NATIONAL RECONNAISSANCE OFFICE

Superheavy Launch

The Coming Paradigm Shift for the Space Industry

SUPRA ET ULTRA

Disclaimer

- This presentation is intended as a thought provoking exercise with unconventional opinions on potential future changes to the space industry as a result of new Superheavy launch capabilities

- This presentation does **NOT** represent NRO direction to industry partners or NRO's priorities regarding current or future acquisitions

Contents

- Launch History
- Super Heavy Launch vehicles, capabilities, and costs
  - Saturn V
  - STS
  - New Glenn
  - Starship System
- Influence on Space Vehicle Design
- Industry Impacts
- Significance to Space Cost Estimating Community

Launch History

1950s	1960s	1970s	1980s	1990s	2000s	2010s	2020s	2030+

Era of Contested Space

Sputnik 1
Explorer 1

10s kg
100s kg
1,000s kg
10,000s kg

Era of bigger SVs

- Larger Launch Vehicle Families
- Higher Launch Reliability
- High Performance Payloads

10/year
1000/year

Smallsat Launches

- Miniaturized Electronics
- Lightweight Low Power Tech
- Proliferated Concepts

Apollo Era 1961 – 1972

Saturn Family
Titan Family

Space Shuttle Era 1981 – 2011

Atlas Family
Delta Family
Titan Family
Space Shuttle

Minotaur

USSF NSSL 2013 - 2024

Atlas Family
Antares
Delta Family
Electron
Falcon Family

Superheavy Launch Era

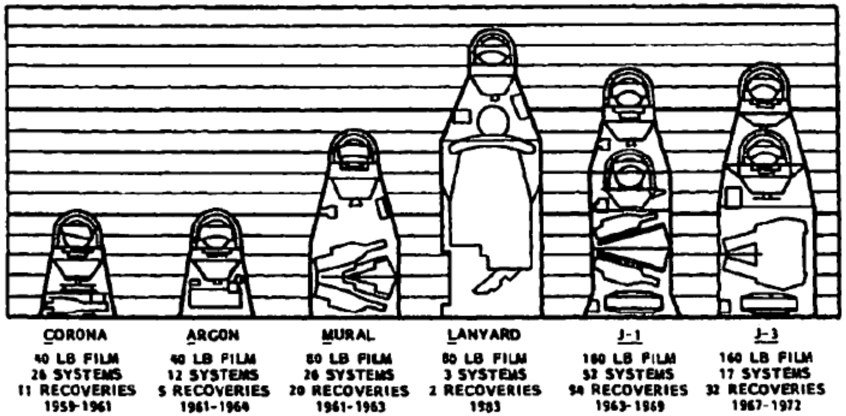
Falcon Family
New Glenn
SLS
Starship
Vulcan

BPO/CAAG

Launch History

- SV Mass increases with launch capability
  - Corona 40-160lbs 1960-1970
  - Hexagon 30,000lbs 1971-1986

