An Affordable Lunar Architecture Emphasizing Commercial and International Partnering Opportunities

A JPL A-Team Study

March 2018

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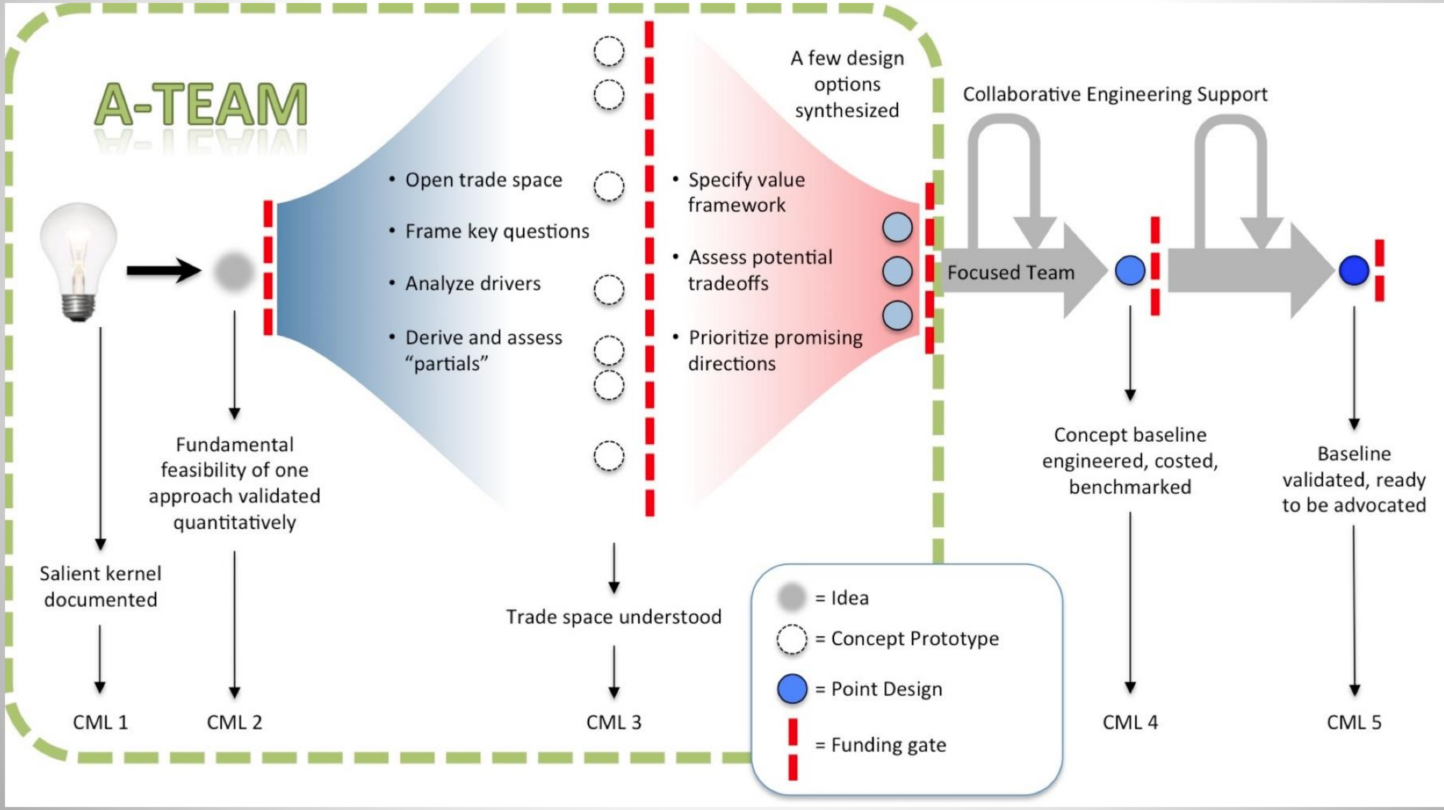
A-Team Studies

- JPL A-Team (Architecture Team) performs concurrent mission studies at the earliest stages of formulation



Graphic from Ziemer, J.K., et al., "Exploring Mission Concepts with the JPL Innovation Foundry A-Team," AIAA-2013-5431

A-Team Studies

- A-Team studies usually complete after one session
  - Four sessions were needed (May 2016 – July 2017)
- This study's lineup

Leon Alkalai	Client, Manager, Strategic Planning Office, and Director, Blue Sky Studies
Randii Wessen	Facilitator
Peter Basch	Documentarian
Robert Shishko	SME – Program Architectures and Affordability Assessments
Brian Wilcox	SME – Autonomous Systems
Nitin Arora	SME – Mission Design
Adrian Stoica	SME – Mobility & Robotic Systems
Scott Howe	SME – Robotics and Habitation Systems
Hoppy Price	SME – Systems Engineering and Program Architectures
John Elliott	SME – Robotic Lunar Exploration

A-Team Study Objectives

- Recognizing (a) the possibility of a shift back to the moon and (b) the growing capabilities and access to capital of commercial space, develop conceptual lunar architectures that could simultaneously:
  - Provide "living on another world" experience;
  - Be affordable;
  - Offer truly significant commercial and international partnering opportunities;
  - Lead to and flow into human missions to Mars in the 2030s/2040s.
- Capture architectures in a systematic way
- Assess affordability concurrently, and in doing so, demonstrate how affordability assessments could enhance the architecture definition process.

Determining Affordability

- Different views as what that means
- NRC 2014 Report, "*Pathways to Exploration: Rationales and Approaches For a U.S. Program of Human Space Exploration*," used a "sand chart" approach
  - Could a human mission be done within NASA's current human spaceflight budget?
  - Could it be done within NASA's current human spaceflight budget that grows to maintain current purchasing power?
- NRC 2014 Report sand charts were based on a methodology and cost data developed by the Aerospace Corporation
  - Methodology has three cost "flavors"
  - Cost estimates from public sources only
  - Needs a multi-faceted description of the architecture

HSF Architectures Can Be Complex

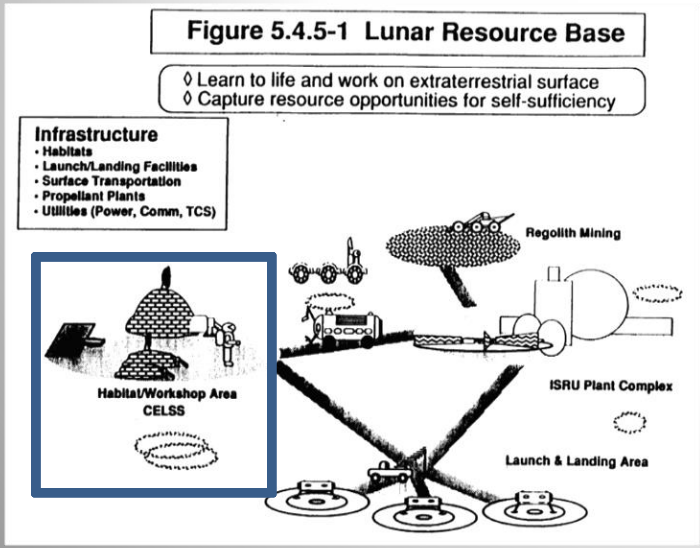
- A well-defined architecture framework is useful in abstracting essential information from the underlying complexity
- DoDAF-inspired Human Spaceflight Architecture Model (HSFAM)* artifacts:

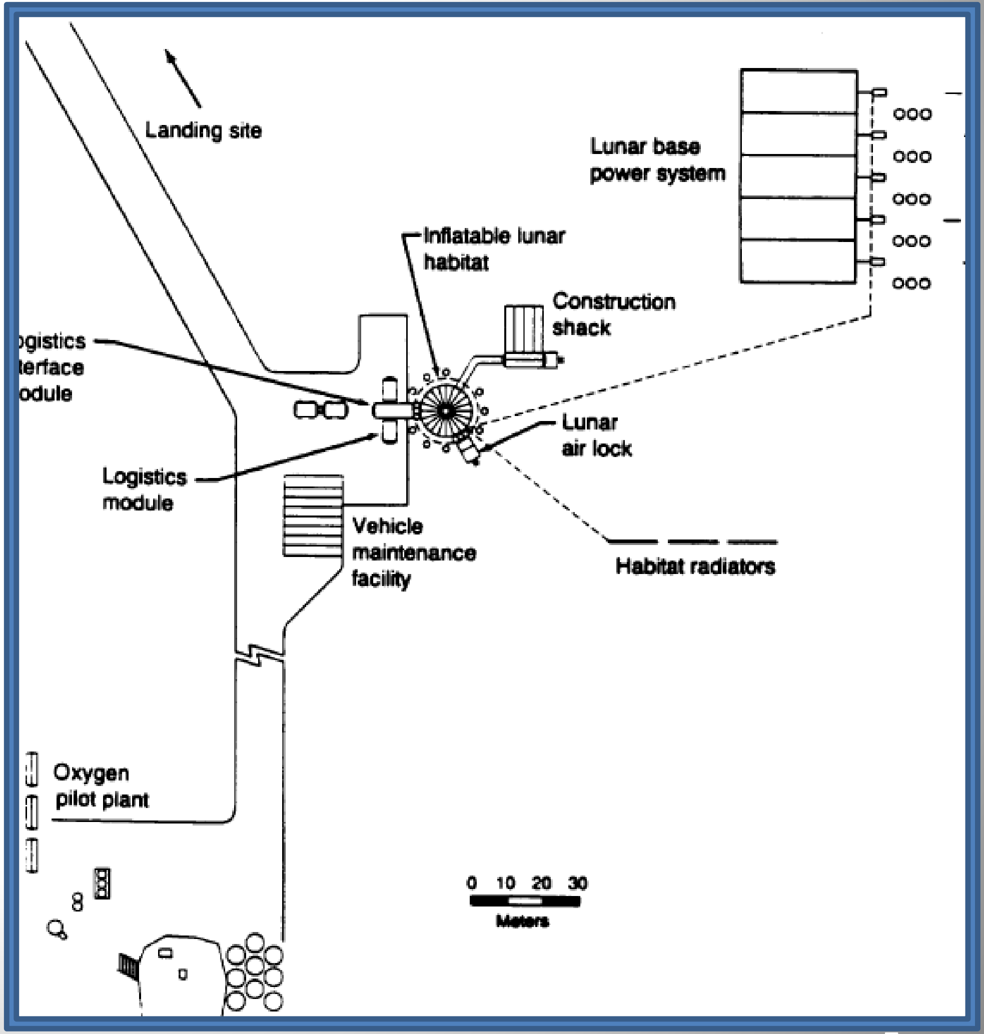
Name	Description of Architectural Content	Classes, Types, and Subtypes
Operational Nodes	Spatial locations in the solar system; locus of an operational function or activity	Surface locations (terrestrial and planetary); orbits; Lagrange points
Systems	Notional objects that fulfill a function; a hardware and/or software build	Based on broad system purposes, e.g., surface mobility, habitation
Operational Functions	Activities that transform inputs (resources) into outputs (other resources or end products), or change their state	Based on broad functional areas, e.g., mission operations, etc.
Milestones	Time-stamped identification of significant changes; milestones are four-dimensional as the spatial location (operational node) is also included	Based on capability achieved, e.g., initial operational capability (IOC)
Measures	Measurable (quantifiable) properties or attributes of interest	Mass, cost, quantity, etc.
Standards	Applicable technical, operational or business standards and rules	ISO, ANSI, Community of Practice (CoP), government-unique, etc.
Flight Types	Arcs (or edges) between operational nodes that form a feasible network along which systems can move	
Flights	Time-stamped assignment of flight types	

*Available at http://hdl.handle.net/2014/45707

Space Exploration Initiative (1989-1993)

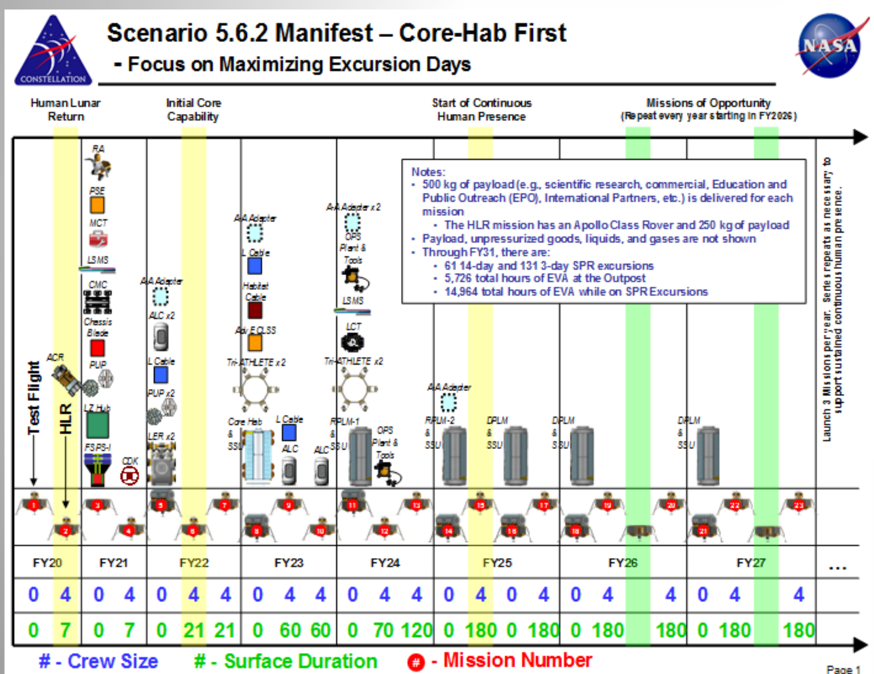
- NASA, *Leadership and America's Future in Space*, August 1987
- NASA, Office of Exploration/Johnson Space Center, *Exploration Studies Technical Report—FY89 Status*, TM-4170, August 1989
- NASA, *90-Day Study on Human Exploration of the Moon and Mars*, November 1989

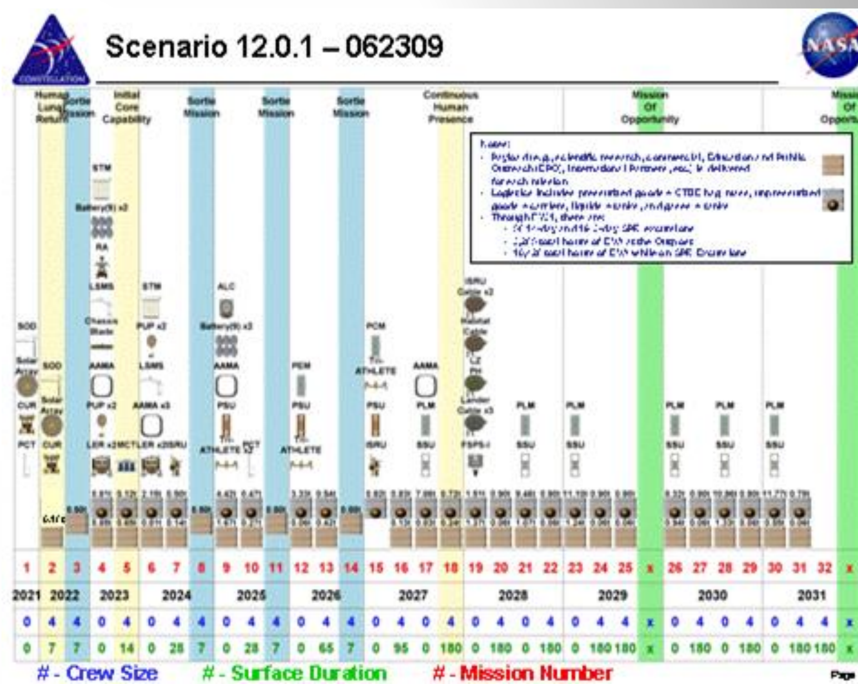




Constellation Program (2005-2010)

