m

Analysis Process Map



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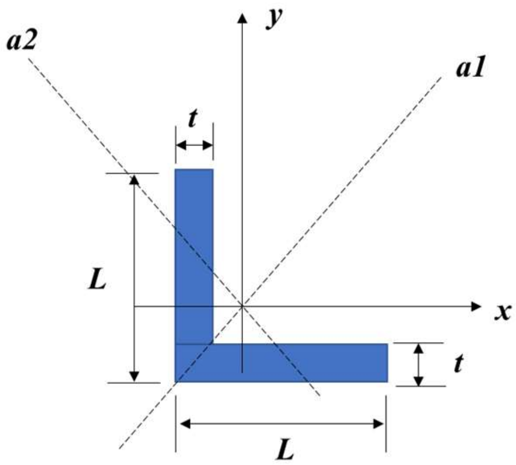
Governing Equations of TCU

Longeron Euler bucking (P_L)	$P_L = \frac{\pi^2 E_c I_l}{b^2} = \frac{(M_{PL} + M_{truss})\, g\, g_f}{4}$
Tower Euler bucking (P_T)	$P_T = (M_{PL} + 0.3 M_{truss})\, g\, g_f = \frac{\pi^2 E_c I_{truss}}{4 H^2}$
Tower mass (M_{truss}) equation	$M_{truss} = A_l\, H\, \rho\, JF \left(4 + 4\beta + 5\sqrt{2}\beta\right)$

Parameters in the governing equations

A_l	Cross-section area of longeron	E_c	Elastic modulus of longeron
b	Length of the longeron	g	Gravitational constant (9.8 m/sec^2)
I_l	Longeron moment of inertia	g_f	Planetary gravitational factor (1/6 for moon)
H	Height of tower	M_{PL}	Mass of payload at top of tower
β	Area reduction factor battens and diagonals	ρ	Longeron density
		JF	Factor to account for joint mass

Governing Equations of TCU (Continued)



Minimum moment of inertia (I_b) of the cross section

$$I_{a2} = \frac{t^4(1 - 6\bar{L} + 8\bar{L}^2 - 4\bar{L}^3 + 2\bar{L}^4)}{12(2\bar{L} - 1)}$$

Cross section area (A)

