Potential large missions enabled by NASA's Space Launch System

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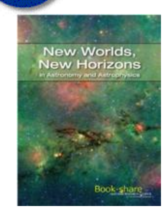
Executive Summary

The payload capacities of NASA's planned Space Launch System (SLS) is a disruptive capability than enables entirely new mission architectures.

- We will review these capacities.
- We will present a flow down from SLS capacities to first order telescope design parameters.
- We will present three specific point designs for potential missions which use the SLS's capacities:
  - ATLAST-8
  - ATLAST-12
  - HabEx-4

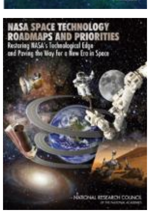
Introduction

Astrophysicists want Larger Observatories



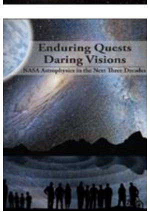
2010 New Worlds, New Horizons Decadal Report:

New Worlds Technology Development (NWTD) Program to "lay the technical and scientific foundations for a future space imaging and spectroscopy mission".



2012 NASA Space Technology Roadmaps & Priorities:

New Astronomical Telescopes that enable discovery of habitable planets, facilitate advances in solar physics, and enable the study of faint structures around bright objects …



2014 Enduring Quests Daring Visions:

8 to 16-m LUVOIR with sensitivity and angular resolution to "dramatically enhance detection of Earth-sized planets to statistically significant numbers, and allow in-depth spectroscopic characterization"; and, "decode the galaxy assembly histories through detailed archeology of their present structure."

Astrophysicists want Larger Observatories

The AURA "Cosmic Birth to Living Earth" Report calls for:

A 12 meter class space telescope with sufficient stability and the appropriate instrumentation can find and characterize dozens of Earth-like planets and make transformational advances in astrophysics.

In response, NASA's "Planning for the 2020 Decadal Survey":

- Habitable Exoplanet Imaging (HabEx)
- LUVOIR Surveyor

as well as Far-IR and an X-Ray Surveyor missions.

Space Launch System Capabilities

"AMATEURS THINK ABOUT TACTICS, PROFESSIONALS THINK ABOUT LOGISTICS"

GENERAL ROBERT H. BARROW, USMC
(COMMANDANT OF THE MARINE CORPS)

Logistics for Space Telescopes are:

- Launch Vehicle Payload Mass Capacity
- Launch Vehicle Payload Volume Capacity
- Budget Amount and Phasing

Launch Vehicle Constraint

All Missions are constrained by their Launch Vehicle.

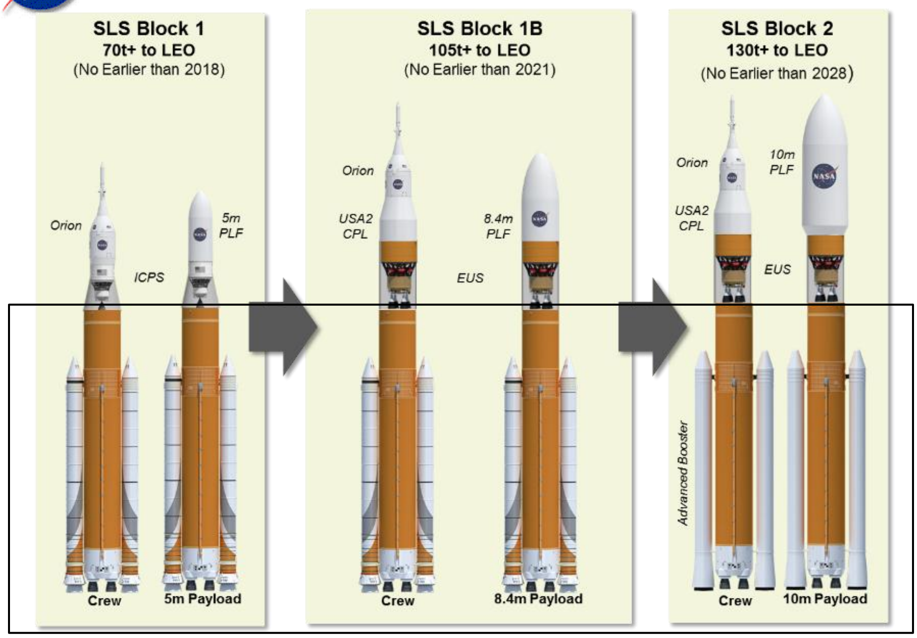
- HST and Chandra were designed for Shuttle