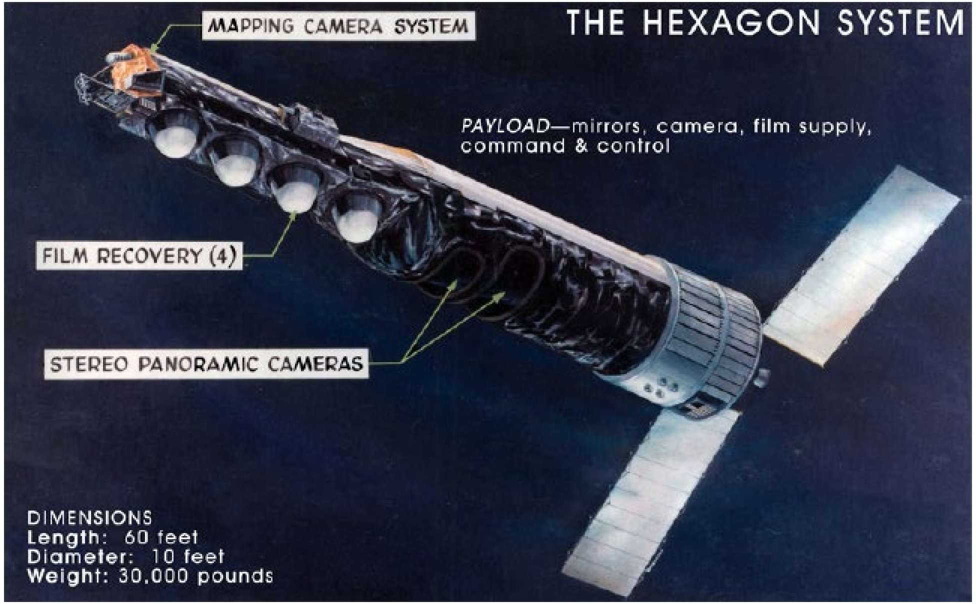
Corona IMINT Payload Growth 1960-1970



Film Weight: 40 lb → 160 lb

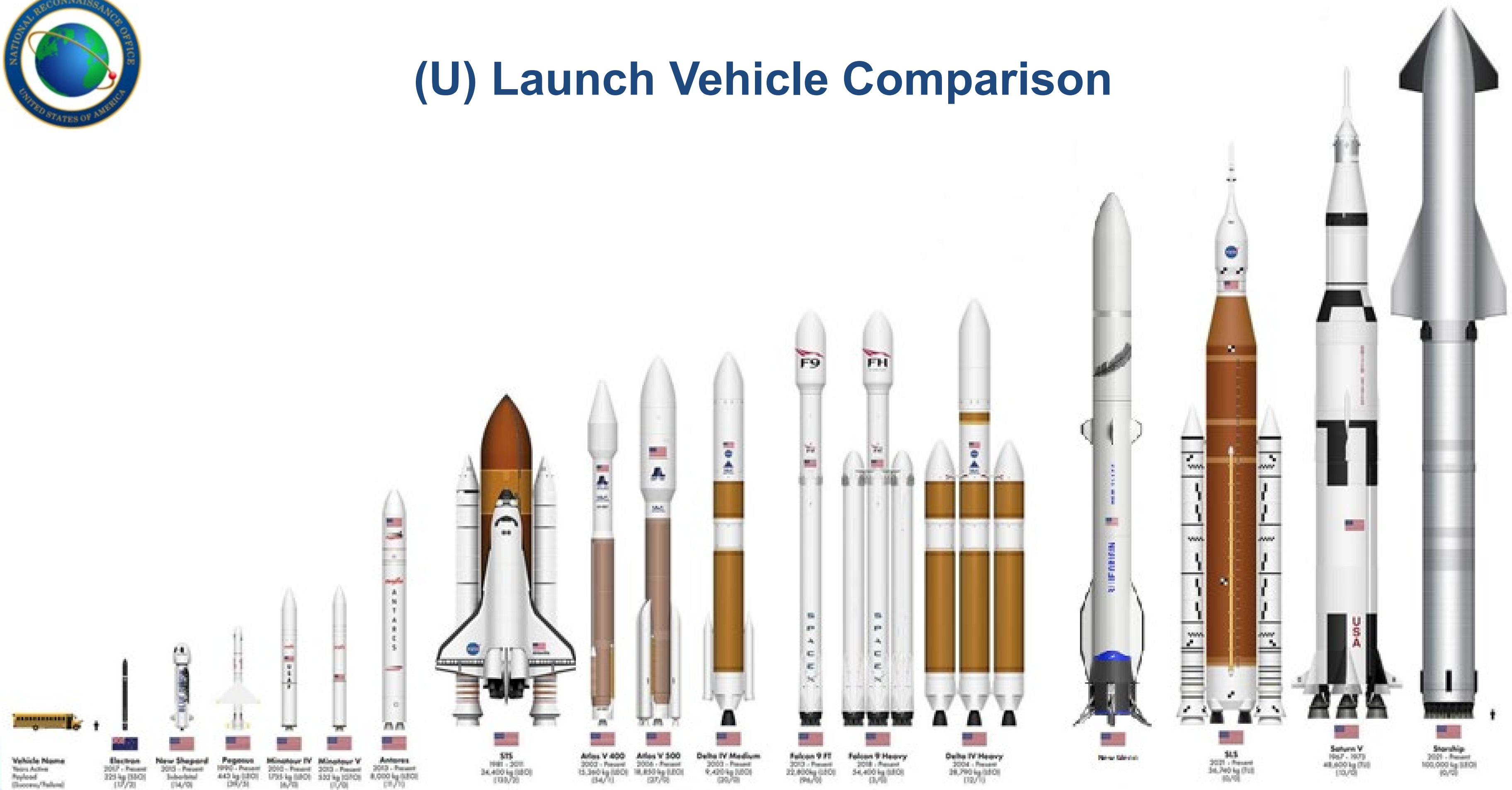
1959 | early 60's | Mid 60s | Late 60's | 1972