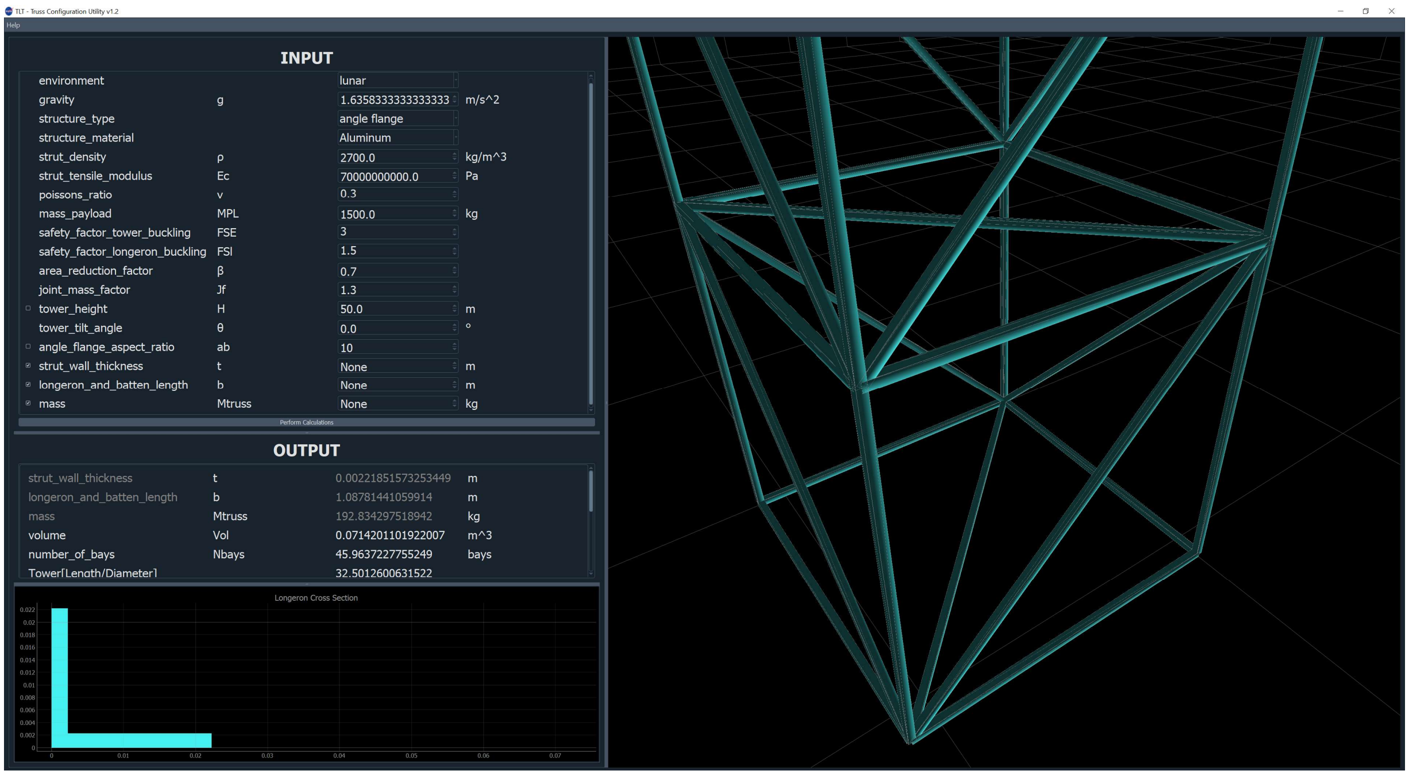
$$A_l = (2\bar{L} - 1)t^2$$

Length-to-thickness ratio

$$\bar{L} = L/t$$

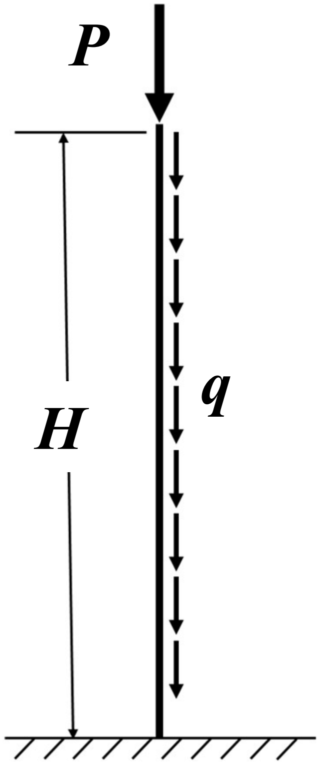
Longeron Euler bucking (P_L)	$P_L = \frac{\pi^2 E \frac{t^4(1 - 6\bar{L} + 8\bar{L}^2 - 4\bar{L}^3 + 2\bar{L}^4)}{12(2\bar{L} - 1)}}{b^2 FSL} = \frac{(M_{PL} + M_{truss})\, g\, g_f}{4}$
Tower Euler bucking (P_T)	$P_T = (M_{PL} + 0.3M_{truss})\, g\, g_f = \frac{\pi^2 E_c b^2\, (2\bar{L} - 1)t^2}{FSE\; 4\; H^2}$
Tower mass (M_{truss}) equation	$M_{truss} = A_l\, H\, \rho\, JF\, \left(4 + 4\beta + 5\sqrt{2}\beta\right)$