	Payload Mass	Payload Volume
Space Shuttle Capacities	25,061 kg (max at 185 km) 16,000 kg (max at 590 km)	4.6 m x 18.3 m
Hubble Space Telescope	11,110 kg (at 590 km)	4.3 m x 13.2 m
Chandra X-Ray Telescope (and Inertial Upper Stage)	22,800 kg (at 185 km)	4.3 m x 17.4 m

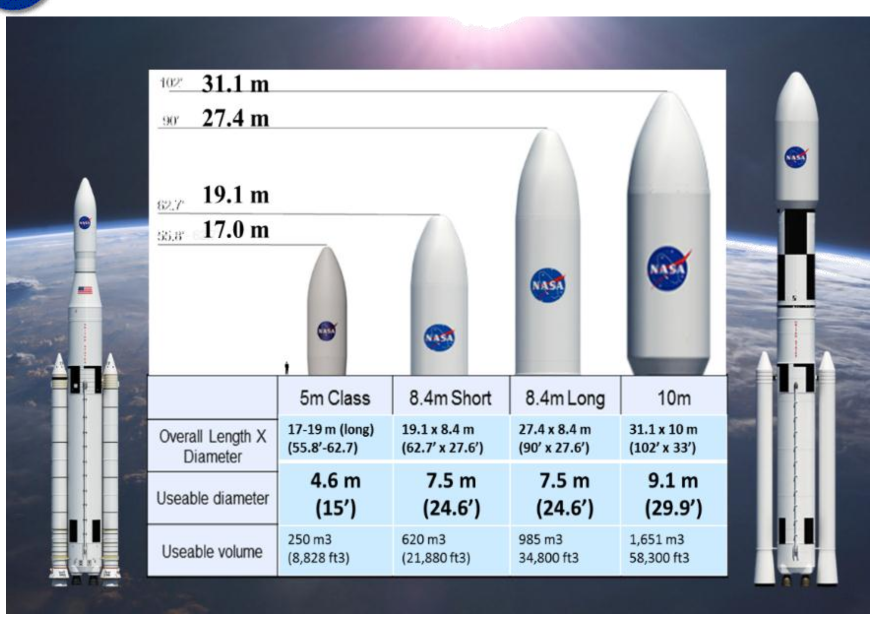
- JWST was designed for Ariane 5

	Payload Mass	Payload Volume
Ariane 5 Capacities	6600 kg (at SE L2)	4.5 m x 15.5 m
James Webb Space Telescope	6530 kg (at SE L2)	4.47 m x 10.66 m

SLS Block Development Schedule

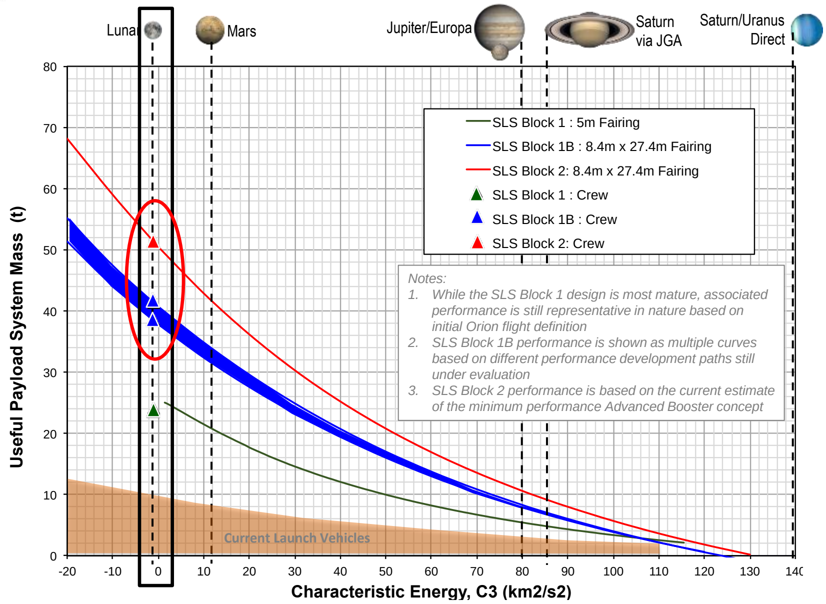


SLS Fairing Capacity



	5m Class	8.4m Short	8.4m Long	10m
Overall Length X Diameter	17-19 m (long) (55.8'-62.7)	19.1 x 8.4 m (62.7' x 27.6')	27.4 x 8.4 m (90' x 27.6')	31.1 x 10 m (102' x 33')
Useable diameter	4.6 m (15')	7.5 m (24.6')	7.5 m (24.6')	9.1 m (29.9')
Useable volume	250 m3 (8,828 ft3)	620 m3 (21,880 ft3)	985 m3 34,800 ft3	1,651 m3 58,300 ft3

SLS Mass Capacity to Destination (C3)



Design for Affordability

Mass Drives Cost

•Some (or many) believe that Mass Drives Cost.