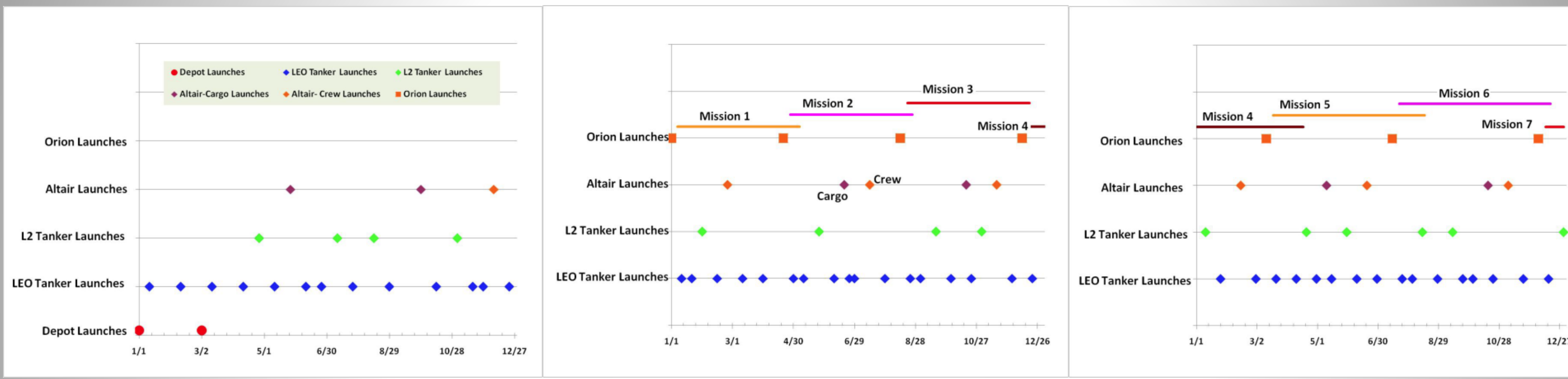
- *Exploration Systems Architecture Study (ESAS),* NASA-TM-2005-214062, November 2005
- Cirillo, W., et al., “Strategic Analysis Overview,” AIAA 2008-7778, September 2008

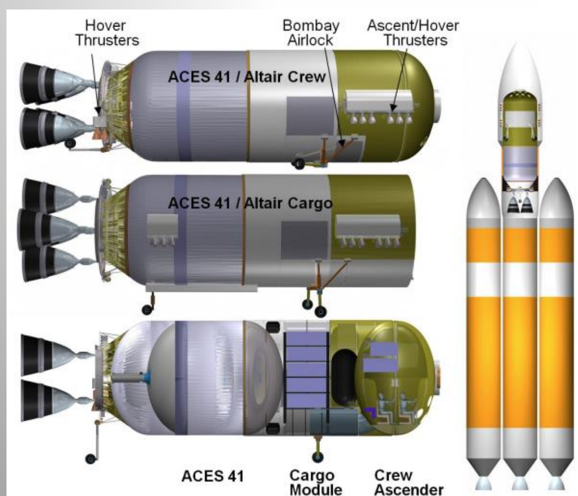


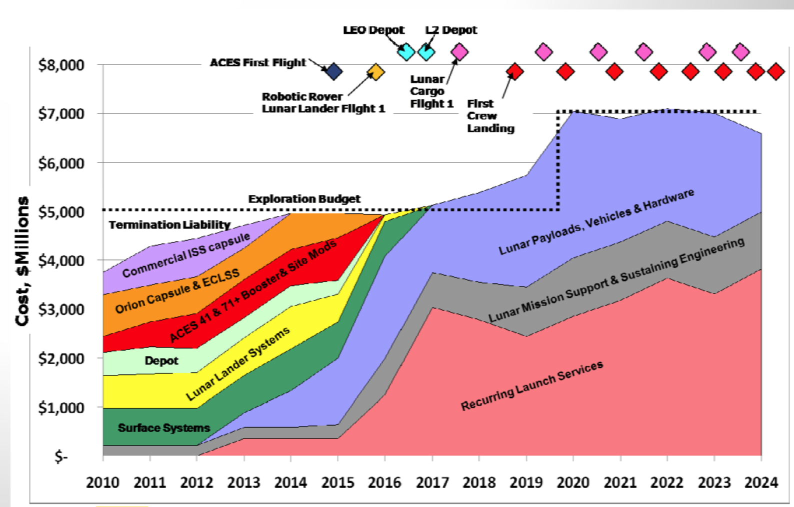


ULA Human Lunar Return Architecture c. 2009

- Zegler, F., et al., “A Commercially Based Lunar Architecture,” AIAA-2009-6567, September 2009

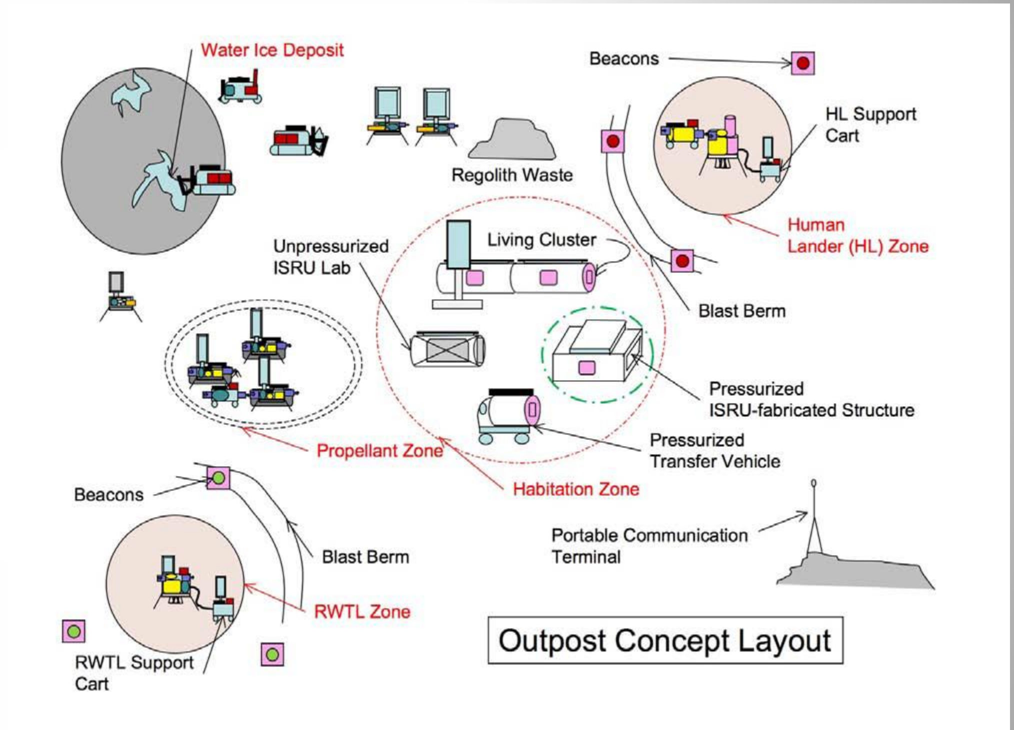






Spudis & Lavoie (S&L) (2010-2016)

- Spudis, P. D., and T. Lavoie, "Mission and Implementation of an Affordable Lunar Return," *Space Manufacturing* **14**, 2010
- Spudis, P. D., and T. Lavoie, "Using the Resources of the Moon to Create a Permanent Cislunar Space Faring System," AIAA 2011-7185, September 2011
- Spudis, P. D., *The Value of the Moon: How to Explore, Live and Prosper in Space Using the Moon's Resources*, Smithsonian Books, Washington DC, 2016
- Lavoie, T., and P. D. Spudis, "The Purpose of Human Spaceflight and a Lunar Architecture to Explore the Potential of Resource Utilization," AIAA-2016-5526, September 2016



