

LEO Commercialization Concept

Vision & Approach

Vision: To make living and working in space commonplace as a means to sustained human deep space exploration and for the improvement of life on Earth.

Approach: Build, launch, and operate a commercial space station to follow the ISS.

Imperatives: Maintain US leadership in space by providing continuous access to LEO. Create a robust LEO market for goods and services produced in space. Provide a sound and reliable transition from ISS to a commercial human rated platform for astronauts, research, manufacturing and other markets.

Concept Image



Team Description

Axiom Space (Lead)

Responsible for all aspects of the architecture, design, development, systems engineering, operations and safety

Major Subcontractors

- TASI
- KBRwyle/SGT
- Intuitive Machines
- Other teaming agreements in work

In collaboration with:

- NASA
- CASIS
- The ISS partner nations

Current investors:

- Hemisphere Ventures
- Starbridge Venture Capital
- Balfour Capital

Schedule

Phase 1: Provide flight opportunities to ISS for commercial astronauts including mission planning, training, operations, logistics, utilization and transportation. **2020 – 2023**

Phase 2: Launch Axiom modules to ISS for early construction of Axiom Station. Expand operations, crew, research, manufacturing and exploration capabilities. Gradual transfer of work and hardware on ISS to Axiom modules. **2023 – ISS EOL**

Phase 3: Axiom Station operating independently following separation from ISS. **ISS EOL -**

December 11, 2018

STUDY TEAM

BLUE ORIGIN TEAM

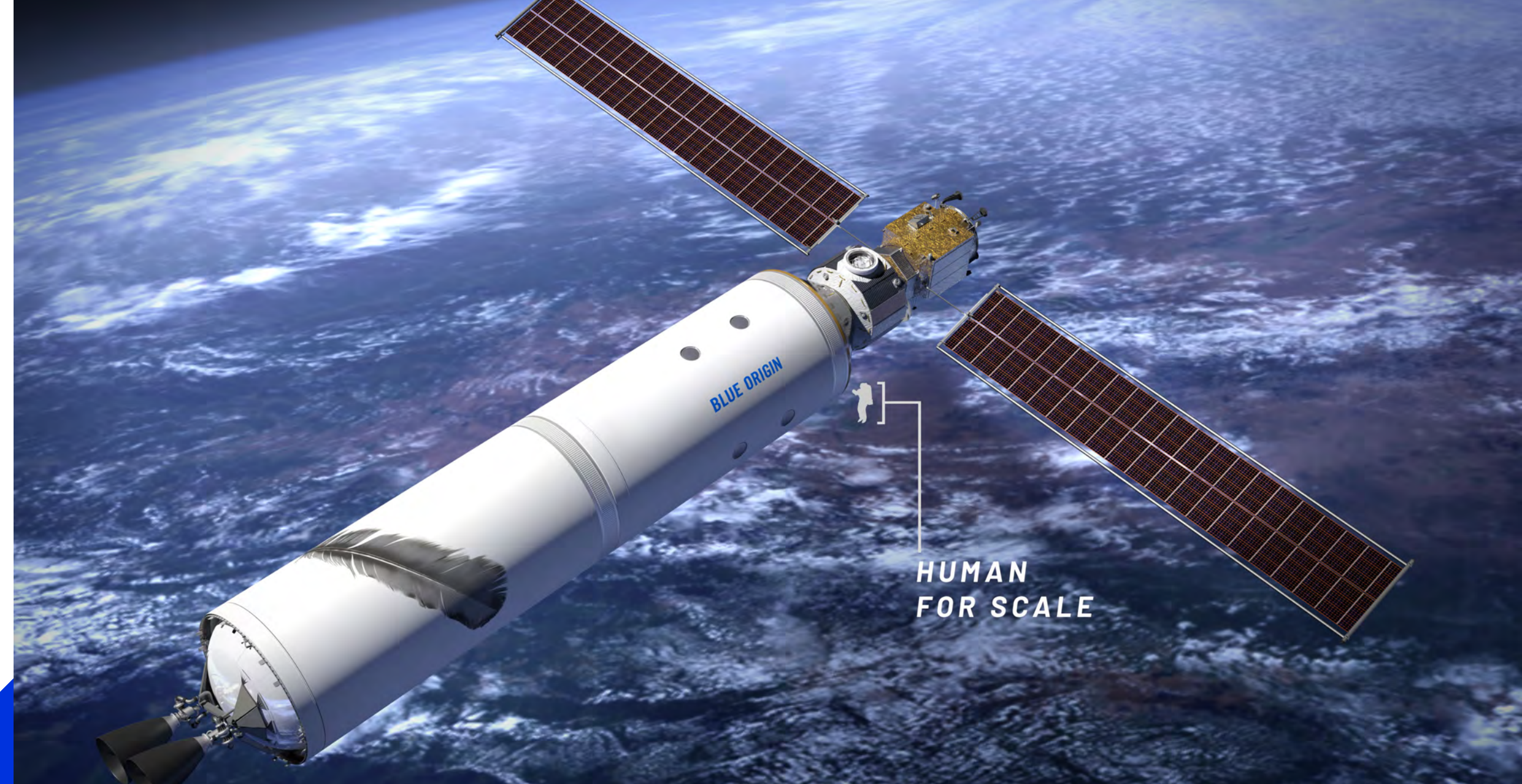
Leading system architecture development and systems engineering including evaluating ECLSS, power systems, structural design, propulsion, and concept of operations

