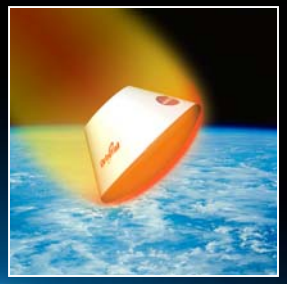
Concept Exploration and Refinement (CE&R)
Concept Area 1 (CA-1) Mid-Term Review



December 1, 2004
Advanced Programs Group
Orbital Sciences Corporation

Looking for the solution
without listening to the problem

is working in the dark

CA-1 Midterm Agenda

Exploration Objectives

Architecture Overview/Definition

System & Element Requirements

Trade Studies & Analysis for Super System & CEV

Technology Requirements

Exploration Programmatic and Technical Risk Assessment

Exploration Objectives

The Primary Governing Document

Goal and Objective

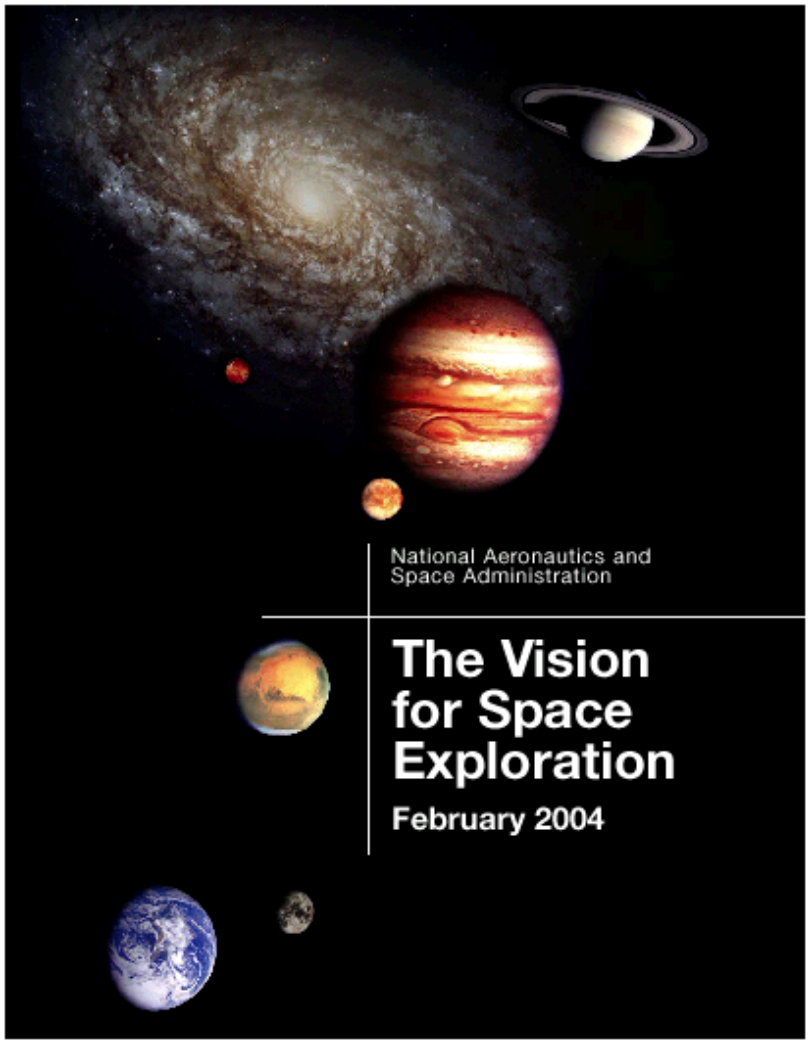
The fundamental goal of this vision is to advance U.S., scientific, security, and economic interests through a robust space exploration program. In support of this goal, the united states will:

–Implement a sustained and affordable human and robotic program to explore the solar system and beyond;

–Extend human presence across the solar system, starting with a human return to the moon by the year 2020, in preparation for human exploration of Mars and other destinations;

–Develop the innovative technologies, knowledge, and infrastructures both to explore and to support decisions about the destinations for human exploration; and

–Promote international and commercial participation in exploration to further U.S. scientific, security and economic interests.



The Recommendations for Implementation

Exploration campaign must be aligned with the findings of the commission to “inspire, innovate, and discover.”

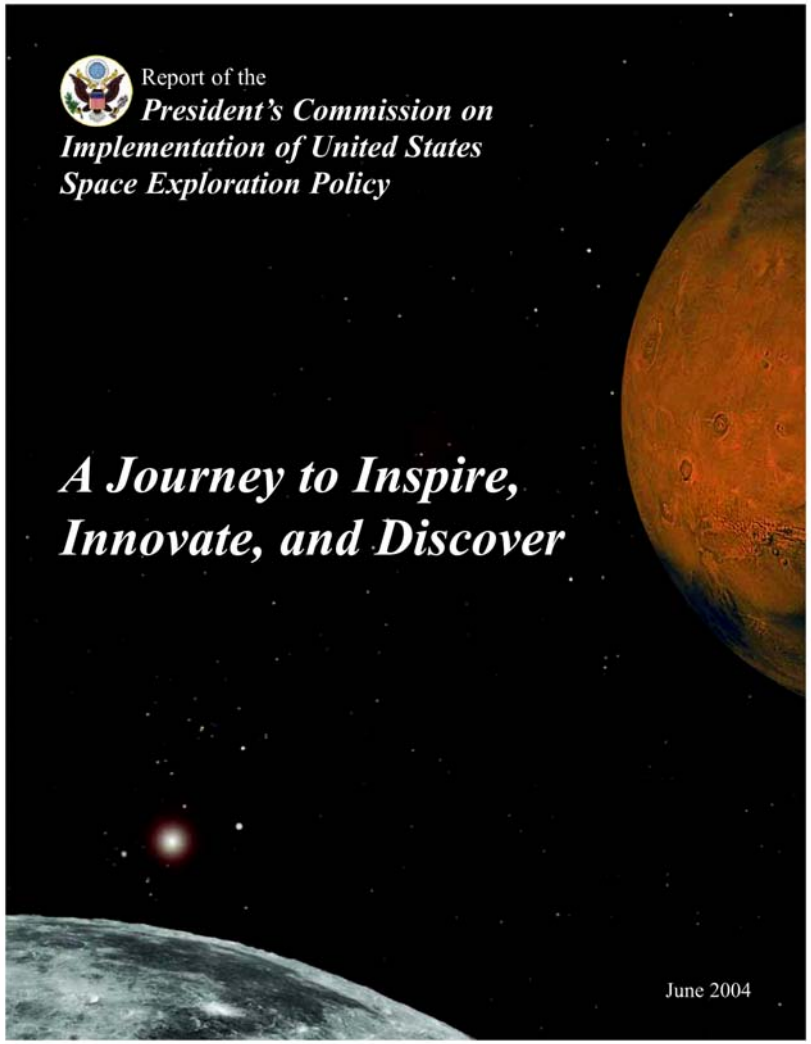
– “… Managed as a significant national priority…”

– “NASA’s relationship to the private sector, its organizational structure, business culture, and management processes - all largely inherited from the Apollo era - must be decisively transformed to implement the new, multi-decadal space exploration vision.

– “The successful development of identified enabling technologies will be critical to attainment of exploration objectives within reasonable schedules and affordable costs.”

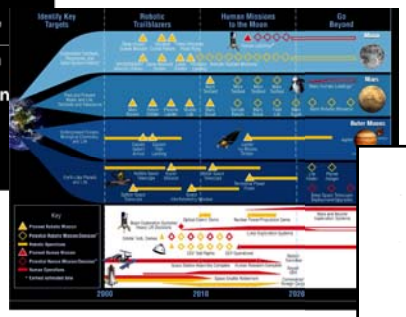
– “… Regular, visible demonstrations of ongoing progress and success;”

– “… An affordable plan that does not require huge peaks in annual funding…”

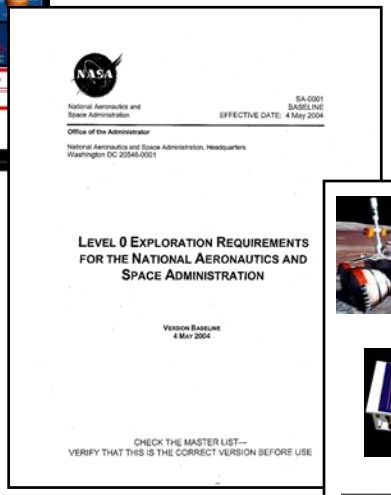


Exploration Systems Flow

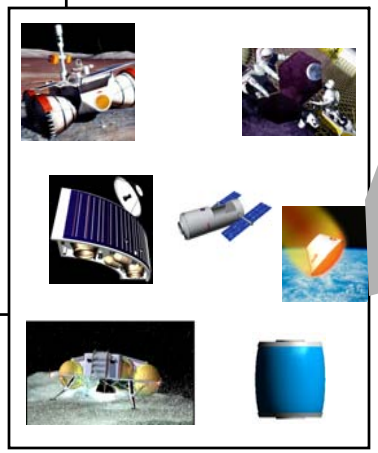
Vision



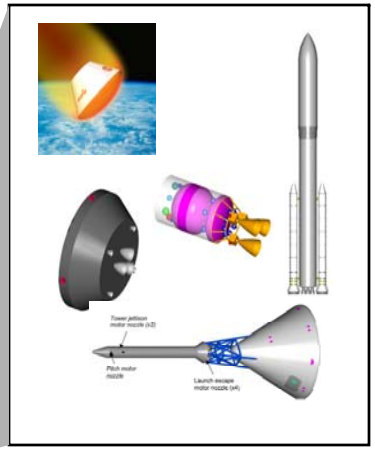
Missions



Requirements



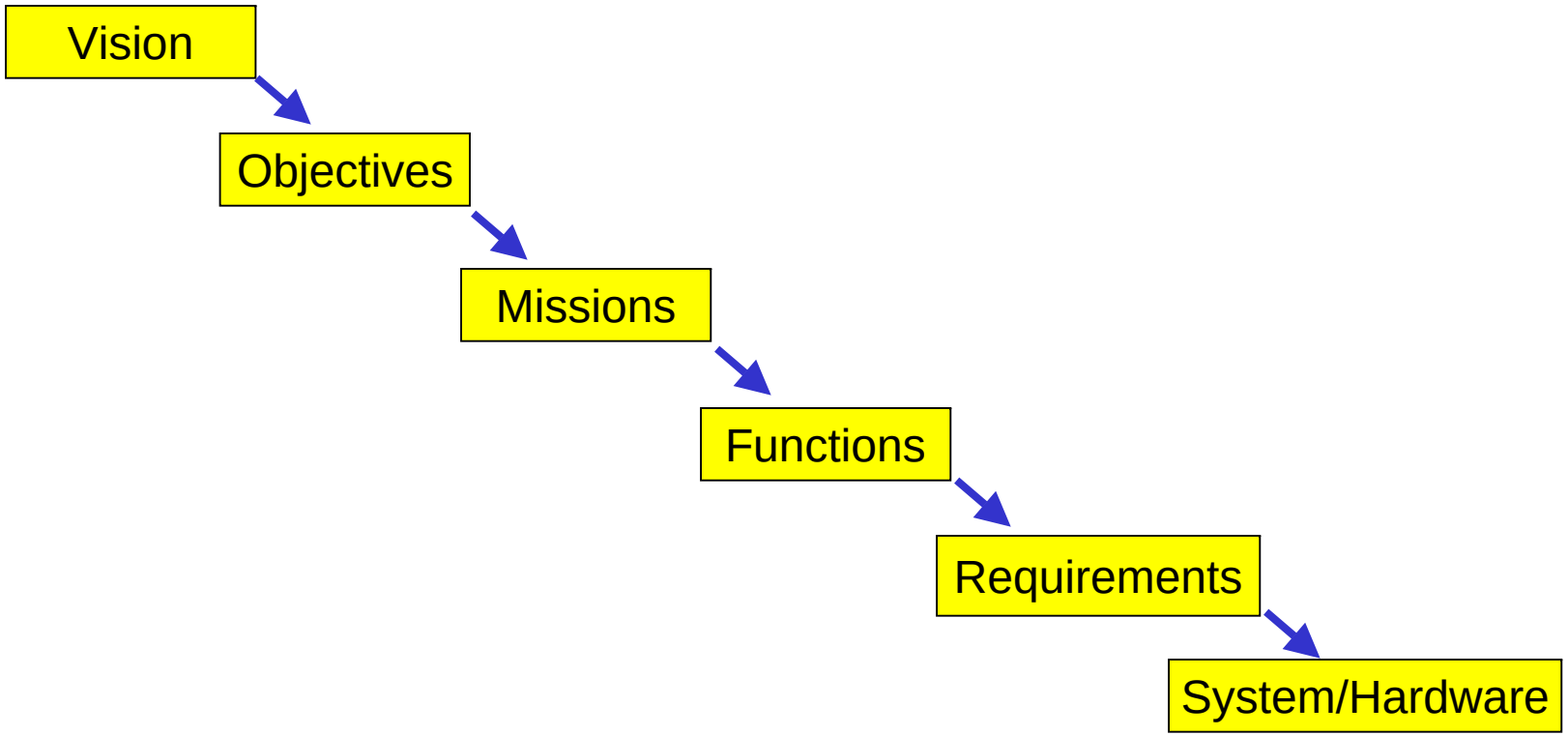
Exploration System (CA-1)



CEV Development (CA-2)

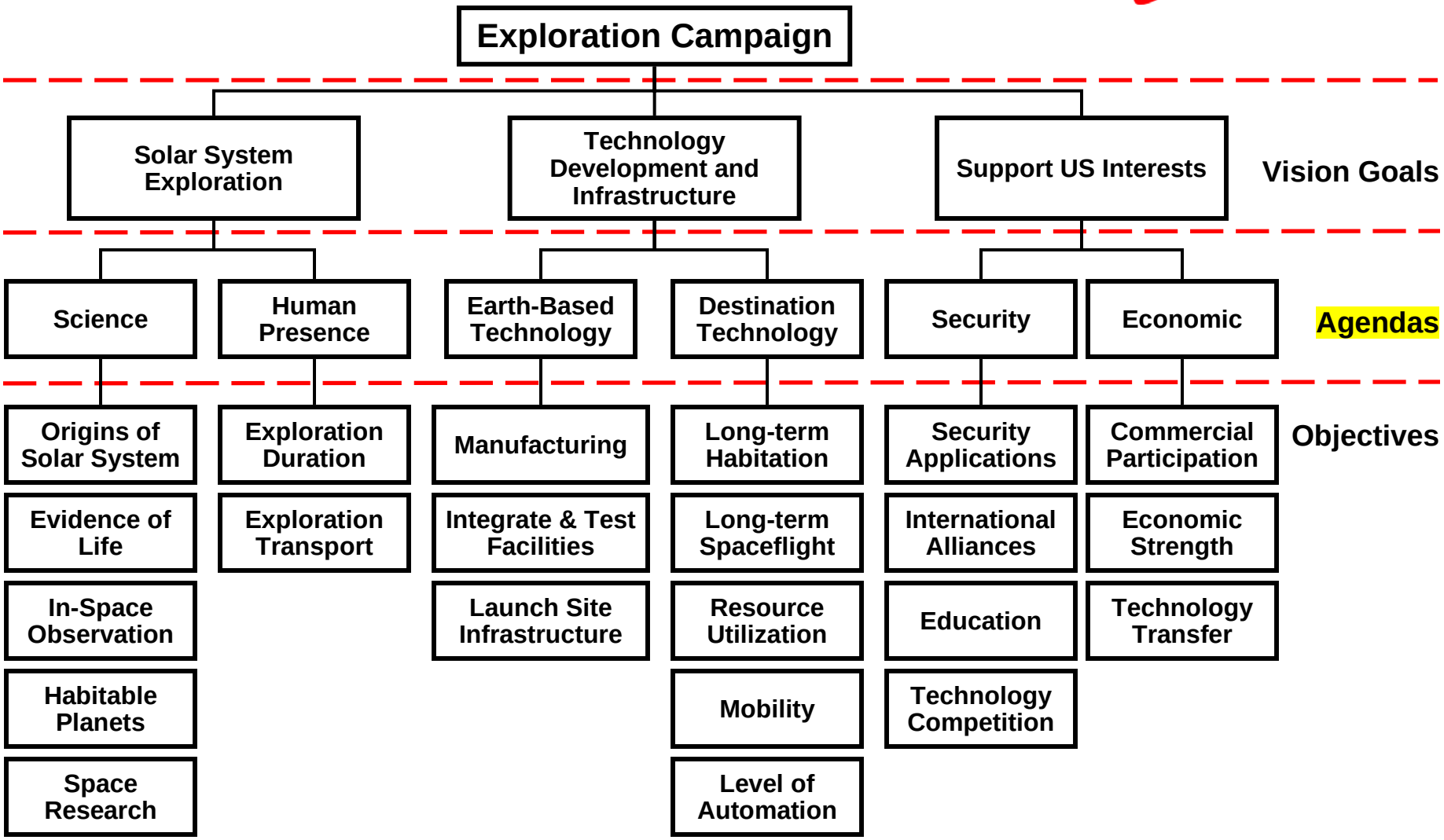
The System of Systems is Derived From and Subject to the Exploration Vision