•But they are mistaken.

•They respond by saying that cost models are all based on cost.

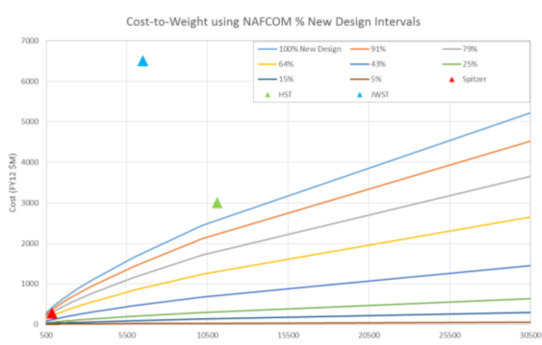
•But they are mistaken.

NAFCOM-12

Based on 30 unmanned, earth orbiting missions:

- Spacecraft Cost ~ Mass to the 0.7 power
- Spacecraft Cost ~ Design Maturity to the 1.5 power

Example: JWST is ~½ the mass of HST (~6500 kg vs 11,110 kg); but, over 2x the cost of HST (~$6.5B Phase A-D vs $3B).



$$Cost[FY12\ \$M] = 3.206 * mass[kg]^{0.719} * percent\ new\ design^{1.516}$$

Mass Margin Reduces Risk & Cost

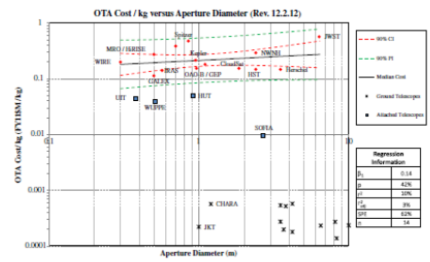
According to the US Air Force:

- Biggest drivers for reducing cost are reuse of heritage components and having a high mass margin.

Fox, Bernard, Kevin Brancato, Brien Alkire, "Guidelines and Metrics for Assessing Space System Cost Estimates", RAND Corporation, 2008.

- Additional evidence of cost saving with high mass margin is:

  - Free-flying telescopes have lowest design margins and highest cost per unit mass.
  - Shuttle attached and SOFIA have different margin rules and lower costs.
  - Ground telescopes have the most robust design margins and lowest cost.



Stahl, H. Philip, "Survey of cost models for space telescopes", Optical Engineering, 49(5) 053004 (May 2010).

Complexity Drives Cost

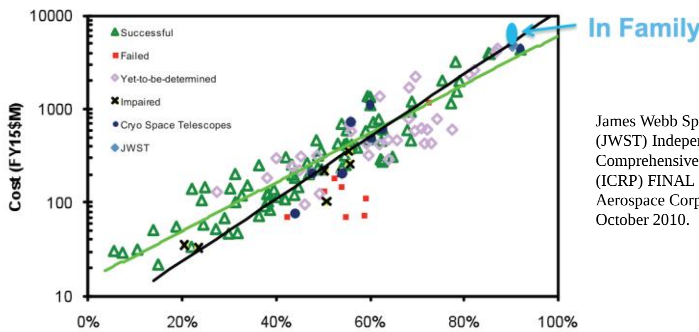
•Complexity is required to package a large mission into a small launch vehicle with its mass and volume constraints.

•The mass and volume capacities offered by the SLS enable simpler designs with higher design allowable mass margins.

•Higher mass margins allows use of standard engineering design practices and reduces ground handling risk.

JWST

The JWST Independent Comprehensive Review Panel found that JWST is "one of the most complex science missions carried out to date and therefore falls at the high end of the range, greater than 90%, on the complexity index."

