Text-

Acce
Developme

Ryan McClelland

NASA Goddard Sp

SPACE

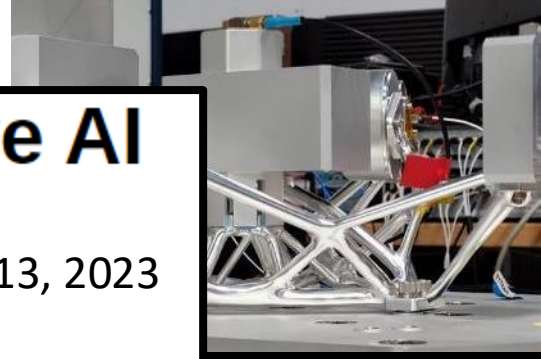
02-17-23

Language, schmanguage: NASA's generative AI builds spaceships

The Register Feb 13, 2023

Or their parts, at least, which look decidedly skeletal for satellite struts

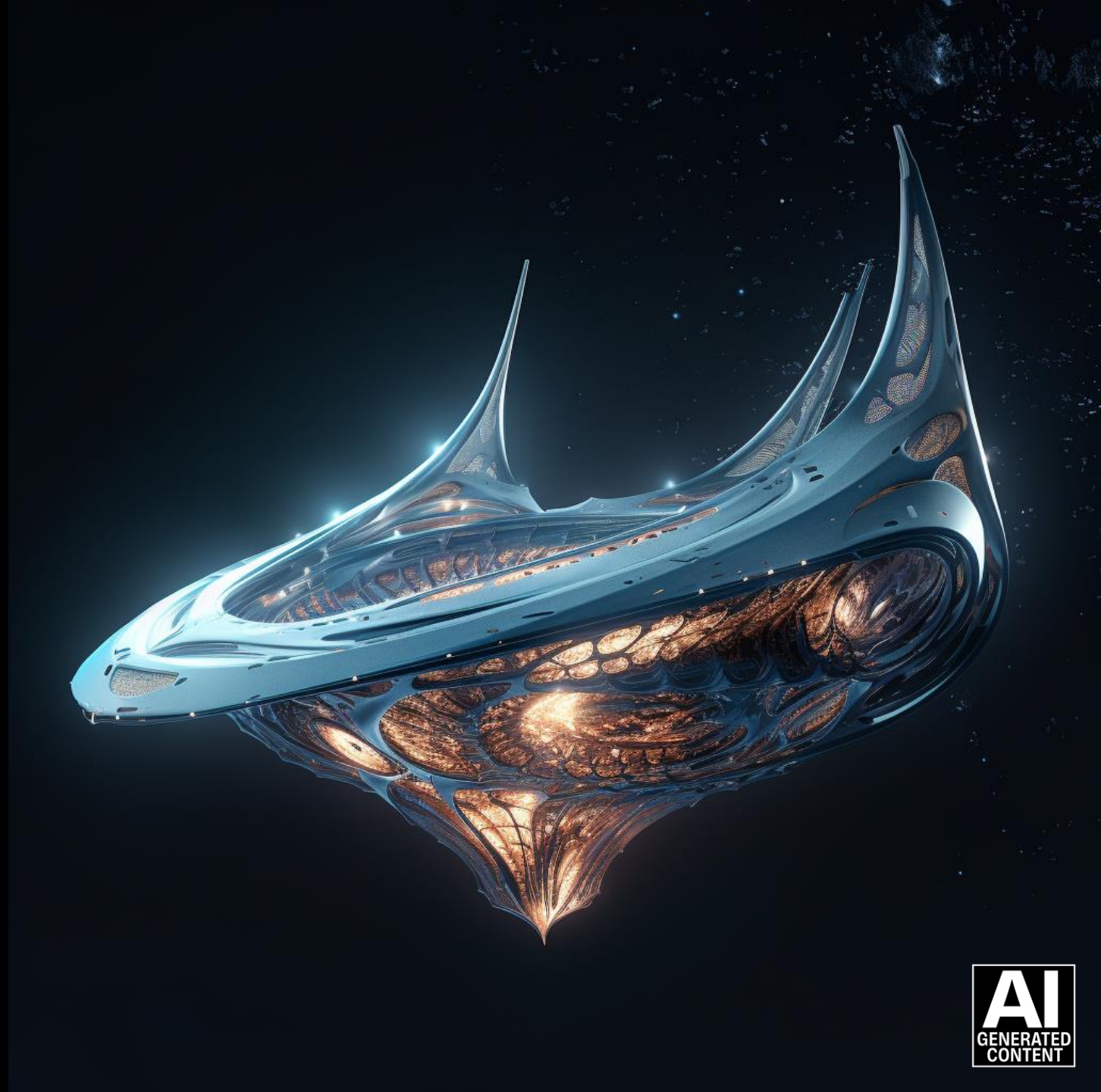
The telltale bony, organic shapes of generatively designed parts are starting to make a big impact at NASA Henry Dennis / NASA

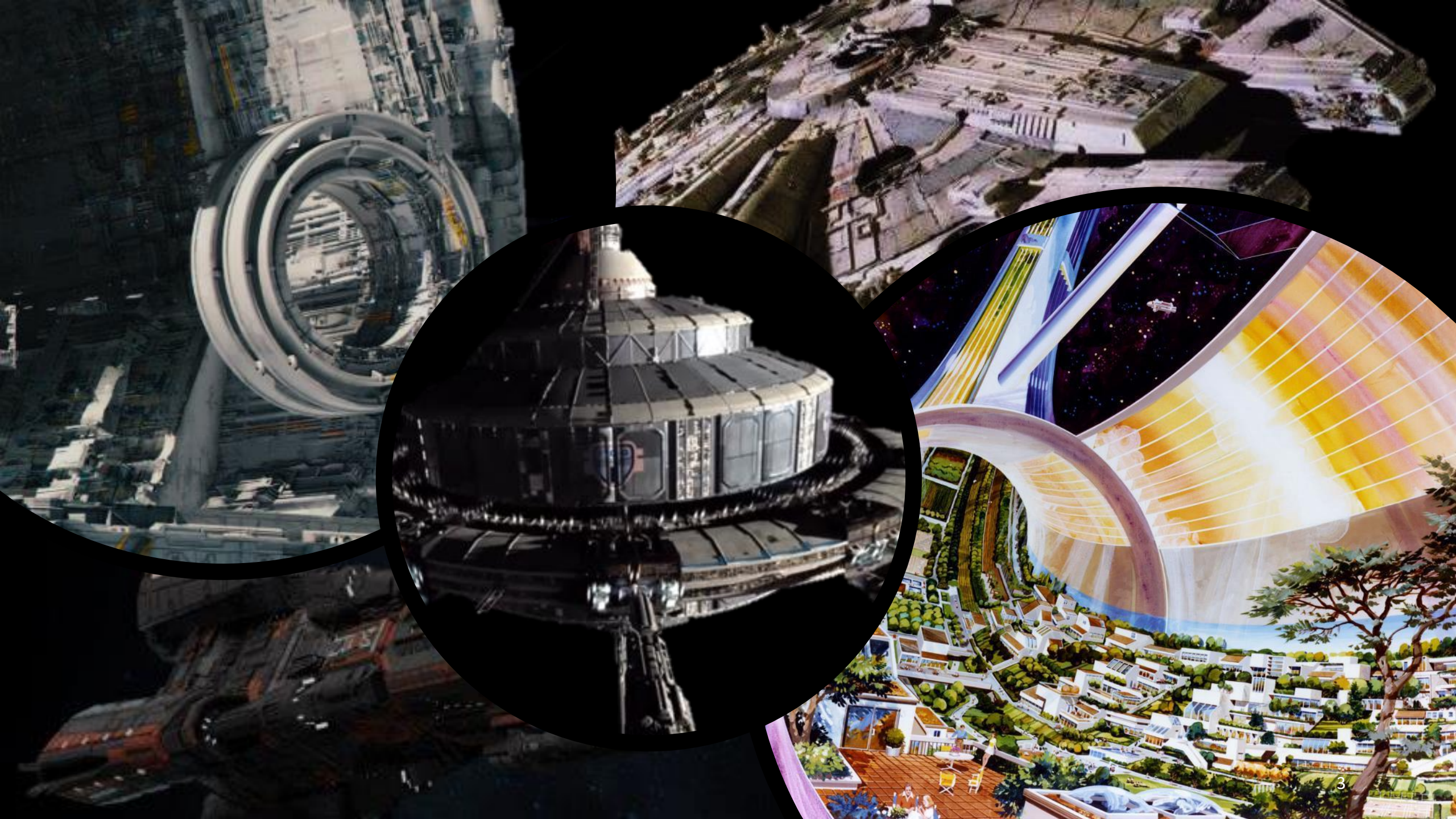


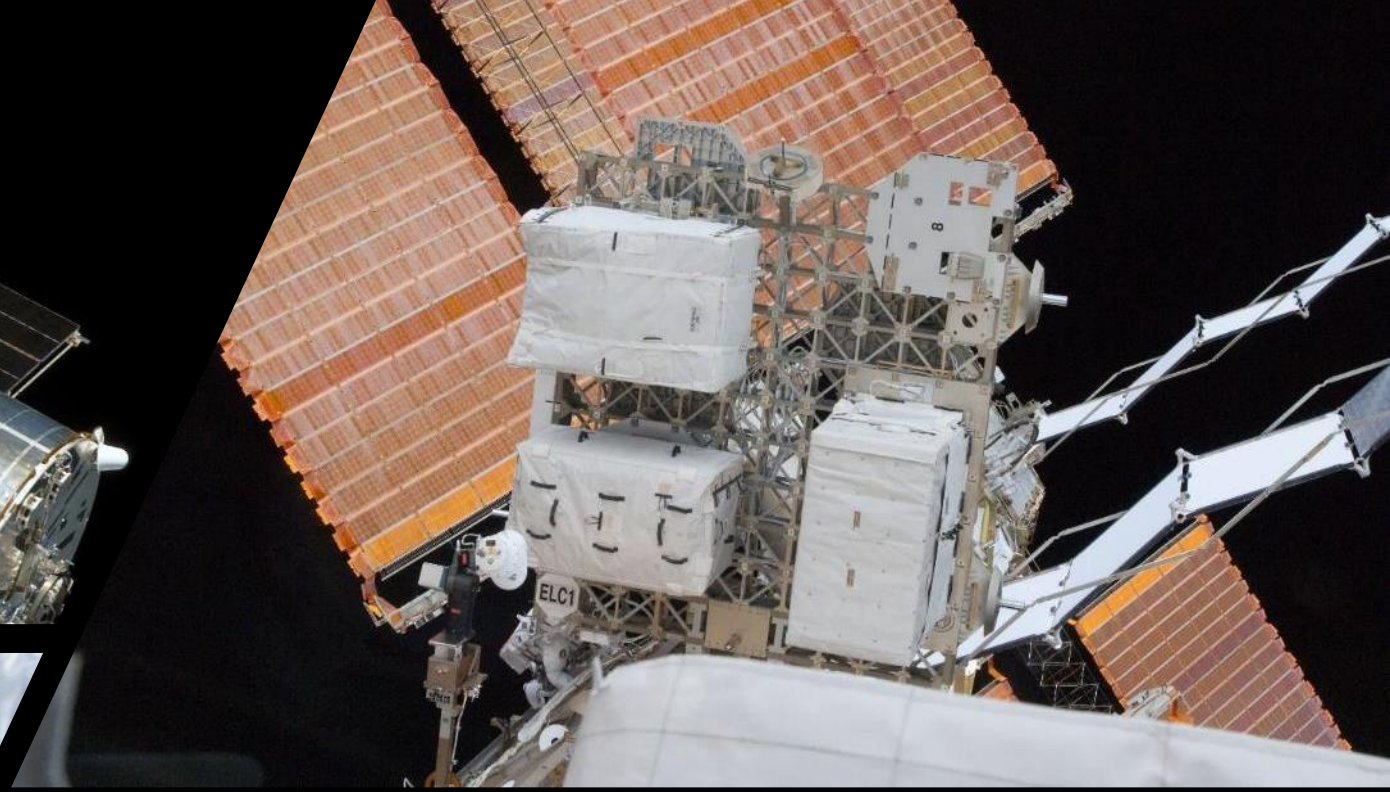
Text-to-Spaceship Vision:

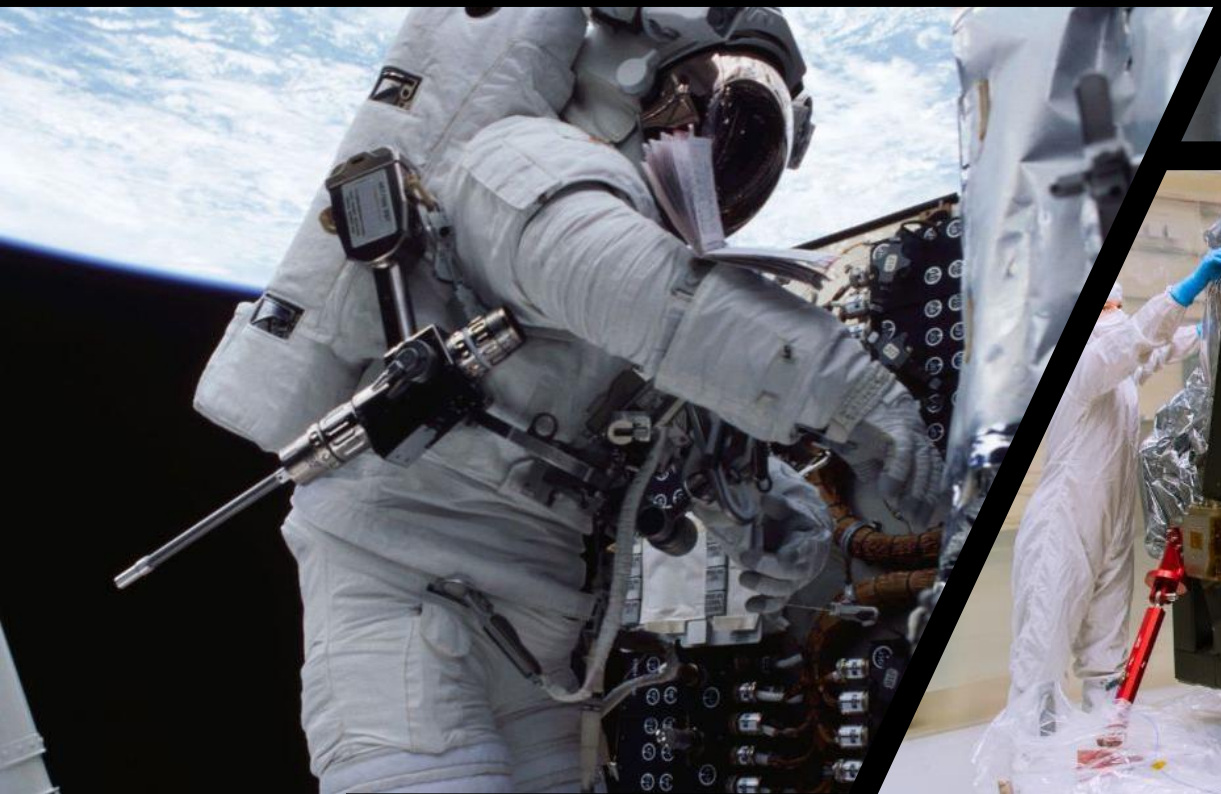
Accelerating Mission Development with AI

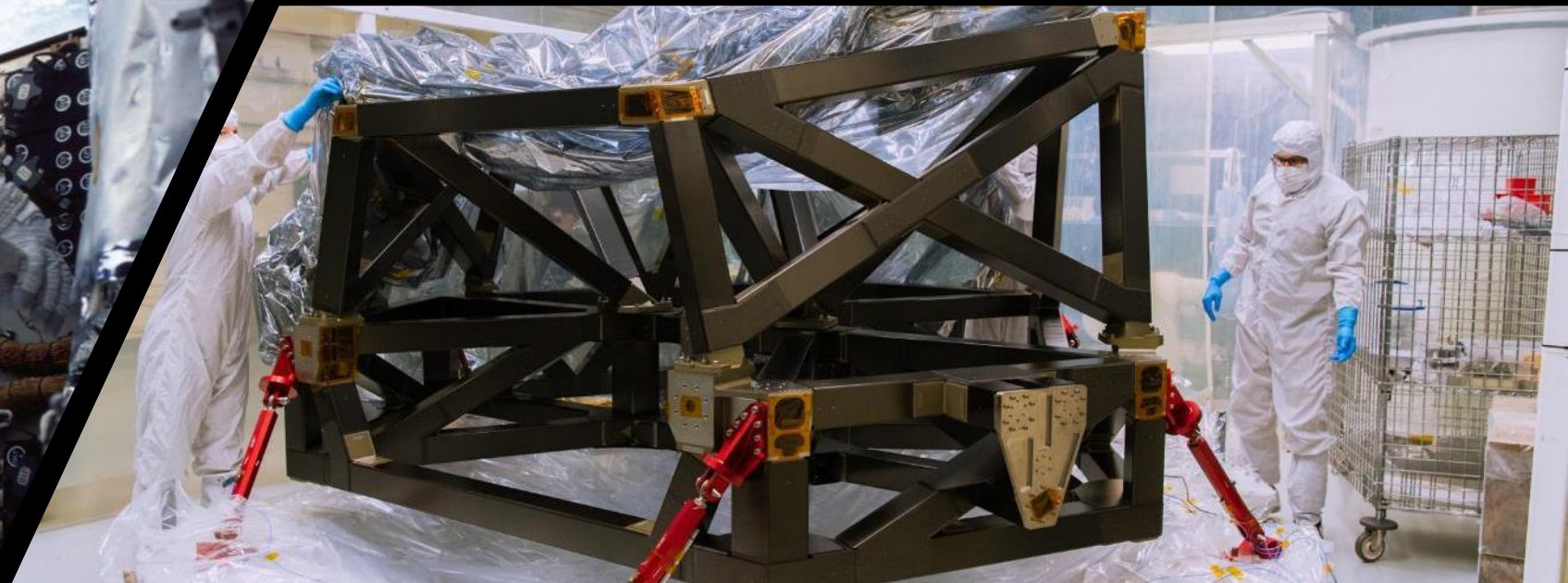
Ryan McClelland / GSFC AI Infusion Lead
NASA Goddard Space Flight Center (GSFC)



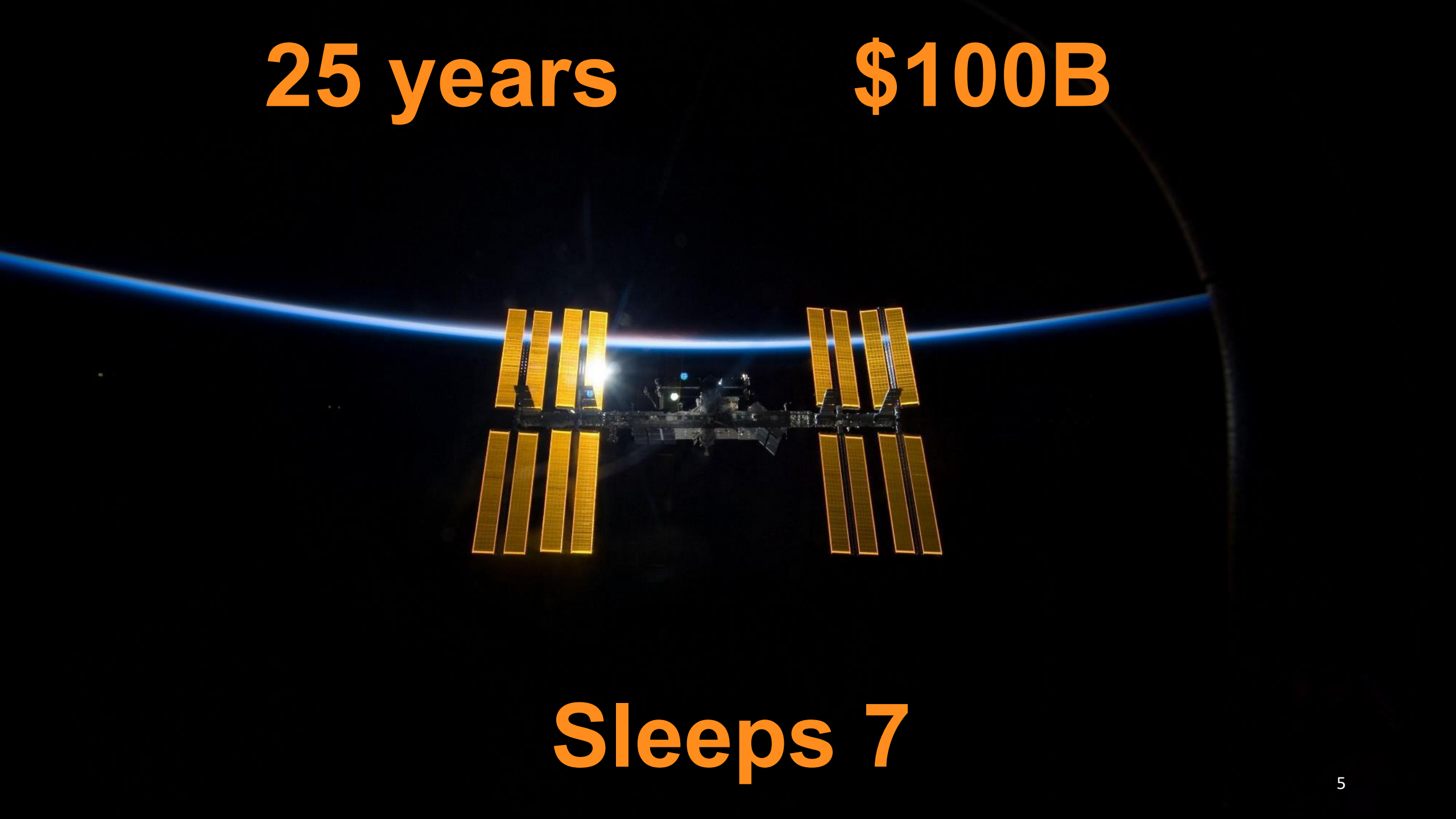



ELC1





25 years $100B



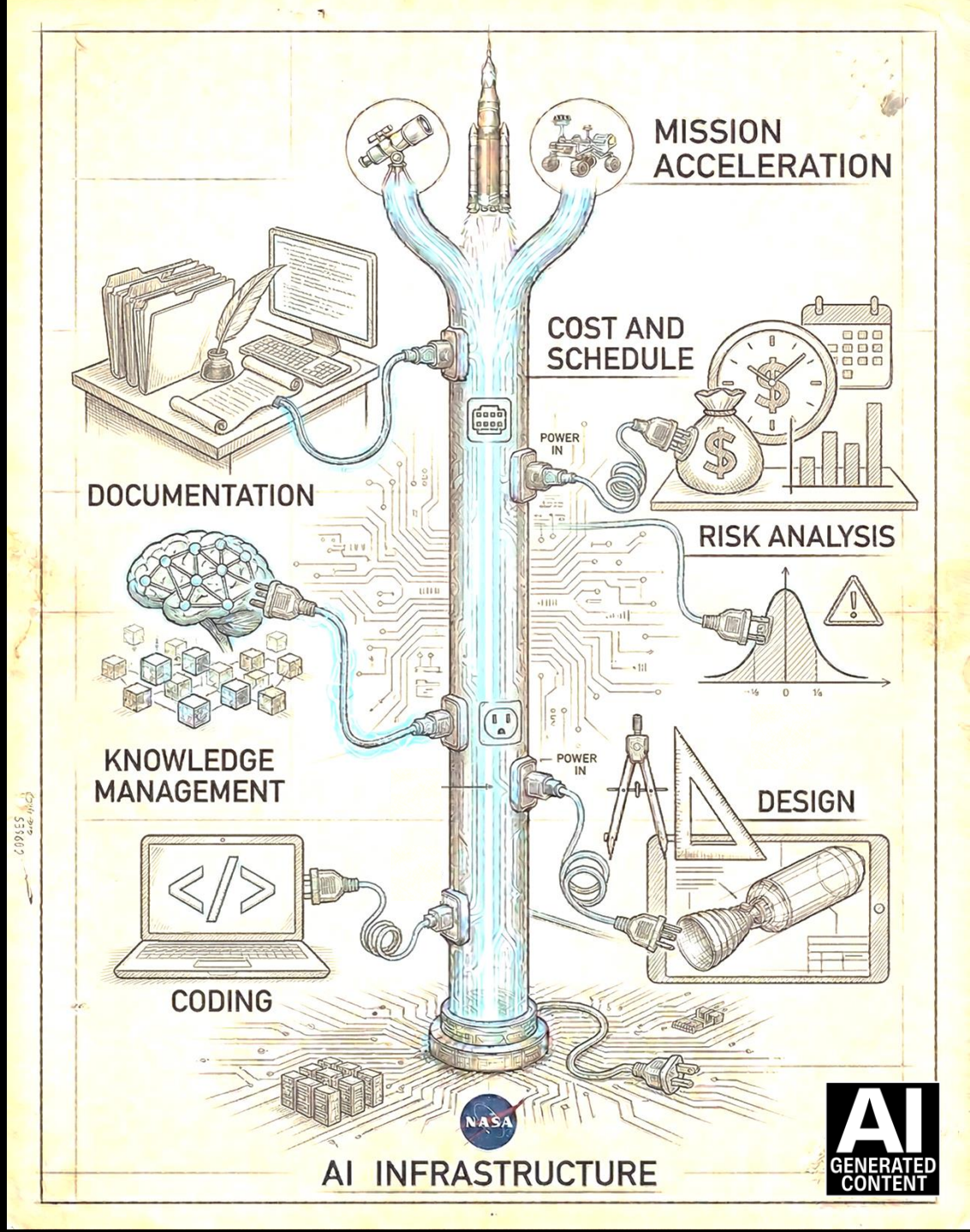
Sleeps 7

“AI is one of the most important things humanity is working on. It is more profound than, I dunno, ***electricity or fire****,”*

