NASA's Plans for Human Exploration beyond Low Earth Orbit

NASA Office of Inspector General

https://oig.nasa.gov/docs/IG-17-017.pdf

Introduction

- Human exploration of Mars has been long-term goal for NASA for more than 50 years
- Change in national priorities in the 1970s shifted the Agency's focus from Mars to low Earth orbit
- NASA is once again pursuing human exploration beyond low Earth orbit, announcing its Journey to Mars in 2015
- Vital to this goal is the successful development of NASA's new spaceflight system
  - Heavy lift rocket—Space Launch System (SLS)
  - Crew capsule—Orion Multi-Purpose Crew Vehicle (Orion)
  - Ground processing and launch facilities—Ground Systems Development and Operations (GSDO)
  - Since 2012, NASA has invested more than $15 billion on these three programs
- In 2017, NASA's near-team goals included an uncrewed flight of the integrated SLS/Orion systems in November 2018 and a first crewed flight as early as 2021
  - Exploration Mission 1 (EM-1)
  - Exploration Mission 2 (EM-2)
- NASA's plans beyond EM-1 and EM-2 are less clear

Audit Objectives

- Assess NASA's plans for and progress towards its first flights of the integrated SLS/Orion systems in the next 2 to 5 years
- Examine the challenges in executing a sustainable and affordable plan to send a crewed mission to Mars in the 2030s or 2040s
- Assess strategies to help reduce the costs associated with the Agency's human exploration efforts

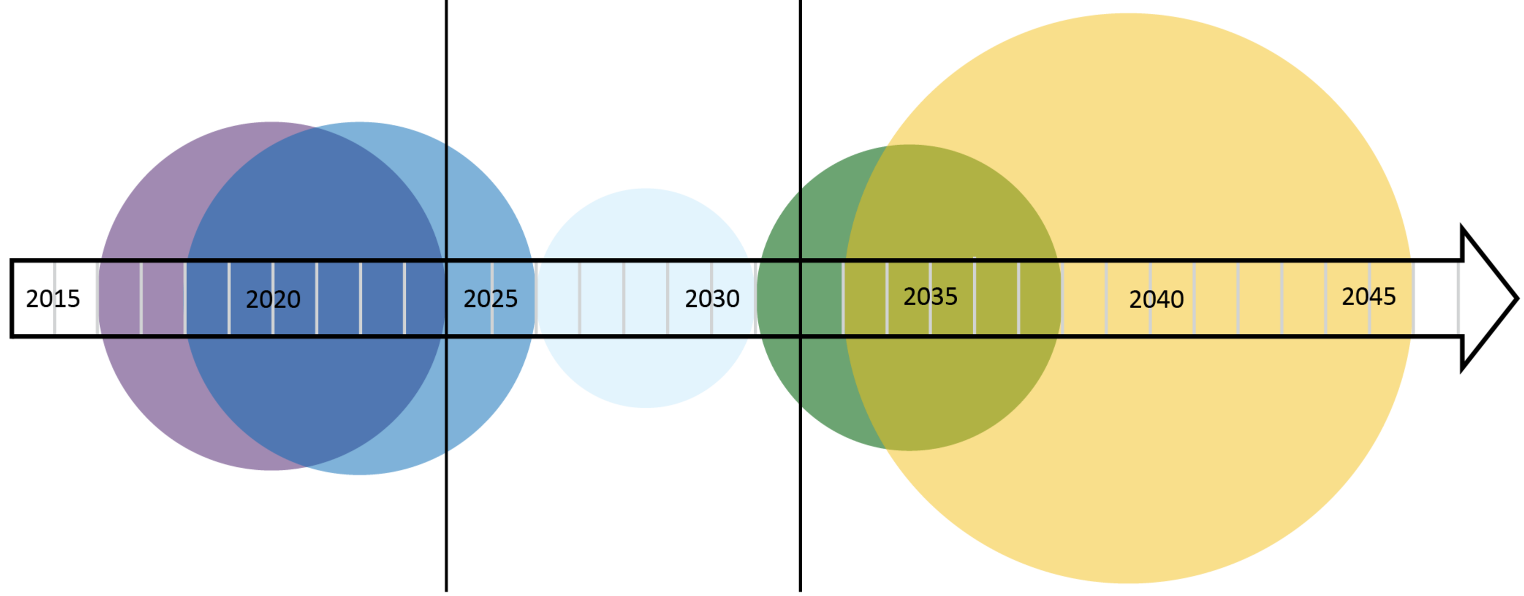
Audit Risks and Challenges

- Large and complex scope
- Lack of established criteria beyond three major systems
- Lack of cost estimates
- Fluctuating and uncertain space policy
- Working with a large number of “pre-decisional” documents