Exploration Objectives - Decomposition and Maturation



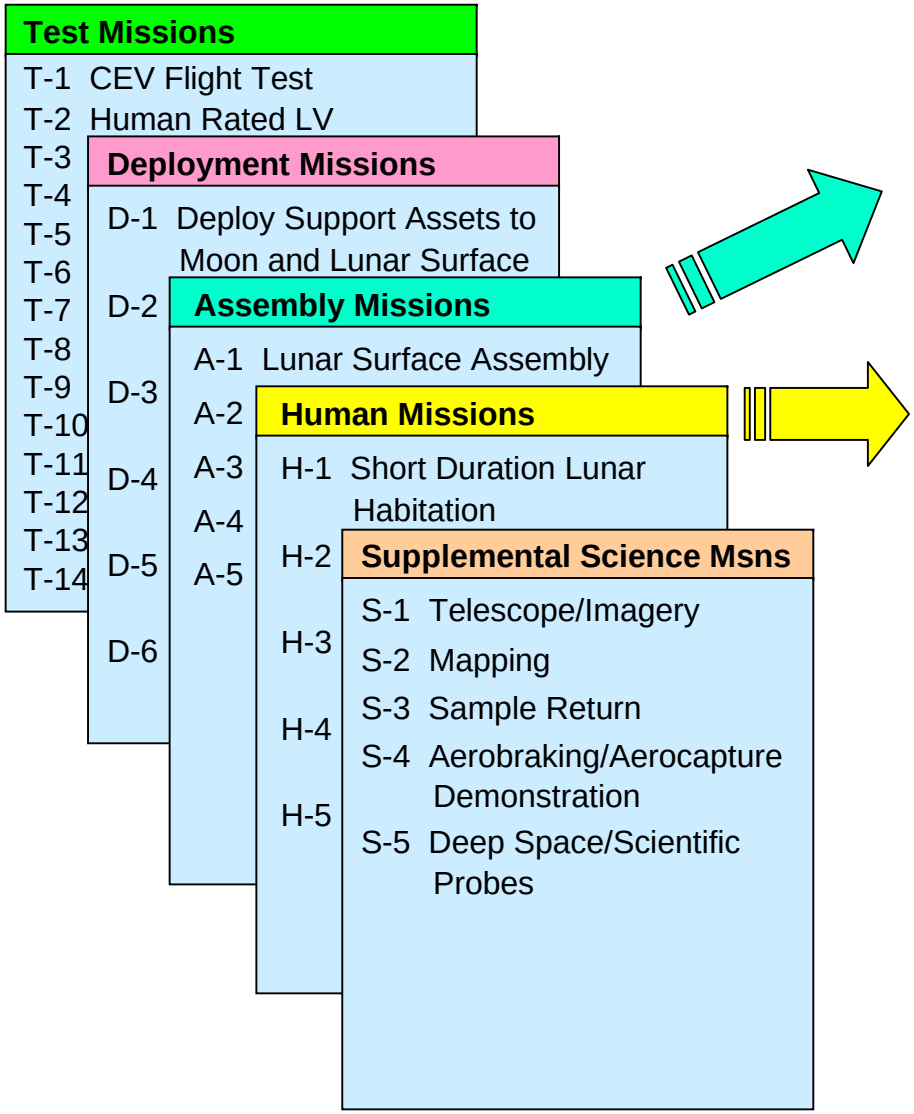
Exploration Vision is Being Decomposed to System Hardware

CE&R Vision to Objectives



Goals and Objectives are Independent of Spiral

Preliminary Mission Categories to Meet Objectives



Assembly

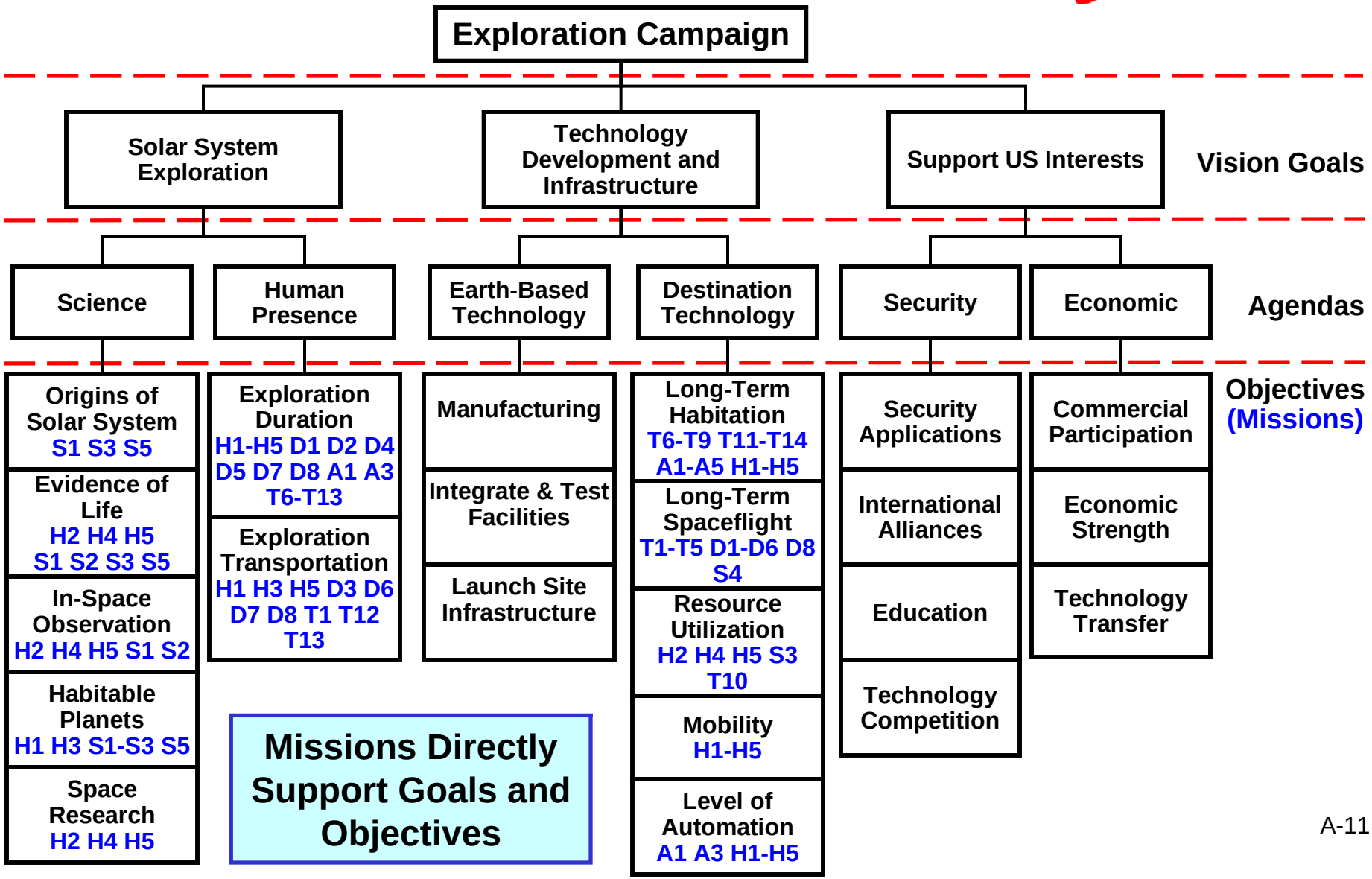
Missions With a *Primary* Objective of Major Infrastructure Assembly Performed by Humans or Robots

Human

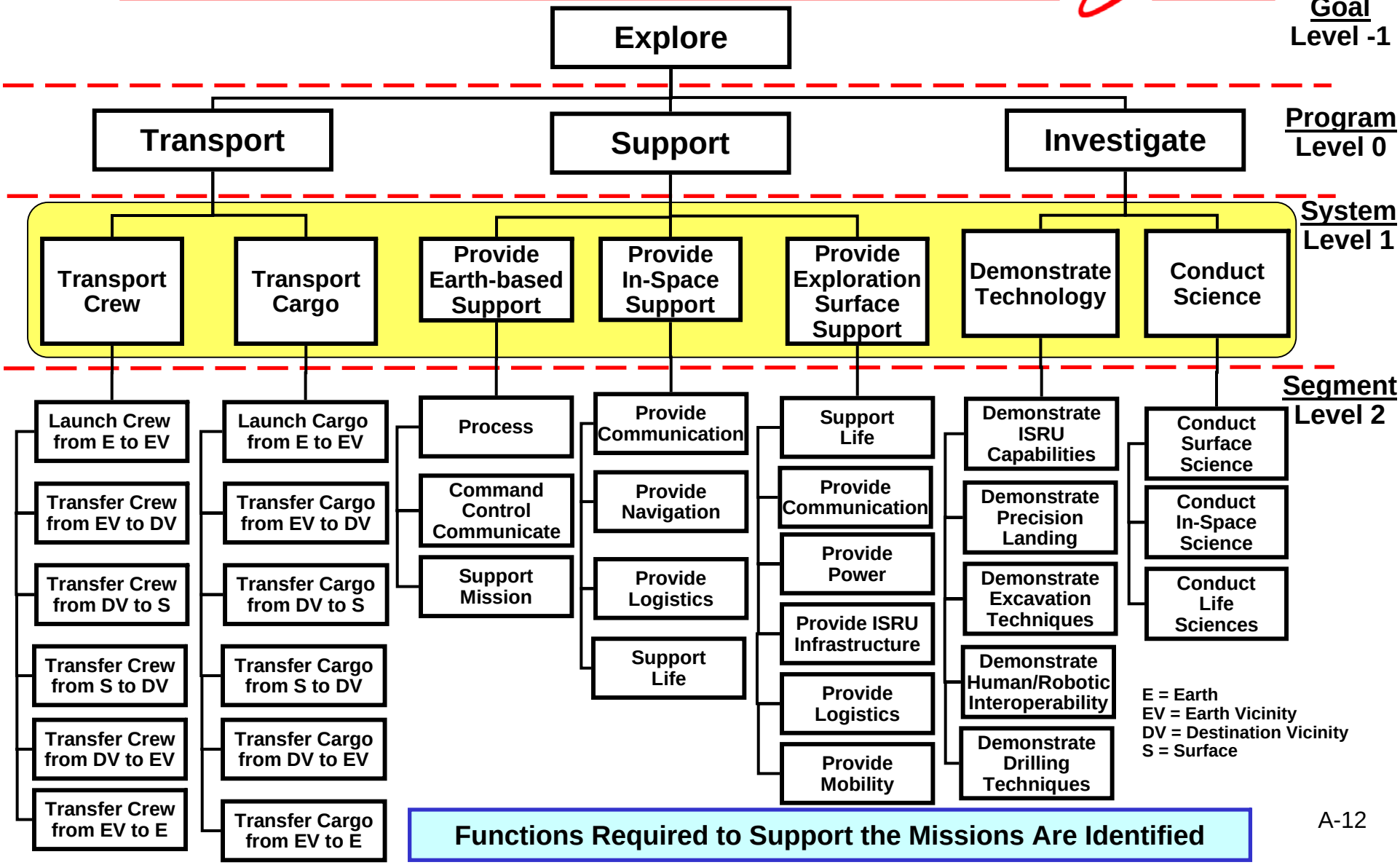
Missions With a *Primary* Objective of Demonstrating Short- or Long-Term Human Habitation of a Destination Beyond LEO. Includes the Science Conducted by Humans in Parallel With the Habitation Demonstration

