THE UNIVERSITY OF TEXAS AT EL PASO

TEAM #1
Long Duration Spacecraft

NG / UTEP Final Presentation
Dec 8, 2025

Agenda

- Team introduction
- Mission Overview
- Concept of Operations
- Requirements
  - Requirement Flow down
  - Requirement Verification and Validation
- Trade Studies
- Design Concept
- Integration and Test
- Risk Assessment
- Proposed Future Work

Team Introduction

Catalina Sanchez

Project Leader

Major: Industrial and Systems Engineering

Experience: Teaching/Research Assistant at Industrial and Systems Department

Carlos Maiti

Data Analyst

Major: Industrial and Systems Engineering

Experience: Research Assistant in Industrial and Systems Department

Javier Meza

Quality & Risk Manager

Major: Industrial and Systems Engineering

Experience: Research Assistant in Industrial and Systems Engineering.

Analaura Castillo

Logistics Coordinator

Major: Industrial and Systems Engineering

Experience: EHS Intern with Schneider Electric

Mission Overview

Design a modular, serviceable, autonomous spacecraft platform for 40+ years of operation in cis-lunar space, with minimized lifetime cost and high adaptability for mission evolution.

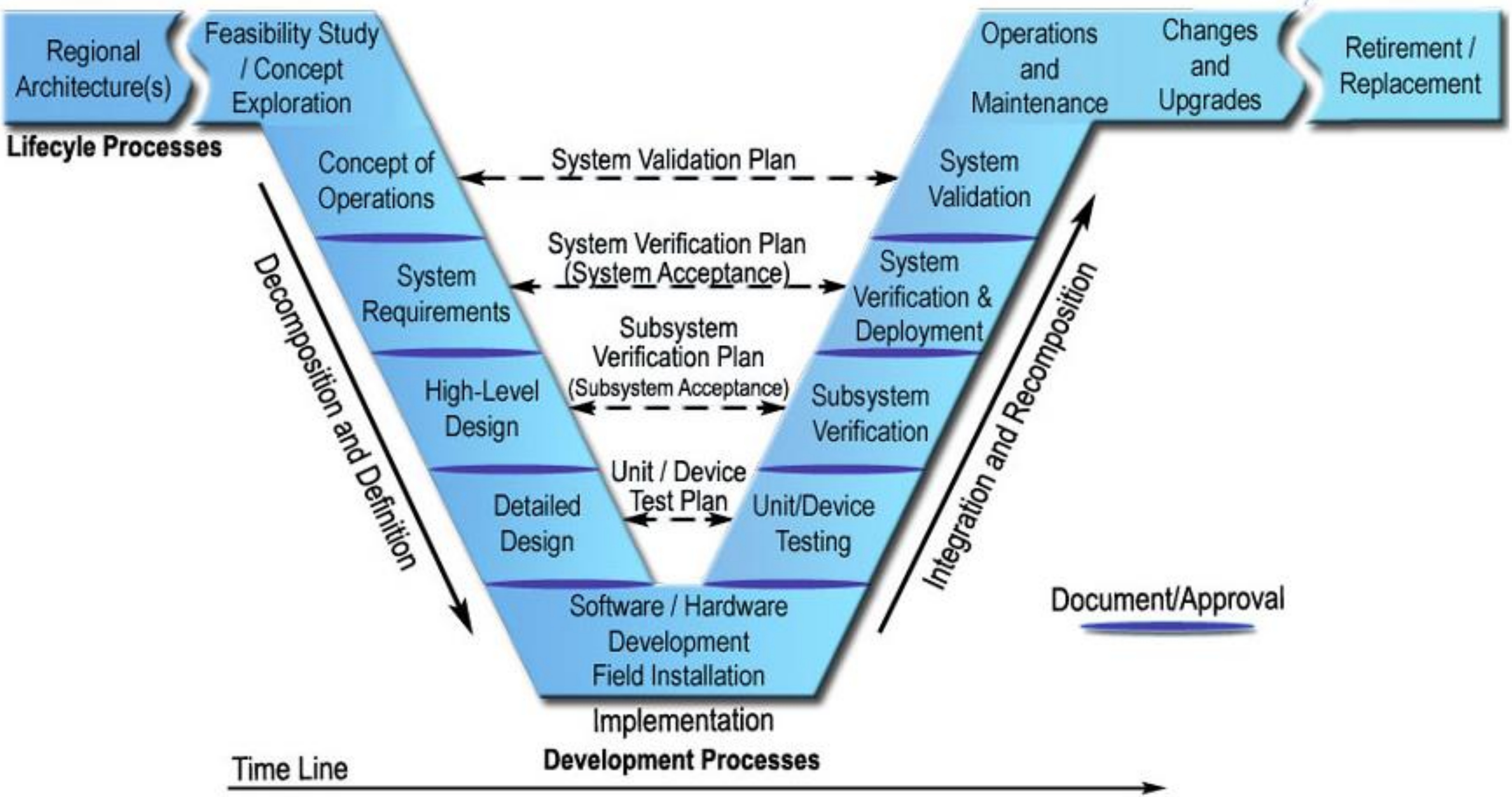
Objective:

Design a spacecraft concept that includes requirement development, testability and how it will be manufactured and serviced.

Mission Stakeholder Needs:

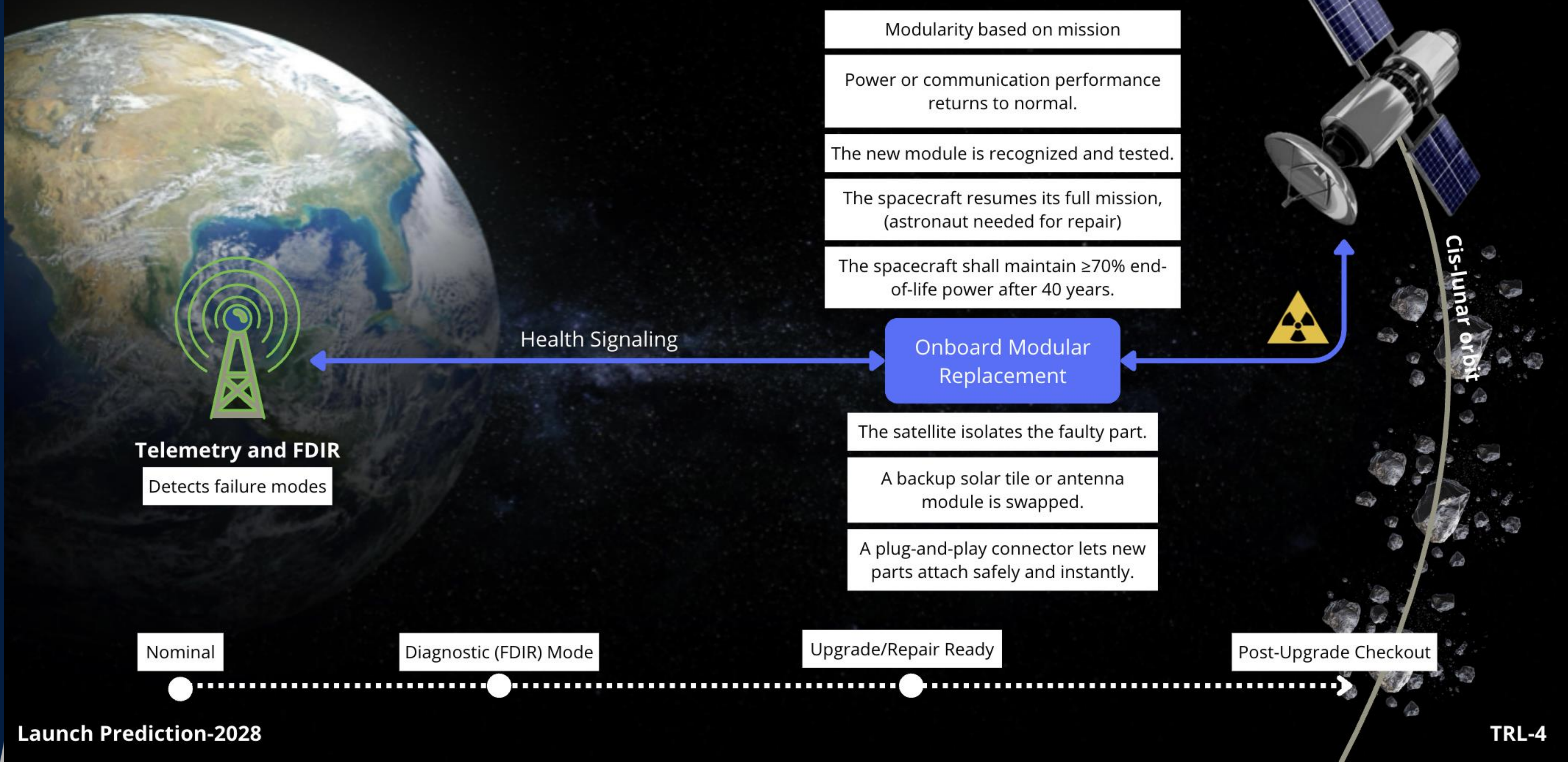
- Requirement Development
- Testability & Manufacturability
- Serviceability