Background

NASA's Plans for the Journey to Mars

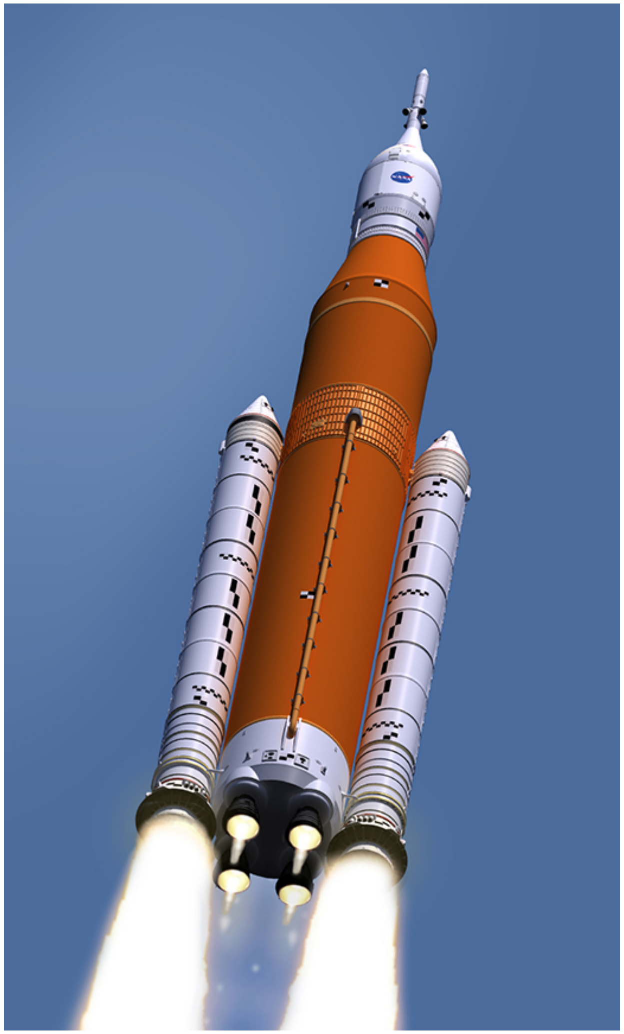
	Earth Reliant (low Earth orbit)	Proving Ground (cislunar space)	Earth Independent (Mars orbit/surface)
Mission Duration	6 to 12 months	1 to 12 months	2 to 3 years
Return to Earth	hours	days	months/years
Time Period	2016 to 2024	mid-2020s to early 2030s	early 2030s to mid-2040s



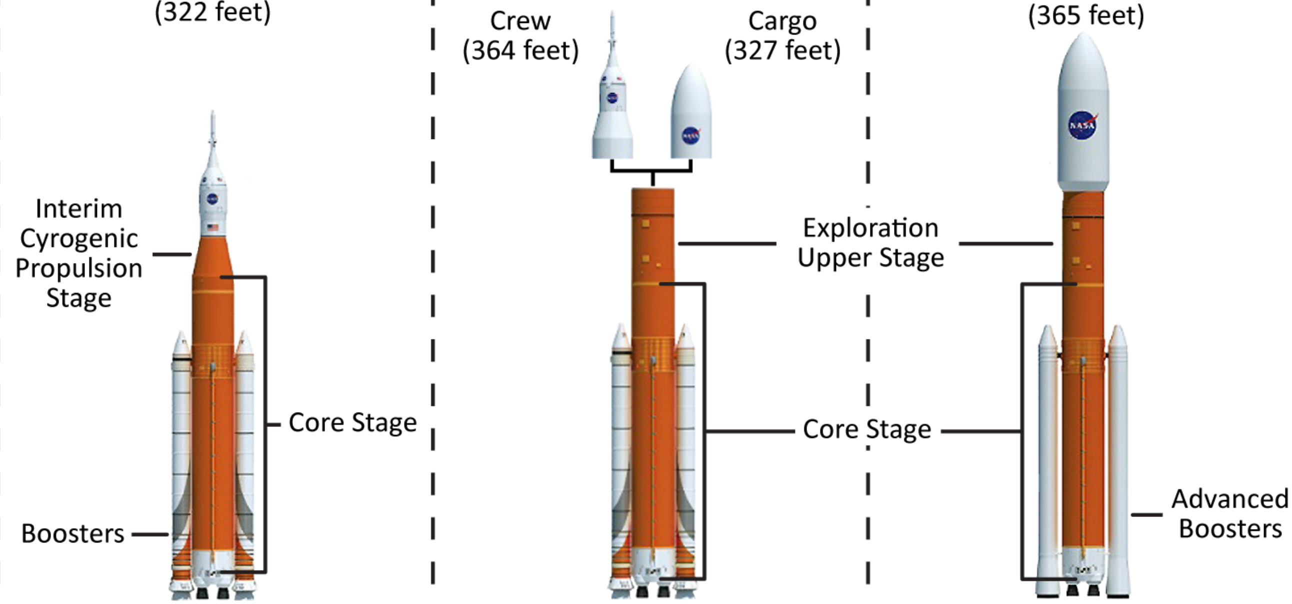
Phase 0	Phase 1	Phase 2	Phase 3	Phase 4
• ISS testing • Commercial crew • Commercial cargo	• EM-1 • EM-2 • Asteroid Redirect Robotic Mission	• Cislunar exploration missions and development of deep space systems	• Mars orbit • Exploration of Mars' moons • Transport system between high and low Mars orbits	• Mars surface • Phase 4a: robotic and preparatory (non-human) missions • Phase 4b: crewed Mars landing (human missions)

Space Launch System (SLS)

- SLS will transport cargo and crew into space for missions in cislunar and Mars orbits
- Leverages technologies from previous programs
- NASA plans to incrementally increase SLS performance capabilities through a series of upgrades to the system’s boosters and second stage