-Sundar Pichai (Google CEO, 2018)

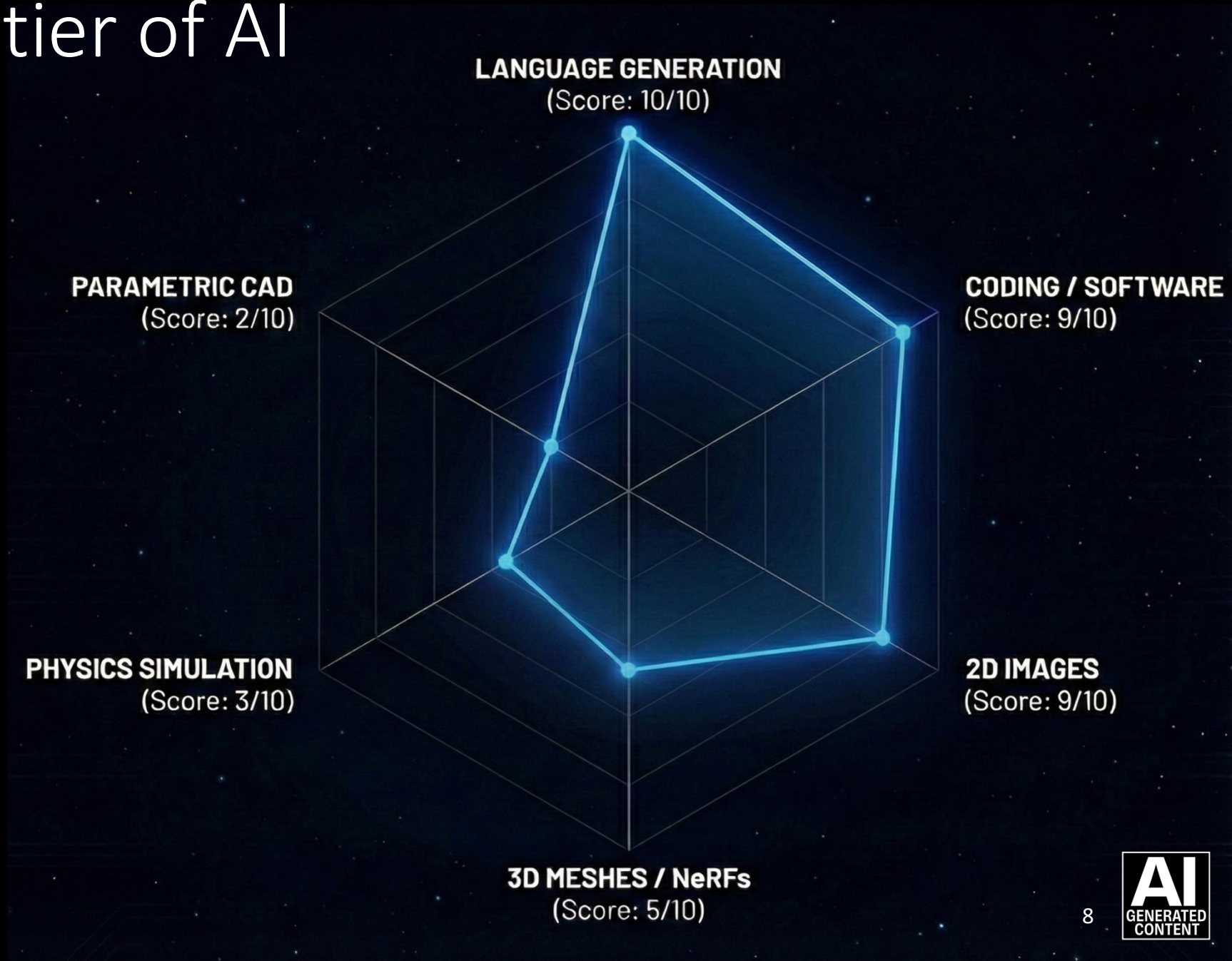
AI for All: LLM Foundation

- NASA's Secure Cloud
- ChatGSFC
- LLM API Portal
- AI-Coding (Claude Code etc)
- Avoid Lock-in
  - Anthropic Claude
  - Gemini (Google Workspace)
  - CoPilot (M365)
  - ChatGPT Enterprise (SCaN)
- Data connections
- Empower workforce 50,000+



The Jagged Frontier of AI

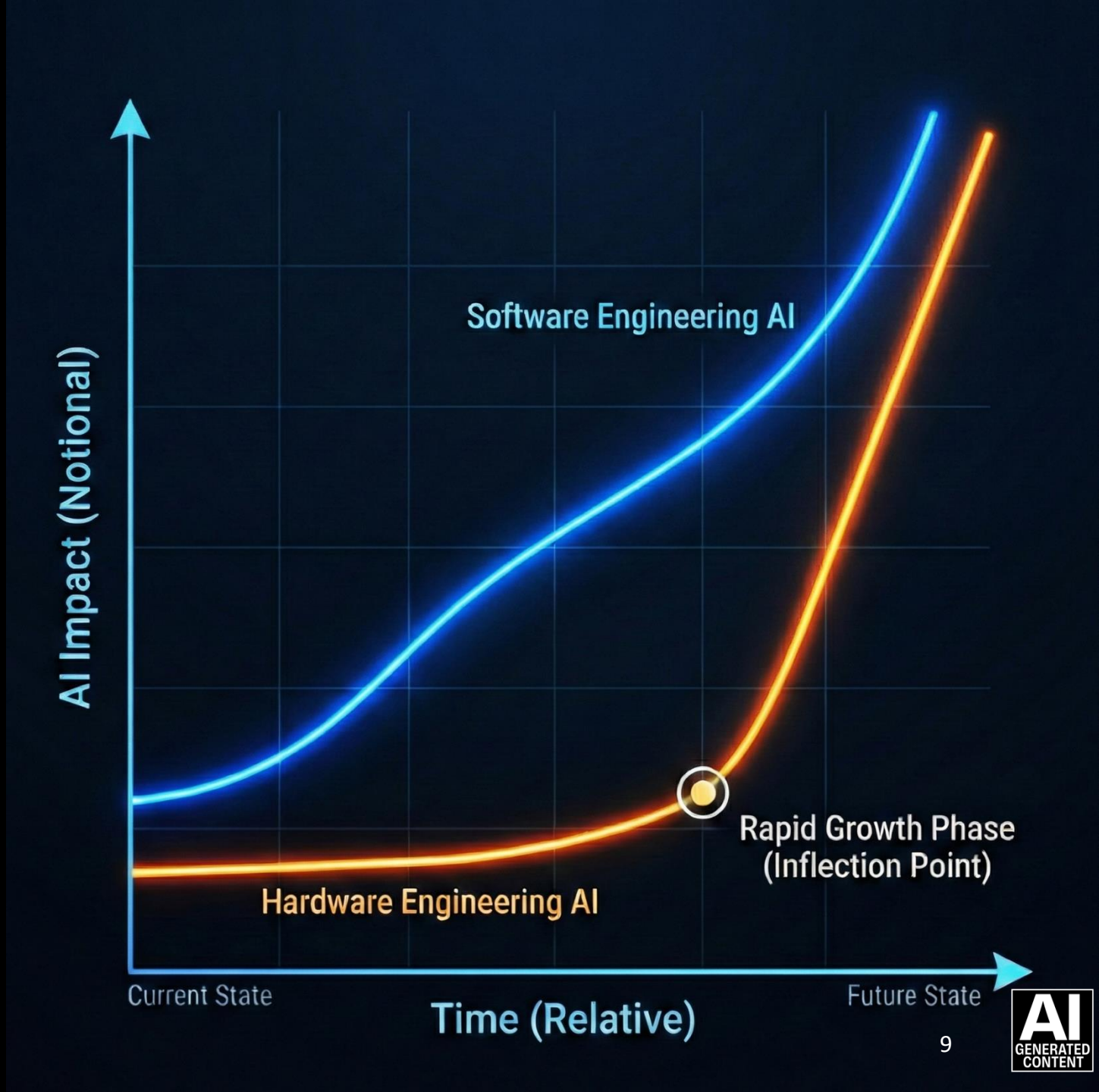
- Data
- CAE tools
- Simulation
- Bits-to-Atoms gap
- Slow iteration



AI GENERATED CONTENT

Change is Coming

- Software tools
- Innovative product companies
  - Divergent
  - Boom
  - Proteus Space



The Mental Model

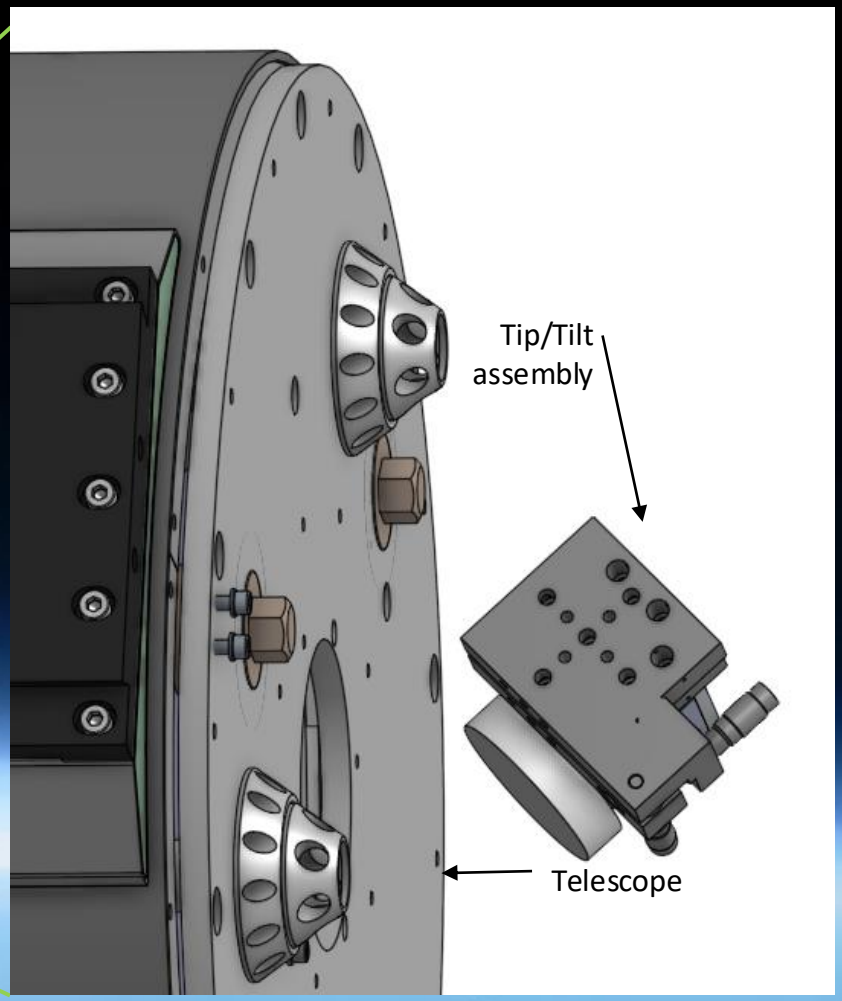
- Text-to-Spaceship Vision
- Iron Man’s JARVIS

- Computers aren’t just calculators
- They are collaborators

NASA EXoplanet Climate Infrared Telescope (EXCITE, Peter Nagler)

40 km

above Earth's surface



Illustration

Image Source: https://www.jpl.nasa.gov/news/nasa-mission-will-study-the-cosmos-with-a-stratospheric-balloon