V-Diagram

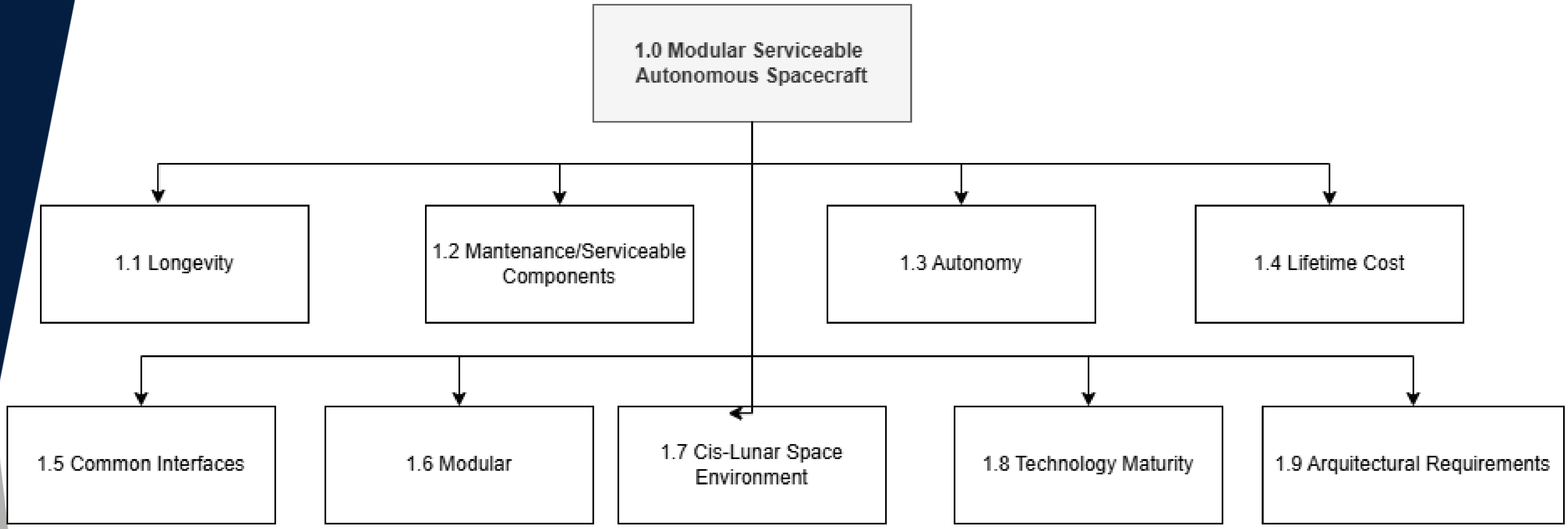

Regional Architecture(s)
Feasibility Study / Concept Exploration
Lifecyle Processes
Concept of Operations
System Requirements
High-Level Design
Detailed Design
Software / Hardware Development Field Installation
Implementation
Development Processes
Unit/Device Testing
Subsystem Verification
System Verification & Deployment
System Validation
Operations and Maintenance
Changes and Upgrades
Retirement / Replacement
System Validation Plan
System Verification Plan (System Acceptance)
Subsystem Verification Plan (Subsystem Acceptance)
Unit / Device Test Plan
Decomposition and Definition
Integration and Recomposition
Document/Approval
Time Line