JOHNSON NANOVENTURES

Contributing to development of habitat architecture, configuration, and in-space operations

BRYCE SPACE TECHNOLOGY

Performing research into potential commercial LEO markets



APPROACH

MARKET-DRIVEN DEFINITION

Determine likely markets through analysis of previous studies, interviews, demand-driven market analysis

Define market-based technical requirements (e.g. volume, cost, power, utilization) that close a sustainable commercial business case

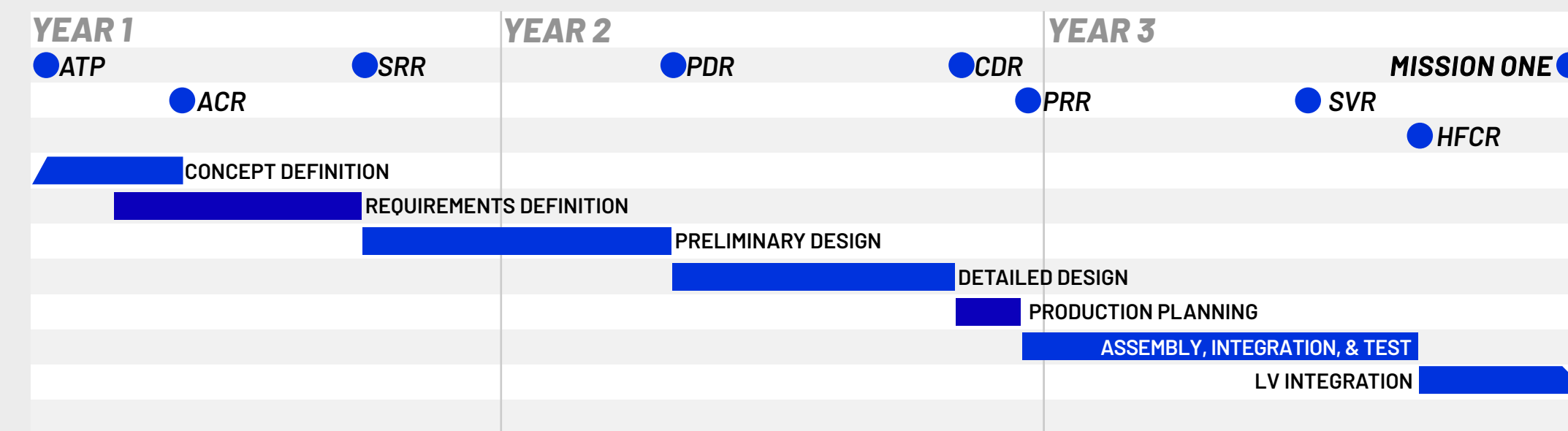
INVESTIGATE HABITATS

Investigate habitats based on a combination of commercially available hardware and Blue Origin manufacturing capabilities, with innovations to reduce development and operational costs by an order of magnitude

ENABLE RAPID PATH TO NEW VENTURES

Leverage Blue Origin's unique breadth of suborbital and orbital capabilities, empowering startups with a faster path to de-risk and deploy innovative and disruptive commercial LEO ventures

Path to LEO Commercial Habitat



ACR
Architectural
Concept Review

PRR
Production
Readiness Review

SVR
System
Verification Review

HFCR
Human Flight
Certification Review

Roadmap to Commercialization of Low Earth Orbit

Vision:

- ISS continues its mission as long as it is able to operate safely and reliably serving as a foundational element to future exploration and the economic development of low-Earth orbit.
- ISS serves as the pathway to increase commercial use of LEO by incubating revolutionary new industries (e.g. space manufacturing) and providing continuity required by commercial markets.

Study Approach:

- The Boeing Company will perform market research, study a range of technical concepts, conduct business analysis and examine the role of Government and evolution of the International Space Station all in context of the economic development and a self-sustaining commercial human spaceflight marketplace in LEO.