Traditional Structure

2 Engineers:

2 days

4 Iterations

~~Performance~~

~~Manufacturing~~

Evolved Structure

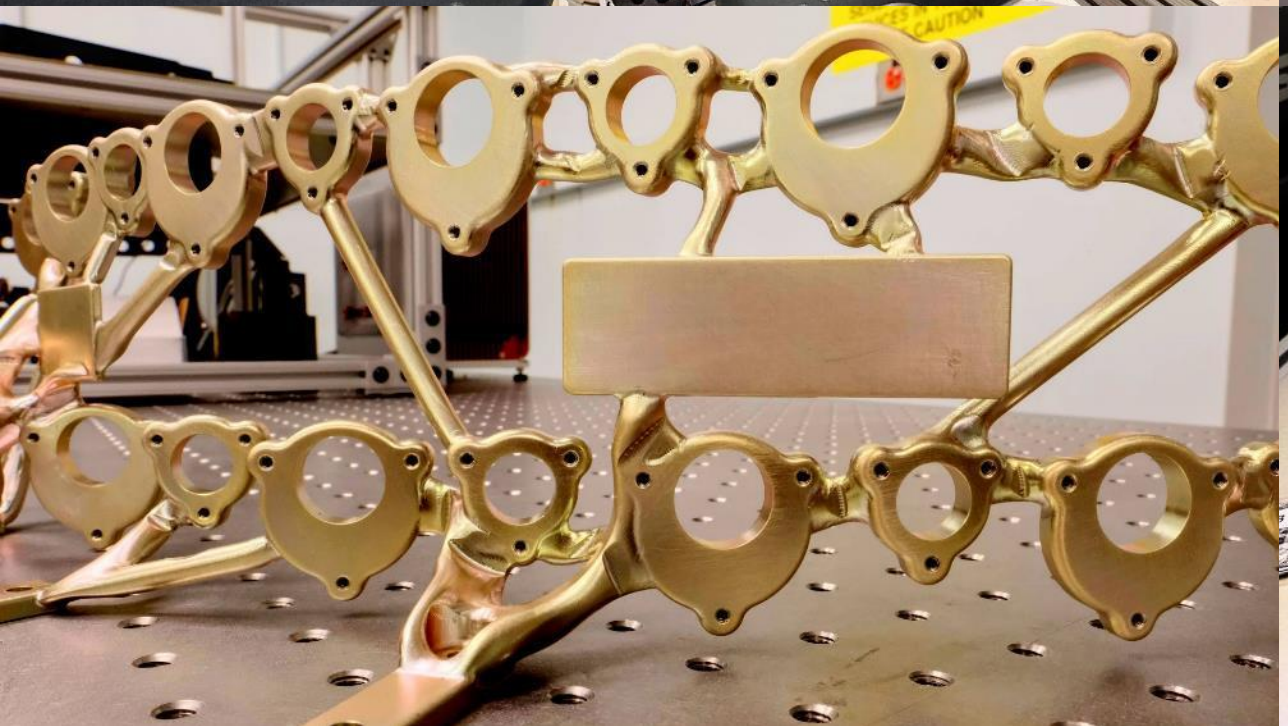
1 Engineers + AI:

1 hour

>100 iterations

Lighter, 3x Stiffer, 10x Stronger

Manufacturing



Evolved Structures Checklist

Title	Numb...	Design co...	Hardware...	Materials ...	Loads	Modes	Keep/Pre...	Obstacle ...	Other not...
DAVINCI+ LDS Sep Bracket	A61	Large box beam supp	Flight	Titanium T64	40G axial re-entry	system >15Hz	Mounting holes for r	pyrotechnical bolts	Use inertial loading f
DAVINCI ZRing	A60	Thermally isolated c	Parallel path des...	Ti6Al4V	Drumstack mass NTE	Above 60 Hz	Two rings of clearanc	top, bottom, center	
Lunar Thermal Heat Switch (TA...	A59		Prototype	Titanium	Thermal switch in mi	No frequency requir	2x 4" disks	3 3/4" keep out zone	
Brackets for TGS IRAD (CAESAR)	A58	TGS = Touch-and-Go	Flight	AL6061-T6	See flight document	>100Hz	Bar, main/central dis	keep open under car	
JOEEE Flywheel structure	A57	tumbling robot - mig	Prototype	AL6061	Spinning flywheel be		motor and plunger n	flywheel volume	
Formaldehyde LIDAR Optical Be...	A55	Airborn LIDAR	Parallel path des...	Aluminum 6061	9g forward, 1g vertic	use standard	mount for the receiv	telescopes and light	
HWO Secondary Mirror Suppor...	A54	Determining an opti	Parallel path des...	HWO Composite	1-2G loading	First Mode >20Hz	Here are the coordia	Build Inside that box	
WaIST - Suborbital Star Tracker	A53	Redesign of part that	Flight	AL6061-T6	61g up and side for s	10x different rocket	4 clearance holes for	no larger than the fo	
STiNG - Balloon Star Tracker	A52	No analysis, just itera	Flight	6061	survive 8 veirtical		bolts on feet tabs	linear stage	
596 Head Expander	A50	Head expander for 5	Parallel path des...	Currently it is Magne	Assume 40 lbs (18.14	Current design 1st m	Keep all bolt pattern	Just bolts and access	Current design is 71l
HWO Backplane (EAC1 config)	A49	Trying to come up wi	Parallel path des...	M55J 954-2 composi	Look at LV loads, Nev	On-orbit stiffness >1	9 hard points to Insti	None to start with	Drew's current desig
Lightweight Flywheel	A48	Internal design effort	Design only	6061 Al or Stainless	40g in x, y, z	as high as possbile @	Inner hub	Hub mount 1.75" dia	use at least 2 symetr
CADR ADR Support	A47	Ultra-low temperatu	Parallel path des...	Vespel SP1	MAC - 40g (from 54C	>150 Hz	Standoff, bolt circles	Standoff, ID can't cha	
LOONS supporting structure	A46	Box/frame holding n	Prototype	Al6061	MAC assumed until c	>100Hz		Space between cryst	
Rate Sensor Mount - DAVINCI	A45	See A44	Flight	Aluminum and Titan	MAC 68g	>150 Hz	Need to figure out m	installation and harn	
Accelerometer Mount - DAVINCI	A44	Accel mount on desc	Flight	Aluminum and Titan	MAC 68g	>150 Hz	Bolt patterns for acc	installation path	
Electronics Box for AutoNGC	A43	Electronics box for A	Prototype						
Roman Propulsion Deck	A42	Rear plate of roman	Design only	AL6061	MAC = 22G	>10Hz	Attachment Point for	tanks	
ALICE Scan Mirror Bracket	A41	Replacing scan mirro	Prototype	Al 6061	MAC loads :: 40-60G	>140Hz (double cont	Use feet brackets fro	NTI with/around opt	mass to beat is curre
Alice M1 and M3	A40	ALICE Evolved optics	Prototype	Aluminum	68g per MAC		fasteners and pins, s		M1 OG mass 121.62
ALICE Grating Mount	A39	Replacing grating mc	Prototype	6061 Aluminum	Mass of those 2 elen	>100 but won't neec	Mount for the gratin	Path of light, the gati	
DraMS Attic Baseplate	A38	Base of the instrume	Parallel path des...	6061 or 7075 if need	Andrew will find out	Current mode 145 H currently 128 Hz	See es_drams_abp.s	See es_drams_abp.s	Facesheets are 2 x 0.
CUVIS Structure	A37	Thermal stability is n CUVIS - imaging spec	Parallel path des...	Invar or Ti for therm	MAC per DV-SYS-REC	nothing specific, use	component mounts	light path per CUVE I	
LEXA Head Unit Housing	A36	LEXA (Light ELement	Prototype	6061 Al	MAC <1kg 68g MXS = 0.385 kg	Stardard >100 Hz	4 bolts to deck interf	Detectors or X-rays a	Look at part consolic
LUVex SCBSF Interface	A34	The LUVex SCBSF Int	Design only	The primary materia	The loads being usec	TBD	The preserve geome	Obstacle geometry is	Exploration of the fa

Evolved Structures Guide for GSFC Applications

Ryan McClelland, NASA Goddard Space Flight Center, Code 550

1 Introduction

1.1 Overview and Motivation

For an introduction to the motivation and technology behind Generative design and Digital Manufacturing, please watch: Ryan McClelland – NASA - Generative Design & Digital Manufacturing at NASA Goddard - CDFAM (youtube.com)

This guide enables optimized structural parts to be designed, validated, and prepared for manufacturing quickly and efficiently. For simple parts with known requirements, designs can be completed and validated by Finite Element Analysis (FEA) in as little as 1 day by an experienced user. This process is tailored to GSFC applications and standards.

The recommendations in the guide should be considered *smart defaults* and are superseded by project-specific requirements.

1.2 Software

Creation of **Preserve** and **Obstacle** geometry can be completed in the user's CAD tool of choice (e.g., Creo, SolidWorks) then exported/imported as a STEP model into a generative solver of their choice; this guide focuses on Fusion 360. **Preserve** and **Obstacle** geometry can be separate bodies parametrically tied to the native CAD. Only the geometry recommended in this guide should be imported into Fusion 360 to keep the Generative Design models as small and simple as possible. Assemblies such as detectors and optical systems should be represented as volumes and interfaces rather than wholly importing them. Care should be taken to align the reference coordinate system used for export with any desired machining axes, since Fusion 360 doesn't currently support multiple coordinate systems. Once in Fusion 360, imported geometry can be moved, rotated, scaled, cut, re-sized, mirrored, etc. within Fusion 360, which includes a full-featured CAD package. **Preserves** and **Obstacle**s can also be created natively within Fusion 360.

Generatively Designed part can be most easily modified within Fusion 360 due to the extensive T-spline editing tools for organic shapes, then output to the user's preferred CAD via STEP for additional modification if needed.

1.2.1 Installing Fusion360

This guide is specific to the Autodesk Fusion 360 Generative Design software but may be updated as other tools come into use.

Download Fusion 360 for Free | Free Trial | Autodesk

This guide assumes you have familiarity with Fusion 360 Generative Design. If not, please complete this tutorial first. This guide does not include click-by-click instructions. Fusion 360 selections, commands, and options are denoted with **bold text**. For general Fusion 360 training (e.g. not Generative specific) check out Fusion 360 fundamentals. Lars Cristensen's Youtube channel is also a popular user resource.

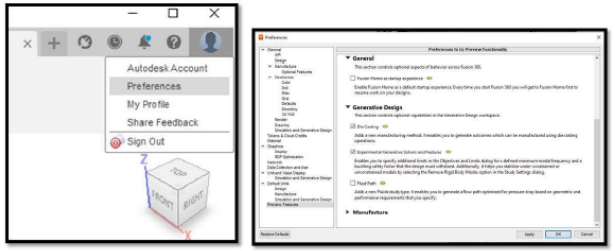
When opening/importing external CAD geometry in Fusion 360, immediately turn on **Design History** so changes are captured in the hierarchy.

1.2.2 Enabling Advanced Features in Fusion 360 (Optional)

Certain features used to require Advanced Features to be enabled in Fusion 360; any of the features referenced in this guide are now incorporated into the main software branch. The following information is included for historical purposes:

There are advanced features in Fusion 360 Generative Design that are considered experimental and require being a part of the "Insiders Program." If you want to use these features:

1. Install Fusion360.
2. Join the Autodesk Insiders Program using the same email you're using Fusion360 with: https://www.autodesk.com/campaigns/fusion-360/insider-program
3. Open your account preferences and select Preview Features in the left pane and select" Experimental Generative Solvers and Features" (It may take up to 24-hours for the options to show)



1.3 Help and Support

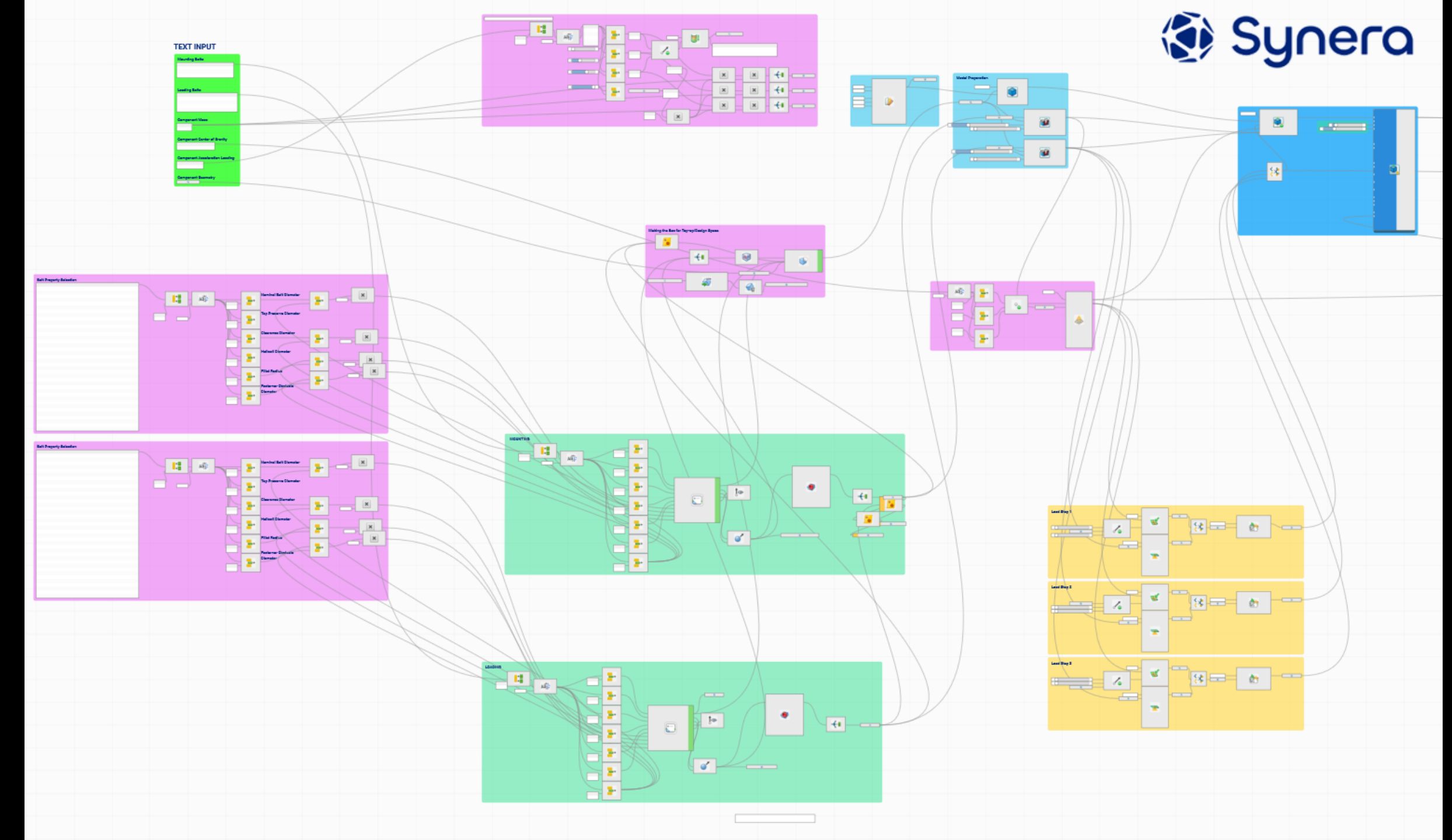
Help is available within Fusion 360 via the help icon in the upper right and the support icon in the lower right. The help icon takes you documentation and the learning panel with context sensitive help. The support icon will allow you to search documentation and learning resources or directly chat with a support agent.