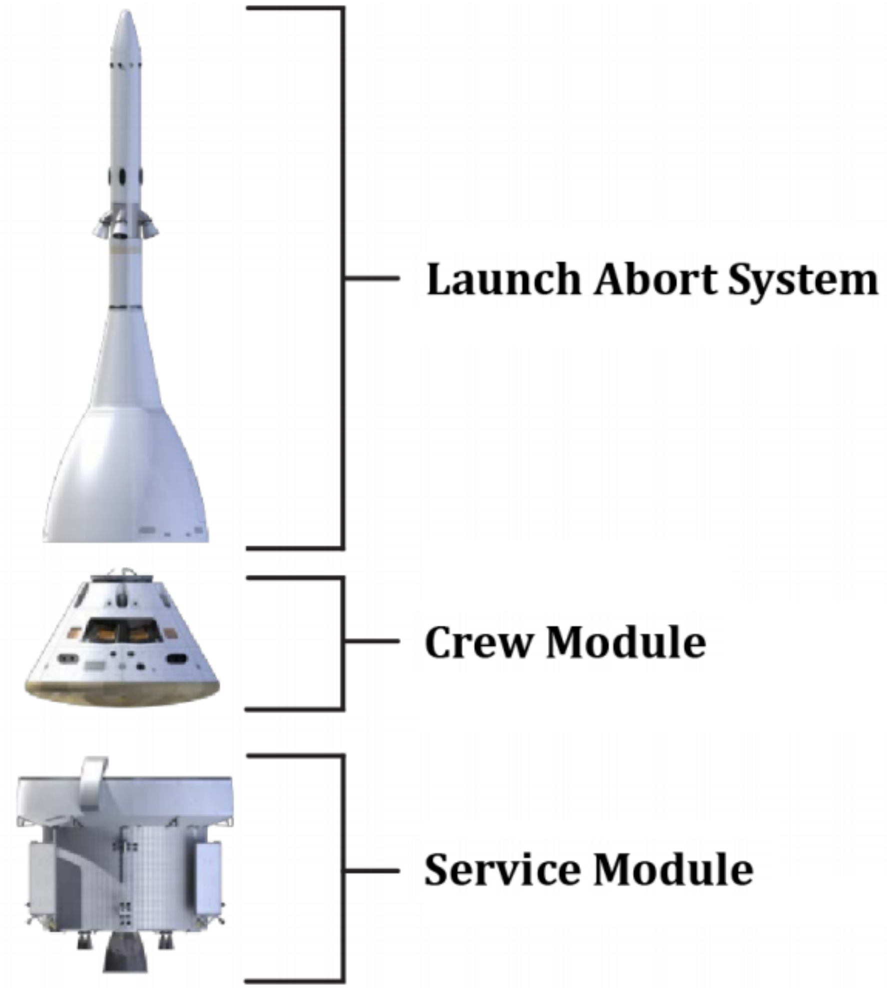
SLS Block 1 (322 feet)	SLS Block 1B	SLS Block 2 (365 feet)



	SLS Block 1	SLS Block 1B	SLS Block 2
Launch readiness date	2020	2024	no earlier than 2028
Vehicles needed	3 to 4	approximately 7	unknown
Upgrades	n/a	Exploration Upper Stage	Advanced Boosters
Cargo payload fairing size (width by height)	n/a	8.4 meters by 27.4 meters	10 meters by 27.4 meters
Co-manifested payload for crew version	n/a	6 to 10 metric tons	10+ metric tons
Upmass to low Earth orbit	70 metric tons	105 metric tons	130 metric tons
Upmass to trans-lunar injection (cargo)	25 metric tons	41 metric tons	45 metric tons
Upmass to trans-lunar injection (cargo)	25 metric tons	37 metric tons	41 metric tons

Orion Multi-Purpose Crew Vehicle (Orion)

- Orion is designed for human exploration beyond low Earth orbit
- Crew module accommodates up to four astronauts for 21 days in 316 cubic feat—similar to the size of a minivan
- Orion will be used in combination with habitation modules and other systems to extend stay and broaden access to Mars or other deep space location



Ground Systems Development and Operations (GSDO)

- SLS launches will use the Kennedy Space Center's processing and launch facilities managed by GSDO
  - Vehicle Assembly Building
  - Mobile Launcher
  - Crawler-Transporter
  - Launchpad 39B

- NASA is also developing command and control software

Additional Systems Required for Journey to Mars

- NASA has identified additional systems beyond SLS, Orion, and GSDO that will be required for Journey to Mars
- These systems are still being conceptualized and have yet to enter official project planning
  - In-space propulsion
  - Long-duration deep space transit habitat
  - Mars orbital transport vehicle
  - Mars lander and ascent vehicle
  - Mars surface habitat

Challenges with NASA's Near-Term Missions Illustrate Difficulty of Deep Space Exploration

- Three separate programs with similar challenges
    - Increasing costs and schedule delays
    - Technical challenges
    - Lack of monetary and schedule reserve
- Spaceflight system software is behind schedule and may affect EM-1 launch date
- NASA’s integration plans for EM-2 are incomplete
- Feasibility of crewed flight on EM-1
- Agency commitments do not capture all SLS, Orion, and GSDO costs

Space Launch System

NASA Lead	NASA Lead Center	Cost as of FY 2016[a]
ESD SLS Program	Marshall Space Flight Center	$7.9 billion

Launch Schedule	Cumulative Estimated Costs
November 2018 (EM-1)	$12.1 billion[b]
August 2021 (EM-2)	$19.1 billion[b]
1+ Launch/Year (Beyond EM-2)	Undetermined[c]