Source: The Corona Story, Dec. 1988, p.84, NRO Approved for Release 30 June 2010



BPO/CAAG

(U) Launch Vehicle Comparison



BPO/CAAG

Source: https://www.visualcapitalist.com/wp-content/uploads/2021/08/Comparing-the-Size-of-The-Worlds-Rockets-Full-Size.html

NASA Saturn V (1967-1973)

- Saturn V is the first Super Heavy Lift Launch Vehicle developed for the Apollo lunar mission
- Development started in 1964
- 13 Successful launches 0 failures
  - 2 uncrewed test launches
  - 3 crewed orbital launches
  - 7 crewed lunar landing launches
  - 1 uncrewed Skylab launch to LEO
- Saturn V program canceled along with Apollo missions due to budget constraints

Saturn V	
Size	
Height	363 ft (110.6 m)
Diameter	33 ft (10.1 m)
Payload Capacity	
LEO	310,000 lbs
TLI	107,100 lbs
Height	
Diameter	21.7 ft (6.6 m)
Volume	
Thrust	
1st Stage	7.89 M lbf
2nd Stage	1.16 M lbf
3rd Stage	.232 M lbf
Cost (FY20)	
Per launch	1.38B
Development	36.5B

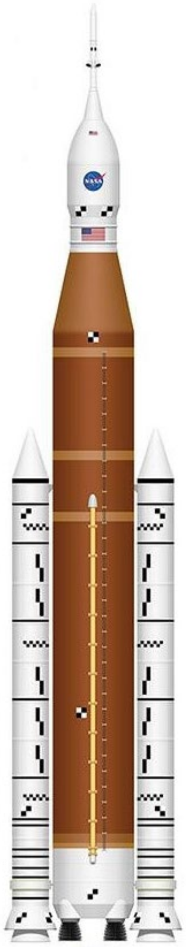
Source: Stages to Saturn a Technological History of the Apollo/Saturn Launch Vehicles
https://history.nasa.gov/SP-4206/contents.htm

NASA Space Launch System (SLS)

- NASA Super Heavy Lift Launch Vehicle being built by Boeing and Northrop Grumman
- Development started in 2011
- Leverages design reuse from Space Shuttle Space Transportation System (STS)
- 1st launch planned for 2022
- Block 2 upgrades with enhanced lift capabilities planned for late 2020s

SLS Block 1	
Size	
Height	365 ft (111.25 m)
Diameter	28ft (8.4 m)
Payload Capacity	
LEO	209,000 lbs
TLI	60,000 lbs
Height	45 ft (13.7 m)
Diameter	16 ft (5 m)
Volume	8,118 ft^3 (229m^3)
Thrust	
Max	8.8M lbf
Cost (FY20)	
Per launch	1.05B
Development	25.6B

*This data is predicted and has not been validated with flight data



Source: Space Launch System Fact Sheet
https://www.nasa.gov/sites/default/files/atoms/files/sls_lift_capabilities_configurations_04292020_woleo.pdf

Blue Origin – New Glenn

- Commercially funded 2 stage launch vehicle with reusable 1st stage
- 7 BE-4 engines that are common to ULA Vulcan Centaur
- Design started 2012 and first launch planned for 4Q2022

New Glenn	
Size	
Height	322 ft (98 m)
Diameter	23ft (7 m)
Payload Capacity	
LEO	99,000 lbs
GTO	30,000 lbs
Height	58.5ft (17.8m)
Diameter	20ft (6.2m)
Volume	16,184 ft^3 ($458m^3$)
Thrust	
1st Stage	3.85M lbf
2nd Stage	0.32M lbf