TCU Functionality and User Interface



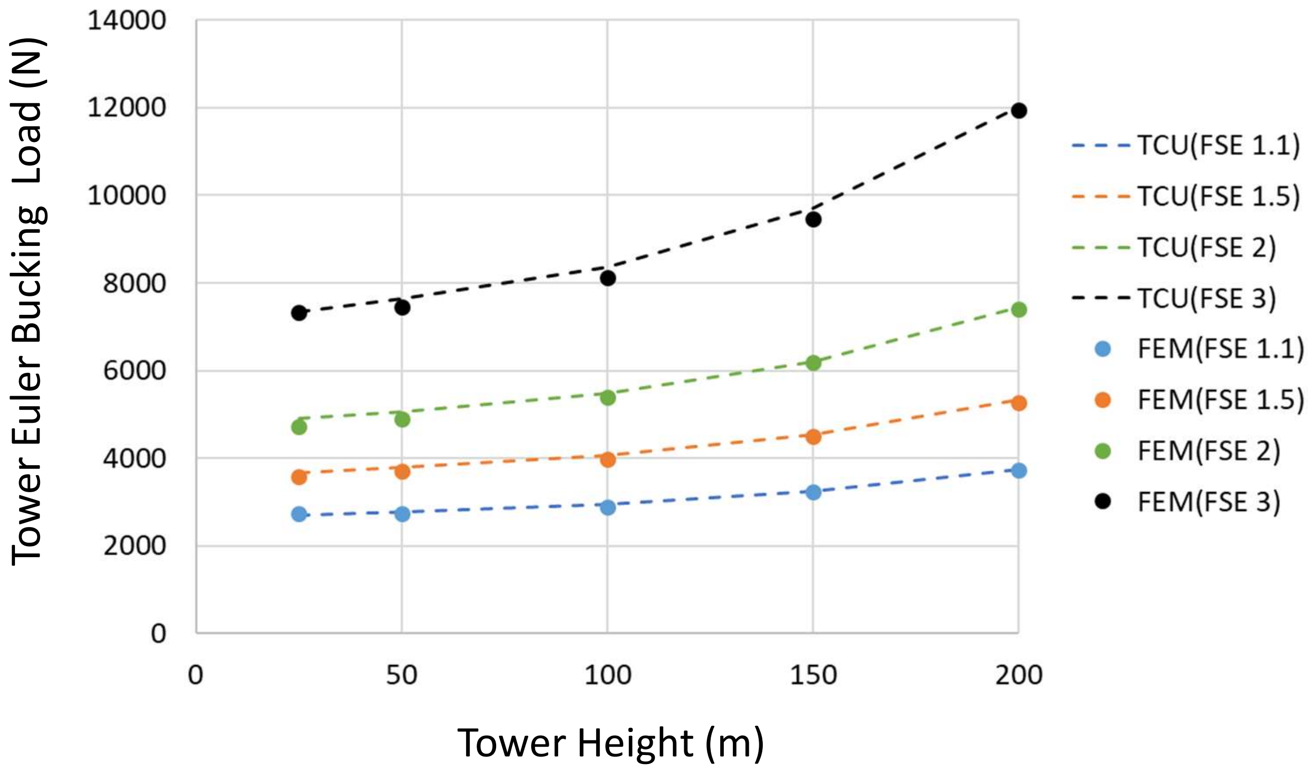
- Developed to rapidly explore the preliminary design space and structural requirements in the lunar environment
- The mass of tower, length of strut of each bay, and other modeling parameters are obtained

Tower Euler Bucking Due to Truss Weight (q) and Tip Load (P)