Proposed System Timeline

TD[d] | Formulation | Implementation

- **2010** Program funded
- **2015** CDR complete
- **2018** Block 1 launch (EM-1)
- **2021** Block 1B launch (EM-2)
- **2023** EM-3 launch; at least one launch per year thereafter

Performance Requirements

Cislunar Missions	Mars Missions	Upmass Goal	Cargo Payload Fairing
Up to two launches per year	Up to three launches per year	130 metric tons to low Earth orbit; 52 metric tons to cislunar orbit	Up to 10 meters wide

- Green Run—test fire of Core Stage engines
- No schedule margin or funding reserves
- Block 1B will have a new second stage (Exploration Upper Stage)

Orion Multi-Purpose Crew Vehicle

NASA Lead	NASA Lead Center	Cost as of FY 2016
ESD Orion Program	Johnson Space Center	$6.1 billion[a]

Launch Schedule	Cumulative Estimated Costs
November 2018 (EM-1)	$8.7 billion[b]
August 2021 (EM-2)	$12.7 billion[b]
1+ launch/year (beyond EM-2)	Undetermined[c]

Proposed System Timeline

Technology Development | Formulation | Implementation

- **2006** Constellation Program
- **2010** Continuation after Constellation Program
- **2015** CDR complete
- **2018** Uncrewed Orion (EM-1)
- **2021** First crewed Orion (EM-2)
- **2023** EM-3 launch; at least one launch per year thereafter

Performance Requirements

Crew Size	Habitat Volume	Mission Duration	Earth Reentry
4	316 cubic feet	Up to 21 days	Up to cislunar orbit

- Delays with service module
- Updates to heat shield after test flight in 2014
- Crewed EM-2 will use life support without a test flight

Exploration Ground Systems

NASA Lead	NASA Lead Center	Cost as of FY 2016[a]
ESD Exploration Ground Systems	Kennedy Space Center	$1.6 billion

Launch Schedule	Cumulative Estimated Costs
November 2018 (EM-1)	$2.6 billion[b]
August 2021 (EM-2)	$4.2 billion[b]
1+ launch/year (beyond EM-2)	Undetermined[c]

Proposed System Timeline

TD[d] | Formulation | Implementation

2010 New funding after transition from Constellation Program

2015 CDR complete

2018 Block 1 launch (EM-1)

2021 EM-2 launch; completion of ground system upgrades

2023 EM-3 launch; at least one launch per year thereafter

Performance Requirements

Launch Capacity	Key Infrastructure
1 per year, surging to 3 per year	Vehicle Assembly Building, Mobile Launcher, Crawler-Transport, Launch Pad 39B, and the Space Command and Control System

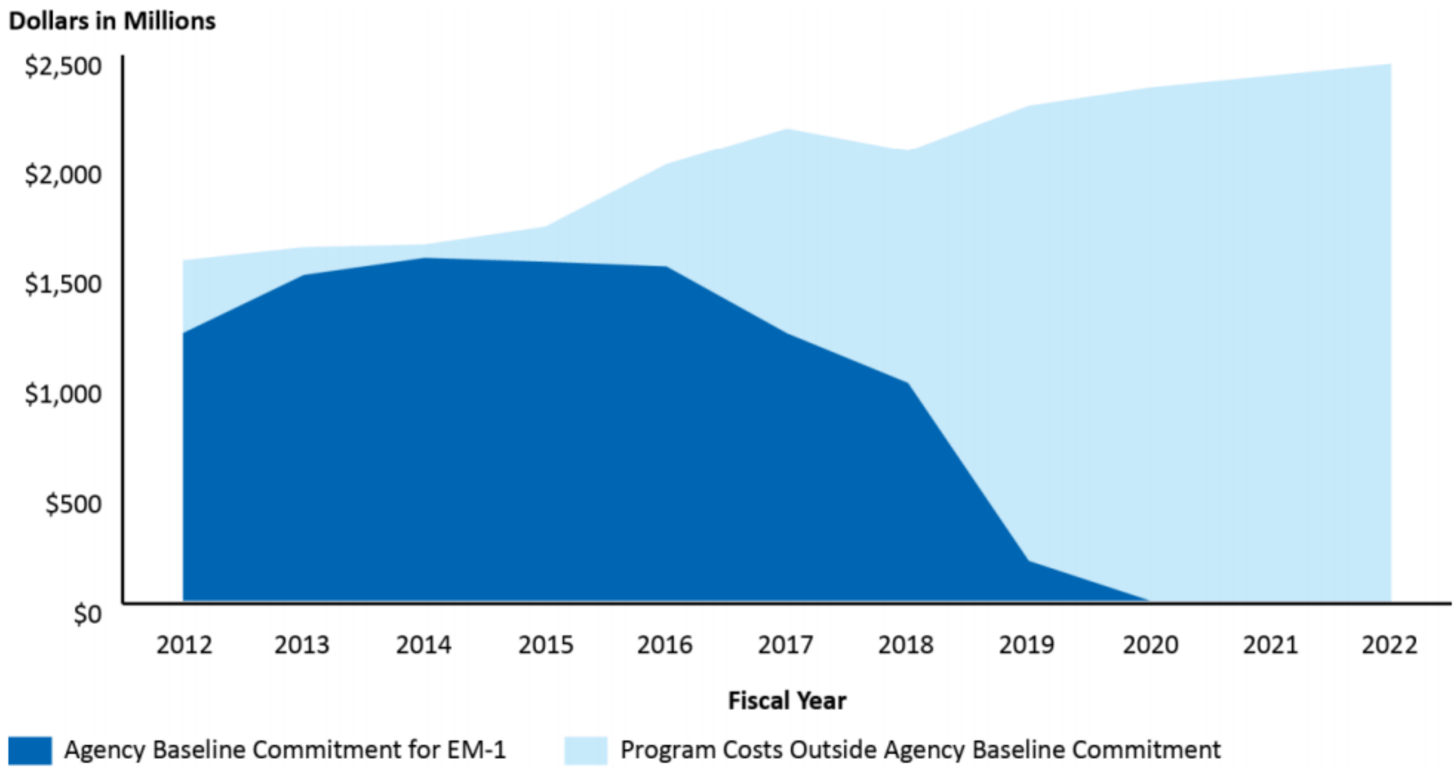
- Modifications to Vehicle Assembly Building and Mobile Launcher
- Schedule concerns due to changing requirements from Orion and SLS