*This data is predicted and has not been validated with flight data

Source: New Glenn Payload Users Guide Revision C

SpaceX– Starship System

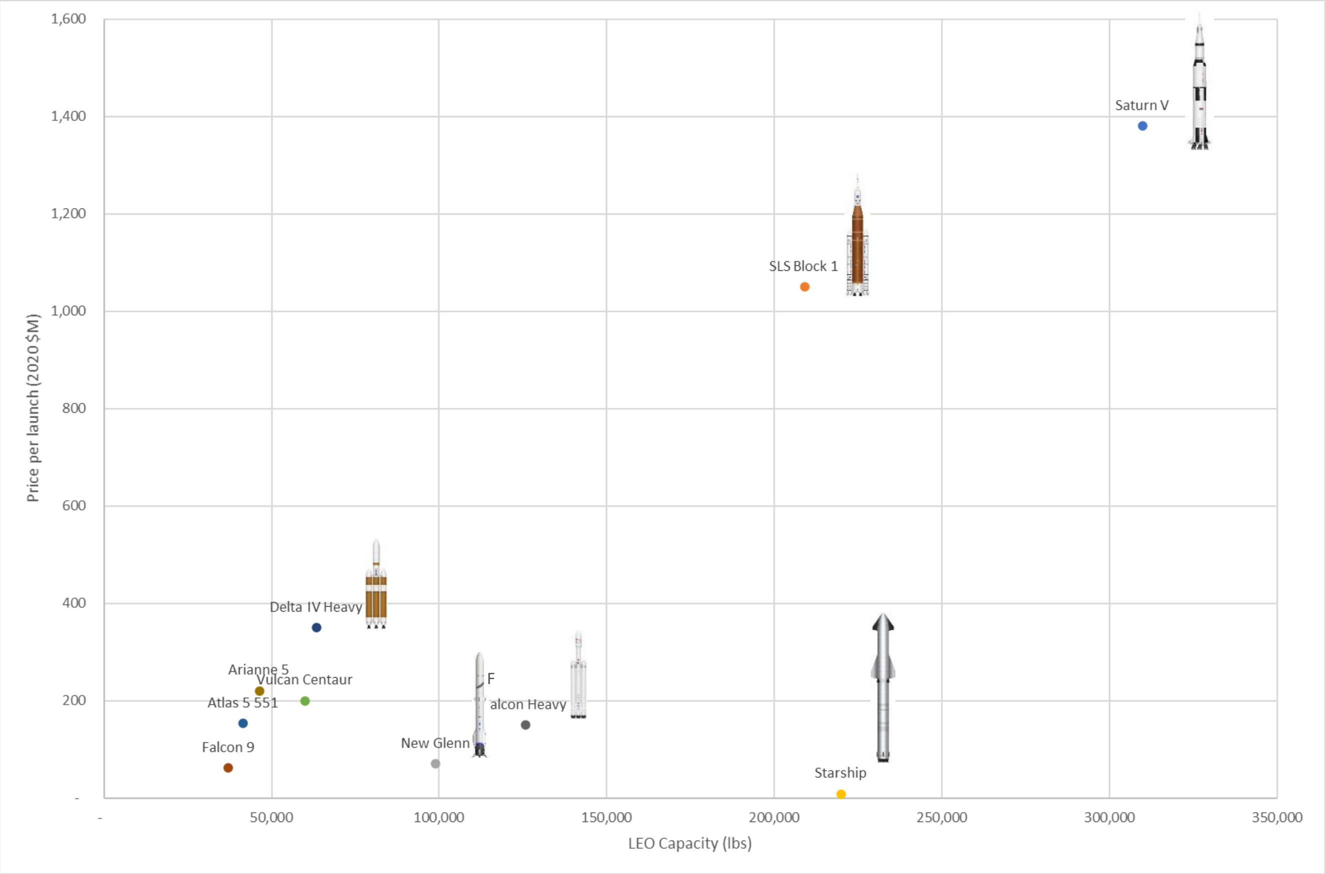
- Commercially funded fully reusable 2 stage super heavy launch vehicle
- Stainless steel construction with flaps to enable controlled descent
- Refuellable on orbit to reach higher orbits or other places in the solar system with large mass capacity
- SpaceX goal for Starship is to colonize Mars
- Development started in 2018 and first test launch expected in 1Q2022