A-Team’s Conceptual Lunar Architecture

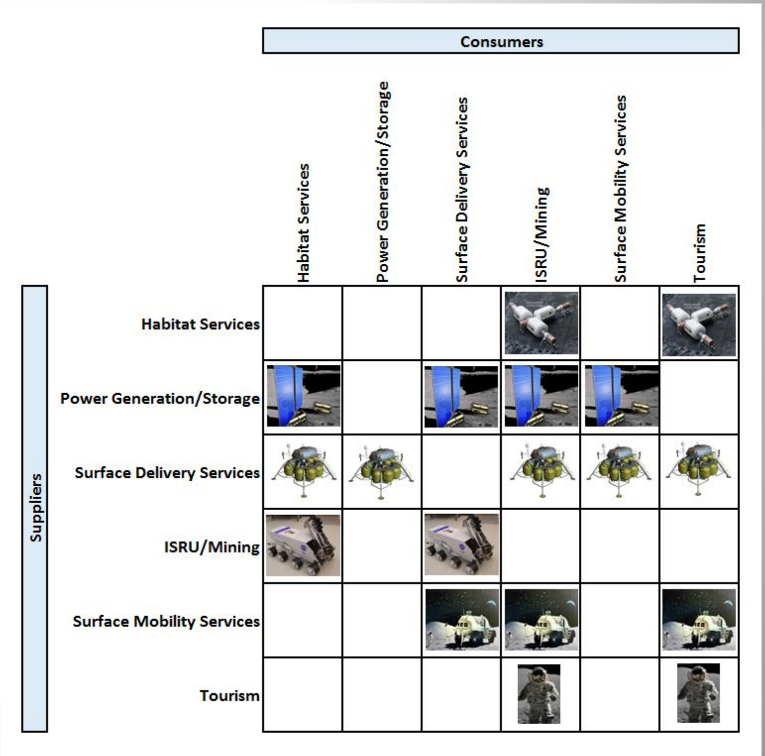
- Initial focus on a Human Lunar Return (HLR) as soon as practical
  - Living on Another World” experience and experimentation
  - Maintain public interest
  - Being first has value.
- Affordability is a political imperative.
- NASA’s role: manage the magnitude of public investment while fostering a private sector cislunar economy through strategic investments such as:
  - Engaging in science and exploration (e.g., Lewis and Clark)
  - Reducing economic risks and resolving some technical uncertainties to create tipping points and real options for space entrepreneurs
  - Performing R&D/DDT&E and first buys of basic systems/services
  - Building public (lunar) infrastructure (e.g., roads, navigation aids, basic communications, logistics nodes, operational knowledge/de-confliction)
  - Acting as an anchor tenant.

A-Team's Conceptual Lunar Architecture

- "Minimal Moon"
  - Sufficient public investment to signal serious intentions regarding lunar exploration and development to commercial investors, but
  - Careful not to displace private investments.
- Role of SLS/Orion
  - Extensive use for both lunar and Mars portions of the architecture
  - Flights rates ramp up: 1/year in first-half 2020s to 2/year in second half, and then to 2.5/year in 2030s/2040s for Mars missions.
  - SLS Block 2 available in 2028
- Are public goals for human space exploration being met?
  - Are private investors coming on board?
  - Are we ready to go to Mars?
- On- and off-ramps (and periodic decision points)

A-Team's Conceptual Lunar Architecture

- Role of the commercial space sector
  - Development of lunar infrastructure systems
  - Supplier of logistics services
- A true cislunar economy develops when commercial entities buy from each other
  - Off-Earth Mining (OEM) and lunar tourism are possibilities.
  - Private sector must determine for itself which cislunar market sectors are worthy of investment.
  - A-Team noted the technical difficulties of OEM.



This 6 x 6 Leontief matrix illustrates how a private sector-to-private sector cislunar economy might work.

The Adjoined "Minimal Mars" Architecture

- Response to NRC 2014 Report
  - Minimize the number of new system developments
  - Use of high TRL technologies
- First presentation of architecture (without costing) at AIAA Space 2014 (August 7, 2014)
- Minimal Mars presented at Humans Orbiting Mars (Mar. 31, 2015), H2M Summit (May 5, 2015), and published in *New Space* (June 2015)
- Revised and re-costed Minimal Mars architecture (July 2016) for OIG Report
- Continued refinement (April 2017 –)

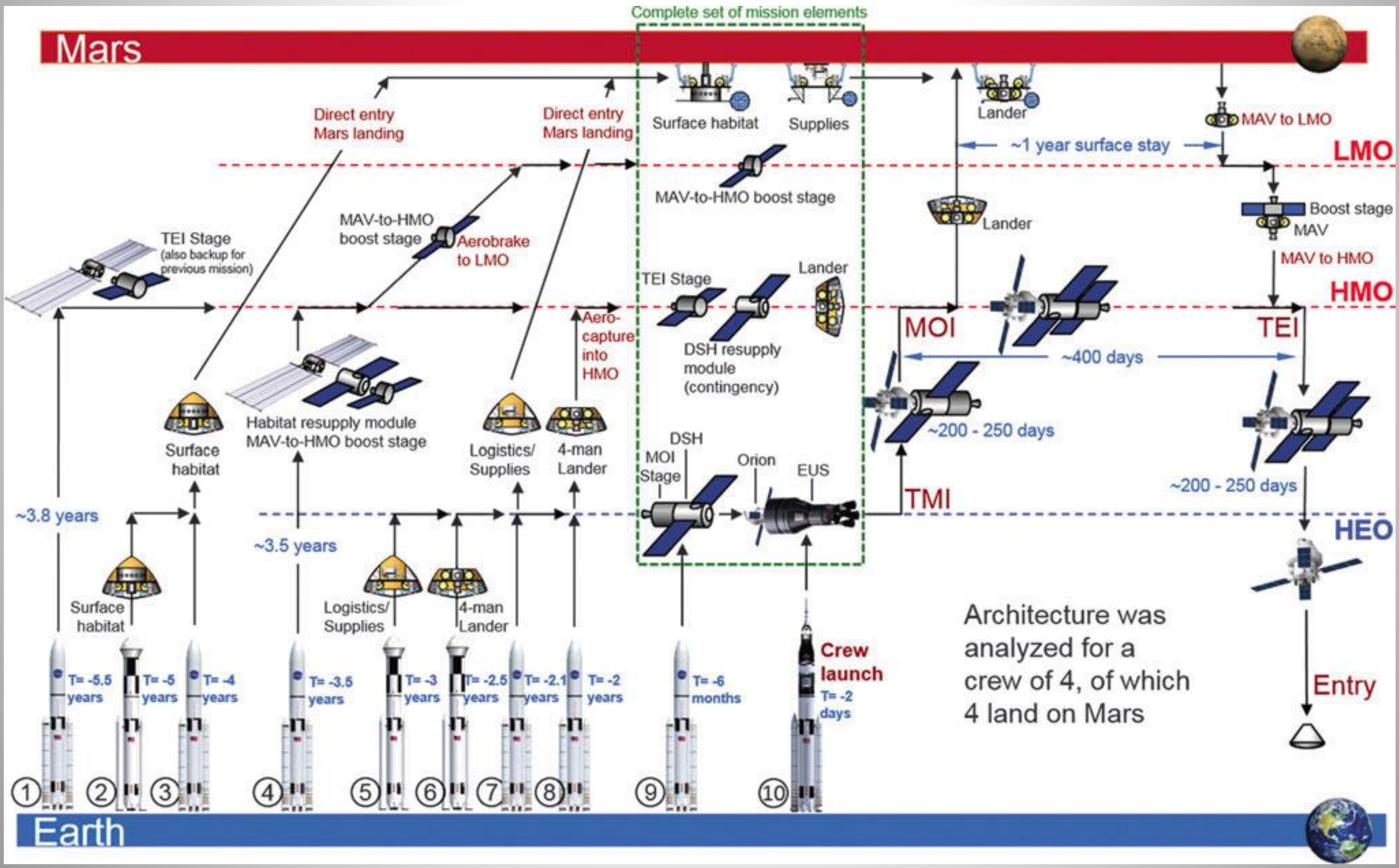
“Minimal Mars” Architecture Systems

- Hoppy Price, John Baker, and Firouz Naderi. “A Minimal Architecture for Human Journeys to Mars”, *New Space*, Vol. 3, No. 2, June 2015 https://doi.org/10.1089/space.2015.0018.