Program Cost and Schedule Commitments

Program Agreements		EM-1 Estimated Life Cycle Costs	EM-1 Launch Readiness Date	EM-2 Estimated Life Cycle Costs	EM-2 Launch Readiness Date	Beyond EM-2 Estimated Life Cycle Costs	Beyond EM-2 Launch Readiness Date
SLS	Internal[a]	$9.3 billion	September 2018	Outside the scope of Agency Baseline Commitment[b]			
	External	$9.7 billion	November 2018				
Orion	Internal	No separate metrics; part of EM-2 program agreement		$10.8 billion	August 2021	Outside the scope of Agency Baseline Commitment[b]	
	External			$11.3 billion	April 2023		
GSDO	Internal[a]	$2.7 billion	September 2018	Outside the scope of Agency Baseline Commitment[b]			
	External	$2.8 billion	November 2018				

- Commitments for each program are not coordinated or combined
- Exceeding costs/schedule requires notifying Congress
- SLS Program external cost commitment of $9.7 billion
  - Assumes November 2018 launch date
  - Does not include costs for EM-2 and beyond

SLS Program Spending Outside Cost Commitments



- Estimated funding through fiscal year 2018: **$12.1 billion**
  - Compared to $9.7 billion cost commitment (EM-1 only, November 2018)
- Estimated funding through fiscal year 2021: **$19.1 billion** (EM-2)
- Through fiscal year 2022, $17 billion will be spent outside cost commitments (Orion, SLS, and GSDO programs)

NASA Challenged to Develop Realistic Cost and Schedule Estimates for Mars Missions Beyond EM-2

NASA Lacked Long-term Requirements and Cost Estimates

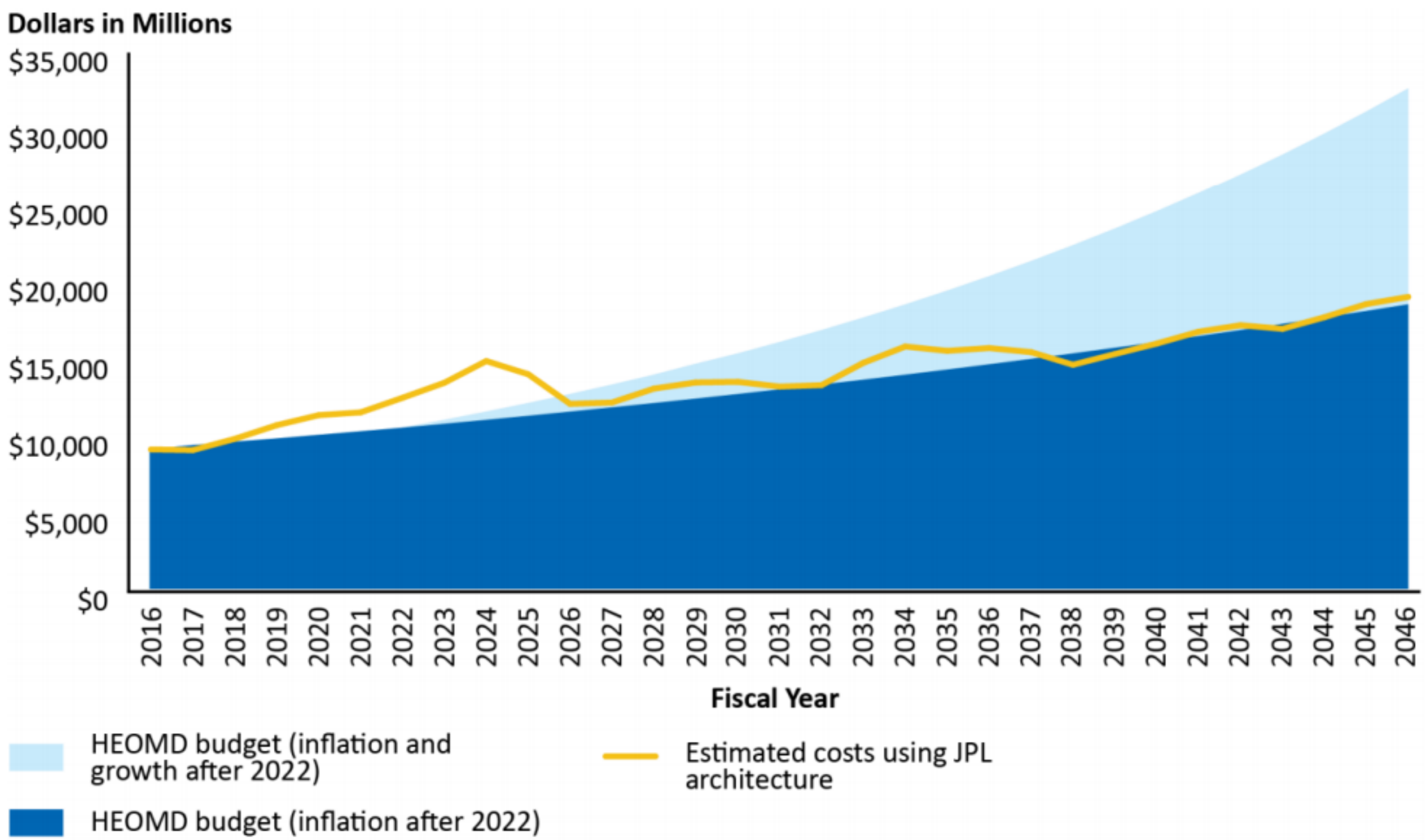
- NASA has established requirements only through EM-2
- No NASA cost estimates for missions beyond EM-2
  - No long-term estimates for total costs or key systems
  - NASA said budget funding assumptions were adequate for Mars missions
- Jet Propulsion Laboratory (JPL) feasibility study shows funding deficit in the early 2020s
  - The Aerospace Corporation reviewed estimates based on NASA OIG inputs to more closely match NASA planning
  - JPL Study showed funding deficit in the early 2020s for critical technology development