Missions Are Being Developed to Ensure That All Agendas Will Be Satisfied

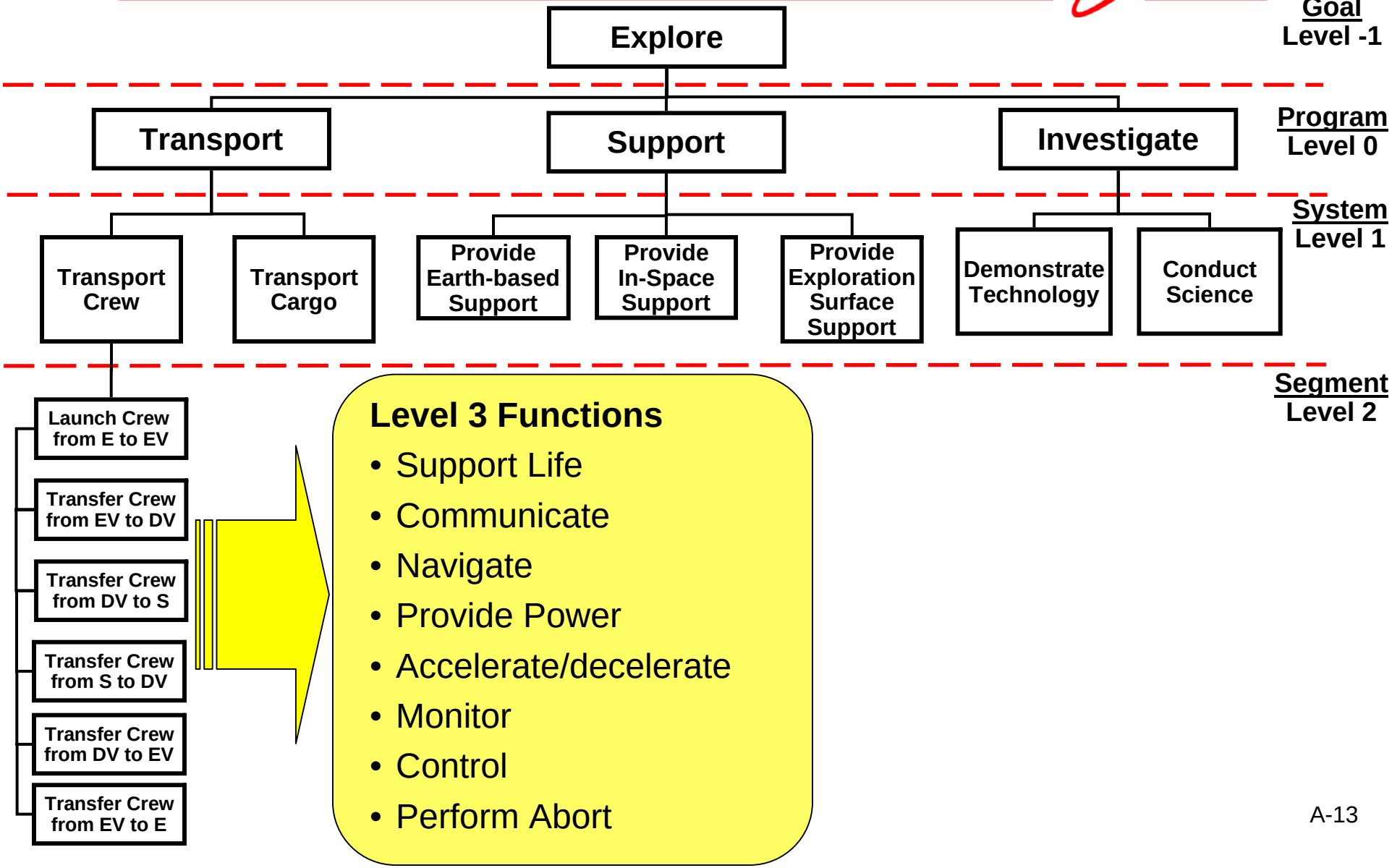
CE&R Vision to Missions



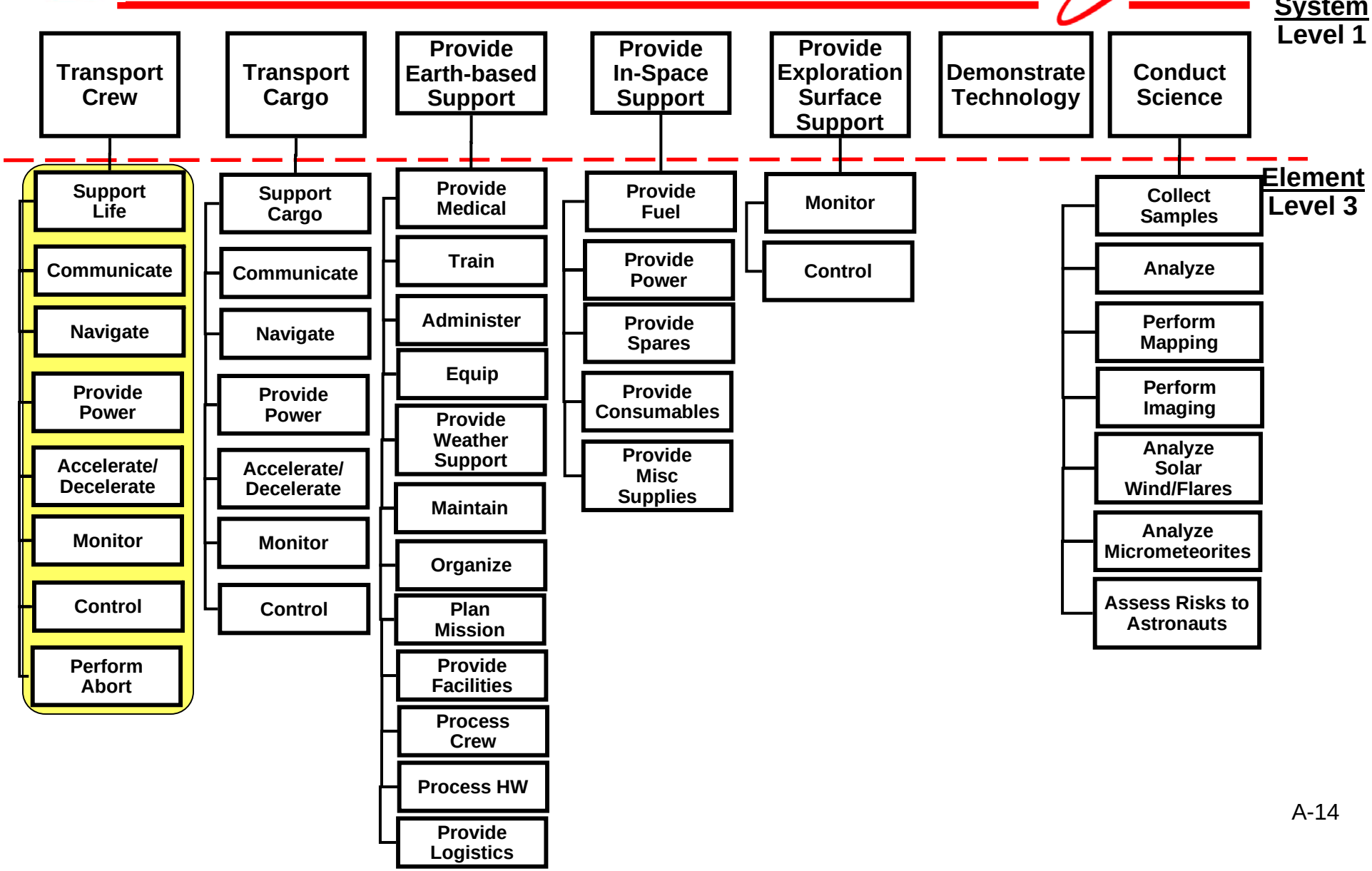
Exploration Campaign
System and Segment Functions



Exploration Campaign
System and Segment Functions



Derived Functions at Level 3

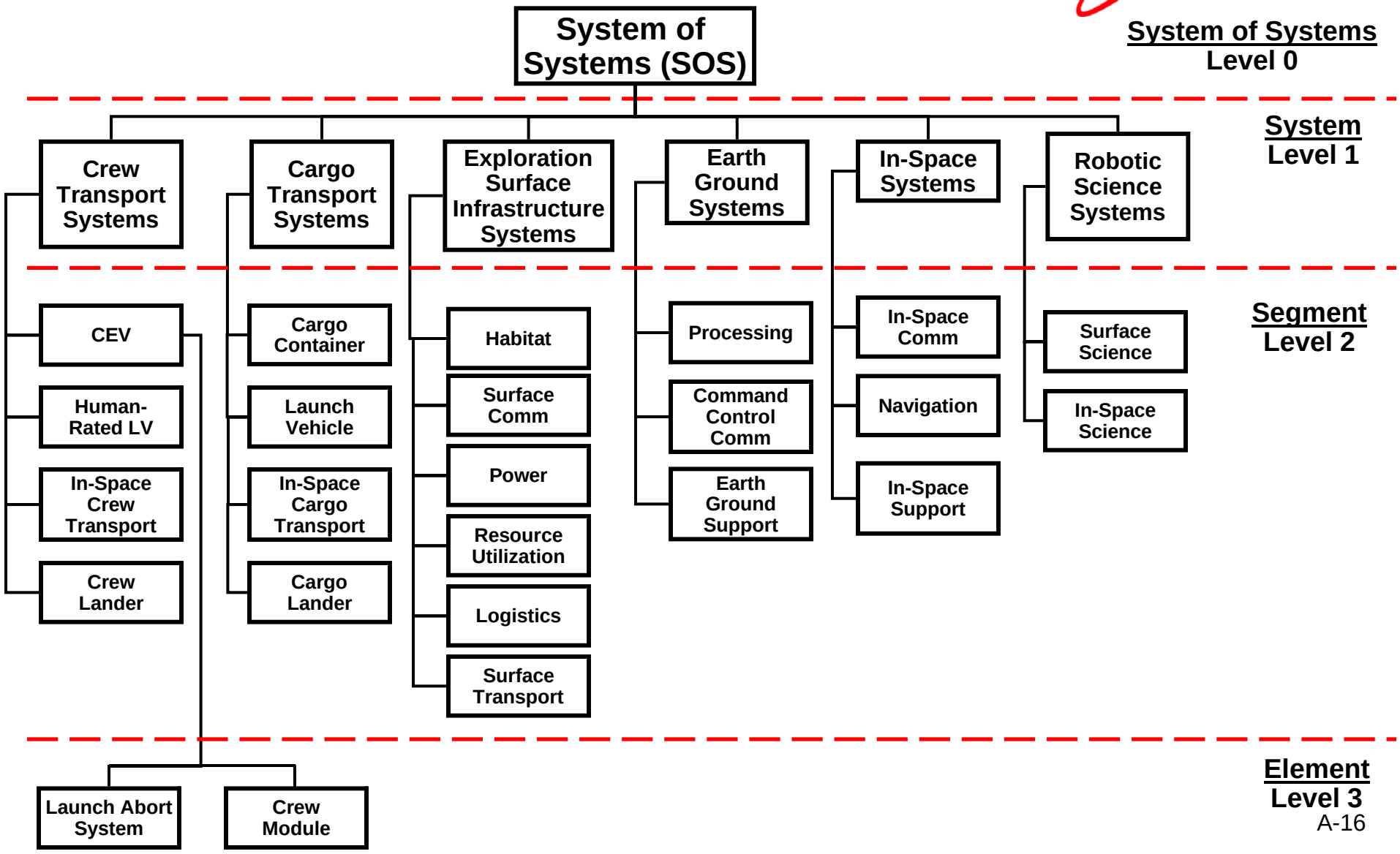


Mapping Functions to Missions

	Program Level 0		Transport											
	System Level 1		Transport Crew											
ID	Category and Mission	Segment Level 2	Transfer Crew to Launch Pad	Launch Crew from E to EV	Transfer Crew from EV to Orbiting Station	Transfer Crew from EV to DV	Transfer Crew from DV to DS	Provide Surface Transport	Provide Surface EVA	Provide In-Space EVA	Transfer Crew from DS to DV	Transfer Crew from DV to EV	Transfer Crew from EV to ES	Transfer Crew from CM to Vehicle/Ship
Assembly														
A1	Lunar Assembly Missions		X	X		X	X	X	X		X	X	X	X
A2	Lunar Orbit Assembly Missions		X	X		X				X		X	X	X
A3	Mars Assembly Missions		X	X		X	X	X	X		X	X	X	X
A4	Mars Orbit Assembly Missions		X	X		X				X		X	X	X
A5	Earth Orbit Assembly Missions		X	X	X					X			X	X
Human														
H1	Short-Duration Lunar Habitation		X	X		X	X	X	X		X	X	X	X
H2	Long-Duration Lunar Habitation		X	X		X	X	X	X		X	X	X	X
H3	Short-Duration Mars Habitation		X	X		X	X	X	X		X	X	X	X
H4	Long-Duration Mars Habitation		X	X		X	X	X	X		X	X	X	X
H5	Deep Space/Other Destination Habitation			X		X	X	X	X		X	X	X	X

69 Functions Mapped to 37 Missions

Exploration Campaign
System Breakdown Structure

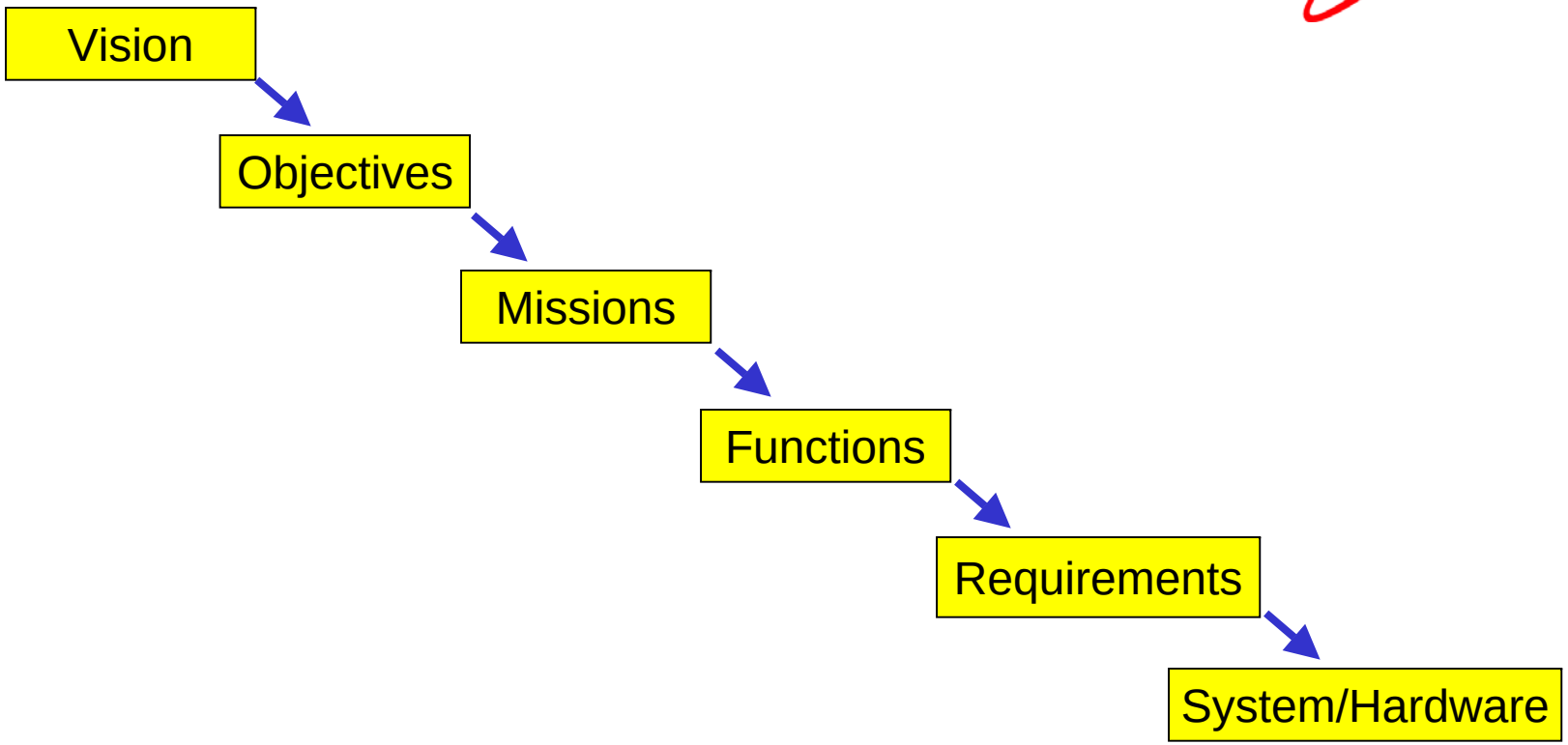


Mapping Functions to Hardware

	Program Level 0	Transport												
	System Level 1	Transport Crew												
	Segment Level 2 Functions	Transfer Crew to Launch Pad	Launch Crew from E to EV	Transfer Crew from EV to Orbiting Station	Transfer Crew from EV to DV	Transfer Crew from DV to DS	Provide Surface Transport	Provide Surface EVA	Provide In-SpaceEVA	Transfer Crew from DS to DV	Transfer Crew from DV to EV	Transfer Crew from EV to ES	Transfer Crew from CM to Vehicle/Ship	
ID	Architecture Element													
CEV	Crew Exploration Vehicle (CEV)		X		X						X	X	X	
SEM	Space Exploration Module		X		X						X	X		
HRLV	Human-Rated Launch Vehicle		X											
EELV	Evolved Expendable Launch Vehicle													
MCS	Modular Containment Systems													
LL	Lunar Lander					X				X				
PF	Processing Facilities		X											
C3	C3 Facilities		X		X	X	X			X	X	X	X	
EGSF	Earth Ground Support Facilities		X										X	
LH	Lunar Habitat													
S	Storage Facilities									X				
SE	Science Equipment													
UR	Unpressurized Rovers						X							
PR	Pressurized Rovers						X							
CF	Communications Facilities						X			X				
RUI	Resource Utilization Infrastructure													
NPF	Nuclear Power Facility													
CS	Communications Satellites		X		X	X	X			X	X	X		
NS	Navigational Satellites				X	X	X			X	X	X		