Starship System	
Size	
Height	390 ft (120 m)
Diameter	30ft (9 m)
Payload Capacity	
LEO	>220,000 lbs
GTO	48,501 lbs
Dual Launch	>220,000 lbs
Height	72 ft (22 m)
Diameter	26ft (8 m)
Volume	39,000 ft^3 (1,100m^3)
Thrust	
1st Stage	16M lbf
2nd Stage	.45M lbf

*This data is predicted and has not been validated with flight data

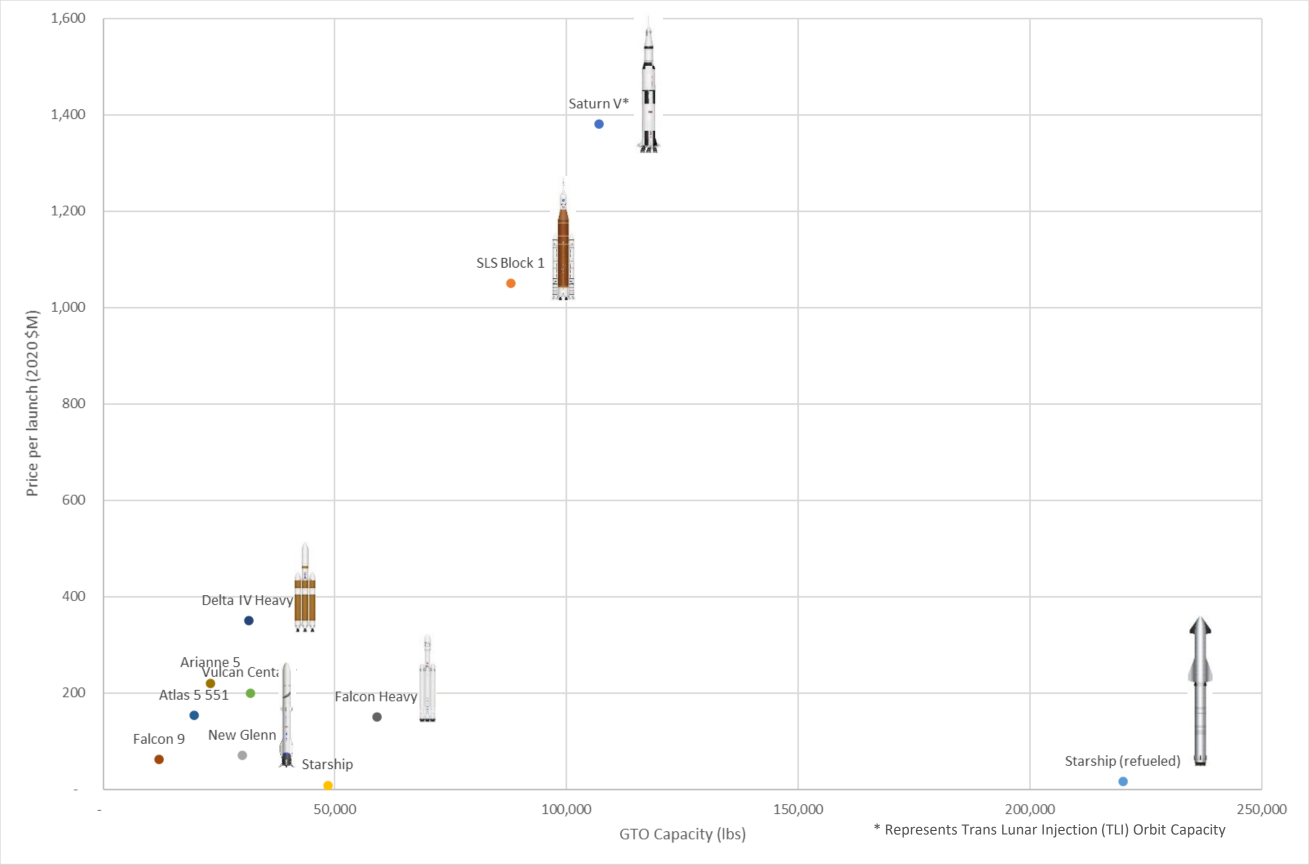
Source: SpaceX Starship User Guide v1

Launch Cost Comparison to LEO



BPO/CAAG

Launch Cost Comparison to GTO



BPO/CAAG

How Could SpaceX Achieve $2M Launch Cost Goal?