Comparison of JPL and NASA Architectures

Architecture Assumptions	JPL Feasibility Study	HEOMD's Journey to Mars Planning
Reliance on new technologies	Relied on key systems already in development to reduce costs and schedule delays, such as hypergolic chemical propulsion to transport crewed missions to Mars orbit, and to and from the Mars surface.	Utilized underdeveloped new systems, such as 1. Fission power for habitation on Mars surface; 2. Oxygen production on the Mars surface; and 3. Liquid oxygen and methane for Mars ascent propulsion.
Scope of system capabilities for initial missions	Architecture limited to system capabilities needed only for initial missions.	Expanded focus on long-term capabilities, such as liquid oxygen and methane propulsion and oxygen production on Mars.
Development investments in the 2020s	Cost estimates were conducted on each system needed in order to achieve the designated Mars missions and showed a significant investment was needed for the development of these systems in the 2020s.	Assumed supportable with flat budgets with incremental increases based on inflation and economic growth.
Extension of ISS funding beyond 2024	Assumed a reduction of ISS funding after 2024.	No analysis related to key systems costs or impact of ISS funding beyond 2024.

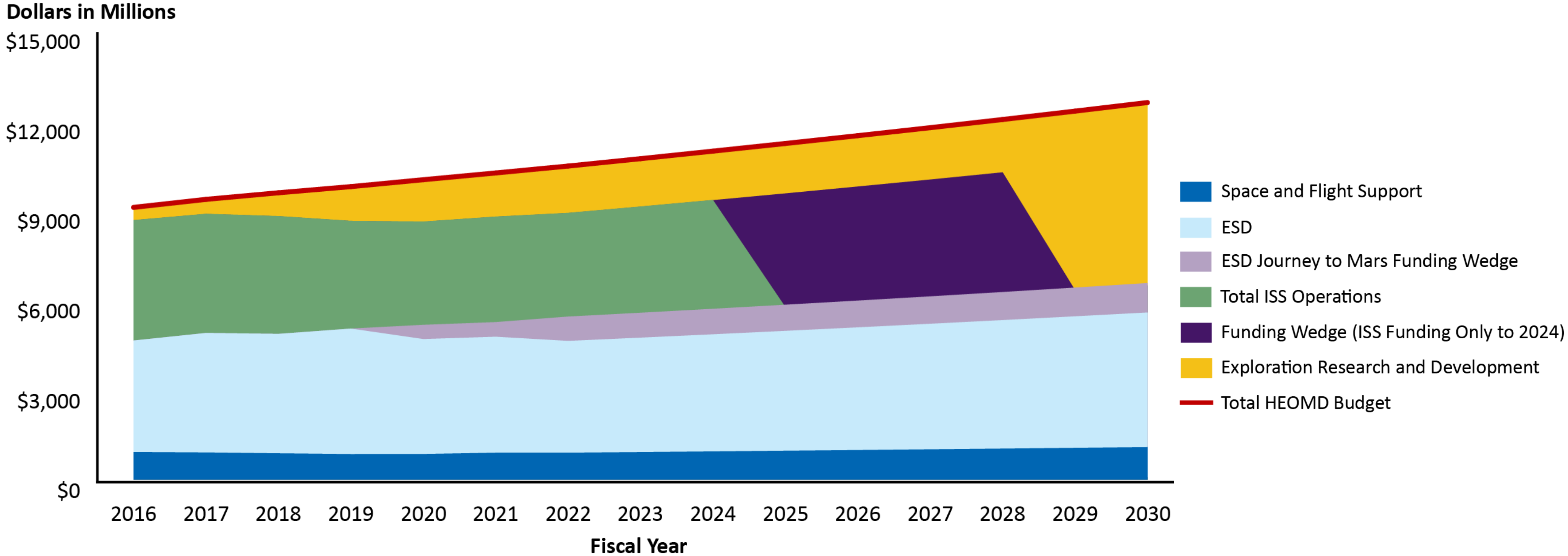
- JPL assumed minimal architecture
  - Less technology development, less robust capabilities
  - Allowed for funding spikes in beginning
- NASA assumed long-term development needs
  - Oxygen production on Mars surface (using fission power plant)
  - New oxygen and methane propulsion engine (to and from Mars surface)
  - Flat budget profiles