Vehicles		# Vehicles per Mission
Orion		1
SLS		6
SEP Tug		2
Deep Space Habitat		1
In-Space Chemical Propulsion Stages		3
Mars Lander		1

“Minimal Mars” Architecture Bat Chart

Conjunction-Class Mission



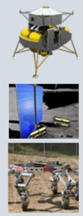
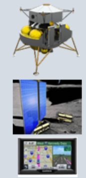
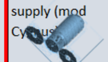
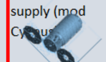
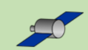
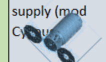
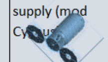
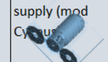
The Dance Card (2021-2035)

SLS/Orion Segment—Largely Lunar Focused

SLS Launches	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Flight Type		SLS Blk-1b		SLS Blk-1b		SLS Blk-1b	SLS Blk-1b	SLS Blk-2		SLS Blk-2	SLS Blk-2	SLS Blk-2	SLS Blk-2	SLS Blk-2	
Flight Name Orion		EM-2 (8-21 days)		EM-3 (8-21 days)		EM-4 (8-21 days)	EM-5	EM-6		EM-7	EM-8	EM-9	EM-10	EM-11	
Co-manifested NASA															
Co-manifested IP				Comm Orbiter-1		Comm Orbiter-2 (for redundancy and full LSP coverage)									
Flight Type					SLS Blk-1b	SLS Blk-1b	SLS Blk-1b	SLS Blk-2	SLS Blk-2	SLS Blk-2	SLS Blk-2	SLS Blk-2	SLS Blk-2	SLS Blk-2	
Flight Name NASA Cargo					Habitat-1 Habitat (>5000 kg) with A-AMA/ tunnel; ATHLETE mobility unit	DAV-1 DAV test (uncrewed)	DAV-2 (HLR) Unpressurized small rover (4 astronauts) with human lander	DAV-3 Unpressurized small rover (4 astronauts) with human lander	Habitat-2 Habitat (>5000 kg) with A-AMA/ tunnel; ATHLETE mobility unit	DAV-4	DAV-5	DAV-6 Unpressurized small rover (4 astronauts) with human lander	DAV-7 Unpressurized small rover (4 astronauts) with human lander	DAV-8	
Flight Type													SLS Blk-2	SLS Blk-2	
Flight Name IP Cargo NASA Cargo													Phobos SEP #1 TEI [illegible] Phobos Transfer Stages 100 kW SEP	Phobos SEP #2 100 kW SEP and Phobos Lander	
Flight Type															
Flight Name NASA Cargo															
Planetary Missions			Europa Clipper on SLS Blk-1b		Possible Europa Lander on SLS Blk-1b				Possible mission on SLS Blk-2						Possible mission on SLS Blk-2
Crew Operations		EM-1 (uncrewed mission) in 2019. EM-2 crew on a free return trajectory delivers		EM-3 crew monitors surface deployments from NRLO.		EM-4 crew performs a dress rehersal for HLR with uncrewed human lunar DAV using stretch version of Orion Service Module (SM); this SM is used on all subsequent lunar missions	EM-5 crew performs 7-14 day surface mission to include outfitting habitat module as needed and assessing previous deployments	EM-6 crew performs 14-28 days surface mission and continues to outfit habitat module with longer-term life support systems; performs repairs as needed		EM-7 crew performs 28-60 day surface mission; connects 2nd habitat and 2nd solar power system; prepares for pressurized crew rover and performs repairs as needed	EM-8 crew performs 28-60 day surface mission; completes integration and checkout of pressurized crew rover and performs repairs as needed	EM-9 crew of government and possibly commercial astronauts perform 60-90 day surface mission	EM-10 crew of government and possibly commercial astronauts perform 60-90 day surface mission	EM-11 crew of government and possibly commercial astronauts perform 60-90 day surface mission; connects 3rd solar power system; deploys longer range communication/ navigation aids	
Crew Return Vehicle		EM-2 Orion		EM-3 Orion		EM-4 Orion	EM-5 Orion	EM-6 Orion		EM-7 Orion	EM-8 Orion	EM-9 Orion	EM-10 Orion	EM-11 Orion	

The Dance Card (2021-2035)

Commercial Segment—Largely Lunar and LEO Focused

Commercial Launches	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Flight Type			Medium ELV	Heavy ELV		Heavy ELV		Heavy ELV	Heavy ELV	Heavy ELV	Heavy ELV	Heavy ELV	Heavy ELV	Heavy ELV	
Flight Name			RP-I	Lunar Lander-1		Lunar Lander-2		Lunar Lander-3	Lunar Lander-4	Lunar Lander-5	Lunar Lander-6	Lunar Lander-7	Lunar Lander-8	Lunar Lander-9	
Cargo Manifested			 Resource Prospector I mission (tele-operated from Earth)	 Stationary solar power system with cables; ATHLETE mobility unit to transport surface components		 Pressurized logistics module (PLM) to be linked with habitat; contains supplies and tools for initial habitat setup; Bulldozing and sintering tools for ATHLETE; navigation aids		 Pressurized logistics module (PLM) to be linked with habitat; contains supplies, spares, and scientific equipment; Resource Prospector (RP) II	 Pressurized logistics module (PLM) to be linked with habitat; contains supplies, spares, and scientific equipment; solar power, cables; navigation aids	 Pressurized logistics module (PLM) to be linked with habitat; contains supplies and spare or replacement ATHLETE	 Pressurized crew cabin and CMC (4 astronauts); rover contains supplies, spares, and scientific equipment; connects to habitat with A-AMA/ tunnel	 Pressurized logistics module (PLM) to be linked with habitat; contains supplies, spares, and scientific equipment; Li-ion batteries or RFCs for rovers	 Pressurized logistics module (PLM) to be linked with habitat; contains supplies, spares, and scientific equipment; Li-ion batteries or RFCs for rovers	 Pressurized logistics module (PLM) to be linked with habitat; contains supplies, spares, and scientific equipment; replacement solar power, cables; L-R navigation aids	
Flight Type					Heavy ELV	Heavy ELV	Heavy ELV	Heavy ELV	Heavy ELV	Heavy ELV	Heavy ELV	Heavy ELV	Heavy ELV	Heavy ELV	Heavy ELV
Flight Name					Possible commercial lunar landing missions	Possible commercial lunar landing missions	Possible commercial lunar landing missions	Possible commercial lunar landing missions	Possible commercial lunar landing missions	Mars DSH to LEO ***LEO PG Systems***	Possible commercial lunar landing missions	Uncrewed 1/2-scale Mars lander test	Possible commercial lunar landing missions	Possible commercial lunar landing missions	Possible commercial lunar landing missions
Cargo Manifested										 Protoflight DSH unit with 40kW pwr/prop bus to LEO					
Flight Type										Medium ELV	Medium ELV	Heavy ELV	Medium ELV	Medium ELV	Medium ELV
Flight Name										Logistics re-supply (mod Cygnus)	Logistics re-supply (mod Cygnus)	IP Chem Stage Test	Logiistics re-supply (mod Cygnus)	Logistics re-supply (mod Cygnus)	Logistics re-supply (mod Cygnus)
Cargo Manifested															
Flight Type										Medium ELV	Medium ELV	Medium ELV	Medium ELV	Medium ELV	Medium ELV
Flight Name										LEO Trng Flt-1	LEO Trng Flt-2	LEO Trng Flt-3	LEO Trng Flt-4	LEO Trgn Flt-5	LEO Trgn Flt-6
Cargo Manifested															
Comments			Could be landed by a Lunar Lander as part of a multi-payload mission		Habitat delivered with large descent stage that serves as a protoflight DAV	Could possibly do Human Lunar Return (HLR) on EM-4		RP II can be operated from the moon or Earth		3-month mission; Cygnus modified with Orion docking adaptor	6-month mission; Cygnus modified with Orion docking adaptor	1/2-scale test at Mars could be performed by a single SLS Blk-2	9-month mission; Cygnus modified with Orion docking adaptor	9-month mission; Cygnus modified with Orion docking adaptor	9-month mission; Cygnus modified with Orion docking adaptor