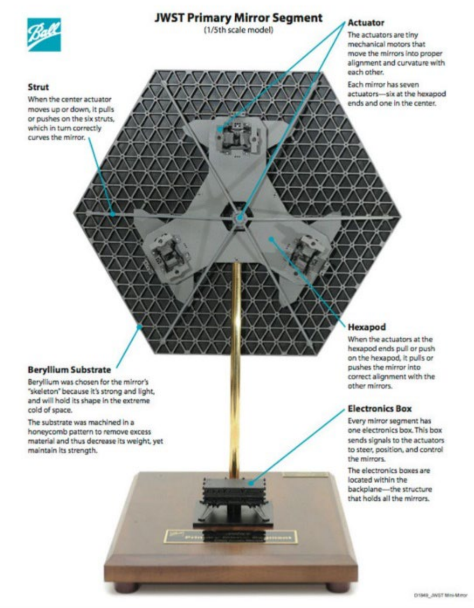
- First fully reusable launch vehicle (1st stage and upper stage)
- Manufactured on continuous 24x7 production lines with more automated production than previous space launch vehicles
- High rate production of Raptor engines (39 per vehicle)
- Stainless steel construction vice expensive carbon fiber and aluminum
- Methalox (liquid methane and oxygen) less expensive propellent than RP-1

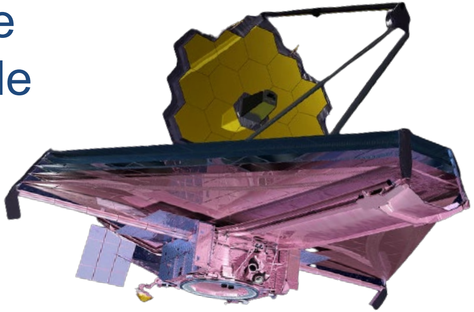
Potential Superheavy Lift Influence on Satellite Design

- Larger apertures (optical and antenna) $\theta = 1.22\ \lambda/D$
- Less expensive materials (Stainless steel vs exotic composites)
- Decreased complexity for deployments
- More onboard fuel (longer design life / replenishment cycles)
- Mass budget for radiation shielding / hardening (enable state of the art electronics)
- Adjunct payloads or companion satellites
- Resiliency improvements

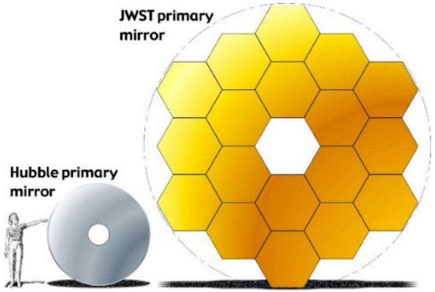
James Webb Space Telescope (JWST)

- $10B JWST cost partially due to design to accommodate weight and volume constraints imposed by launch vehicle





- 6.5m Hexagonal Segmented Mirror
  - Beryllium substrate
  - Honeycomb pattern
  - Aligning the primary mirror segments as though they are a single large mirror means each mirror is aligned to 1/10,000th the thickness of a human hair
- 5 Layer Sunshield
  - Kapton material (.05-.025mm) thick
  - 22m x 12m (69.5ft x 46.5ft)



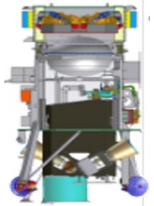
Source: James Webb Space Telescope
https://www.jwst.nasa.gov/