HEOMD Budget Assumptions Compared to JPL Estimates



- HEOMD budget assumptions: **$545 billion** (optimistic) vs. **$410 billion** (realistic)
- JPL architecture with The Aerospace Corporation cost estimate: **$450 billion** through 2046
    - Deficit of $16 billion (fiscal years 2018 through 2026)
- Mars missions are feasible when comparing NASA budget assumptions to JPL/Aerospace cost estimates

Funding Critical System Development and the Impact of ISS Funding



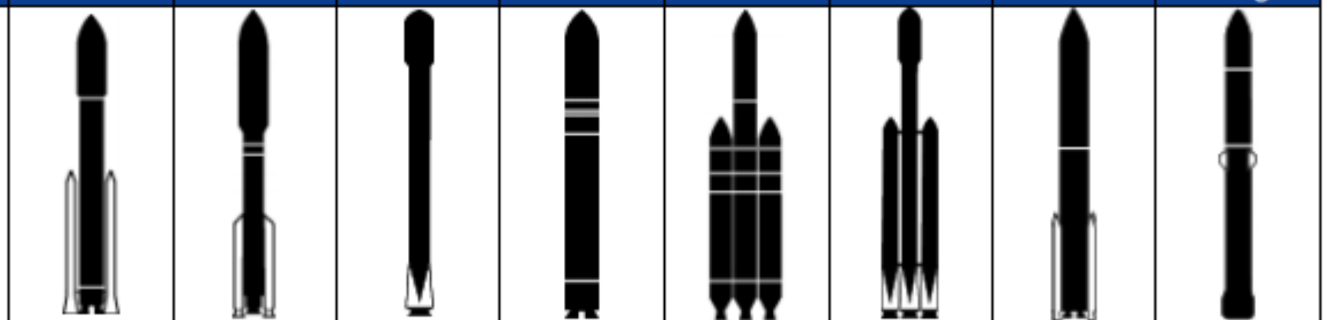
- JPL/Aerospace analysis showed a need for early investment in critical systems (**~$16 billion** deficit in early 2020s)
- Ending the ISS in 2024: **~$16 billion** funding wedge (mid- to late 2020s)
- NASA may need more money in the early 2020s and should make a decision on the ISS to determine mid-2020 funding or there could be delays of 3 years or more for Mars missions

NASA Pursuing Options to Make the Journey to Mars Less Costly

NASA Pursuing Options to Make the Journey to Mars Less Costly

- Program management strategies to reduce costs
  - Goal of reducing program costs to $2 billion a year from $3.5 billion
  - Integration approach using exploration systems development
  - Incremental development
  - Reusing systems
  - Acquisition strategy
  - Technology development
- Partnerships with other space agencies may provide opportunities for collaboration and cost savings
- Commercial partnerships may help defray costs

Commercial Launch Options

	NASA	Commercial Currently in Service				Commercial Currently in Development		
	SLS Block 2	Atlas V	Falcon 9	Antares 230	Delta IV Heavy	Falcon Heavy	Vulcan ACES	New Glenn 3-Stage
								
Scheduled completion date	No earlier than 2028	Currently in service	Currently in service	Currently in service	Currently in service	2017	2023	Not reported
Cargo payload fairing size (meters)	10	5	5.4	3.9	5.2	5.2	5	
Upmass to low Earth orbit (metric tons)	130	7.4–17.9	11.2–15	4.4	25.5	–	–	
Upmass to cislunar orbit (metric tons)	52	2.1–6.3	1.9–3.5	1.5[a]	10.5	6.1–12.9	14	
Upmass to Mars (metric tons)	41	1.4–4.8	Not applicable	1[a]	8.1	3.9–9.3	10.5	

- NASA has adjusted its plans to include lunar missions—the size and scope are not finalized yet
- Commercial options are cheaper but less capable than the SLS
- Continued debate over government-run space system development versus commercial

Potential International Partners

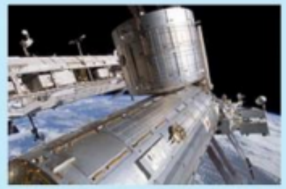
Canada

- Robotic devices to support arriving cargo vessels, movement of supplies and equipment, and maintenance of the Station
- Station-unique ground support elements

Europe

- Flight systems to supply and reboost the ISS
- ISS module – the European pressurized laboratory
- Station-unique ground elements

Japan



- Station modules – Japanese Experiment Module and Logistics Module
- Flight systems to supply the Station
- Station-unique ground elements

Russia

- Flight systems to supply the Station and transport astronauts
- Station modules – research module, and service module with propulsion and docking systems
- Station-unique ground elements

United States

- Flight systems to build and supply the Station
- Station modules and infrastructure, including a habitation module, laboratory modules, and docking systems
- Station-unique ground elements

- ISS partnerships provide a working model for human exploration beyond low Earth orbit
- Significant international partner interest in lunar missions