69 Functions Mapped to 23 Level 2 Segments

Exploration Objectives - Decomposition and Maturation

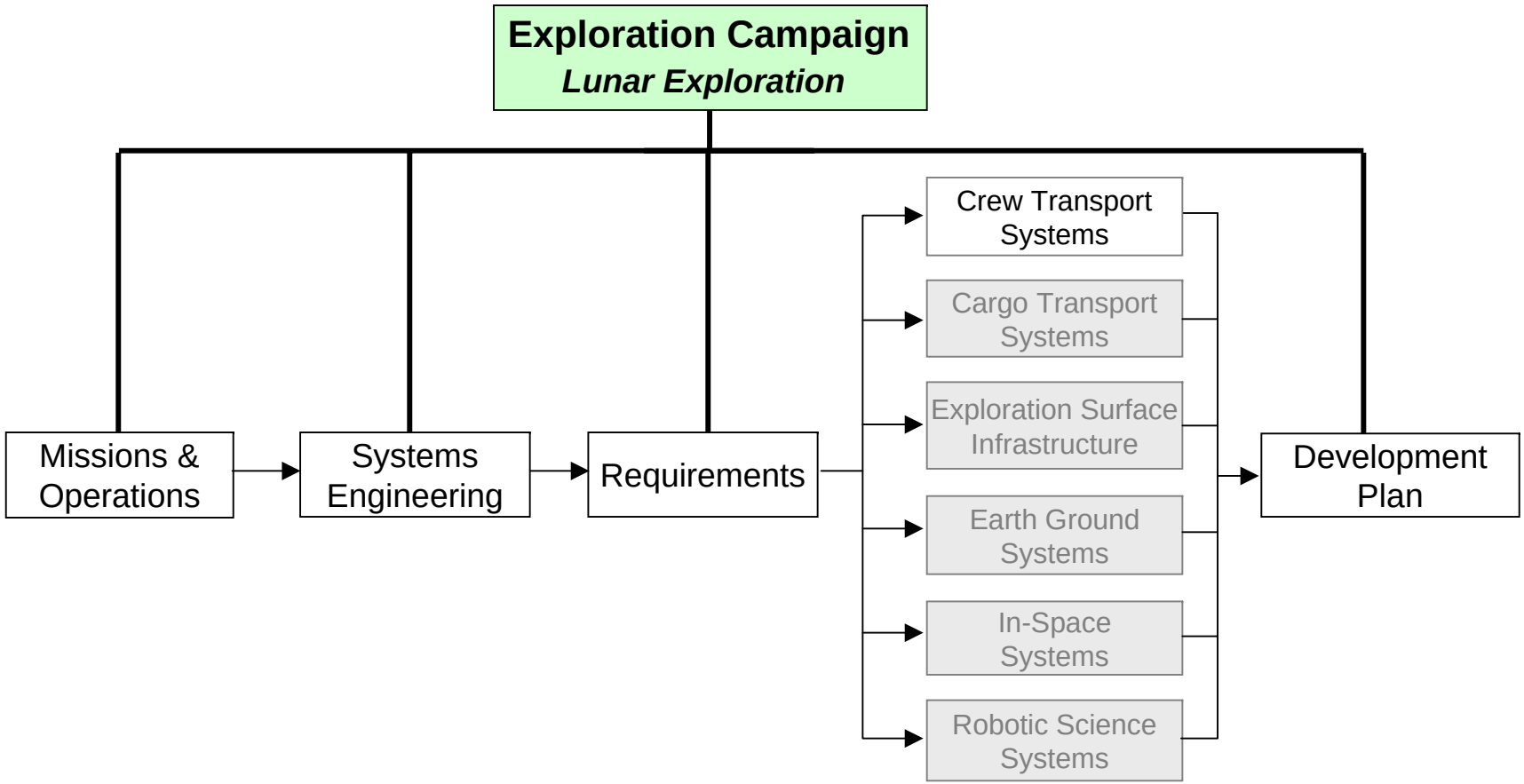


This Process;

- **Makes Sure We Have Captured and Implemented the Total Vision**
- **Ensures That We the Contractor Fully Understand What System Must Do**
- **Reveals That the Vision Starts Now… Not When Hardware Begins Flying**

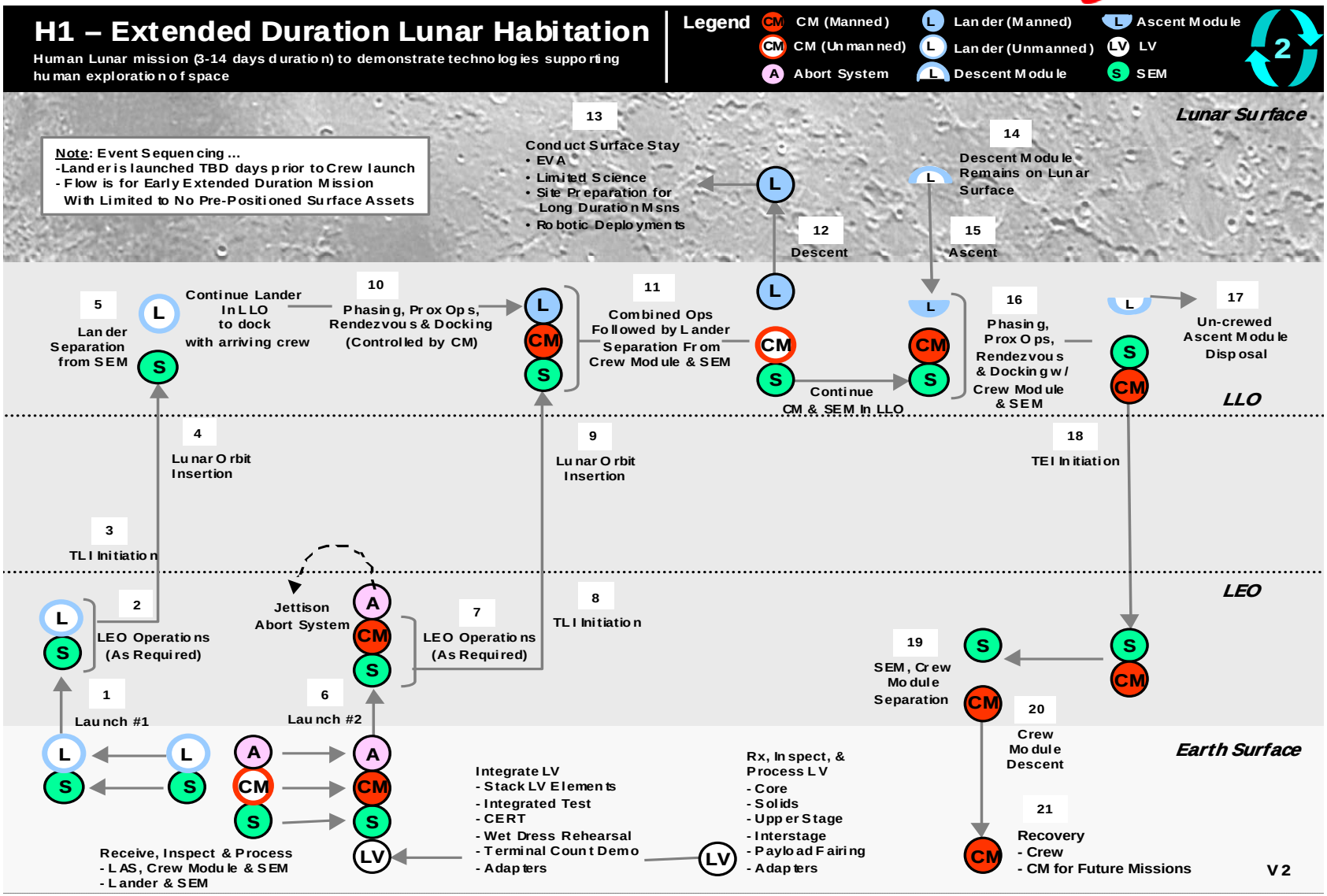
Campaign Overview & Mission Definitions

Orbital's Primary Ground Rule

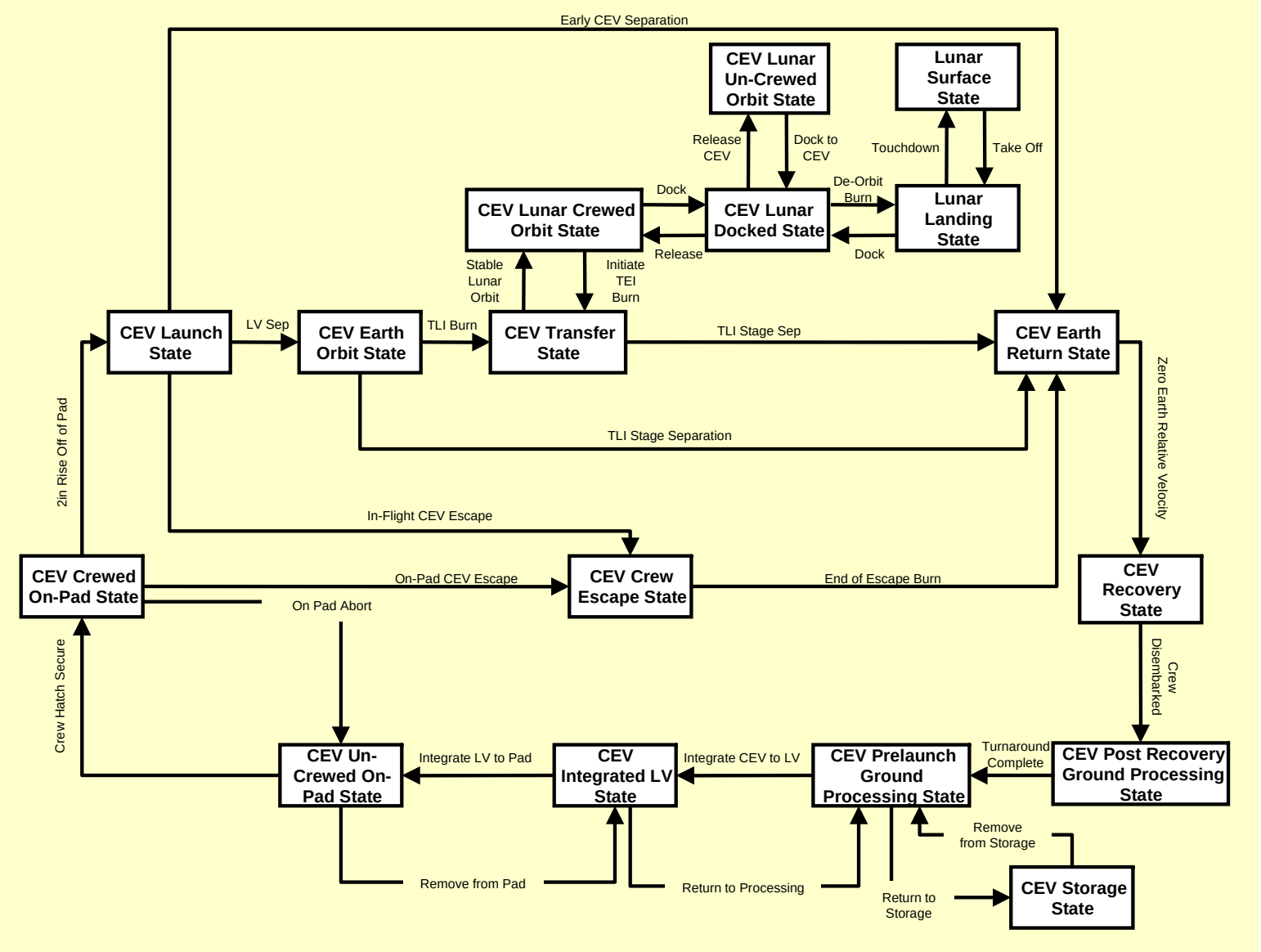


Missions and Operations Drive the Concept Refinement Process

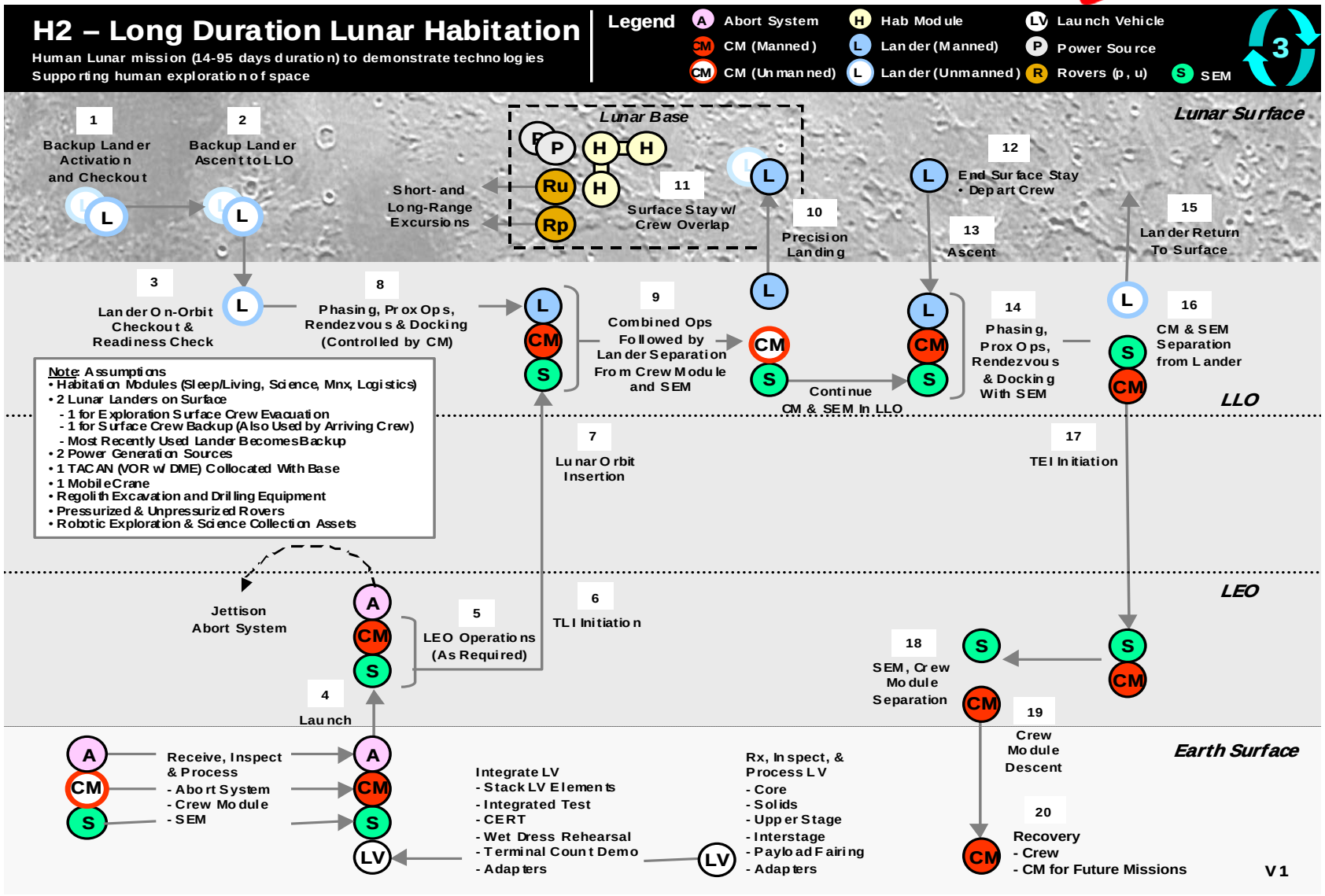
Mission Operations Flow
Extended Duration Lunar Habitation