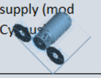
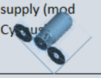
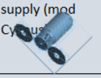
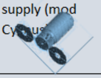
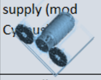
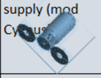
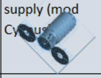
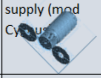
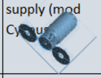
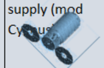
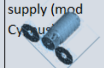
The Dance Card (2036-2050)

SLS/Orion Segment—Largely Mars Focused

SLS Launches	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Flight Type	SLS Blk-2	SLS Blk-2				SLS Blk-2				SLS-Blk-2				SLS Blk-2	
Flight Name Orion	EM-12 (Lander test crew at moon)	EM-13 (Phobos crew)				EM-14 (Mars-1 crew)				EM-15 (Mars-2 crew)				EM-16 (Mars-3 crew)	
Co-manifested NASA															
Co-manifested IP															
Flight Type			SLS Blk-2	SLS Blk-2	SLS Blk-2	SLS Blk-2	SLS Blk-2	SLS Blk-2	SLS Blk-2	SLS Blk-2	SLS Blk-2	SLS Blk-2	SLS Blk-2	SLS Blk-2	SLS Blk-2
Flight Name			Mars SEP #2	Mars Lander #1	Mars Cargo #1	EUS #2	Mars SEP #4	Mars Hab #1	Mars Cargo #2	EUS #5	Mars SEP #6	Mars Hab #2	Mars Cargo #3	EUS #8	Mars SEP #8
NASA Cargo			DSH-based logistics module and 100 kW SEP	Mars DAV	Mars Surface Cargo Lander	EUS for Mars Surface Cargo Lander TMI	DSH-based logistics module and 100 kW SEP	Mars Surface Habitat	Mars Surface Cargo Lander	EUS for Mars Surface Cargo Lander TMI	DSH-based logistics module and 100 kW SEP	Mars Surface Habitat	Mars Surface Cargo Lander	EUS for Mars Surface Cargo Lander TMI	DSH-based logistics module and 100 kW SEP
Flight Type	SLS Blk-2	SLS Blk-2	SLS Blk-2	SLS Blk-2	SLS Blk-2	SLS Blk-2	SLS Blk-2	SLS Blk-2	SLS Blk-2	SLS Blk-2	SLS Blk-2	SLS Blk-2	SLS Blk-2	SLS Blk-2	SLS Blk-2
Flight Name	Mars lander test at moon	Phobos DSH	Mars SEP #1	EUS #1	Mars SEP #3	Mars DSH #1	Mars Lander #2	EUS #3	Mars SEP #5	Mars DSH #2	Mars Lander #3	EUS #6	Mars SEP #7	Mars DSH #3	Mars Lander #4
IP Cargo		MOI Stage	TEI and MAV Boost Stages		TEI and MAV Boost Stages	MOI Stage			TEI and MAV Boost Stages	MOI Stage			TEI and MAV Boost Stages	MOI Stage	
NASA Cargo	Mars DAV	Phobos DSH	100 kW SEP	EUS for Mars DAV TMI	100 kW SEP	Mars DSH	Mars DAV	EUS for Mars DAV TMI	100 kW SEP	Mars DSH	Mars DAV	EUS for Mars DAV TMI	100 kW SEP	Mars DSH	Mars DAV
Flight Type								SLS Blk-2				SLS Blk-2			
Flight Name NASA Cargo								EUS #4 EUS for Mars Surface Hab TMI				EUS #7 EUS for Mars Surface Hab TMI			
Planetary Missions															
Crew Operations	EM-12 crew conducts a full-scale test of the Mars DAV at the moon	EM-13 crew rendezvous and docks with the Phobos DSH; TMI is performed by the crew launch EUS; MOI is performed by the IP-provided chemical stage				EM-14 crew rendezvous and docks with the Mars DSH; TMI is per-formed by the crew-launch EUS; MOI is performed by the IP-provided chemical stage; Mars-1 is an opposition class (surface stay ~24 days) mission				EM-15 crew rendezvous and docks with the Mars DSH; TMI is per-formed by the crew-launch EUS; MOI is performed by the IP-provided chemical stage; Mars-2 is an conjuction class (surface stay >1 year) mission				EM-16 crew rendezvous and docks with the Mars DSH; TMI is per-formed by the crew-launch EUS; MOI is performed by the IP-provided chemical stage; Mars-3 is an conjuction class (surface stay >1 year) mission	
Crew Return Vehicle														EM-13 Orion	

The Dance Card (2036-2050)