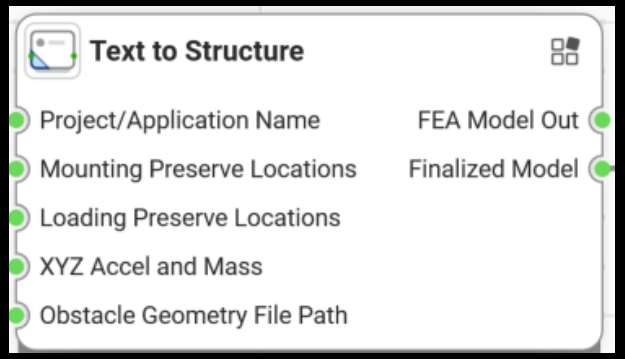
More information on Generative Design, including discussion/help within the GSFC community can be found on the Generative Design MS Team. Please request permissions at the link.

1.4 Evolved Structures through the Mission Lifecycle

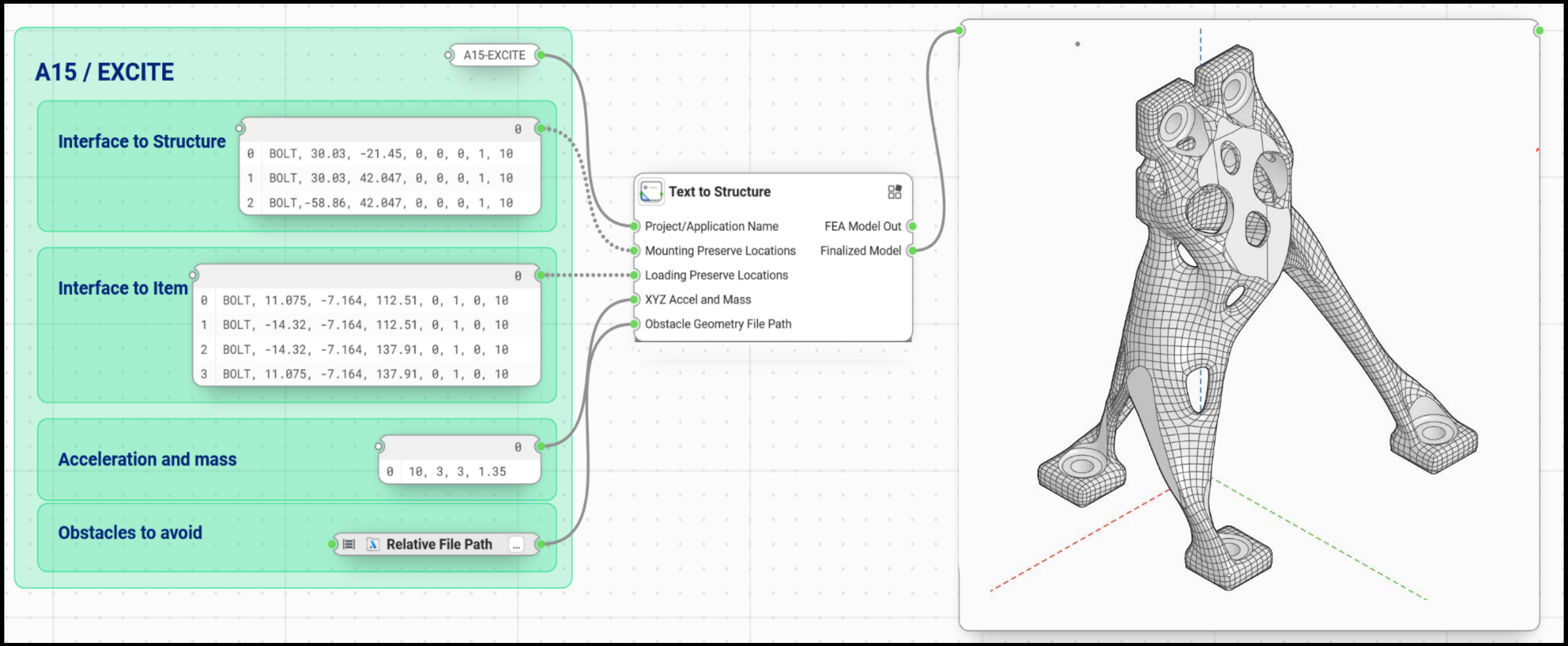
Structure requirements evolve throughout the project lifecycle, especially for larger missions. The Evolved Structures process is well-suited to this iteration; once the requirements are defined as described in the sections below, generating new designs based on new or updated requirements is much faster than the traditional approach.

Figure 1-1 shows how Evolved Structures fit into the project life cycle. The design is iterated as requirements change and system-level design and modeling are refined. This is the same as for


TEXT INPUT
Mounting Bolts
Leveling Bolts
Component Mass
Component Center of Gravity
Component Acceleration Leveling
Component Geometry
Bolt Property Selection
Nominal Bolt Diameter
Tap Preserve Diameter
Clearance Diameter
Helicoil Diameter
Fillet Radius
Fastener Obstacle Diameter
Bolt Property Selection
Nominal Bolt Diameter
Tap Preserve Diameter
Clearance Diameter
Helicoil Diameter
Fillet Radius
Fastener Obstacle Diameter
Model Preparation
Level Step 1
Level Step 2
Level Step 3
Synera


Text to Structure
Project/Application Name
Mounting Preserve Locations
Loading Preserve Locations
XYZ Accel and Mass
Obstacle Geometry File Path
FEA Model Out
Finalized Model

Text-to-Structure



A19 / STAR-X

STAR-X

Interface to Structure

	0
0	BOLT, -197.021, -113.75, 0, 0, 0, 1, 10
1	BOLT, -227.50, 0, 0, 0, 0, 1, 10
2	BOLT, -197.021, 113.75, 0, 0, 0, 1, 10
3	BOLT, 197.021, 113.75, 0, 0, 0, 1, 10
4	BOLT, 227.50, 0, 0, 0, 0, 1, 10
5	BOLT, 197.021, -113.75, 0, 0, 0, 1, 10

Interface to Item

	0
0	BOLT, 50, -110, 50, 0, 0, -1, 10
1	BOLT, 110, -50, 50, 0, 0, -1, 10
2	BOLT, 110, 50, 50, 0, 0, -1, 10
3	BOLT, 50, 110, 50, 0, 0, -1, 10
4	BOLT, -50, -110, 50, 0, 0, -1, 10
5	BOLT,-110, -50, 50, 0, 0, -1, 10
6	BOLT,-110, 50, 50, 0, 0, -1, 10
7	BOLT, -50, 110, 50, 0, 0, -1, 10

Acceleration and mass

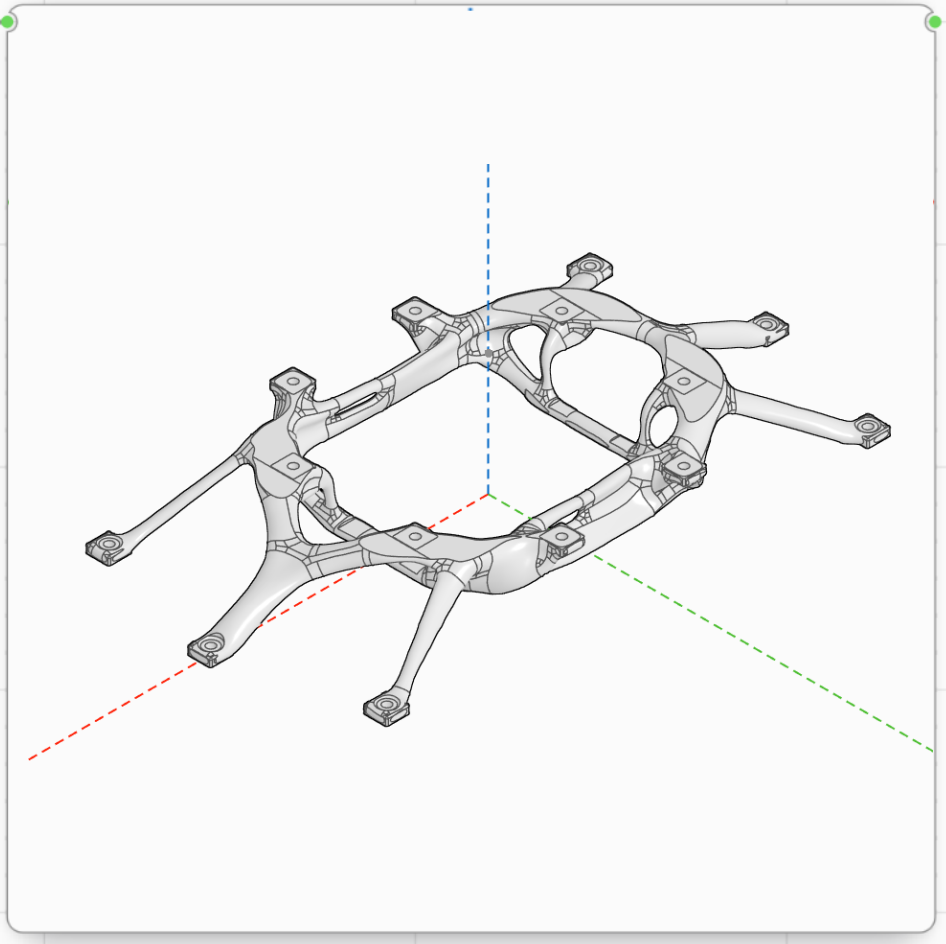
	0
0	9, 9, 18, 5.8

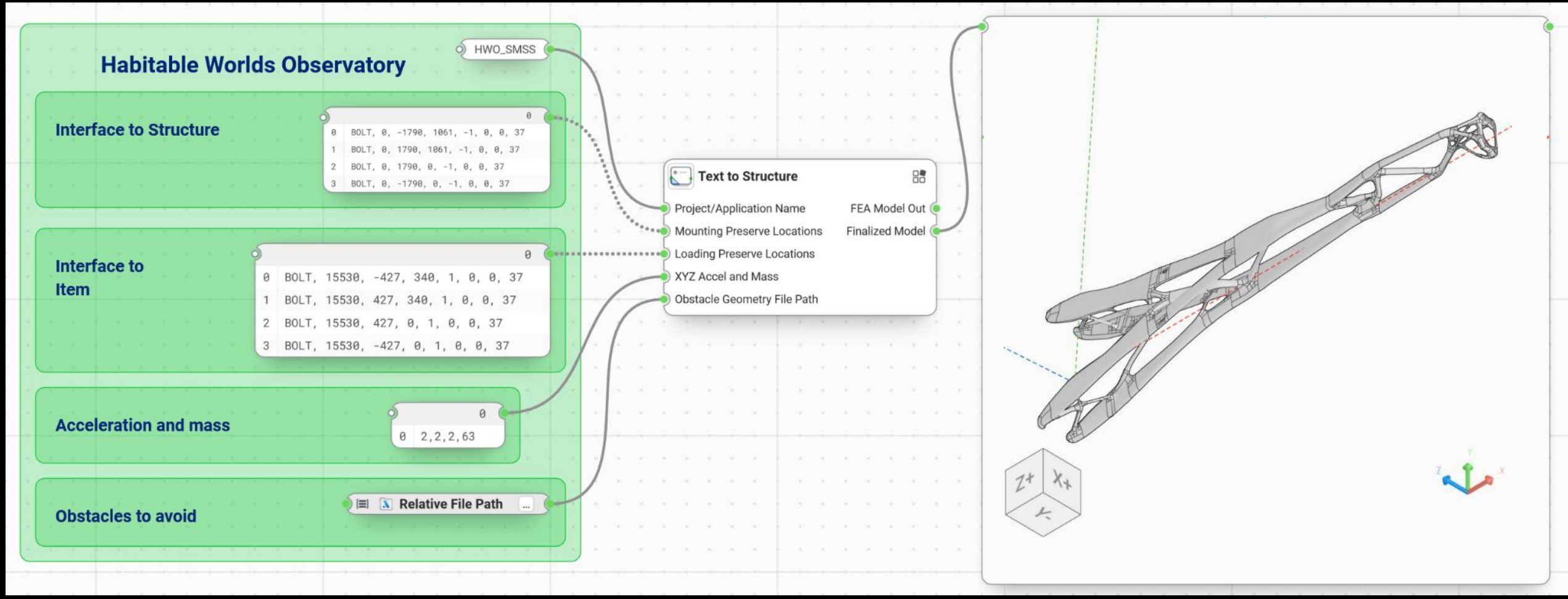
Obstacles to avoid

Relative File Path ...