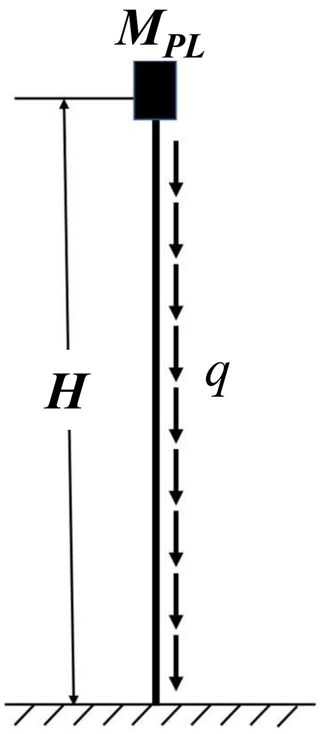


$$P + 0.3\ q\ H = \frac{\pi^2 EI}{FSE\ 4\ H^2}$$

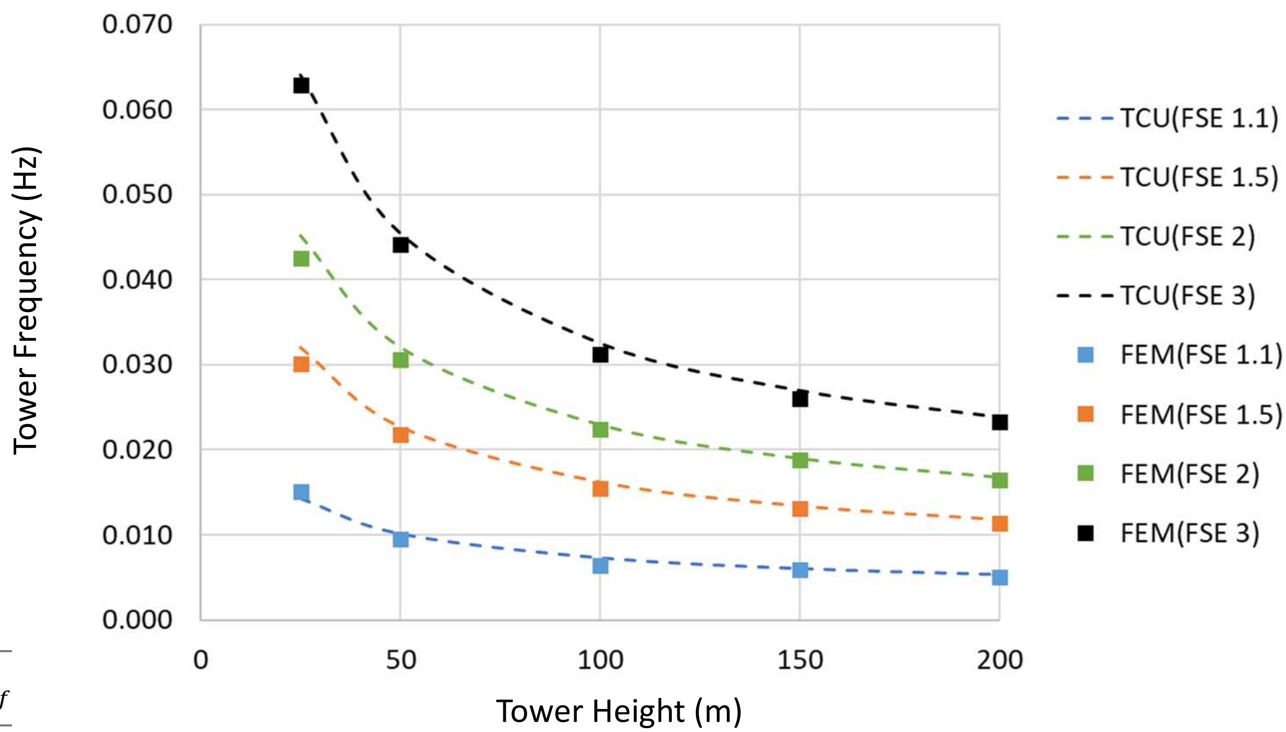
Timoshenko, *Theory of Elastic Stability*



Fundamental Frequency of Tower Due to Tip Mass (MPL) and Distributed Mass (q)