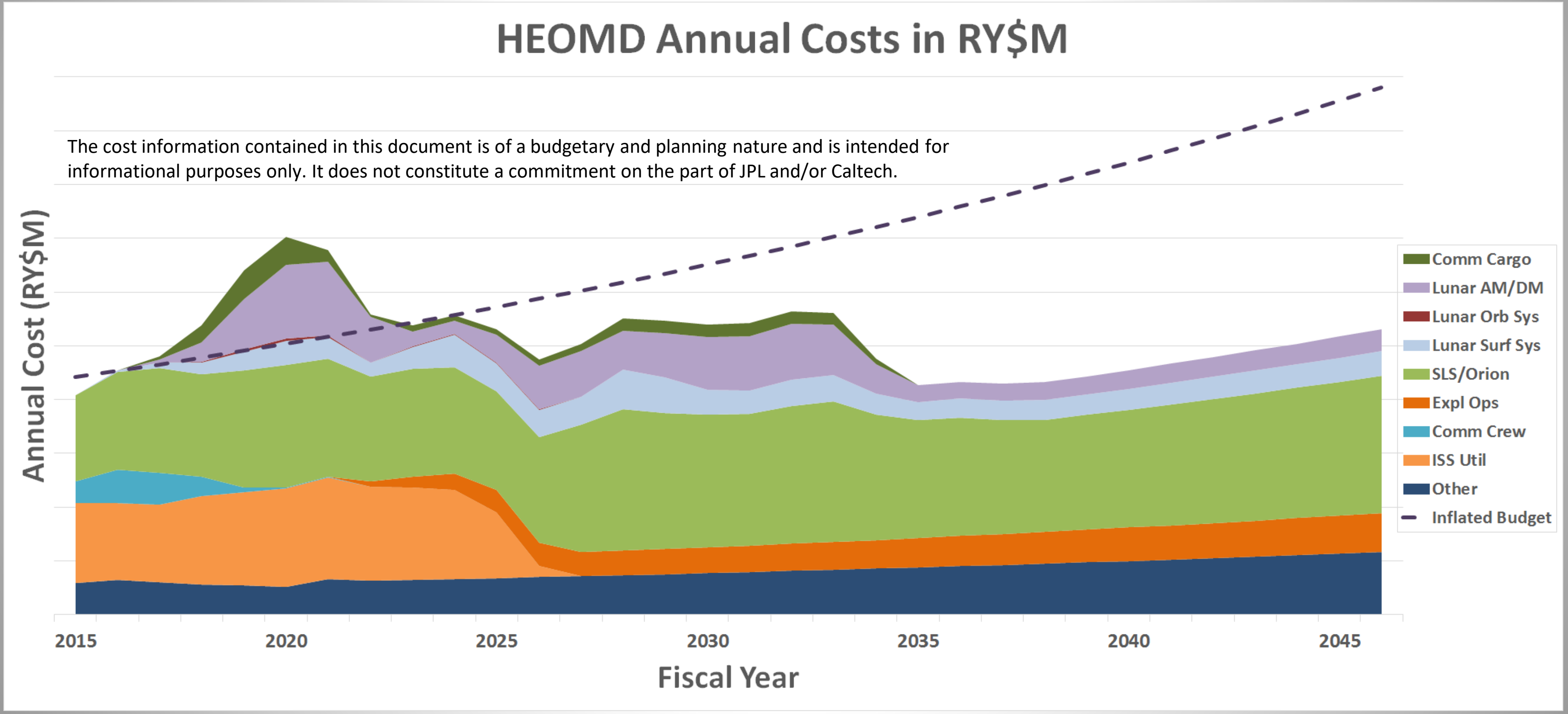
Commercial Segment—Largely LEO Focused

Commercial Launches	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Flight Type															
Flight Name															
Cargo Manifested															
Flight Type	Heavy ELV	Heavy ELV	Heavy ELV	Heavy ELV	Heavy ELV	Heavy ELV	Heavy ELV	Heavy ELV	Heavy ELV	Heavy ELV	Heavy ELV	Heavy ELV	Heavy ELV	Heavy ELV	Heavy ELV
Flight Name	Possible commercial lunar landing missions	Possible commercial lunar landing missions	Possible commercial lunar landing missions	Possible commercial lunar landing missions	Possible commercial lunar landing missions	Possible commercial lunar landing missions	Possible commercial lunar landing missions	Possible commercial lunar landing missions	Possible commercial lunar landing missions	Possible commercial lunar landing missions	Possible commercial lunar landing missions	Possible commercial lunar landing missions	Possible commercial lunar landing missions	Possible commercial lunar landing missions	Possible commercial lunar landing missions
Cargo Manifested															
Flight Type	Medium ELV	Medium ELV	Medium ELV	Medium ELV	Medium ELV	Medium ELV	Medium ELV	Medium ELV	Medium ELV	Medium ELV	Medium ELV	Medium ELV	Medium ELV	Medium ELV	Medium ELV
Flight Name	Logistics re-supply (mod Cygnus	Logistics re-supply (mod Cygnus	Logistics re-supply (mod Cygnus	Logistics re-supply (mod Cygnus	Logistics re-supply (mod Cygnus	Logistics re-supply (mod Cygnus	Logistics re-supply (mod Cygnus	Logistics re-supply (mod Cygnus	Logistics re-supply (mod Cygnus	Logistics re-supply (mod Cygnus	Logistics re-supply (mod Cygnus	Logistics re-supply (mod Cygnus	Logistics re-supply (mod Cygnus	Logistics re-supply (mod Cygnus	Logistics re-supply (mod Cygnus
Cargo Manifested															
Flight Type	Medium ELV	Medium ELV	Medium ELV	Medium ELV	Medium ELV	Medium ELV	Medium ELV	Medium ELV	Medium ELV	Medium ELV	Medium ELV	Medium ELV	Medium ELV	Medium ELV	Medium ELV
Flight Name	LEO Trgn Flt-7	LEO Trgn Flt-8	LEO Trgn Flt-9	LEO Trgn Flt-10	LEO Trgn Flt-11	LEO Trgn Flt-12	LEO Trgn Flt-13	LEO Trgn Flt-14	LEO Trgn Flt-15	LEO Trgn Flt-16	LEO Trgn Flt-17	LEO Trng Flt-18	LEO Trng Flt-19	LEO Trng Flt-20	LEO Trng Flt-21
Cargo Manifested															
Comments	9-month mission; Cygnus modified with Orion docking adaptor	9-month mission; Cygnus modified with Orion docking adaptor	9-month mission; Cygnus modified with Orion docking adaptor	9-month mission; Cygnus modified with Orion docking adaptor	9-month mission; Cygnus modified with Orion docking adaptor	9-month mission; Cygnus modified with Orion docking adaptor	9-month mission; Cygnus modified with Orion docking adaptor	9-month mission; Cygnus modified with Orion docking adaptor	9-month mission; Cygnus modified with Orion docking adaptor	9-month mission; Cygnus modified with Orion docking adaptor	9-month mission; Cygnus modified with Orion docking adaptor	9-month mission; Cygnus modified with Orion docking adaptor	9-month mission; Cygnus modified with Orion docking adaptor	9-month mission; Cygnus modified with Orion docking adaptor	9-month mission; Cygnus modified with Orion docking adaptor

Costing the A-Team Architecture

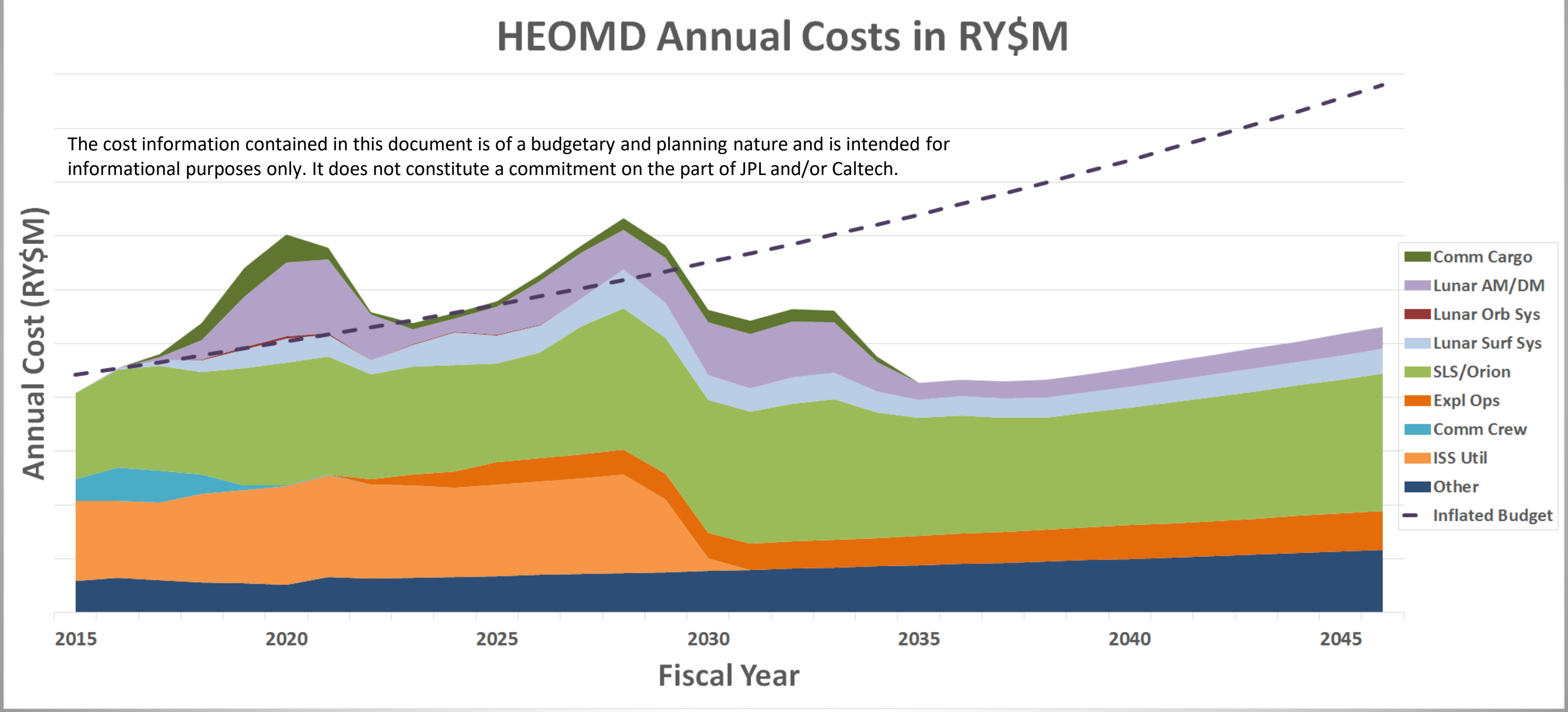
- Applied the Aerospace Corporation methodology.
  - Generally retained Aerospace cost data for Mars portion
  - Cost data for lunar surface systems from Constellation Program estimates
  - SEP costs from ARM
  - Updated actual costs for on-going programs
  - For the contemporary Lunar Module, converged three sources of data
- Made significant improvements in the Excel © software that generates the sand chart.
- International contributions for lunar and Mars portions
  - Upgraded Orion Service Module (SM)
  - Lunar communications infrastructure
  - Chem stages (MOI, TEI, MAV-to-HMO Boost)