Text to Structure

- Project/Application Name
- Mounting Preserve Locations
- Loading Preserve Locations
- XYZ Accel and Mass
- Obstacle Geometry File Path
- FEA Model Out
- Finalized Model




Habitable Worlds Observatory
HWO_SMSS
Interface to Structure
0
0 BOLT, 0, -1790, 1061, -1, 0, 0, 37
1 BOLT, 0, 1790, 1061, -1, 0, 0, 37
2 BOLT, 0, 1790, 0, -1, 0, 0, 37
3 BOLT, 0, -1790, 0, -1, 0, 0, 37
Interface to Item
0
0 BOLT, 15530, -427, 340, 1, 0, 0, 37
1 BOLT, 15530, 427, 340, 1, 0, 0, 37
2 BOLT, 15530, 427, 0, 1, 0, 0, 37
3 BOLT, 15530, -427, 0, 1, 0, 0, 37
Acceleration and mass
0
0 2,2,2,63
Obstacles to avoid
Relative File Path
Text to Structure
Project/Application Name
Mounting Preserve Locations
Loading Preserve Locations
XYZ Accel and Mass
Obstacle Geometry File Path
FEA Model Out
Finalized Model
Z+
X+
Y-

Text 2 Structure Demo

Text2Structure_Demo

Interface to Structure

	0
0	BOLT, 30.000, 345.800, 180.000, 0.000, -1.000, 0.000, 22
1	BOLT, 170.000, 345.800, 180.000, 0.000, -1.000, 0.000, 22
2	BOLT, 30.000, 345.800, 320.000, 0.000, -1.000, 0.000, 22
3	BOLT, 170.000, 345.800, 320.000, 0.000, -1.000, 0.000, 22

Interface to Item

	0
0	BOLT, 13.185, -6.987, 311.15, 0, 0, -1, 2
1	BOLT, 13.185, 6.987, 311.15, 0, 0, -1, 2
2	BOLT, -13.185, -6.987, 311.15, 0, 0, -1, 2
3	BOLT, -13.185, 6.987, 311.15, 0, 0, -1, 2

Acceleration and mass

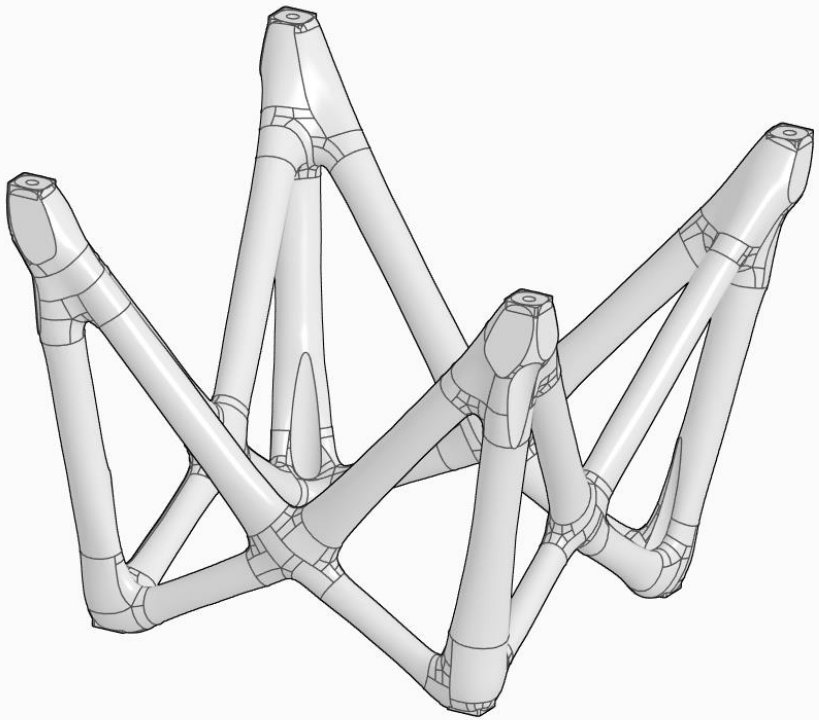
	0
0	65,65,65, 3.00

Obstacles to avoid

Relative File Path ...

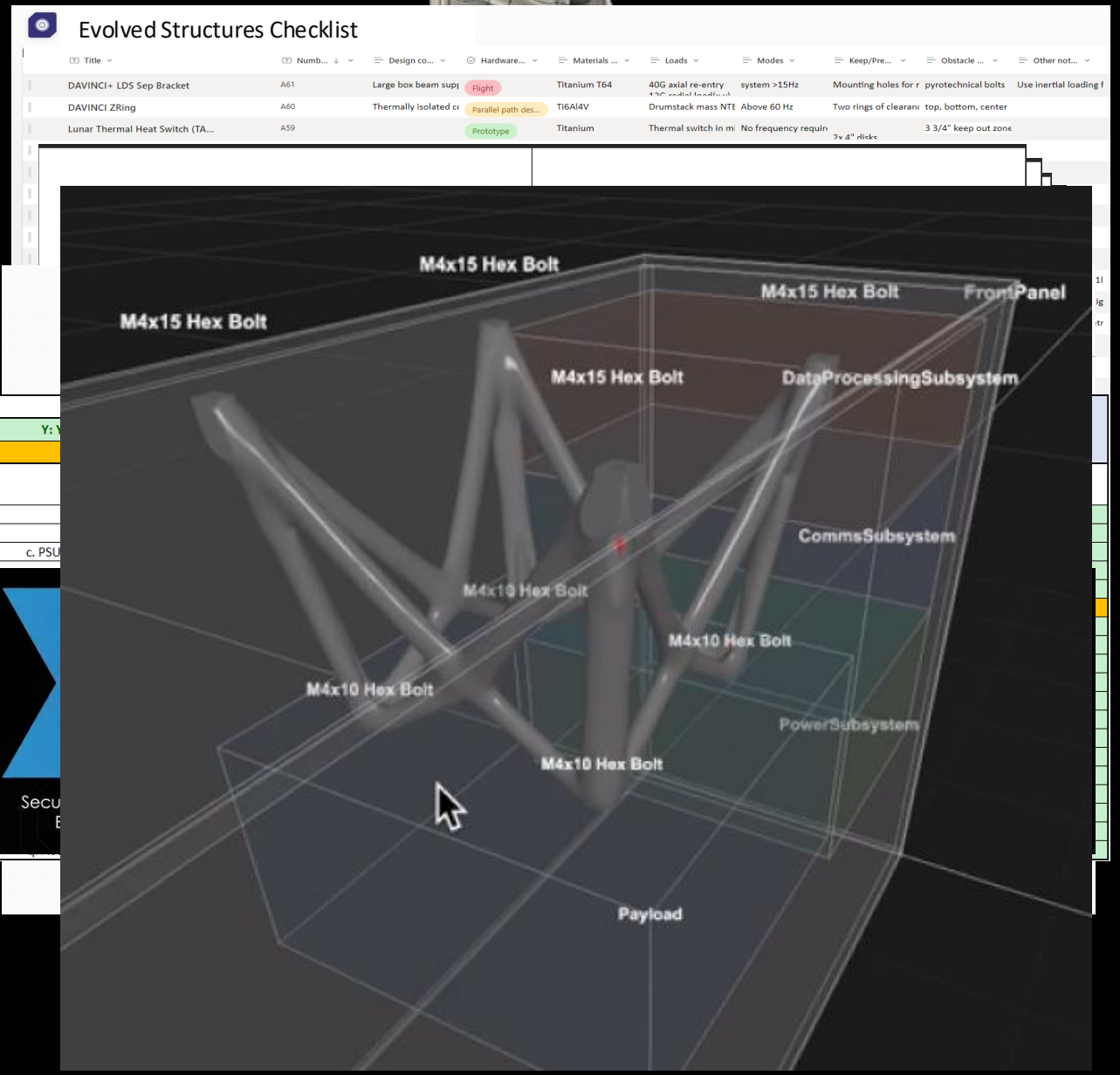
Text to Structure

- Project/Application Name
- Mounting Preserve Locations
- Loading Preserve Locations
- XYZ Accel and Mass
- Obstacle Geometry File Path
- FEA Model Out
- Finalized Model



The Playbook: AI for Hardware

- Example: Text-to-Structure
- Automate an engineering process
  - Select simulation/design engines
  - Standardize the Inputs and Outputs
  - Document the design process
  - Create automated workflow
  - Verify with Evals
  - Scale using cloud deployment
- Connect to Agents