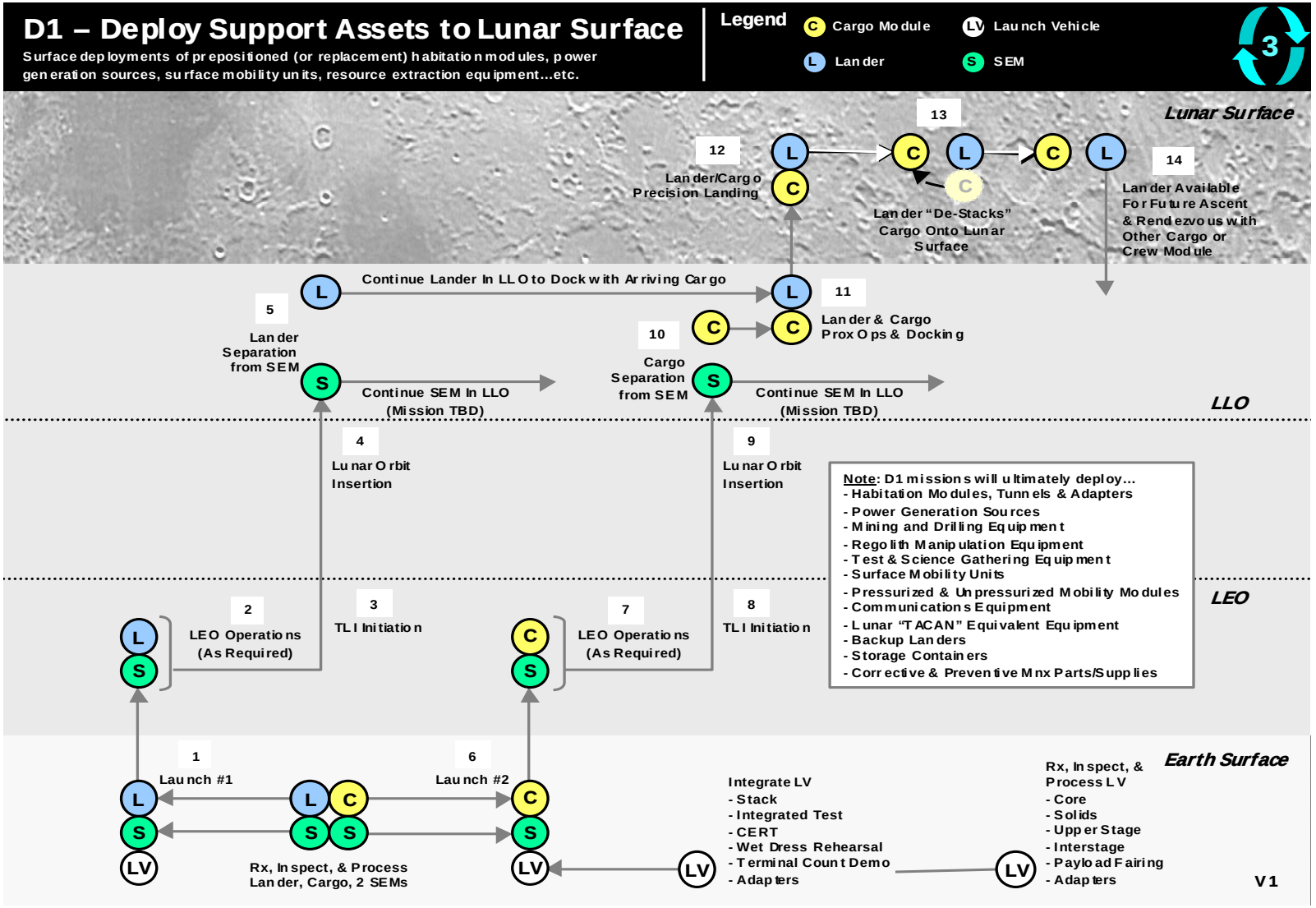
Missions Generate Functions



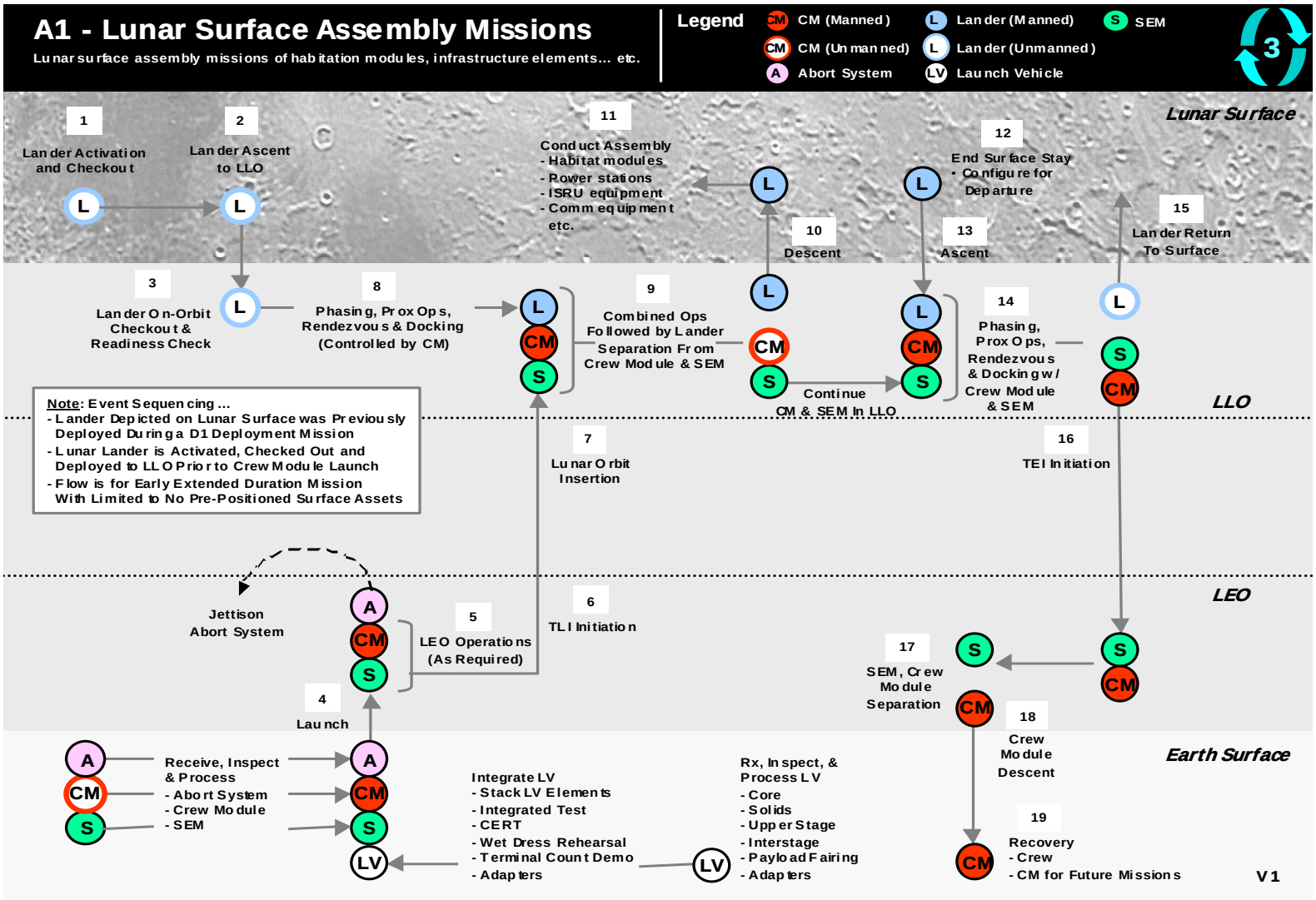
Mission Operations Flow
Long Duration Lunar Habitation



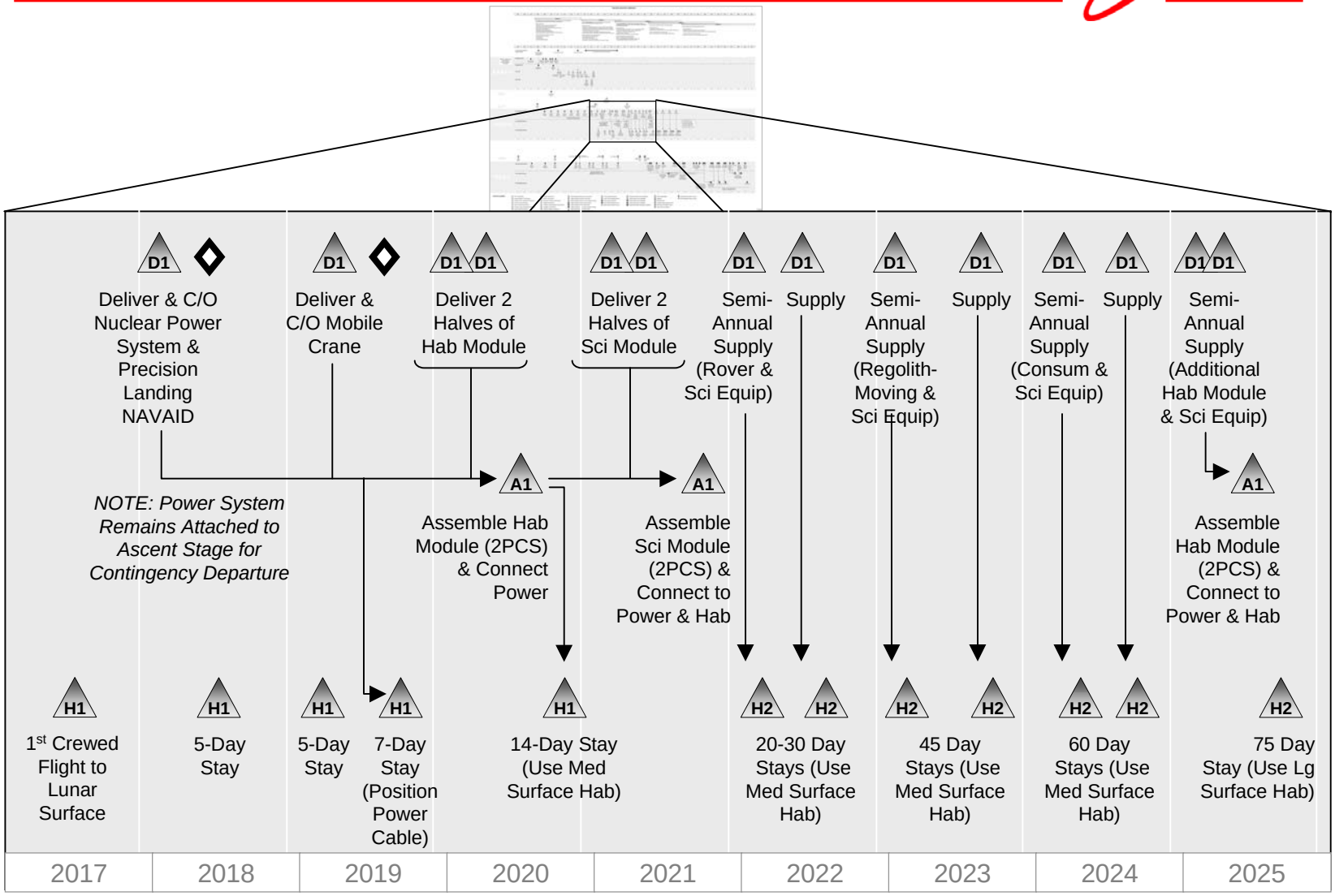
Mission Operations Flow
Deploy Assets to Lunar Surface



Mission Operations Flow
Lunar Surface Assembly

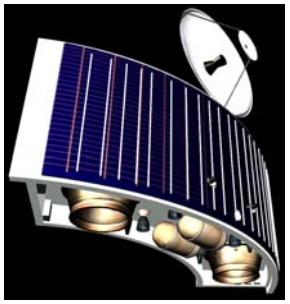


Exploration Campaign Overview
Initial Lunar Missions



The Exploration System and Updates

Earth Ground Systems

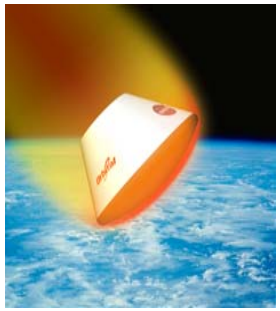


In-Space Systems

Robotic and Science Systems

Exploration Surface Infrastructure

Cargo Transport Systems

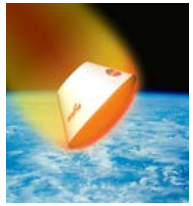


Crew Transport Systems

Exploration System
Crew Transfer System (CTS) Segment

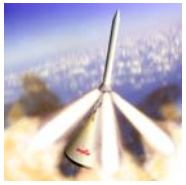
Crew Module Functions

The CM provides crew habitation from launch to lunar orbit and return to the earth surface. The CM will rendezvous and dock with the Lunar Lander in lunar orbit. The CM will operate uncrewed in lunar orbit while the crew is on the moon. In addition, the CM provides the communication and navigation assets to transfer data/voice/video to other mission assets and the ground.



Launch Abort System Functions

The LAS provides the abort capability during Earth ascent up to 200,000 ft after which SEM provides high altitude abort capability.



Space Exploration Module Functions

The SEM provides the propulsive capability to transfer the CM or Lunar Lander from LEO to lunar orbit and return to Earth. The SEM also provides additional consumables and power to the CM.