A-Team Minimal Moon with HLR in 2027



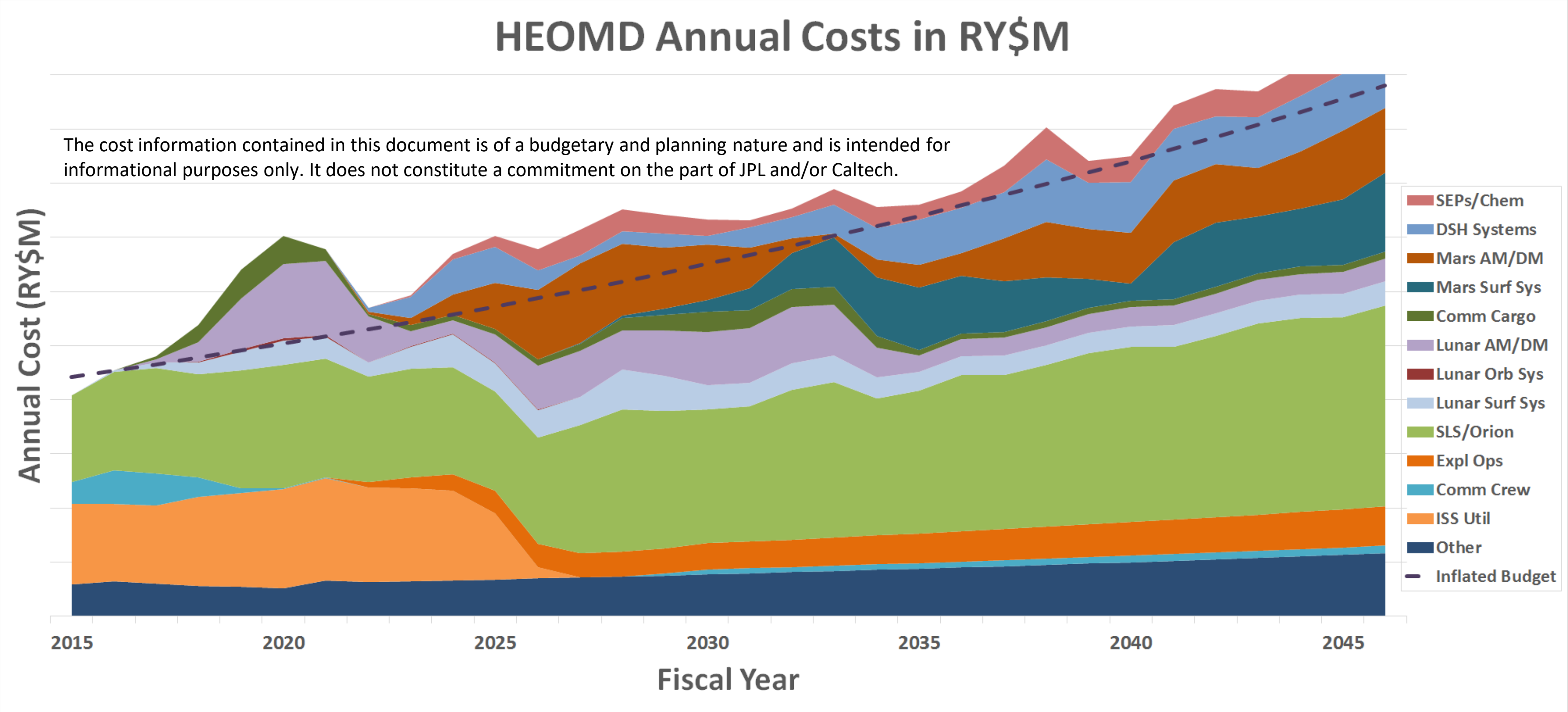
Scenario Name	First Mars System Mission	First Mars Landing	ISS EOPM
Min Moon with Human Lunar Return in 2027	N/A	N/A	2024

A-Team Minimal Moon with HLR in 2027



Scenario Name	First Mars System Mission	First Mars Landing	ISS EOPM
Min Moon with Human Lunar Return in 2027	N/A	N/A	2028

Team Study Minimal Moon with HLR in 2027+ Minimal Mars with First Mars Mission in 2037



Scenario Name	First Mars System Mission	First Mars Landing	ISS EOPM
Min Moon with Human Lunar Return in 2027	2037	2041	2024

Summary

- The A-Team conceptual lunar architecture reflects a strategy of:
  - Returning humans to the moon first, gaining knowledge and experience there
  - Fostering a true cislunar economy
  - Sending humans to Mars, when that becomes public policy.
- The magnitude and timing of NASA funding are important considerations, so we performed a concurrent affordability assessment.
- Lunar portion of the architecture is designed to accomplish four goals:
  - Performing basic science and exploration
  - Returning humans safely to (and from) the lunar surface
  - Reducing commercial risk and lowering the barriers to entry for commercial ventures by investing in some basic infrastructure, and
  - Enlisting international partners in extending that infrastructure.
- Commercial opportunities include, but are not limited to:
  - P-P-P in developing a heavy lunar cargo lander, lunar surface systems
  - OEM/ISRU opportunities, should the location, quantity, and extractability of lunar resources prove technically feasible and commercially favorable
  - Lunar logistics services for NASA as anchor tenant and for other commercial ventures
  - Resupplying and ferrying astronauts to the LEO Gateway used for Mars training and DSH system testing
- Final thought

BACKUP

Possible Figures-of-Merit / Care-Abouts

- Time from program start to human lunar return (i.e., length of assembly sequence)
- Number of international partners/participation opportunities
- Commercial value of ISRU activities
- Launch mass margins
- Surface power margins
- Annual logistics (consumables and spares) margins following human lunar return
- Total crew-days following human lunar return
- Crew-days devoted to science activities/exploration (IVA and EVA separately)
- Radius of explorations (robotic and human)
- Human population size at HLR + 10 years, HLR + 20 years, HLR + 50 years

Additional References

- Richard W. Orloff, *Apollo by the Numbers: A Statistical Reference*, NASA SP-2000-4029, NASA History Division, Washington, DC, 2000.
- NASA Office of the Inspector General, “NASA’s Plans for Human Exploration Beyond Low Earth Orbit,” Report No. IG-17-017, Washington, DC, April 13, 2017.
- Robert Shishko. “Human Spaceflight Architecture Model Data Dictionary, 1.0”, [on-line document]. http://hdl.handle.net/2014/45707.
- Robert Shishko, Hoppy Price, Brian Wilcox, et al., “An Affordable Lunar Architecture Emphasizing Commercial and International Partnering Opportunities,” IEEE Aerospace Conference, Big Sky, MT, March 2018.