Smallsat

ELEMENTS

ARTIFACTS

REFERENCES

Helpful Commands

Object Reference: @

Chat Newline: SHIFT + ENTER

Undo: CTRL + Z

Redo: CTRL + Y

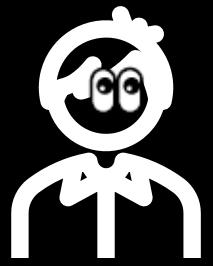
Log

AUTO-DEPTH

0 / 6000 chars

Credits Remaining: 998677

Text-to-Telescope



Telescope Supervisor Agent

Requirements Decomposition Tool

Optical Design Agent

Optomechanical Design Agent

Analysis Agent

Reporting Agent

Python-based reinforcement learning AI tool

Computational design tool for optical mounts

Mechanical Analysis Tool

Documentation generation tool

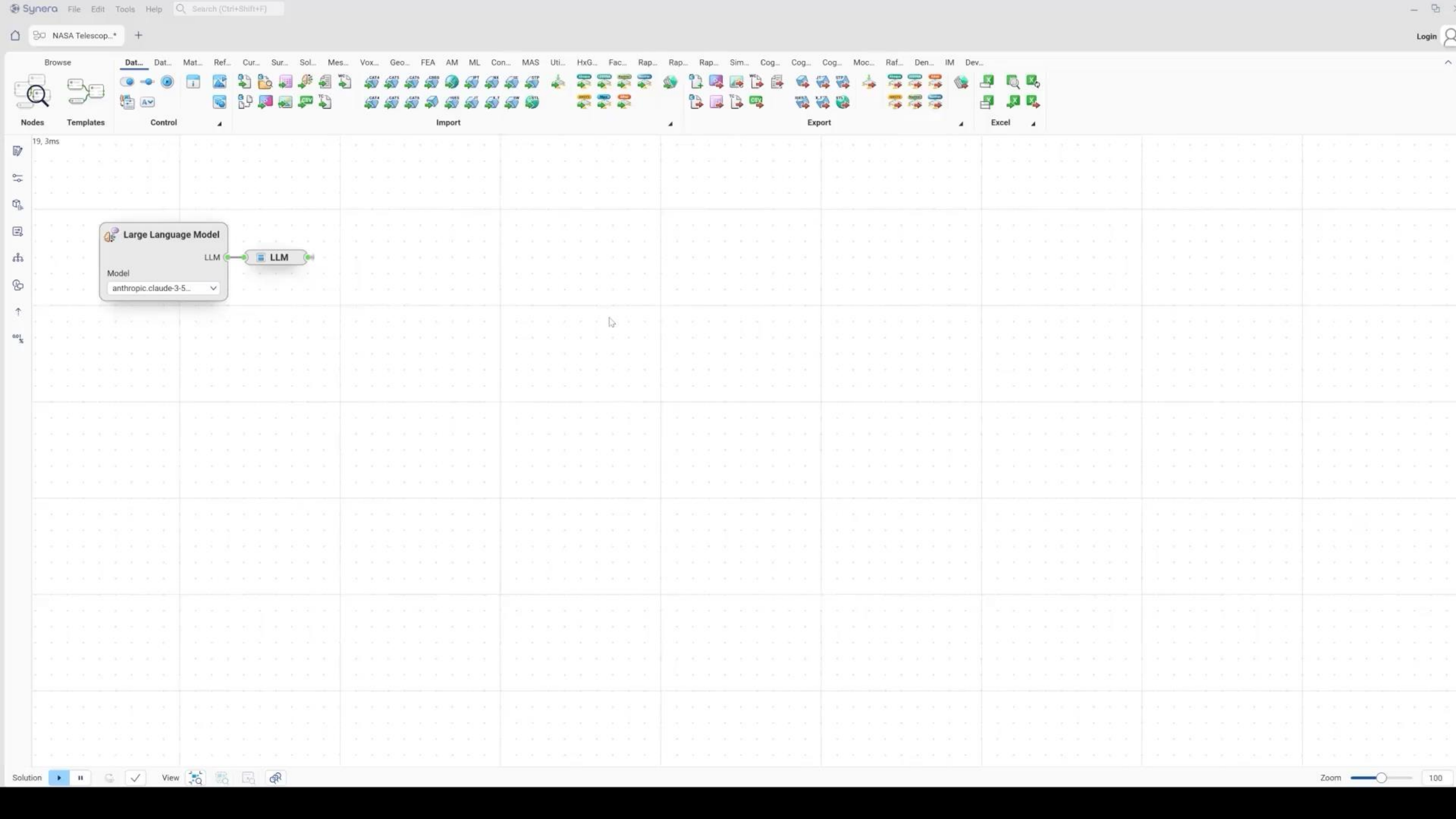
Ray Trace Engine

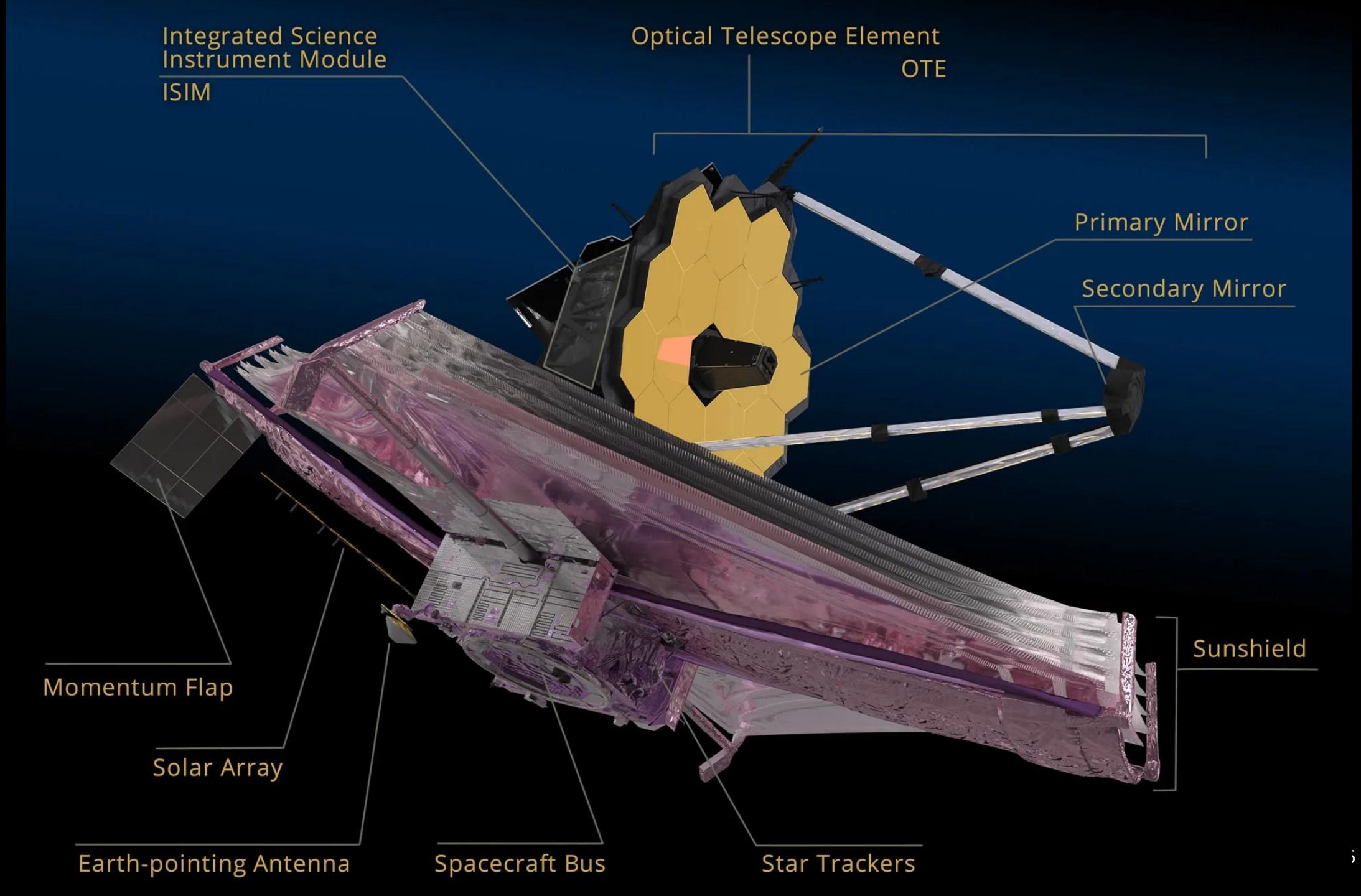
CAD Engine

Simulation Engine

Cheaper

Faster


Synera
File
Edit
Tools
Help
Search (Ctrl+Shift+F)
NASA Telescop...*
Login
Browse
Nodes
Templates
Control
Import
Export
Excel
19, 3ms
Large Language Model
LLM
Model
anthropic.claude-3-5...
LLM
Solution
View
Zoom
100

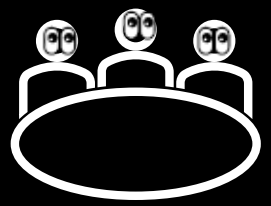

Integrated Science Instrument Module
ISIM
Optical Telescope Element
OTE
Primary Mirror
Secondary Mirror
Sunshield
Momentum Flap
Solar Array
Earth-pointing Antenna
Spacecraft Bus
Star Trackers

The Role of AI Agents

- Convert our goals into standard INPUTS
- Help apply KNOWLEDGE
- Apply common sense and INTUITION
- Orchestrate automation TOOLS
- Communicate with other AGENTS
- Help us interact with OUTPUTS
- Act as design COLLABORATORS

The Agentic Engineering Future

- An ecosystem of cloud-deployed, agent-accessible design tools
  - Linked by agentic orchestration layer
  - Agents access both INTERNAL and EXTERNAL tools and agents (API/MCP/A2A)



Text-to-Spaceship in Action

BOOP! Piggyback

T2S-1 Payload

Conclusion

- AI is radically changing the way missions are developed
- Accelerate development and unlock game-changing performance improvements
- Accelerate our understanding and exploration of the universe

”It is difficult to say what is impossible, for the dream of yesterday is the hope of today and the reality of tomorrow.”
- Robert H. Goddard

YouTube recording

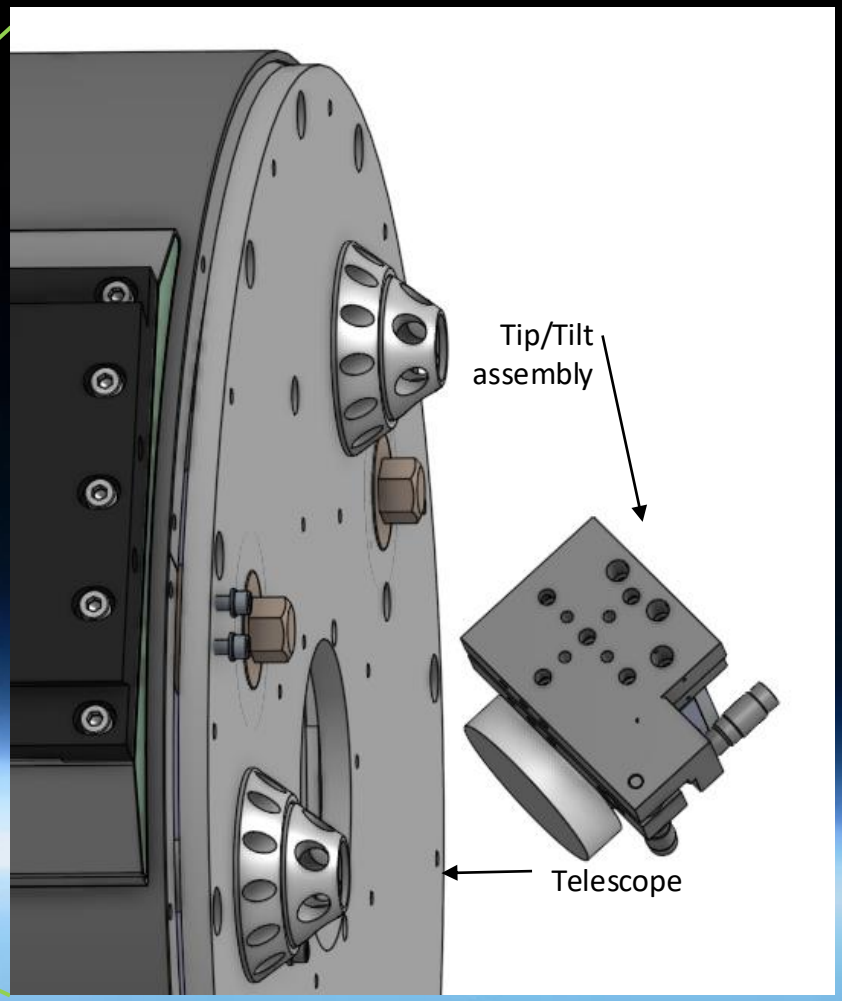
LinkedIn

Backup

NASA EXoplanet Climate Infrared Telescope (EXCITE, Peter Nagler)

40 km

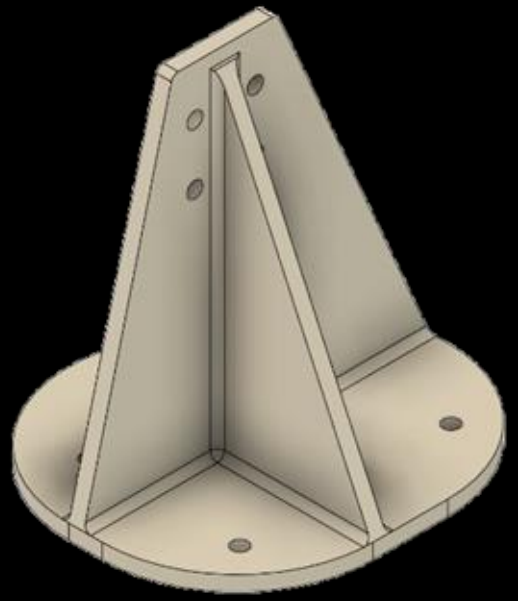
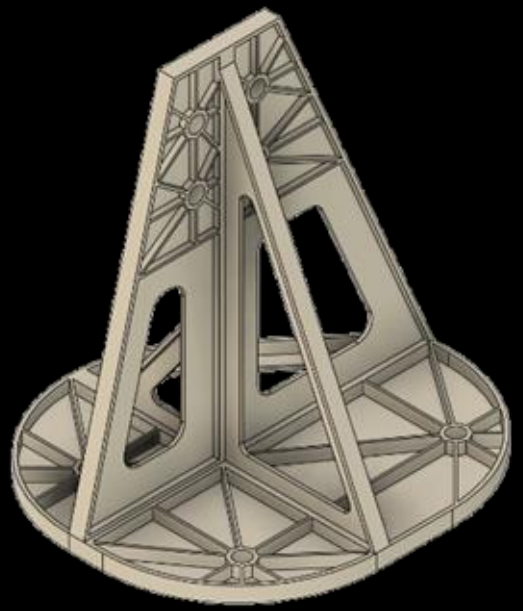
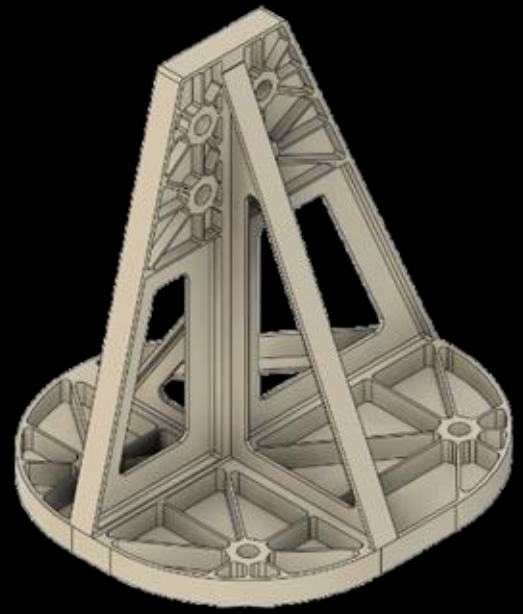
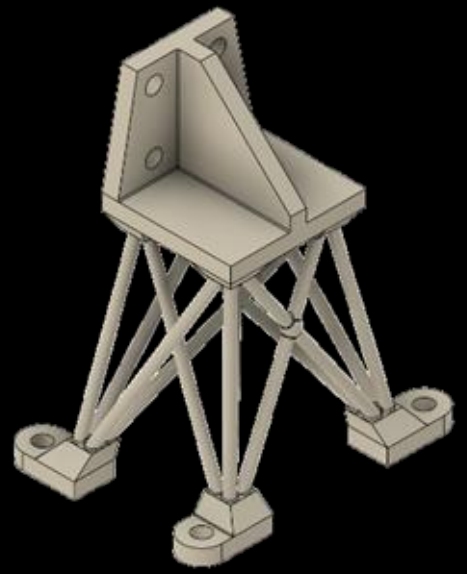
above Earth's surface