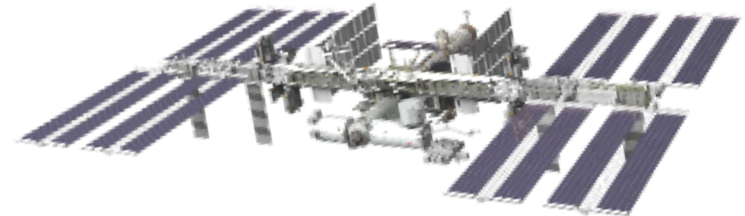
Team Description:

- Boeing is a global aerospace leader providing spaceflight hardware to the commercial market. The Boeing study team includes industry leading partners with a range of business and technical commercialization expertise.



Concept Image:

- Boeing will examine the viability of multiple technical concepts and assesses the respective capabilities against market demand.



ISS Attached Module



Crew Tended Free-flyer



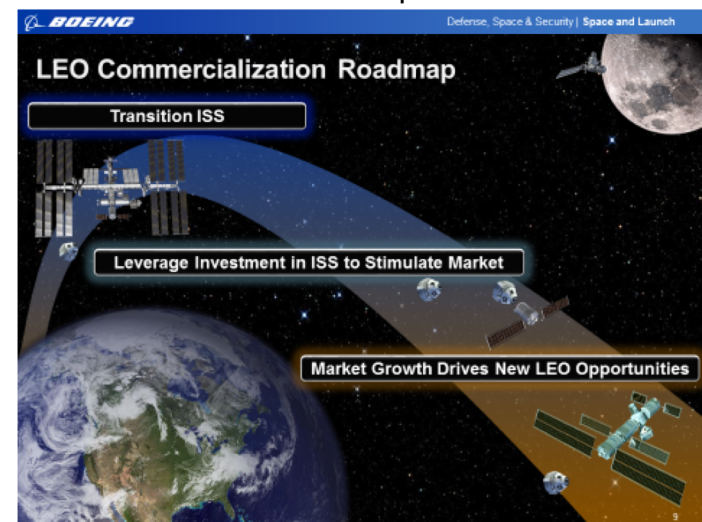
Multi-Element Platform



Large Multi-Element Platform

Schedule:

- The economic development of LEO embraces the evolution of the ISS and government actions to grow the private sector demand for services in space.



Vision and Approach

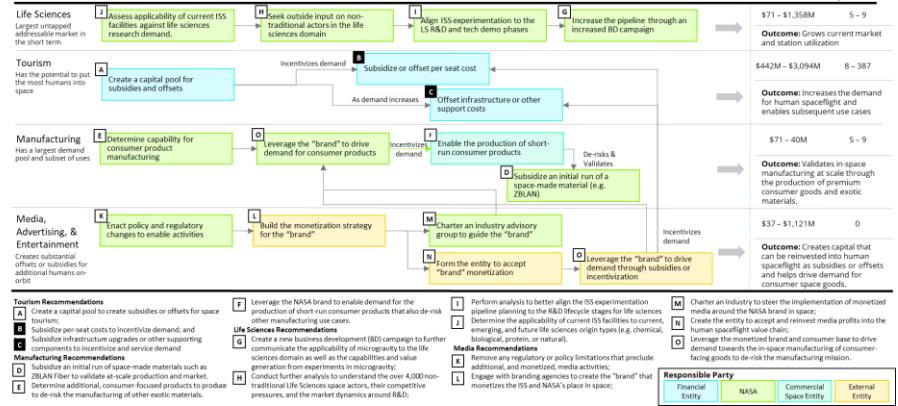
- The proposed partial study will provide a **roadmap** with **insights and recommendations** on the viability of Human Spaceflight and the evolution of the commercial space economy. The study includes a **current and future state analysis** of HSF in commercial LEO operations.
- Through **research, economic, and technical analysis**, Deloitte will deliver this framework to NASA along with a detailed analysis of the current and potential **roles of Government**.
- The outputs include a roadmap, final report, and supporting data files.

Team Description

- With a combined **80 years of technical expertise**, we have experience in developing actionable strategies that address complex regulatory, administrative, and governance requirements.
- Our experts have launched rockets, deployed satellite remote sensing systems, implemented global telecom solutions leveraging commercial satcom, analyzed the commercial space economy, and secured private investment for space technology companies.
- Our team includes Kirsten Armstrong and Spacexchange.

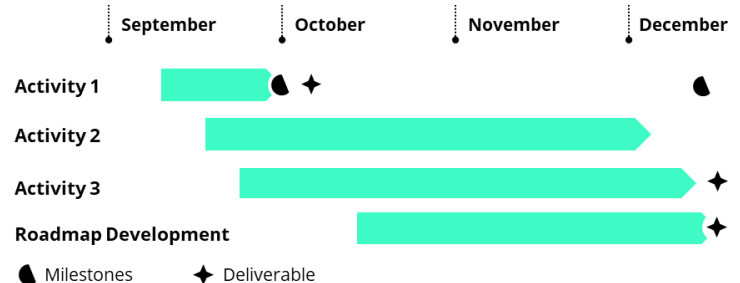
Roadmap

This roadmap details the 15 specific recommendations that focus on developing commercial opportunities and enabling additional human spaceflight demand. While the recommendations are linked together to provide paths and methods for incentivizing demand, these recommendations are meant to provide a collective path towards increased value generation in LEO.