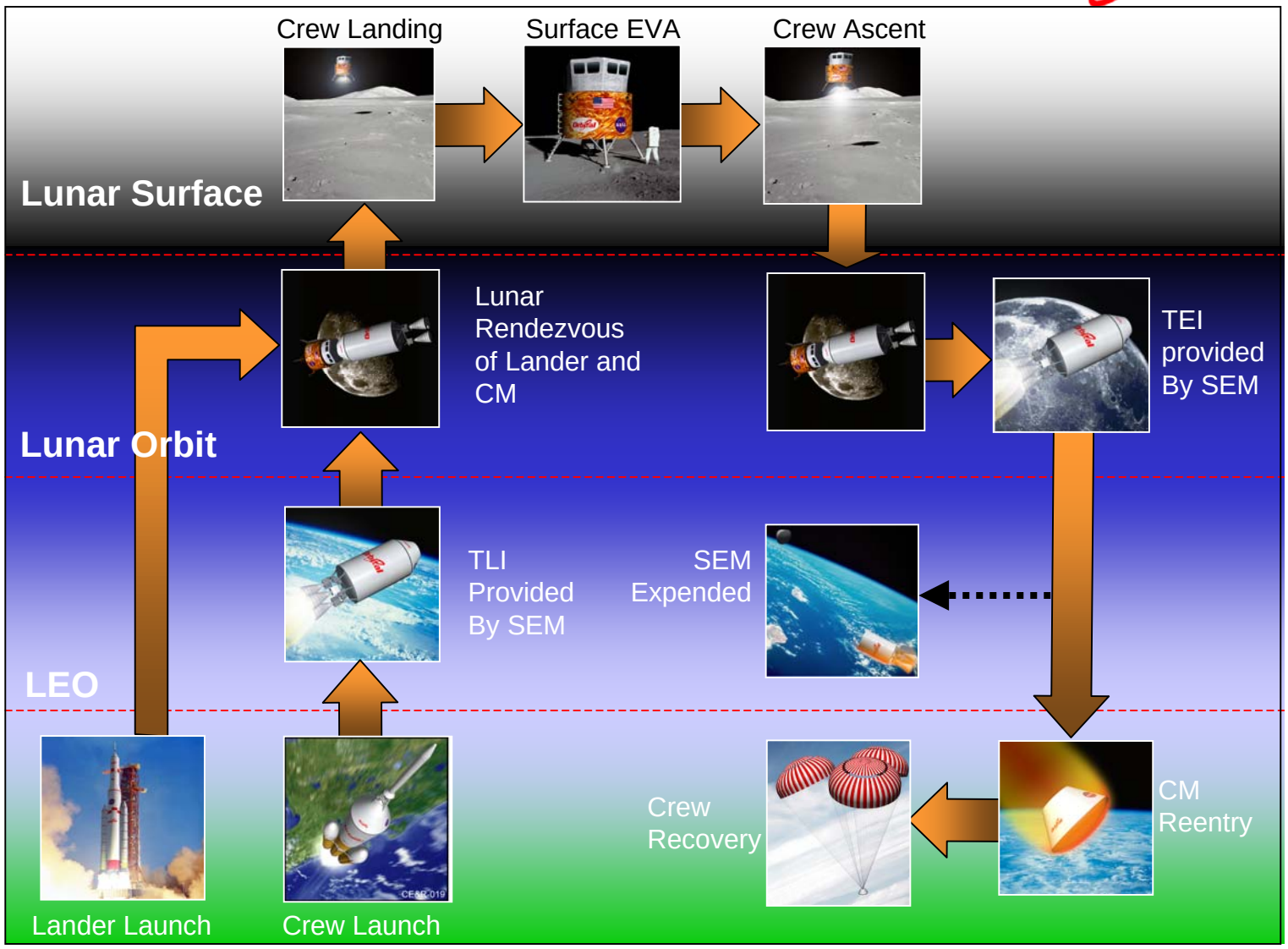
Heavy Lift Launch Vehicle Functions

The HLLV provides the necessary lift capability to launch the CM, SEM, Lunar Lander and other mission elements into LEO.

Lunar Lander Functions

The LL provides crew habitation from lunar orbit to the lunar surface and return to lunar orbit. The LL provides surface EVA capability for the crew. The LL provides the communication and navigation assets to transfer data/voice/video to other missions assets and the ground.

Lunar Habitation
Mission System Elements



Habitation Mission Alternatives

- Multiple Outpost Capability: TBD Day Capable Outpost Anywhere on Lunar Surface
  - Outpost at Next Site of Interest or Continue at Previous Site
  - Earth is Logistics Hub

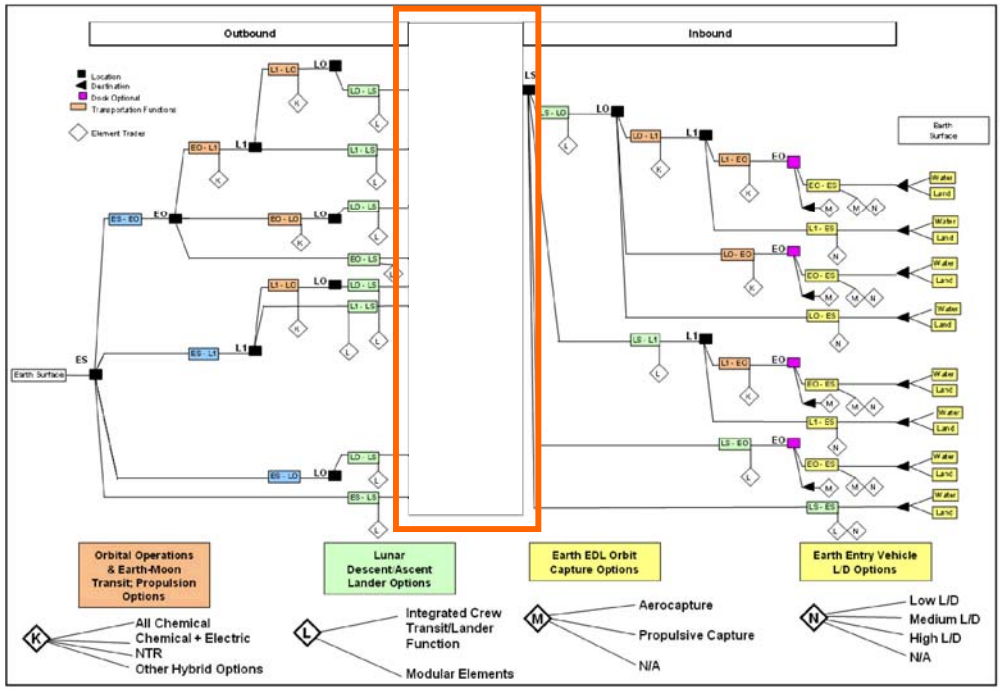
- Lunar Logistics Base: Establish Single Lunar Base and Provide for Distributed Exploration Capability
  - Rovers for Local Exploration
  - Lander “Hops” for More Distant Exploration
  - Moon is Logistics Hub

- Lunar Orbiter: Provide 90 Day Capable Lunar Orbiter With Surface Excursion Capability Anywhere on Lunar Surface
  - Multiple Short Excursions to Lunar Surface (2 Crew?)
  - LLO Is the Logistics Hub

Exploration Philosophies to Be Evaluated

- Minimum Effort to Attain Spiral Objectives
  - Do Not Establish Permanently Occupied Lunar Base
  - Plan to End Substantial Lunar Operations So Funds Can Be Used for Spiral 4
- Minimum Number of Launches to Meet Exploration Vision
  - Operations, Feasibility, and Cost Limit Annual Launches to About 10-12 HLLVs
  - Define Exploration Campaign With This Constraint
- Permanently Crewed Lunar Outpost
- Mars Mission Analog Using Lunar Orbiter and Surface Habitat

Logistics Hub Trade

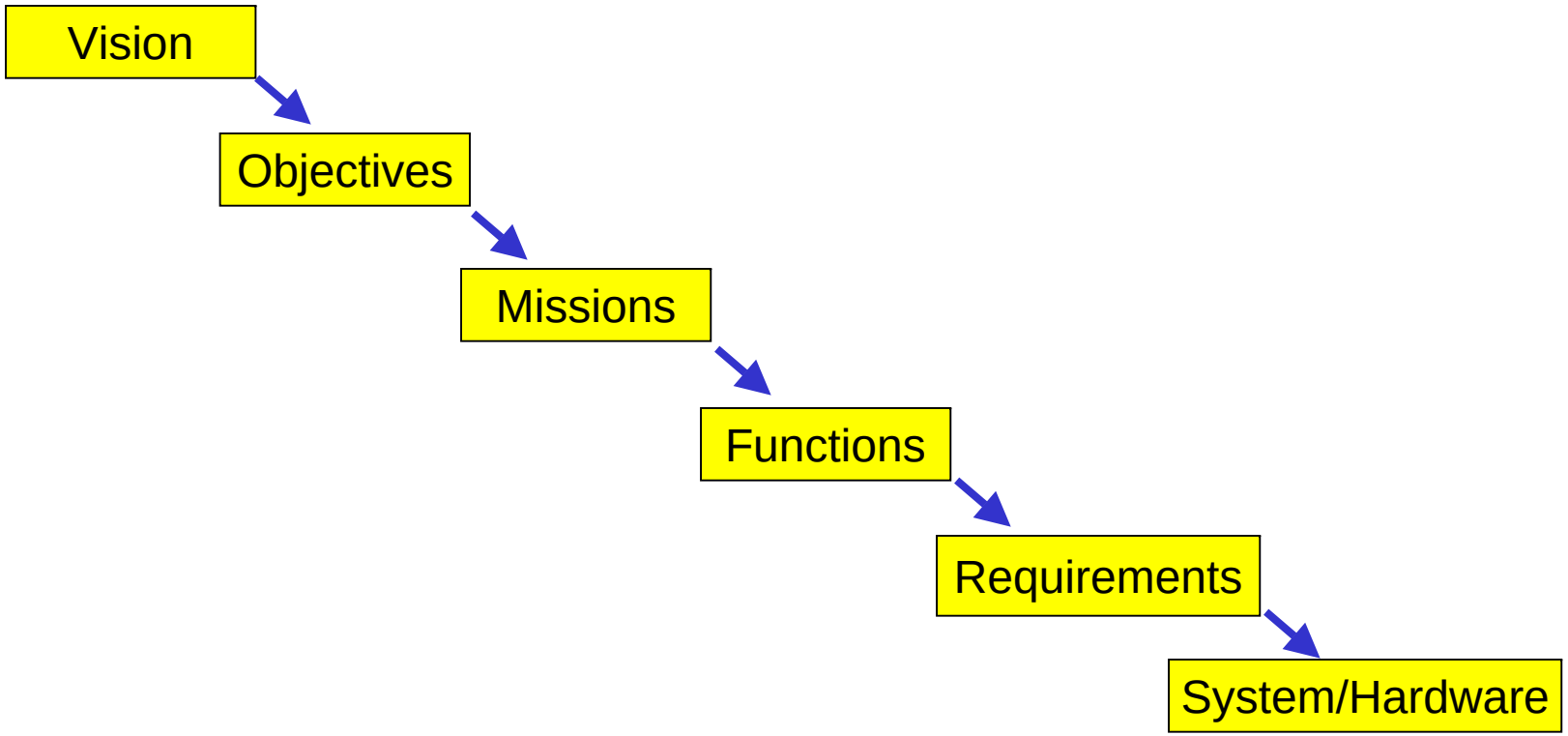


Preliminary Evaluation of Logistics Hub

- Extends NASA Work in This Area
- Objective is Complete Lunar Coverage
- Must Provide Operational Flexibility
- Must Account for Cost Considerations

System and Element Requirements

Exploration Requirements - Decomposition and Maturation



Exploration Vision is being Decomposed to Requirements

Vision to Missions to Requirements

NASA L0 1.3 L1 1.2

NASA shall conduct human lunar expeditions to further science,

NASA shall conduct the first extended human expedition to the lunar surface as early as 2015, but no later than the year 2020, in preparation for human exploration of Mars and other destinations.

(NASA Level 0 May 2004)

Orbital Objective

Gradually increase human lunar stay times to understand conditions for crew health, safety and performance for exploration of Mars and other destinations

Orbital Mission

H1 Extended Duration Lunar Habitation:
Human lunar mission (3-14 days duration) to demonstrate technologies supporting human exploration of space

Orbital Function

Transport Crew from Earth to Destination Surface
Transport Crew from Destination Surface to Earth

Orbital L0 Requirement

The Exploration Program shall conduct human lunar expeditions as early as 2015, but beginning no later than the year 2020.

Orbital L1 Requirement

The CTS shall provide a Crew Exploration Vehicle (CEV) to deliver four crew from the Earth's surface to the Moon and return them to Earth.

Orbital L2 Requirement

The CEV shall transfer four crewmembers from Earth to the Moon and safely return them.

The CEV shall be capable of returning four de-conditioned crewmembers from the Moon to Earth.

Related Trades:
Exploration Crew Size
In-Space Crew Transport
Lunar Lander Functionality
Lunar Base Location

ESS Technical and Programmatic Driving Requirements

- Technical
  - Crew Size - ESS0160, ESS0250
  - Lunar Mission Duration - ESS0140, ESS0150, ESS0260
  - Lunar Mission Location - ESS0140, ESS0150, ESS0260
  - Flight Rate - ESS0170, ESS0180
  - Monthly Lunar Mission Opportunity - ESS0190, ESS0300
  - Spiral 2 Definition States No Pre-Deployed Surface Systems on Lunar Surface (ESS0160 Rationale, Glossary)
- Programmatic
  - 2014 CEV IOC - EPR0520
  - 2010 CEV Flight Test - EPR0540
  - 2015-2020 Human Lunar Mission - EPR0510
  - Separate Crew from Cargo - EPG0830

CTS Spiral 1, 2, 3
Driving Requirements

Spiral 1

- CVS0030A - This high level of ascent success probability forces the use of Shuttle-derived or Saturn-derived launch systems (versus EELV launch systems).

Spiral 1, 2, 3

- CTS0125H - This forces an airlock (of full cabin depressurization capability) onto the CTS, as opposed to only having EVA capability from lunar lander (i.e. 2 systems that must provide EVA capability).

Spiral 2, 3

- CTS0130G - This would also force the CTS to have an airlock if CTS0125H was not already a requirement.

- CTS0360G - During Spiral 3 this requires the same interface mechanism to be used for in-space docking as for ground (on-surface) docking of Exploration elements. This may not be feasible.

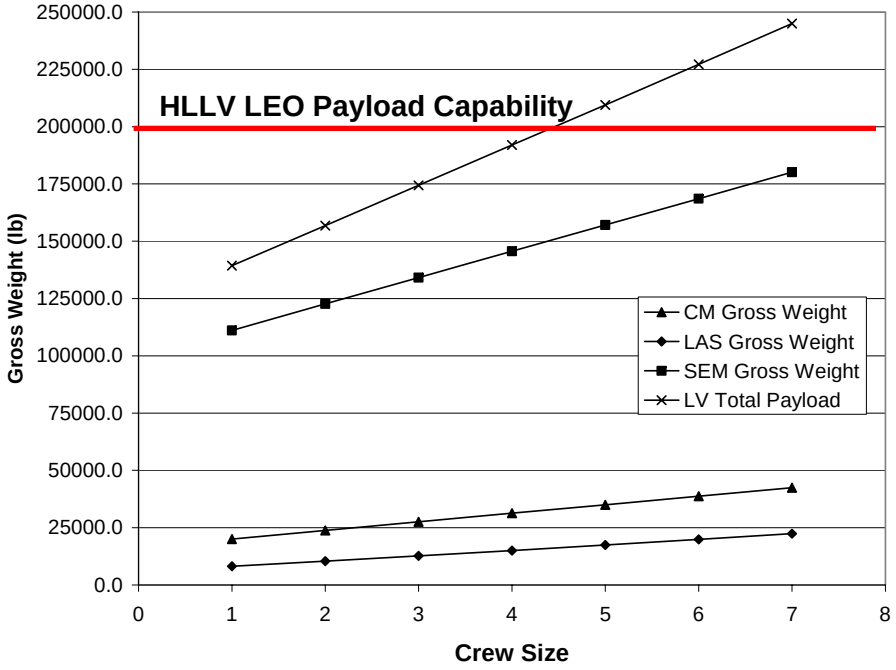
- CEV0250G - This forces the CEV propulsion system(s) and their consumables to be used rather than allowing use of another element's systems (e.g, lunar lander thrusters or consumables).