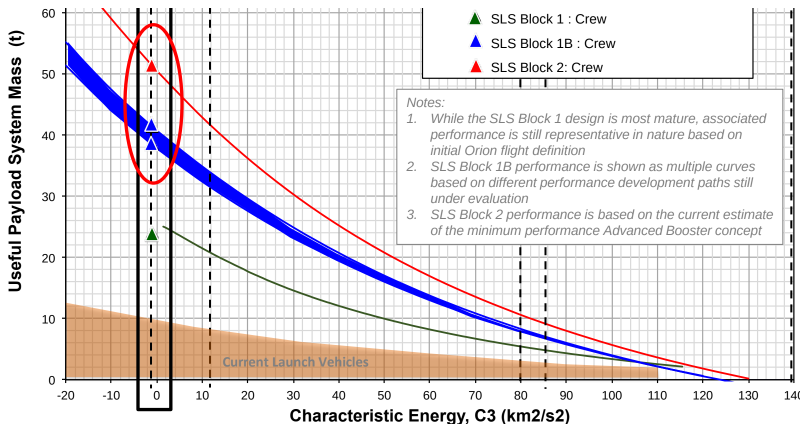


James Webb Space Telescope (JWST) Independent Comprehensive Review Panel (ICRP) FINAL REPORT, The Aerospace Corporation, 29 October 2010.

SLS Enabled Mass Design Rules

SLS Mass Capacity to Destination (C3)

Available Maximum Payload Mass after Margin for Select SLS Vehicles				
SLS	Block-1B min	Block-1B max	Block-2 (10m)	Block-2 (8.4m)
Projected Mass to SE-L2	35,000 kg	40,000 kg	45,000 kg	50,000 kg
Max Payload with 30% Margin	26,900 kg	30,800 kg	34,600 kg	38,500 kg
Max Payload with 43% Margin	24,500 kg	28,000 kg	31,500 kg	35,000 kg



Mass Flow Down

Mission architecture is driven by mass and volume.

While below is arbitrary, sub-system allocations are reasonable.

SLS	Block-1B	Block-2 min	Block-2 max
Max Payload Mass with 43% Margin	24,500 kg	31,500 kg	38,500 kg
Spacecraft Allocation (20% of Payload)	5,000 kg	6,250 kg	7,500 kg
Observatory Allocation (80% of Payload)	20,000 kg	25,000 kg	30,000 kg
Science Instruments (10% of Observatory)	2,000 kg	2,500 kg	3,000 kg
Telescope (PMA, SMA, and Structure) (90%)	18,000 kg	22,500 kg	27,000 kg
SMA and Structure	8,000 kg	10,000 kg	12,000 kg
Primary Mirror Assembly Allocation	10,000 kg	12,500 kg	15,000 kg
Primary Mirror Assembly Areal Mass	[kg/m^2]	[kg/m^2]	[kg/m^2]
4 meter diameter (12.5 m^2)	800	1000	1200
8 meter diameter (50 m^2)	200	250	300
12 meter diameter (100 m^2)	100	125	150
16 meter diameter (200 m^2)	50	62.5	75

Areal Mass for PMA is consistent with state of art.

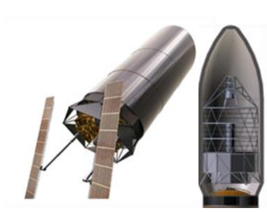
- 2.4 m HST is 1860 kg for a 460 kg/m^2 areal mass
- 6.5 m JWST is ~1750 kg for a ~70 kg/m^2 areal mass
- 30 m TMT projected areal mass is 150 kg/m^2

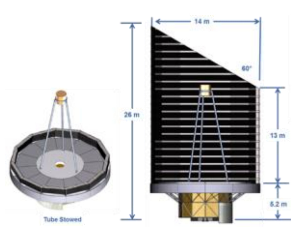
Point Designs

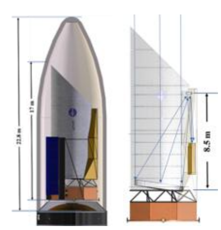
Point Designs

The MSFC Advanced Concept Office has produced mission concepts for three specific SLS based point designs:

ATLAST-8	8m on-axis monolithic aperture telescope for potential LUVOIR Surveyor mission
ATLAST-12	12m on-axis segmented aperture telescope for potential LUVOIR Surveyor mission
HabEx-4	4 m off-axis telescope for potential Habitable Exoplanet mission



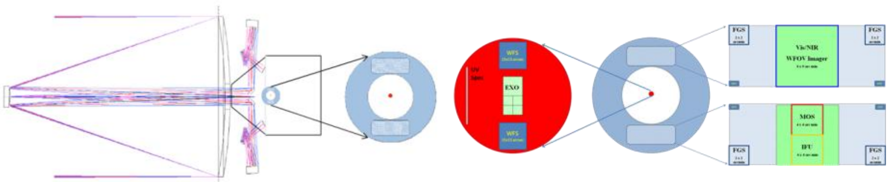




Common Design Features

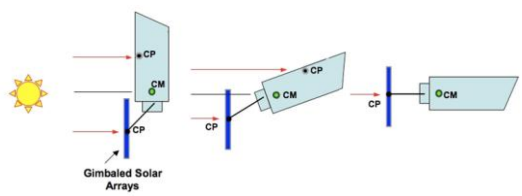
All three use a dual foci Cassegrain/TMD optical design.