Schedule

- Deloitte's project is defined as a partial study, delivering a roadmap and recommendations. Therefore, we do not have schedule milestones such as PDRs and CDRs.
- Our planned delivery is Dec 21, 2018.



KBRwyle LEO Commercialization Study Quad Chart

KBRwyle Team

Vernon McDonald, PhD- Senior Vice President KBRwyle
 Laurie Labra – Program Manager KBRwyle, IMOC/MSOC
 Michael Lembeck, PhD – Cepstone, LLC
 Eric Morano, PhD – KBRwyle Department Head, FILMSS Planning-
 Education and Public Outreach
 Bruce Pittman – Director, Commercial Space Development,
 OffWorld, Inc.
 Dan Heimerdinger, PhD- President and CEO, Exostrategies
 Evelyn Vance, PhD- Chief Operating Officer, Exostrategies
 Floyd Hamilton – KBRwyle Department Manager, IMOC
 Shannon Melton –KBRwyle Program Integration Manager, REMIS
 Bus. Dev.
 Jim Kukla – KBRwyle Vice President, Business Development
 Ronnie Doud- KBRwyle Senior Manager, Contracts

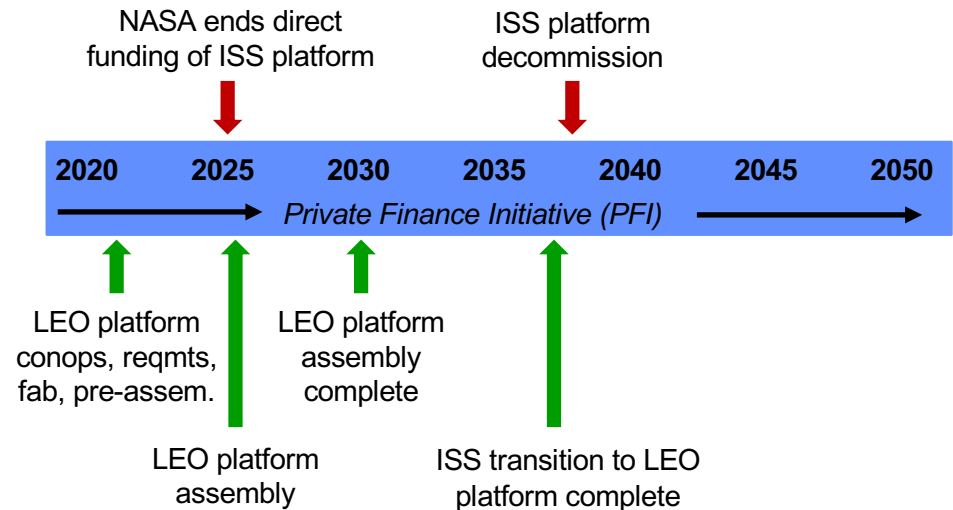
Technical and Commercial Approaches

- 1) Analyze current and prior business in LEO habitats
 - *Establish indicators of business success*
- 2) Evaluate the market space for LEO habitats
 - *Identify government and commercial market requirements*
 - *Determine constraints to market growth such as logistics*
- 3) Define business edge case definitions and evaluations
 - *Determine best alignment of market, risks, and costs with potential revenue*
 - *Evaluate market requirements against habitat capability*
- 4) Assess business cases for use of Public Private Partnerships (PPP) to assist Government in achieving financial objectives
 - *Evaluate business case attributes against PPP attributes*

Proposed Business Cases

- 1) Commercial operator (ISS)
 - Contractor invests in marketing excess ISS capacity, adds logistics, and/or crew augmentations
- 2) Commercial operator (ISS) with platform sized to logistics
 - For-profit operator invests in marketing, maintenance, operations, logistics, crew augmentations
- 3) Commercial operator (ISS) leasing platform to other operators
 - For-profit operator invests in marketing, maintenance, IP removal; potentially invests in other operator modules
- 4) Contractor operator (ISS/New LEO Platform)
 - For-profit operator invests in marketing excess ISS capacity and crew support as a transition platform; Invests in assembly, maintenance, ops, marketing of new LEO platform

PFI Conceptual Timeline



Lockheed Martin LEO Commercialization Study



Vision & Approach:

- Lockheed Martin envisions a vibrant LEO marketplace with both domestic and International government and commercial customers
- Our approach:
 - Employ alternative business models that enable a transition from a government owned and operated platform to a lower cost commercial marketplace that maintains National Lab status for scientific pursuits, assured government access, and International Partner objectives
 - Down select between a range of solutions for ISS evolution to better position for commercialization of a habitable platform in LEO
 - Encourage US private sector towards LEO through stable government investments, streamlined process, and reliable launch cadence along with near term risk reduction demonstrations of new technologies that will catalyze activity in LEO (e.g. ISMA)

Concept Image:



Team Description:

- Lockheed Martin is a global security and aerospace company that provides U.S. and international customers with capabilities that have defense, civil, and commercial applications
- Our team includes:
 - Deep Space Systems, Inc. – Communication Architectures
 - Lunar Resources, Inc. – In-Space Assembly
 - Made In Space – In-Space Manufacturing & Assembly

Schedule

Major Tasks/Activity	Calendar Year							
	2018	2019	2020	2021	2022	2023	2024	2025
<u>Risk Reduction</u> LM ISMA		ISMA Planning	ISMA Ground Demo	ISMA Flight Demo			On Ramp Commercial Applications	
MIS ZBLAN	In-Space 3D Printing	ZBLAN Flight Demo		ZBLAN Extended Flight Demo				
LRI In-Space Vacuum Deposition		Vacuum Deposition Flight Demo			Visible Mirror On-Orbit Production			
<u>Privatization & Evolution</u>				Transition Period				Commercial Operations

LEO Commercialization Study – McKinsey

Vision & Approach:

- **Market Assessment:** Take an economic view of how the market for human spaceflight activities in LEO will evolve based on an independent assessment of demand drivers, and anticipated supply of LEO habitable space
- **Suggested Actions:** Develop levers, or actions, with quantifiable impact that preserve optionality for commercial space while mitigating risk to NASA that the market does not mature as readily as expected and it is left in a situation where it has a significant cost burden in order to preserve access to human spaceflight in LEO
- **Road Map:** Outline road map that includes “revisit points” where NASA can refresh economic analyses based on market evolution, how to run the suggested action, and how to manage uncertainty in the program

Key Findings:

- Expect NASA, other sovereign astronauts, and tourism to be the largest drivers of demand for habitable space (~90% of demand)
- Total expected demand in 2025 (~6 people full-time) could be served by a single ISS-capacity module
- Left to its own devices, the market may develop a mismatch between supply and demand (too many modules, not enough occupants or vice versa)
- NASA could aim to take specific actions that (a) stimulate demand for human spaceflight and other LEO industrial applications; (b) encourage the number of habitats launched to match demand through greater transparency; and (c) provide a conducive environment for US commercial activities in LEO

Team Description:

- McKinsey & Co. is a global management consulting firm that serves a broad mix of private, public, and sector institutions
- Analysis draws on many sources:
 - Interviews with 42 experts, well-versed in 18 areas of potential commercial demand (e.g., space tourism, pharma R&D, fiber optics, sponsorships, satellite servicing, asteroid mining), venture capital, and the space industry/technologies
 - >40 third-party reports and data sources
 - McKinsey internal databases and tools (including space start-up and investment database)

Levers for Action:

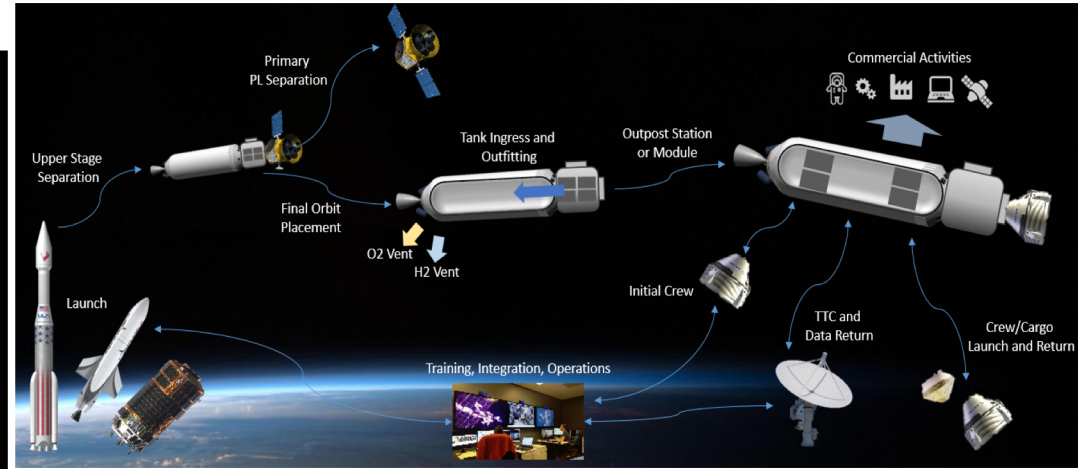
- NASA could begin enacting programs to (a) stimulate demand and drive down launch costs; and (b) support and foster the development of commercial habitats
 - One program is a public-private partnership with commercial launch providers to accelerate the timeline of high-operating-tempo launch services to the ISS, resulting in reduced launch costs and stimulating commercial demand
 - The other program is an industry partnership to evolve commercial habitats (with lower operating costs than the ISS) through docking port access, technical assistance, and an early commitment for NASA to become the “major customer” of one or more habitats