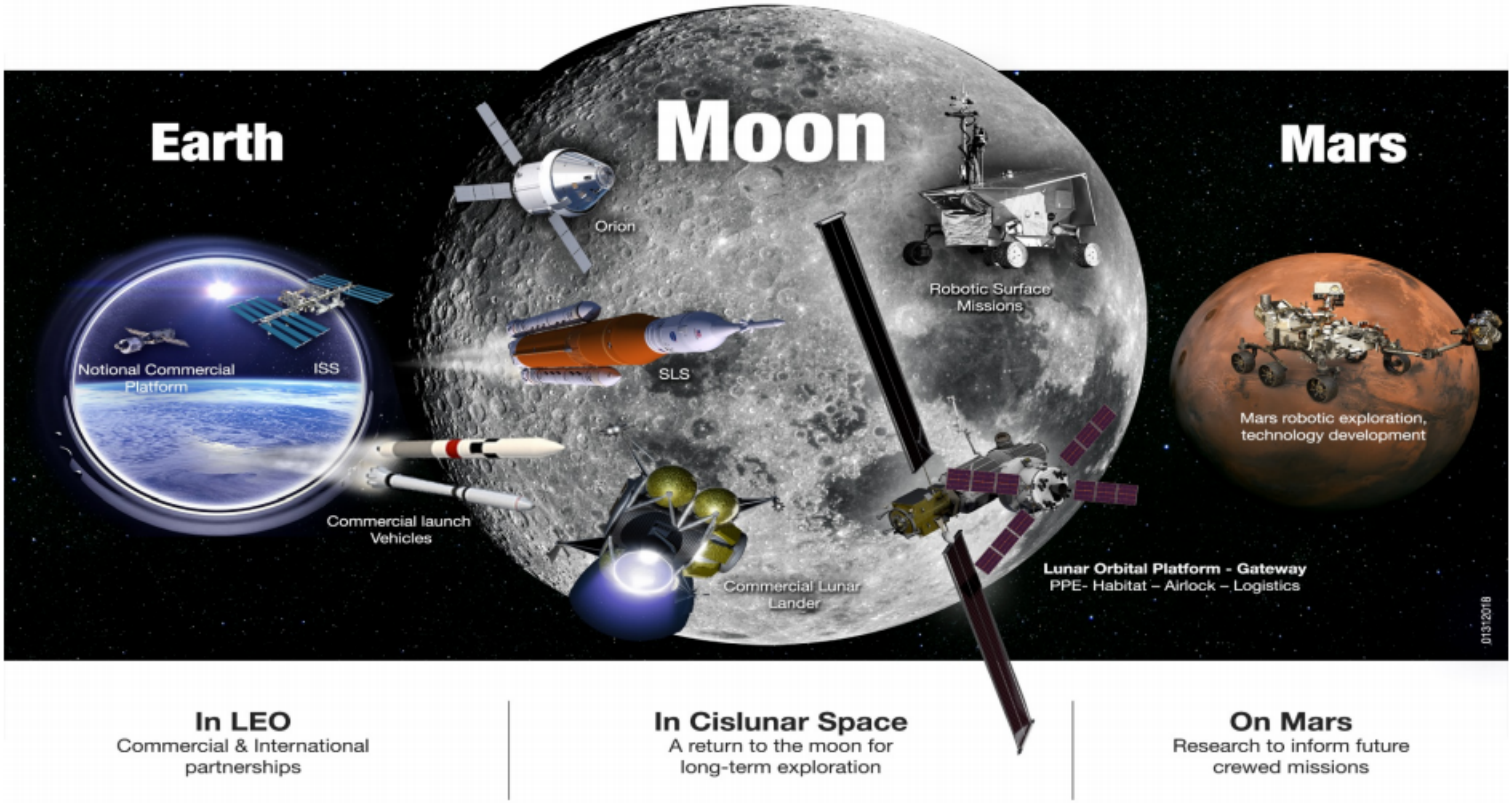
Recommendations

1. Complete an integrated master schedule for the SLS, Orion, and GSDO programs for the EM-2 mission. **(Concur)**
2. Establish more rigorous cost and schedule estimates for the SLS and GSDO programs for the EM-2 mission mapped to available resources and future budget assumptions and independently reviewed by the Office of the Chief Financial Officer **(Partially Concur)**
   - OIG response: "*While we understand the challenges posed by the appropriations process and the difficulty of projecting long-range life-cycle costs, the Agency is currently spending significant amounts of money on EM-2 without an official cost estimate for these programs*. [. . .] *In our judgment, a detailed EM-2 cost estimate would allow Agency officials and external stakeholders to better understand the mission's progress and the full costs involved.*"

Recommendations (cont.)

3. Establish objectives, need-by dates for key systems, and phase transition mission dates for the Journey to Mars. **(Concur)**
4. Include cost as a factor in NASA's Journey to Mars feasibility studies when assessing various missions and systems. **(Concur)**
5. Design a strategy for collaborating with international space agencies in their cislunar space exploration efforts with a focus on advancing key systems and capabilities needed for Mars exploration. **(Concur)**
6. Incorporate into analyses of space flight system architectures the potential for utilization of private launch vehicles for transportation of payloads. **(Concur)**

Current Human Exploration Plans



- NASA Human Exploration Update Presentation from March 2018:
https://www.nasa.gov/sites/default/files/atoms/files/heo_fy_2019_nac_briefing_-_03.26.2018_v2tagged.pdf

Conclusion

- Ongoing cost increases and schedule delays for EM-1 and EM-2
- NASA needs to set realistic expectations of the long-term funding needed for Mars missions (+$400 billion)
- Critical development needed in the 2020s for Mars missions
- Continuing the ISS could impact the schedule for Mars missions
- International and commercial partnerships could help defray these costs

Questions?

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