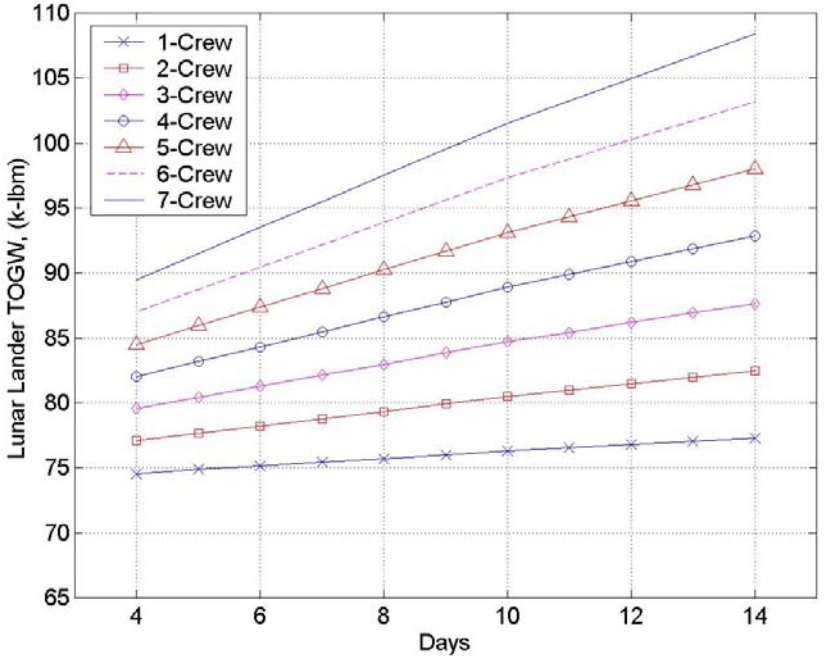
Requirement Sensitivities

ESS0160 - conduct human exploration on the lunar surface with 4 crew members (TBR-12).

ESS0250 - …, and an objective of 6 crew members (TBR-15).

ESS0140 - The ESS shall conduct extended-duration human exploration missions (threshold of 4 days, with an objective of 14 days) to any designated location in the polar region of the Moon (TBR-1).





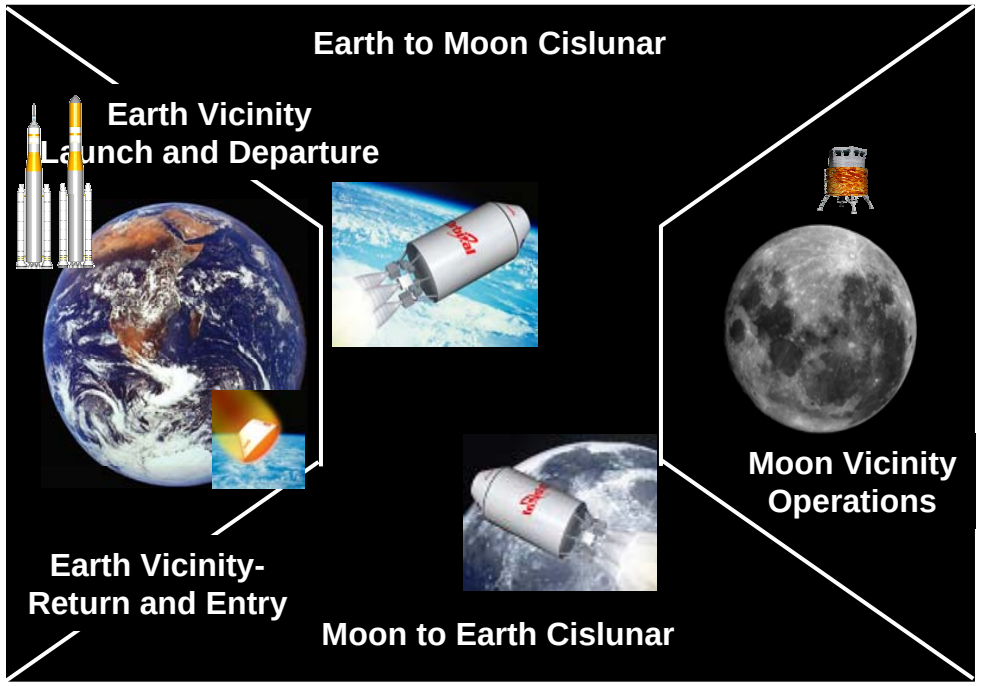
Mass Sensitivity to Requirements Drivers

Feedback on EMSD Requirements

- ESS Technical
  - ESS0260 - Mission Duration (42 to 98 Days) Looks Reasonable for Lunar Exploration, but is Insufficient as a Mars Precursor
  - ESS0260 - Specifying Lunar South Pole for Spiral 3 is Likely Premature Or Requiring Global Lunar Access in Spiral 2 is Unnecessary.
  - ESS0650 Orbital Debris Restrictions for Earth Orbit - Should Have Similar Orbital Debris Requirements for Lunar and Trans-lunar Orbits
- ESS Programmatic
  - EPR0520 - Contractor Architecture Will Determine When Test Flights Should Be Performed
  - EPR0560 - These Interfaces Should Be Generic Enough to Include Docking/mating and Both In-space and On-surface
  - EPR0620 - There Is No Equivalent Program Requirement Like This for Advancing the U.S. Economic and Security Interests
- Glossary
  - Need Definition of Cargo in Context of Separation of Crew and Cargo Guideline (EPG0830)

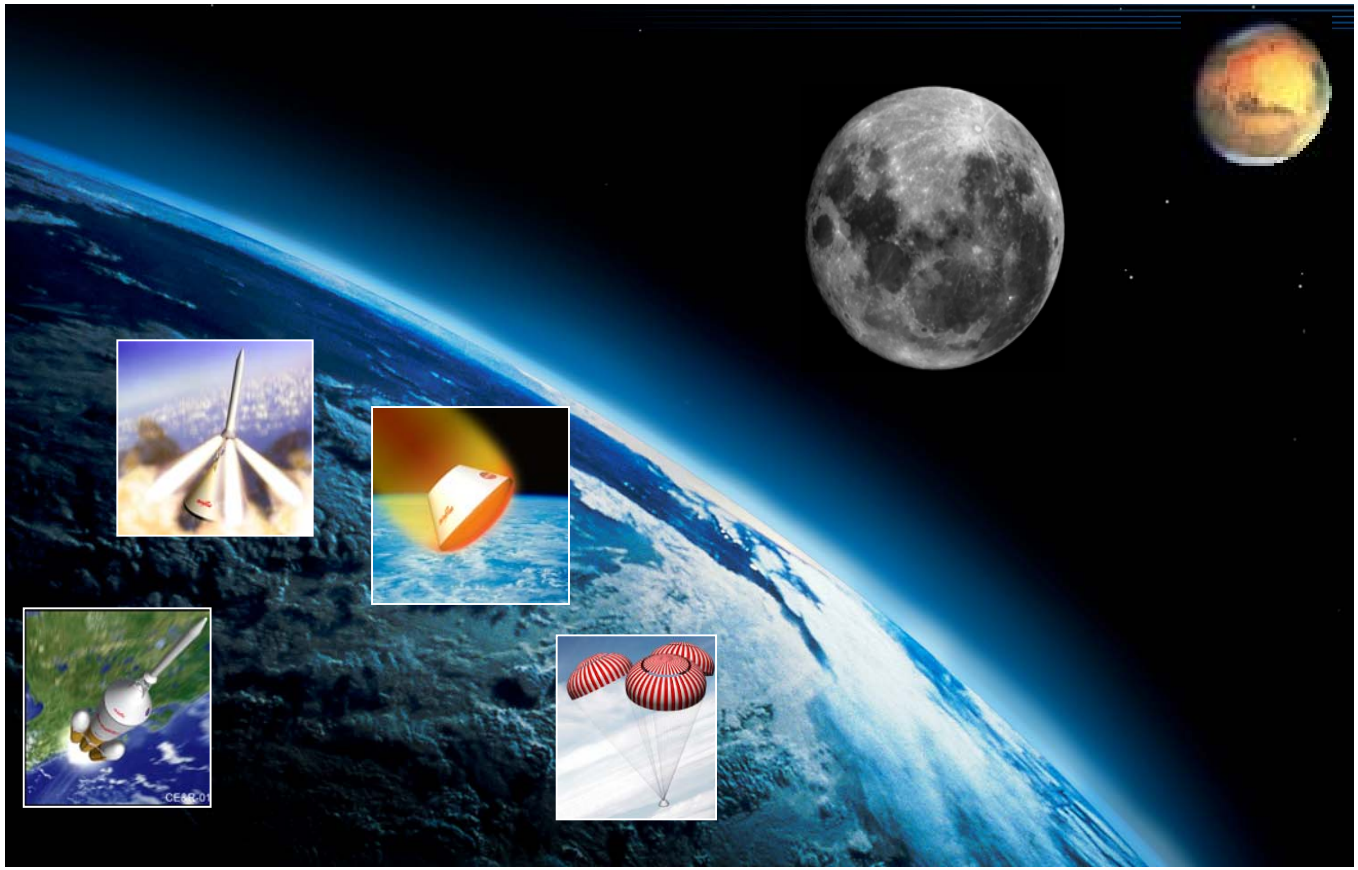
Trade Studies and Analysis for Super System and CEV

System Trades



- Level of ISRU Reliance
- Exploration Logistics Hub Location
- Mars Exploration Approach
- Abort and Safe Haven Options
- Number of Launches Required to Demonstrate Spiral Capability

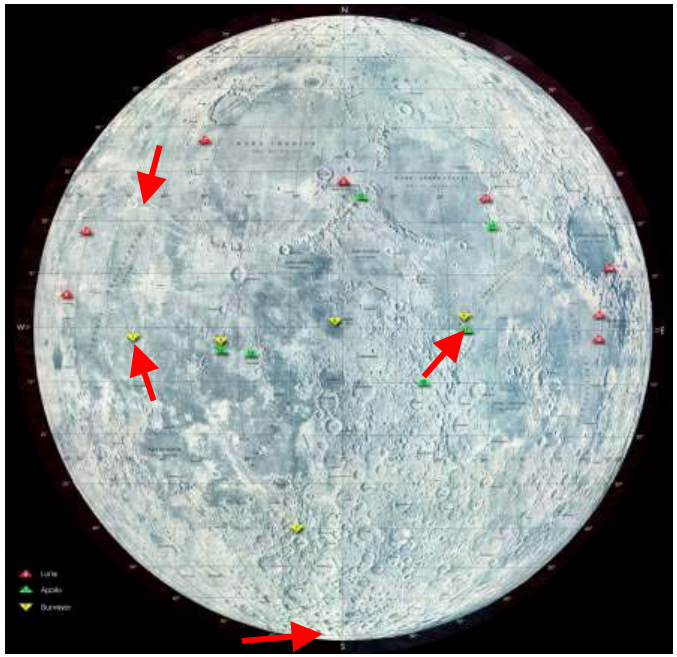
Abort and Safe Haven Trades



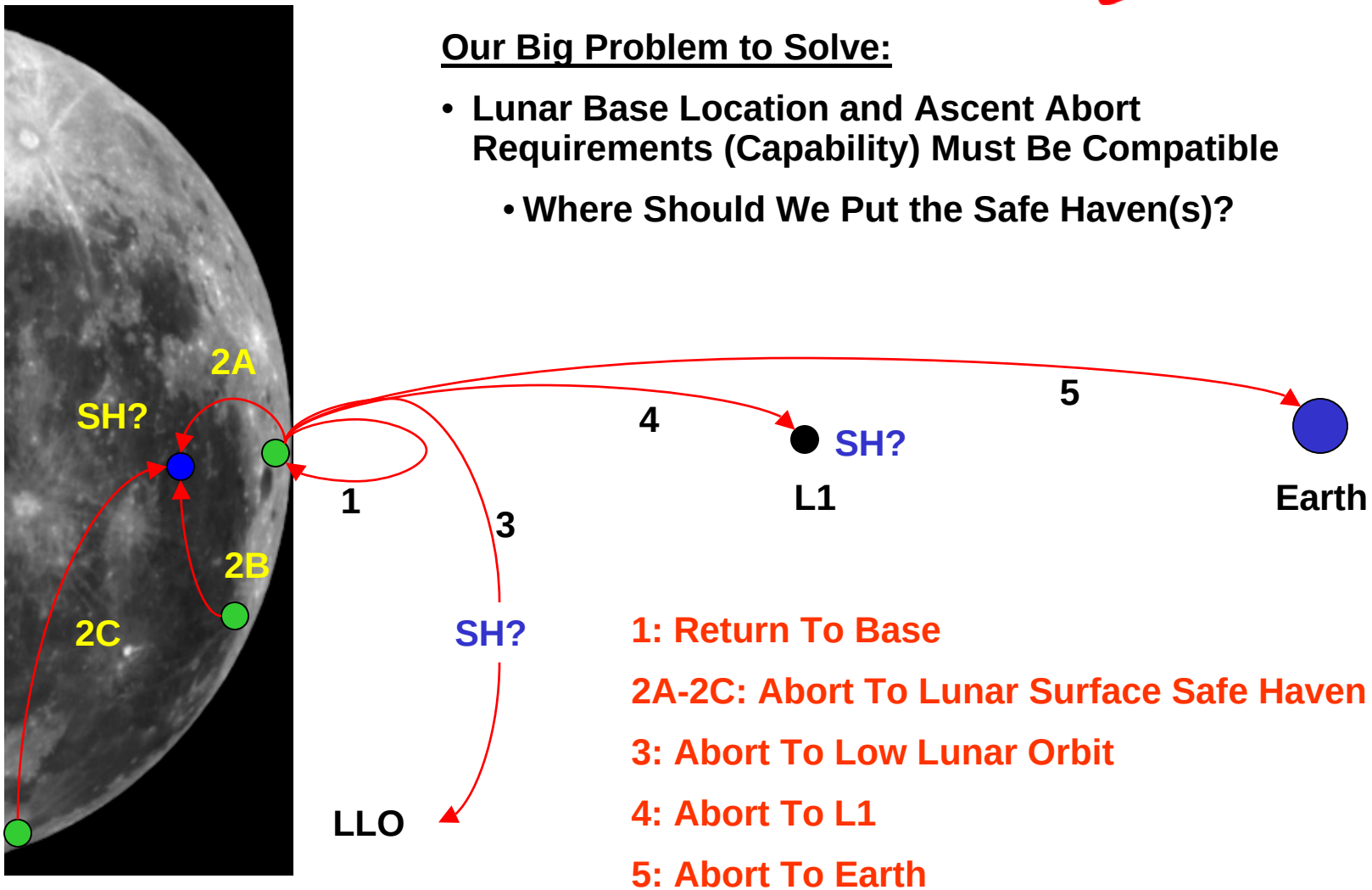
Issues and Design Drivers for Moon and Mars Ascent Abort Are Not Well Understood Despite Design Experience For Earth.