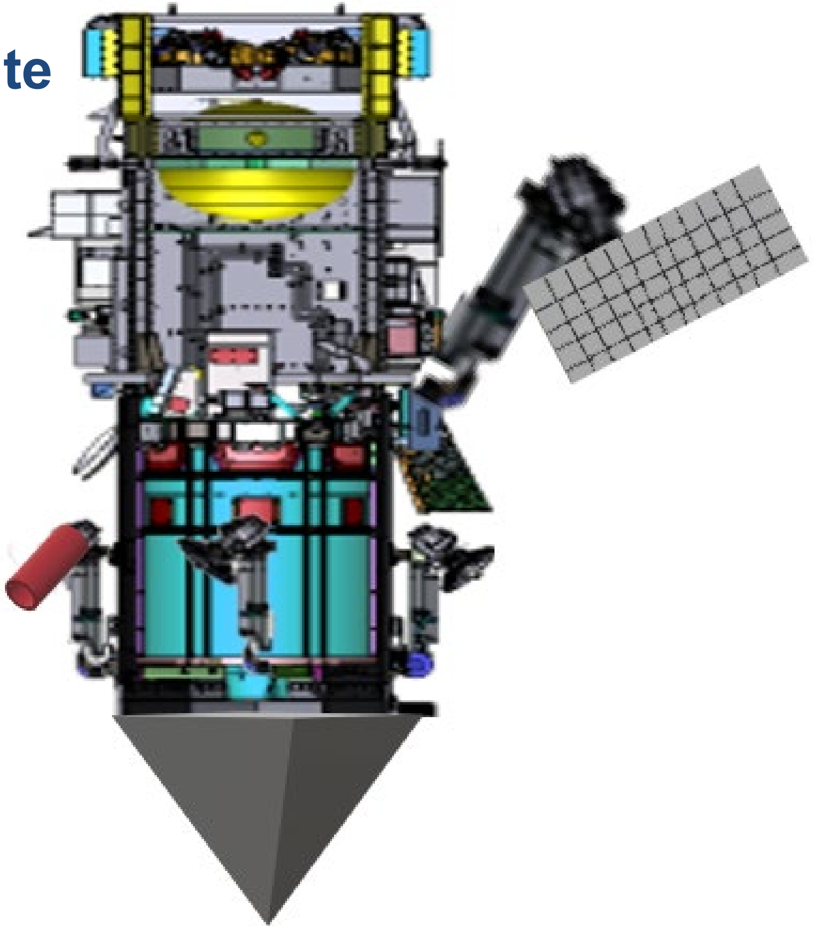
Satellite Resiliency Enabled by Superheavy Launch

- Large thrusters and fuel – evasive maneuvers and targeting challenge
- Robust materials like steel and titanium to fend off kinetic attacks
- Radar absorbing materials
- Shielding of electronics against electromagnetic pulse or directed energy attacks
- Redundant communication paths (e.g. optical and RF; DDL and crosslink)
- Situational awareness sensor payloads
- Companion satellites for defense purposes

Typical vs SuperHeavy Satellite

2.5m





7.5m

Industry Impacts – Facilities and Logistics

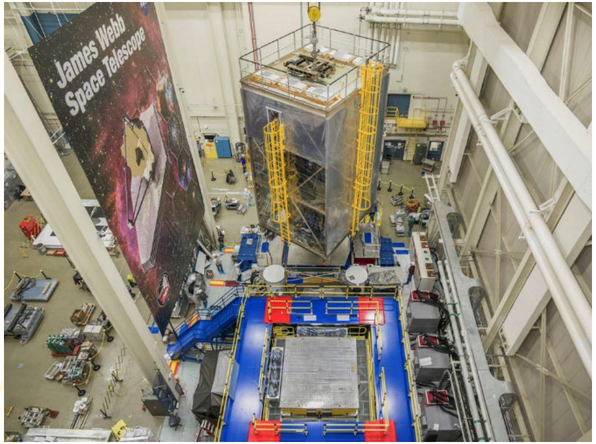
- New facilities will be required to accommodate supersized satellites
  - Larger high bays
  - Bigger doors
  - Reinforced concrete floors
- Superheavy sized SVs require water transport
- SV factories may have to relocate to the coast and build docks for SV to reach launch sites
- SV factories will require new tooling for larger SVs
  - Giant welders for tanks
  - Large castings for stainless steel parts