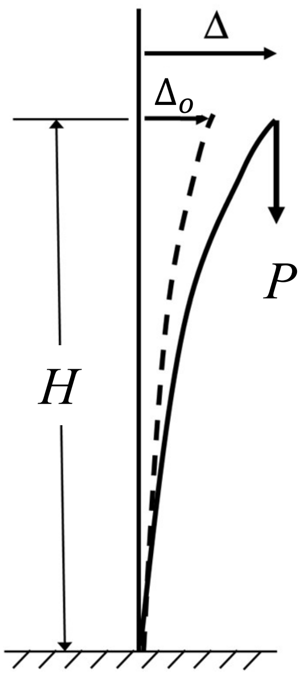


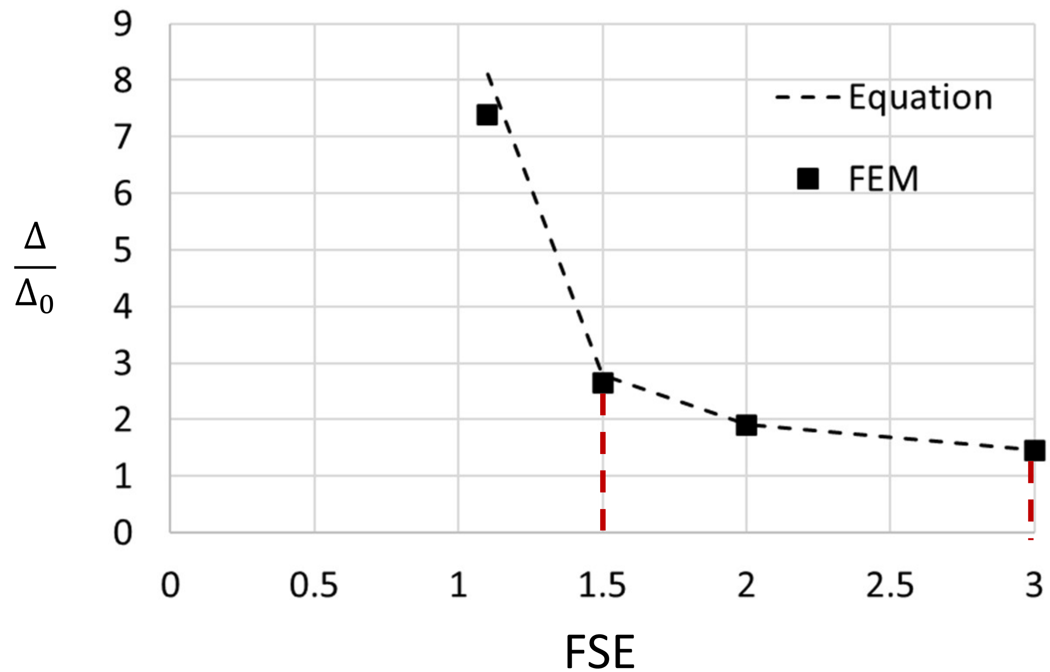
$$f = \frac{1}{2\pi}\sqrt{\frac{\frac{\pi^4}{32}\frac{EI_l}{H^3} - \left(\frac{\pi^2}{16}\frac{2M_{PL}+qH}{H} - \frac{1}{4}q\right)gg_f}{M_{PL} + \frac{3\pi-8}{2\pi}Hq}}$$



Wahrhaftig, A, et al., "The first frequency of cantilevered bars with geometric effect: a mathematical and experimental evaluation," *J Braz. Soc. Mech. Sci. Eng,* (2013) 35:457–467.

Lateral Deflection of the Tower Tip





$$\frac{\Delta}{\Delta_0} = \frac{1}{1 - \frac{1}{FSE}\frac{P}{P_T}}$$

Timoshenko, *Theory of Elastic Stability*

Summary

- Tall Lunar Tower (TLT) and the development of a sizing and design tool, the Truss Configuration Utility (TCU) were presented
- Three governing equations of TCU were introduced
- Verification and validation (V&V) studies of the TCU were performed to determine if the TCU reliably sizes the truss structure based on the inputs
- V&V studies of the TCU with finite element models proved that the TCU was capable of defining a TLT structure when given a desired tip payload, structure height, and material properties