Lunar Base Location Trade

- Determine Fixed Location on Lunar Surface for Long Duration Missions
- Trading Three Alternate Locations Against Baseline - Mare Tranquilitatis
  - Alternates: Aristarchus, Oceanus Procellarum, South Pole - Aikin Basin
- Current Trade Status
  - Balancing Safety Concerns for Landing Against Increased Science and Technology Demonstration
  - Key Discriminators
    - Conditions for Safe Landing
      - Terrain
      - Lighting
      - Approach
    - Anytime Return



Lunar Base Location Versus Ascent Abort/Safe Haven Trades



Our Big Problem to Solve:

- **Lunar Base Location and Ascent Abort Requirements (Capability) Must Be Compatible**
  - **Where Should We Put the Safe Haven(s)?**

1: Return To Base

2A-2C: Abort To Lunar Surface Safe Haven

3: Abort To Low Lunar Orbit

4: Abort To L1

5: Abort To Earth

Technology Requirements

Technology Requirements
Human Habitation Missions

Enabling Technology Requirements	Exploration Missions										Exploration Systems						Spiral Applicability			ROM Dev Risk vs IOC Date
	Assembly			Human		Supp. Science		Deployment			CTS (Crew)	CTS (Cargo)	ESIS	EGS	IS	RSS	Spiral 1	Spiral 2	Spiral 3	
	A1	A2	A5	H1	H2	S2	S3	D1	D2	D7										
Automated rendezvous and docking	X	X	X	X	X		X	X	X		X	X			X	X		X	X	Min
Autonomous/Remote controlled crane/surface systems	X				X		X	X					X						X	Min
Closed-loop life support	X				X								X						X	Min
Consumables transfer (air/water)	X				X						X	X	X	X	X				X	Min
Cryogenic fluid management	X			X	X	X					X		X	X	X				X	Min
Docking mechanism - universal androgynous housing	X			X	X	X	X	X	X		X	X			X			X	X	Min
Information management system	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Min
Helmet mounted heads-up display	X			X	X						X							X	X	Min
Lightweight human-rated TPS	X			X	X						X						X	X	X	Min
Long duration science equipment					X	X	X						X		X	X			X	Min
Lunar (L1) communications relay satellite	X	X		X	X			X	X						X					Min
Lunar landing aids	X			X	X		X	X				X	X			X		X	X	Min

Enhancing Technologies

Enhancing Technologies	Exploration Missions										Exploration Systems						Spiral Applicability			ROM Dev Risk vs IOC Date
	Assembly			Human		Supp. Science		Deployment			CTS (Crew)	CTS (Cargo)	ESIS	EGS	IS	RSS	Spiral 1	Spiral 2	Spiral 3	
	A1	A2	A5	H1	H2	S2	S3	D1	D2	D7										
Nuclear power (propulsion)	X				X			X				X							X	Mod
Composite pressure vessels				X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	Min
Automated planning s/w	X	X	X	X	X	X	X	X	X	X	X		X	X	X			X	X	Min
Air bags (soft landing-Earth)	X	X	X	X	X						X			X			X	X	X	Min
Inflatable structures	X			X	X			X					X		X			X	X	Min
Closed-loop life support (Greenhouse/Food Production)	X				X			X					X						X	Min
ISRU				X	X								X					X	X	Min
Landing platform	X			X	X			X			X	X	X						X	Min
Pressurized mobility	X			X	X								X						X	Min
New Earth-based crawlers	X	X	X	X	X	X	X	X	X	X				X			X	X	X	Min
Lunar GPS	X			X	X			X					X		X	X		X	X	Min
Lunar surface pressurized garage					X								X						X	Min

High Priority Technologies

- Enabling
  - Autonomous Rendezvous Systems
  - Nuclear Power Generation
  - Space Radiation Protection
  - Mico-Meteoroid Protection
  - Lightweight Ablator TPS
  - Integrated Vehicle Health Management Systems
- Enhancing
  - ISRU
  - Nuclear Propulsion
  - Inflatable Structures
  - Closed Loop Life Support (Greenhouse/Food Production)

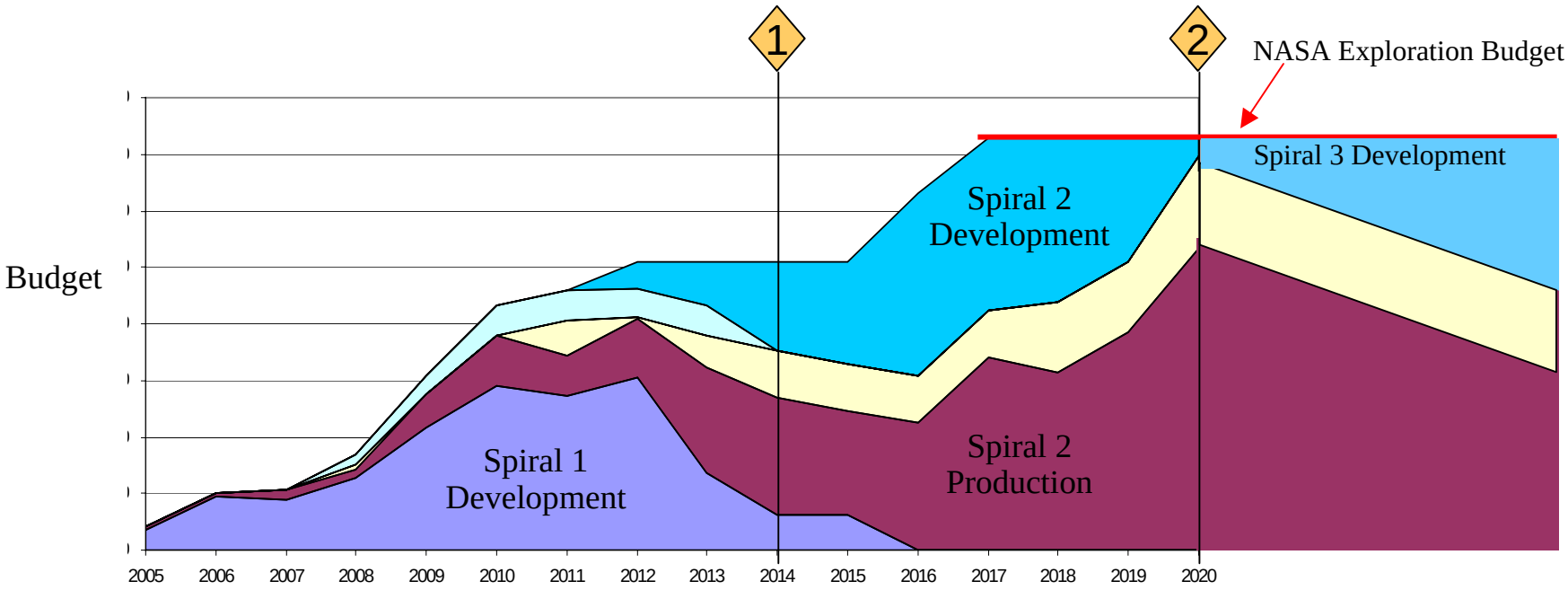
Exploration Programmatic and Technical Risk Assessment

Assessment of Significant Risks

Human Space Flight Safety | Mission Success Criteria | Technology Readiness

Risk #	Spiral 1 and 2 Risk Titles	Phase		Category						Spiral	
		Development	Operational	Programmatic	Technical (Safety)	Cost	Schedule	Operations	Sustainability/ External	1	2
E01	Moon/Mars Systems and Operations Incompatibility	X	X					X			X
C07	Spiral 1 Launch Failure	X		X		X	X			X	
C12	Industry Laborforce Limits for Supporting Two CEV Teams	X		X					X	X	
C11	ISS Requirements Creep	X		X						X	
C06	Requirements Management Between Spirals	X		X						X	
C09	Impact of Other Launch Vehicle Failure (EELV/Shuttle)	X	X				X			X	X
C10	Stakeholder Buy-in	X	X						X	X	X
C08	CEV Deorbit Propulsion Module Cost	X				X				X	
C16	Autonomous Rendezvous and Docking Robustness and Reliability		X		X			X		X	X
C15	Micro Meteoroid Damage Protection Robustness and Reliability		X		X			X		X	X
C14	Space Radiation Protection Robustness and Reliability		X		X			X		X	X
C13	TPS Robustness and Reliability		X		X			X		X	X
C05	Development of Autonomous Rendezvous Technologies	X			X					X	X
C04	Development of Improved Micro Meteoroid Damage	X			X					X	X
C03	Development of Space Radiation Protection	X			X					X	X
C02	Development of Thermal Protect... Descent Safety	X								X	

The Spiral Transition Problem



A Strategy for Spiral Transitions Is Needed

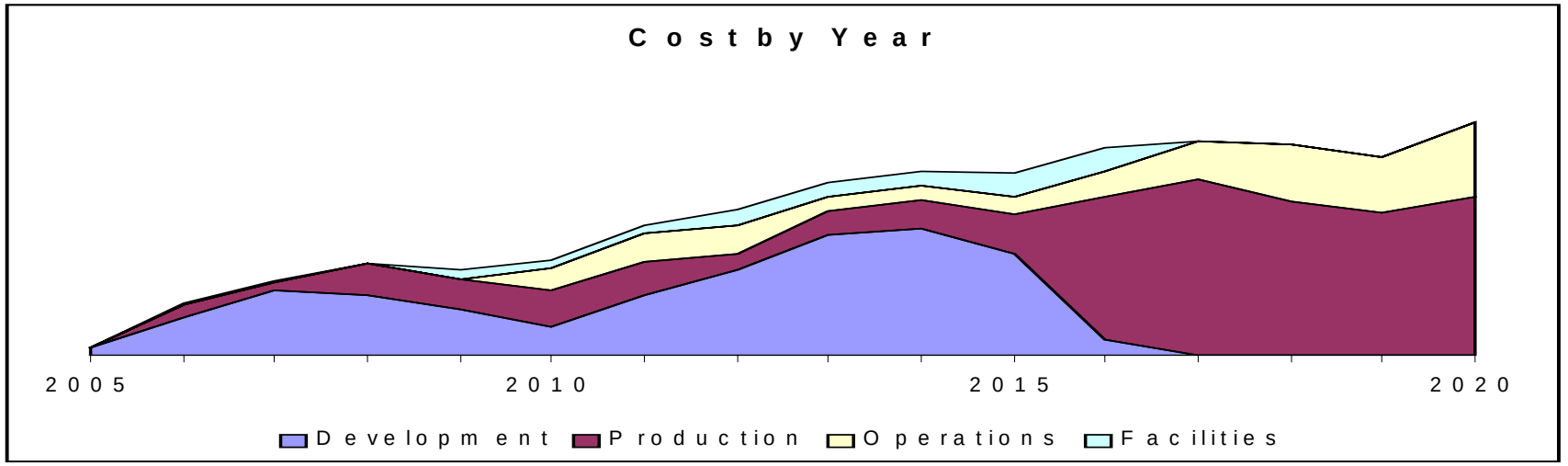
Architecture FOM Assessment

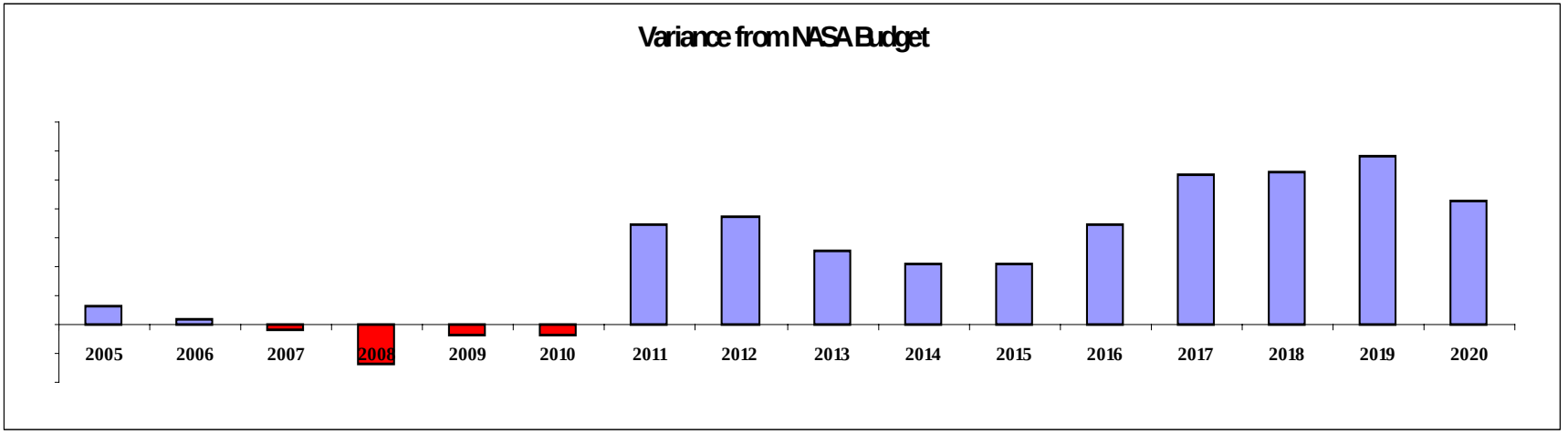
Safety and Mission Success

- 7 of 9 Abort Modes Identified are architecturally executable
- 41 Critical Events Identified and Ranked for the H1 lunar Mission using 2-Launch HLLV Lunar Orbit Rendezvous Scenario
- TBD Inter-Element Design Redundancies Being Evaluated Based on Top-Level FMECA and Safety Analyses Results with Focus on Preventing / Minimizing LOC
- TBD Hours to Return to Earth (Mission Abort)

Affordability

- Orbital's Architecture Requires About 76% of NASA's Planned Budget





Effectiveness and Extensibility

- System Applicability/Evolvability to Mars
  - Systems Evolvable for Mars Missions
    - HLLV, CM, SEM
  - Technologies Evolvable for Mars Missions
    - Closed-loop Life Support, Nuclear Power, Autonomous Rendezvous, Cryogenic Fluid Management, Information Management, Lightweight Ablator TPS, In-space Navigation, Radiation Shielding

- System Complexity
  - 17 Interfaces Among Spiral 2 Elements
    - 7 Simple, 6 Intermediate, 4 Complex

- Mission Complexity
  - 6 Major Elements (4 Unique), 2 Dockings, 19 Day Mission (10 days on Surface)

Development Risk and Schedule

- Only 3 New Technologies Required for Spiral 2 Missions
  - Precision Lunar Landing
  - LOX/Methane Propulsion
  - Space Radiation Protection
- No High Risk Technologies Required for Spiral 2 Missions
  - Only 7 Technologies < TRL 6 Today
  - All Can Be TRL 6 by 2008 FSD Start
- 2014 IOC is Not Threatened by Technology Development Risk
  - 7 Moderate, 43 Minimum Risk Developments
- 2014 IOC is Not Threatened by System Development Risk
  - CEV
  - HLLV

Summary

What We Accomplished

- Mapped the Vision to Objectives, Missions, Functions, Requirements, and Elements
- Started Manifesting the Exploration Campaign Missions

What We Learned/Observed

- Coupling of Lunar Base Selection and Lunar Abort/Safe Haven Capability
- It's Primarily a Transportation and Logistics Problem
- Lunar/Mars Operations Need to Be Compatible and Traceable
- Need a Budget Strategy at Spiral Transitions to Ensure Sustainability

What Problems We Are Still Working

- Establish Strong Link Between the Exploration Architecture and U.S. Science, Security and Economic Interests
- Define Requirements for the Other Architecture Segment and Elements
- Evaluate More Efficient Methods of Conducting the Exploration Missions