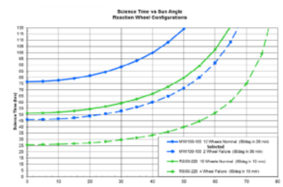
- Cassigren foci is Narrow Field, for Coronagraph & UV IFU
- TMA foci is Wide Field, for Imager & Multi-Object Spectrograph



Momentum Management for at least 3000 second Exposures

- ATLAST-8 & -12 balance Solar Pressure with articulated Solar Panels
- To avoid vibrations, HabEx uses oversized redundant reaction wheels





Payload Accommodation

SLS Fairing Volume enables architectures with minimal deployments.

- HabEx-4 is sized for SLS Block-1B 8.4-m x 27.4-m fairing
- ATLAST-8 & -12 are sized for SLS Block-2 10-m x 31.1-m fairing.

HabEx-4

ATLAST-8

ATLAST-12

Mass Budget

SLS Mass Capacity enables high mass margin Architectures:

- HabEx-4 is sized for SLS-1B and requires ~ 50% of available mass
- ATLAST-8 & -12 are sized for max mass of SLS-2 with 10-m fairing.

	HabEx-4 Mass [kg]	ATLAST-8 Mass [kg]	ATLAST-12 Mass [kg]
TOTAL PAYLOAD WET MASS	10,300	33,300	33,300
TOTAL PAYLOAD DRY MASS	9,300	28,800	28,800
Observatory	5,300	23,600	23,600
Telescope	4,600	21,800	21,800
Primary Mirror Assembly	1,600	12,750	12,750
Primary Mirror	1,000	8,500	8,500
Primary Mirror Support Sturcture	500	4,000	4,000
Mechanisms	100	250	250
Secondary Mirror Assembly	100	550	550
Optical Bench Structure	500	5,000	5,000
Auxillary Optic Assembly	200	1,500	1,500
Thermal & Stray light Control	2,200	2,000	2,000
Science Instruments	700	1,800	1,800
Spacecraft	3,000	4,200	4,200
Structure	1,000	1,500	1,500
Propulsion	200	400	400
Attitude Control System	500	500	500
Command and Data Handeling	300	300	300
Communications	300	300	300
Power	500	1,000	1,000
Thermal	200	200	200
Propellant	1,000	4,500	4,500
Payload Adapter Fixture	1,000	1,000	1,000

Recent desire is PM with higher stiffness, thus current design is ~2500 kg for PM and ~1250 kg for Support.

Well within available mass margin.

Structures

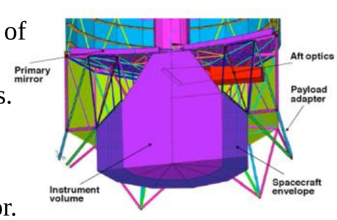
Stiff Structures are critical to a space telescope's ability to:

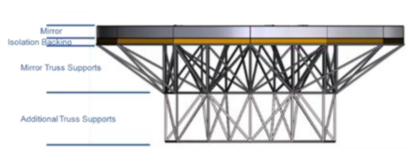
- Survive Launch
- Achieve and Maintain a Stable Wavefront

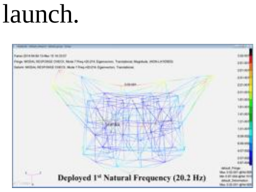
SLS Mass & Volume Capacities enable Stiff Structures:

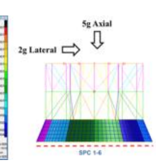
- o Stiffness is achieved via structural 'depth' (i.e. volume) and 'mass'.

- ATLAST-8 PM Structure provides a 10X margin of safety to mirror during launch by distributing forces between 66 axial and lateral support points.
- ATLAST-12 PM Structure is 4-meters deep to achieve a 20 Hz first mode. It survives 5g axial and 2g lateral loads with 1.4 ultimate safety factor. 4mt mass is driven by 20 Hz not by launch.









Conclusions

- The payload capacities of NASA's planned Space Launch System (SLS) is a disruptive capability.
  - 8.4 and 10.0 meter fairings
  - 45 to 55 mt to SE-L2

- SLS's mass and volume capacities enable new classes of mission architectures that use payload design simplicity to reduce cost.

- Presented three point designs for potential missions:
  - ATLAST-8
  - ATLAST-12
  - HabEx-4

Any Question?