LEO COMMERCIALIZATION STUDY - NANORACKS

Vision & Approach

- Development of a set of commercial ecosystems comprising repurposed upper stages from multiple providers, to ensure market and U.S. Space Program resiliency
- The technique of reusing existing on-orbit hardware enables a lowering of prices, and an opening of access to a broader array of commercial customers
- NanoRacks does not propose seeking a “killer app” but facilitating a “killer ecosystem”
- Multiple Outposts, Multiple Orbits, Crewed & Uncrewed, attached and detached from ISS



Team Description

- **Team Economic Rationale:** NanoRacks strongly believes that a single-point solution to LEO Commercialization is unsustainable – just as there must be multiple crewed vehicles able to access the ISS, there must be multiple providers for usable on orbit commercial space. This requires a vibrant market of suppliers and buyers.
- **Ecosystem Approach:** NanoRacks Surveyed the market to find capable, promising contributors to the Outpost-facilitated LEO Commercial environment.
 - **Hardware Providers:** ULA, Stratolaunch, Space-BD
 - **Service Providers:** Olis Robotics, DSI, KSAT, Altius, TVA
 - **Users:** Space-BD, SA, MIS, Lunar Resources

Projected Schedule – Centaur Specific

Demo / Op	Upper Stage	Crewed	2019	2020	2021	2022	2023	2024	2025
Demo	Centaur 3	Uncrewed		█					
Demo	Centaur 3	Uncrewed			█				
Op	Centaur 3	Uncrewed				█			
Demo	Centaur 5	Uncrewed					█		
Op	Centaur 5	Uncrewed						█	
Op	Centaur 3	Crewed							█
Op	Centaur 5	Crewed							█
Op	Centaur 5	Crewed							█
Op	Centaur 5	Crewed							█

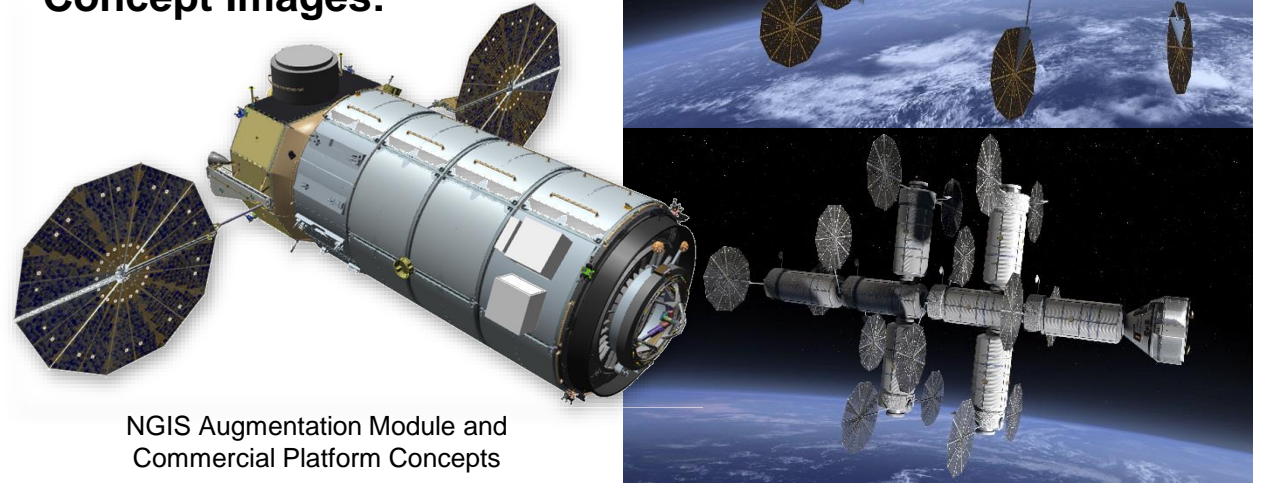
- **2019 – 2022:** Technical concept reaches test phase; first uncrewed platforms perform orbital tests and function as basic science platforms
- **2022 – 2025:** Technical concept reaches maturity; multiple uncrewed platforms in orbit conducting commercial activities with full ecosystem of services; crewed platforms performing tourism and other commercial astronaut functions