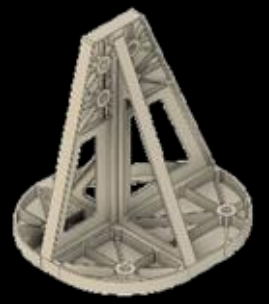
Illustration

Image Source: https://www.jpl.nasa.gov/news/nasa-mission-will-study-the-cosmos-with-a-stratospheric-balloon

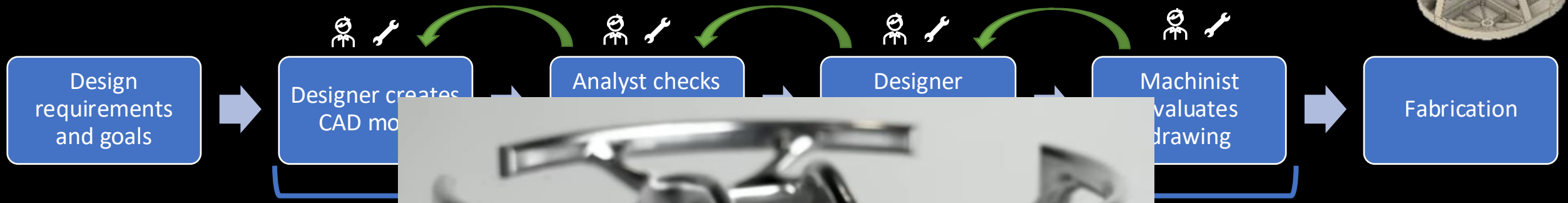
Application Example: Human Designer and Analyst

Iteration #1	Iteration #2	Iteration #3	Iteration #4
			
Stiffness ~~Mass~~ Manufacturing	~~Stiffness~~ Mass ~~Manufacturing~~	~~Stiffness~~ ~~Mass~~ ~~Manufacturing~~	Stiffness Mass ~~Manufacturing~~

Evolved Structures: Paradigm Shift



Traditional Process



Evolve

Demonstrated: Requirements to parts in-hand in <48 hours

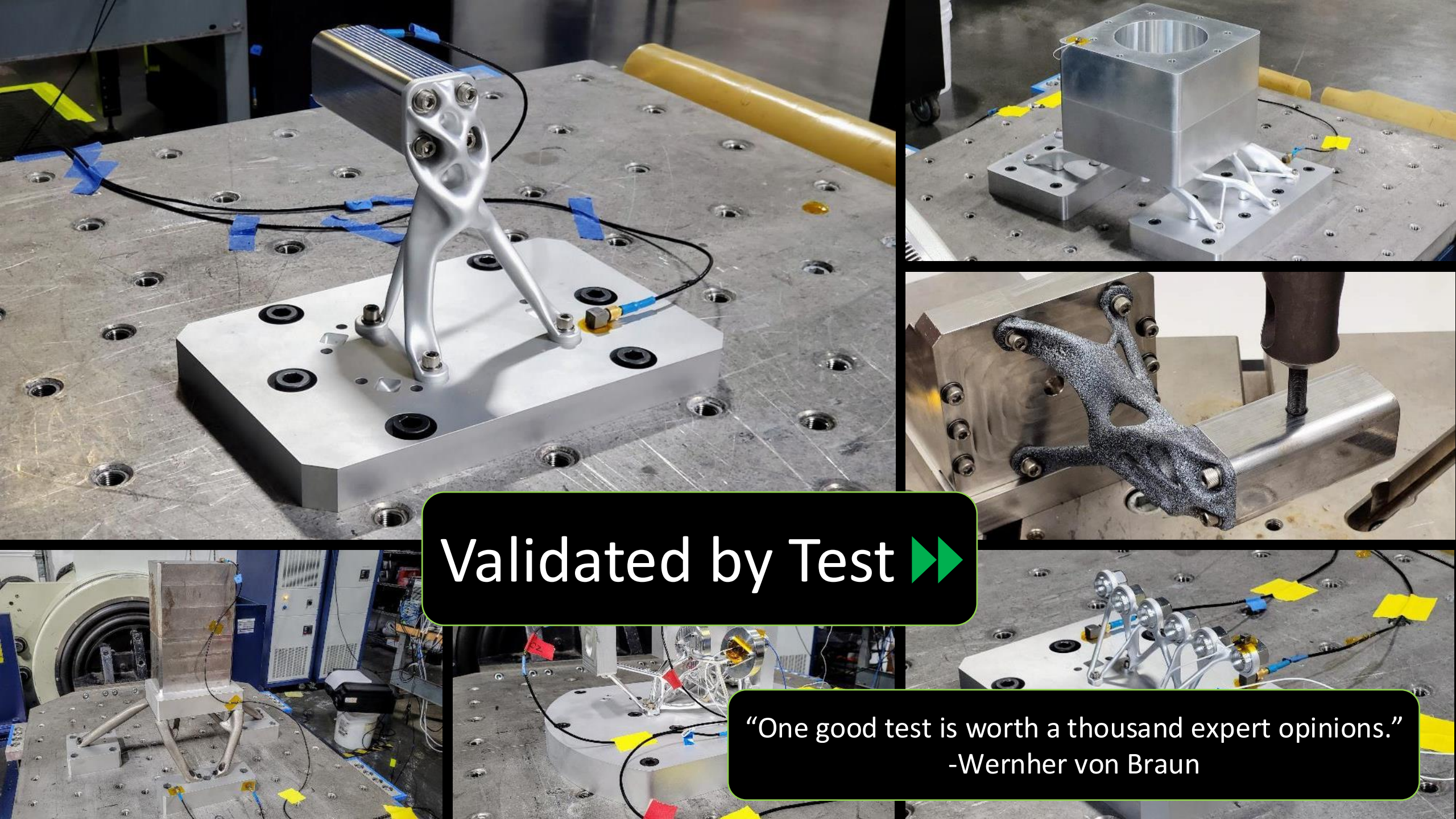
Digital Manufacturing

- Manufacturing processes makes parts directly from CAD files
  - CAD to Machine code (e.g., gcode)
  - Robot runs the code and makes the part
- Automated CNC
  - Computer Aided Manufacturing (CAM) creates gcode
  - CNC robot runs the gcode
  - Exception: Protolabs – automated machine shop
- Additive Manufacturing (AM, 3D printing)
  - Slicer software generates gcode from CAD
  - AM robot runs the machine code – e.g. L-PBF
- Digital Manufacturing ≠ Additive Manufacturing

Image source: https://www.protolabs.com/services/cnc-machining/

Image source: https://www.youtube.com/watch?v=Byj1ON4x4vY

Image source: https://www.ge.com/news/reports/these-engineers-3d-printed-a-mini-jet-engine-then


Validated by Test
“One good test is worth a thousand expert opinions.”
-Wernher von Braun

Generative Design: How the process works

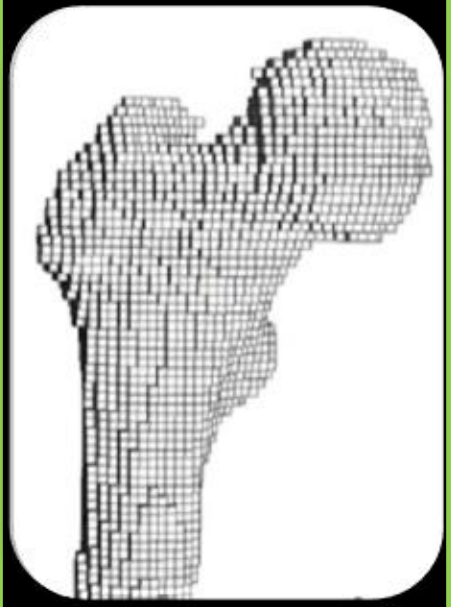
AI: Computer systems able to perform tasks that normally require human intelligence

AI Generates Designs; checks requirements and fabrication

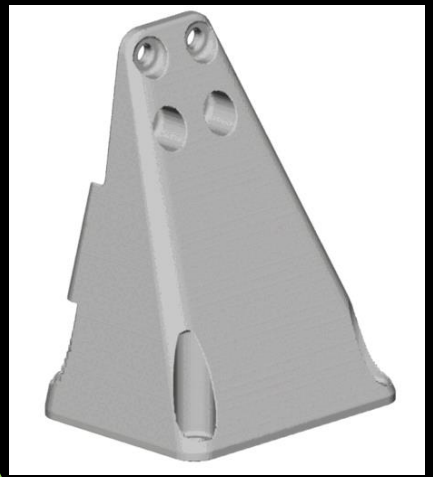
Hours-Days

User inputs

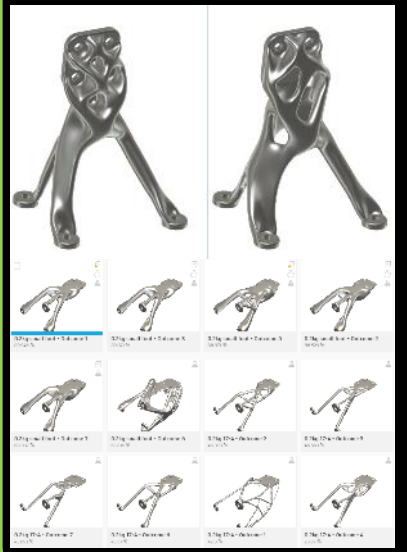
Create voxel mesh of design space



Run Topology Optimization

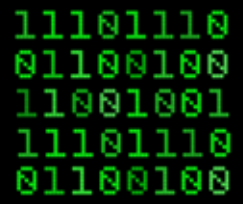


Output results for user review

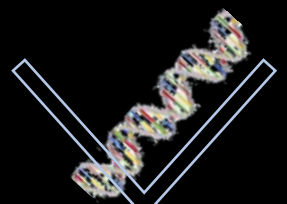


Reconstruct CAD model of selected outputs

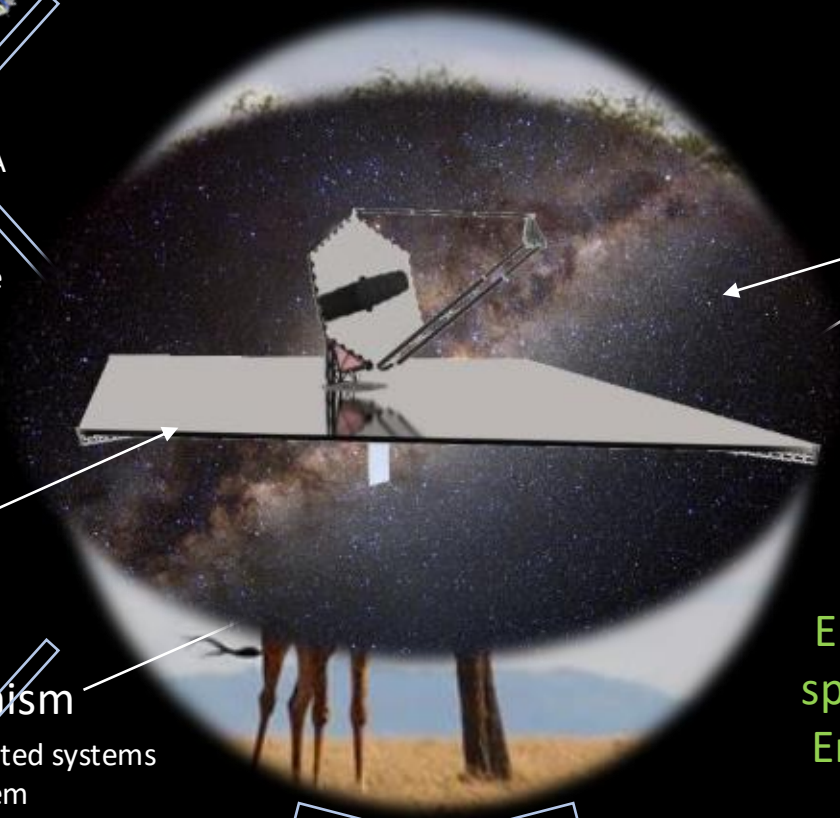
Evolving an optimal spaceship - Combining Digital Twins, MBSE, and Artificial Intelligence



Digital Twin design data evolves through iterations in response to simulated environments (analysis/IM/MBSE)



Organism's DNA evolves though generations in response to the environment



Environment

- Orbit
- Thermal environment
- Science data targets
- etc

Environment

- Geography
- Temperature
- Food sources
- etc

Spacecraft

- Discrete interconnected systems
  - Structures
  - Propulsion
  - C&DH
  - etc

Organism

Discrete interconnected systems

- Skeletal system
- Muscular system
- Nervous system
- etc

Goal: surviving offspring

Goal: science data return

Enable *more science per dollar* by automating spaceflight hardware development with Digital Engineering technologies, while infusing high-value intermediate technologies