US Launch Facilities

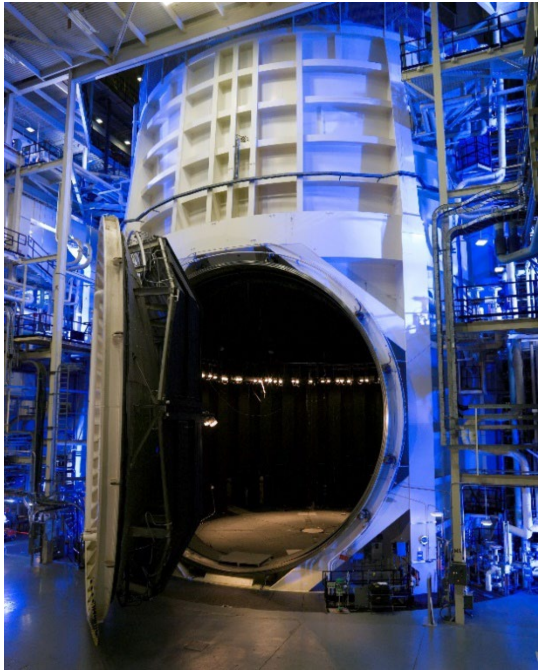

Pegasus Barge Carrying SLS Booster Core

Industry Impacts – Support Equipment

- New larger support equipment
  - Cranes
  - Vibe table
  - Thermal-vac chamber
  - Acoustic shock chambers



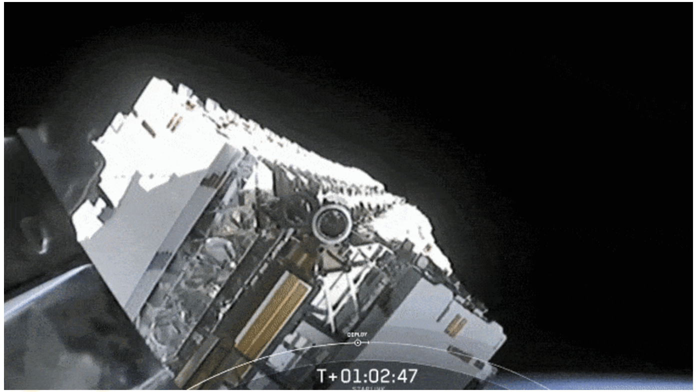
JWST Vibration Testing



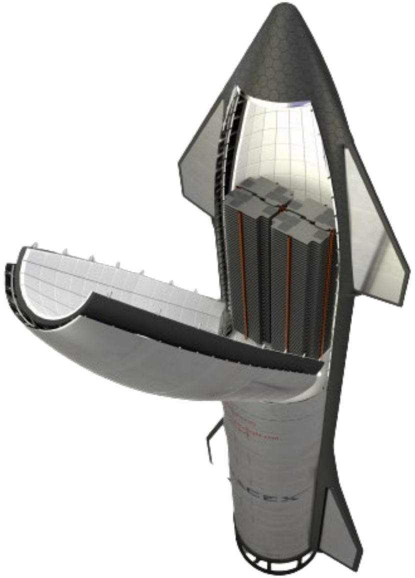
Johnson Space Center ThermoVAC Chamber

Proliferated Constellations

- Proliferated smallsat constellations can be launched on a single launch vehicle
- Starship upper stage can orbit adjust to deliver satellites to different orbital planes



60 Starlink Satellites Being Deployed by Falcon 9



SpaceX President Gwynne Shotwell claims Starship may launch 400 Starlink Satellites in one launch

Significance to the Space Cost Estimating Community

- The space cost estimating community relies heavily on parametric cost estimating relationships (CERs)
- Weight is a crucial cost driver in the majority of space hardware recurring CERs due partially to mass constraints
- Superheavy Satellites may have hardware with a fundamentally different relationship between cost and weight than historical data due to
    - Different materials
    - No effort spent light-weighting
    - Increased redundancy
    - Reduced complexity for deployments

Significance to the Space Cost Estimating Community

- 81 of 86 NRO CAAG Box Level Recurring CERs include weight as a cost driver
- 27 of 29 NRO CAAG Box Level Non-Recurring CERs include weight or AUC based on a REC CER that uses weight as a cost driver

Closing

- Superheavy launch vehicles will be available by the end of this decade
- Government and industry may want to open the trade space to consider space vehicle designs with less stringent mass and volume constraints and take advantage of this opportunity to enhance mission and resiliency
- Industry may want to plan for and invest in facilities, tooling, and support equipment to accommodate superheavy sized space vehicles
- Space cost estimating community may need to develop alternate methods to mass based CERs

Questions?

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New Glenn Payload Users Guide Revision C

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