NGIS Study for the Commercialization of LEO

Vision & Approach:

- Evolutionary roadmap using Northrop Grumman Innovation Systems' (NGIS) Cygnus, and Cygnus-derived vehicles, to develop a sustainable LEO market
 - Long-Duration Cygnus: Capable of operations and hosting of commercial payloads as an attached or free-flying module with flights of one year or more
 - Augmentation Module: Cis-lunar vehicle in formulation for NextSTEP-2 adapted for LEO operation with habitation, node, and logistics capabilities
 - Augmenting ISS: Optimize utilization of the ISS by augmenting with AM capabilities with habitable space, outfitting, checkout of cislunar systems, and as the first elements of a co-orbiting, complementary commercial platform
 - NGIS Commercial LEO Station: Augmentation Module-based commercial station to provide complementary services to ISS as a free-flying platform, and the basis for a future evolved commercial platform

Concept Images:




NGIS Augmentation Module and Commercial Platform Concepts

Team Description:


- Five studies performed in partnership with three subcontractors:

 Study #1: Market Analysis of LEO Commercialization Options

 Study #2: Cygnus Applications for Commercialization in LEO

 Study #3: Reconfiguration of ISS

 Study #4: Commercial LEO Space Station

 Study #5: Enabling-Science Using Free-Flying and Att. Platforms

- Additionally, supported Blue Origin and SpaceAdventures on their LEO commercialization concepts using Cygnus and Cygnus-derived vehicles

Schedule:

MANIFEST		2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030																		
CISLUNAR VARIANT	GATEWAY ELEMENTS					AM-U			AM-H																						
	GATEWAY LOGISTICS						Gateway-1	Gateway-2	Gateway-3	Gateway-4	Gateway-5	Gateway-6	Gateway-7																		
LEO VARIANT	ISS LOGISTICS	NG-11	NG-12	NG-13	NG-14	NG-15	NG-16	NG-17	NG-18	NG-19	NG-20	NG-21	NG-22	NG-23	NG-24	NG-25	NG-26	NG-27	NG-28	NG-29	NG-30	NG-31	NG-32	NG-33	NG-34	NG-35	NG-36	NG-37	NG-38	NG-39	NG-40
	NGCLSv2 ELEMENTS																														

*ISS/NGCLSv2 AM-L Missions Capable of Flying To/Between Both Destinations

Legend: ▲ Cygnus ▲ Long-Duration Cygnus ▲ AM-H ▲ AM-U ▲ AM-L

LEO-NRA-023

- Long-Duration Cygnus Flights 1-per-year through CRS2
- First flight of AM-H to ISS on NG-18/19 in 2022, providing cargo, habitable space, and checkout of systems for cislunar Gateway support
- Separation from ISS in 2025 to create a free-flying, co-orbiting, complementary platform

LEO Commercialization – SNC’s Flexible, Multi-Use Platform Architecture for LEO Services

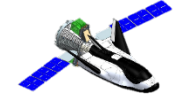
Vision & Approach:

- Modify Dream Chaser Cargo for powered payload and crew configurations; upmass, downmass, and human transport services
- LEO platform for long duration activities, capable of hosting partner modules or ISS elements with additional life past decommission
- Modular, flexible, and reuse oriented architecture with services focus- adaptive to future market directions
- Utilize LEO as an integration point for all Cislunar activities in a hub and spoke network-reduce overall costs through economies of scale

Concept Image:



Crewed Dream Chaser

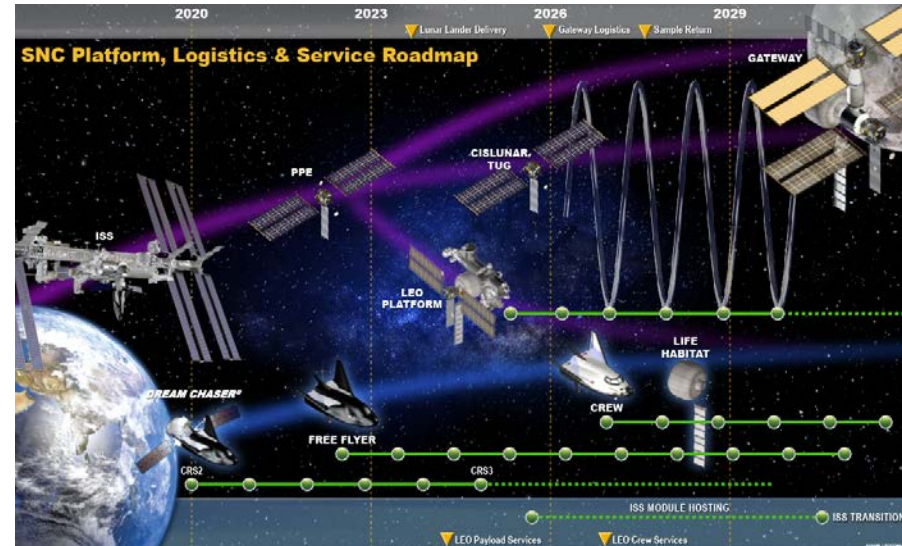


Uncrewed Dream Chaser

Team Description:

- Prime – Sierra Nevada Corp
- Key Partners – Platform Development
 - Lockheed Martin, Aerojet Rocketdyne, L3, Draper, ASI, MDA, ILC Dover
- Key Partners – Operations
 - SNC is actively working with domestic and international companies to develop an operational approach to address the global market and maximize revenues

Schedule





Study for the Commercialization of LEO

Vision & Approach:

- Evolutionary roadmap consists of a three-staged transition from the current ISS operational paradigm to an entirely independent private space station by 2028
 - Stage 1 - ISS Stand-alone and attached – re-purposed Cygnus delivery vehicle
 - Stage 2 - ISS Attached – Add node and multiple Cygnuses
 - Stage 3 - ISS Attached until Free-flying – add large hab, logistics module and capability as needed
- Provide commercial services to private sector and government clients, primary markets would include:
 - Government crew and science programs
 - Private astronauts and media
 - In-space manufacturing and satellite related services

Concept Image:



Team Description:

- PI is Tom Shelley, President, Space Adventures
- Space Adventures' team includes:
 - Made in Space
 - NanoRacks
 - Radiant Solutions.

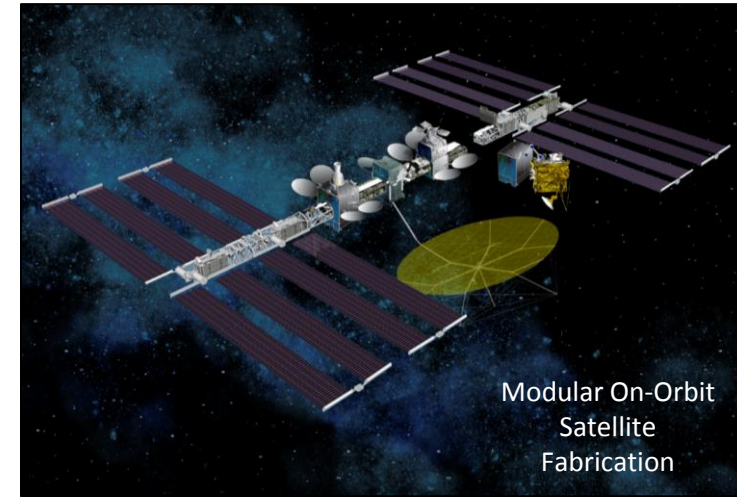
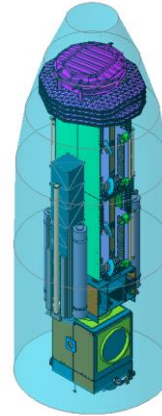
Schedule

- Stage 1 – 2019 to 2023 – Commercial Start-up
- Stage 2 – 2024 to 2026 – Commercial Phase-in
- Stage 3 – 2027 to beyond – Commercial Growth

Approach

- Market Demand: GEO Data/Broadband satellites addresses increasing demand for established broadband, mobile, flexible communications, and GEO TV satellites as market continues to grow (emerging markets for LEO satellites and on-orbit servicing are economic upsides)
- Business Case: LEO On-Orbit Satellite Assembly using LEO platforms for Modular Subsystem Assembly with future possible follow-on Modular Upgrades to Subsystem Assembly & On Orbit Servicing
- ISS is critical for scaled demonstrations and concept maturation for risk reduction and investment confidence
- Business case closes with 100% commercial sales w/initial gov. investment
- Budget for platform closes business case and not specific to specific provider
- External assembly of satellites of unconstrained size, construct structures, payloads, antennas of unprecedented capacity
- Commercial launch and tugs for deployment, including LEO to GEO tug services
- Business structure using private multi-use platforms, assumes private sector/institutional investment financed with opportunity to diversify risk with partnerships

Concept Image



Modular On-Orbit
Satellite
Fabrication

Team Description

Lead: Space Systems Loral (SSL) Palo Alto, CA

Partners/Subcontractors: SSL Robotics (Pasadena & Houston), Existing Commercial Satellite Supply Chain, Existing commercial launch systems, Habitat Developers (Nanoracks, Space Adventures)

Customers: Satellite Owner / Operators: Telesat, Intelsat, SES, Eutelsat, Optus, Echostar, Asiasat, + ~30 others

Key Investors: Private sector / institutional investment, Commercial Financing, with US Gov. support