CONOPS: Modular Serviceable Spacecraft

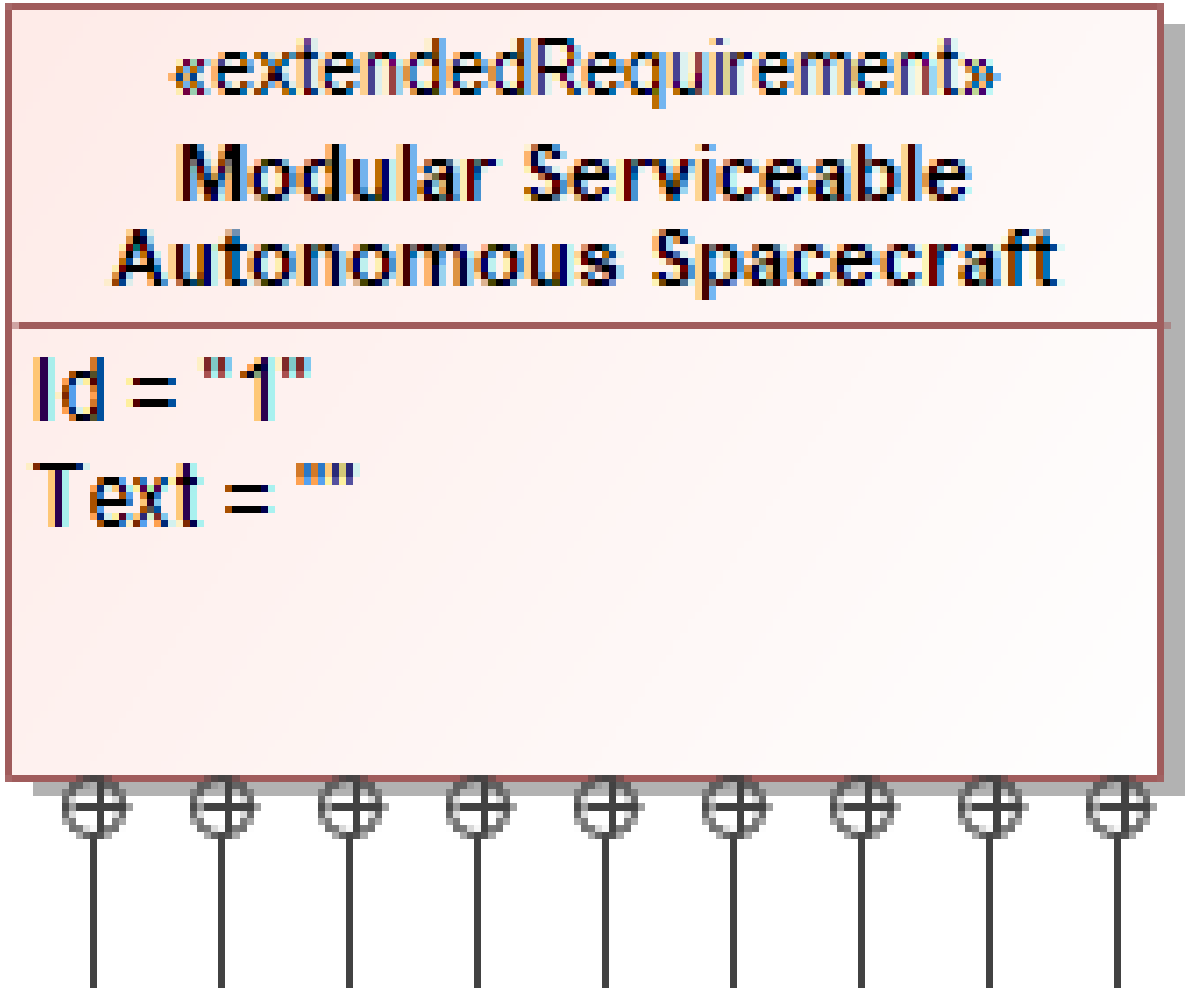
The spacecraft shall sustain on-orbit operations for ≥ 40 years through modular replacements using the UMIM



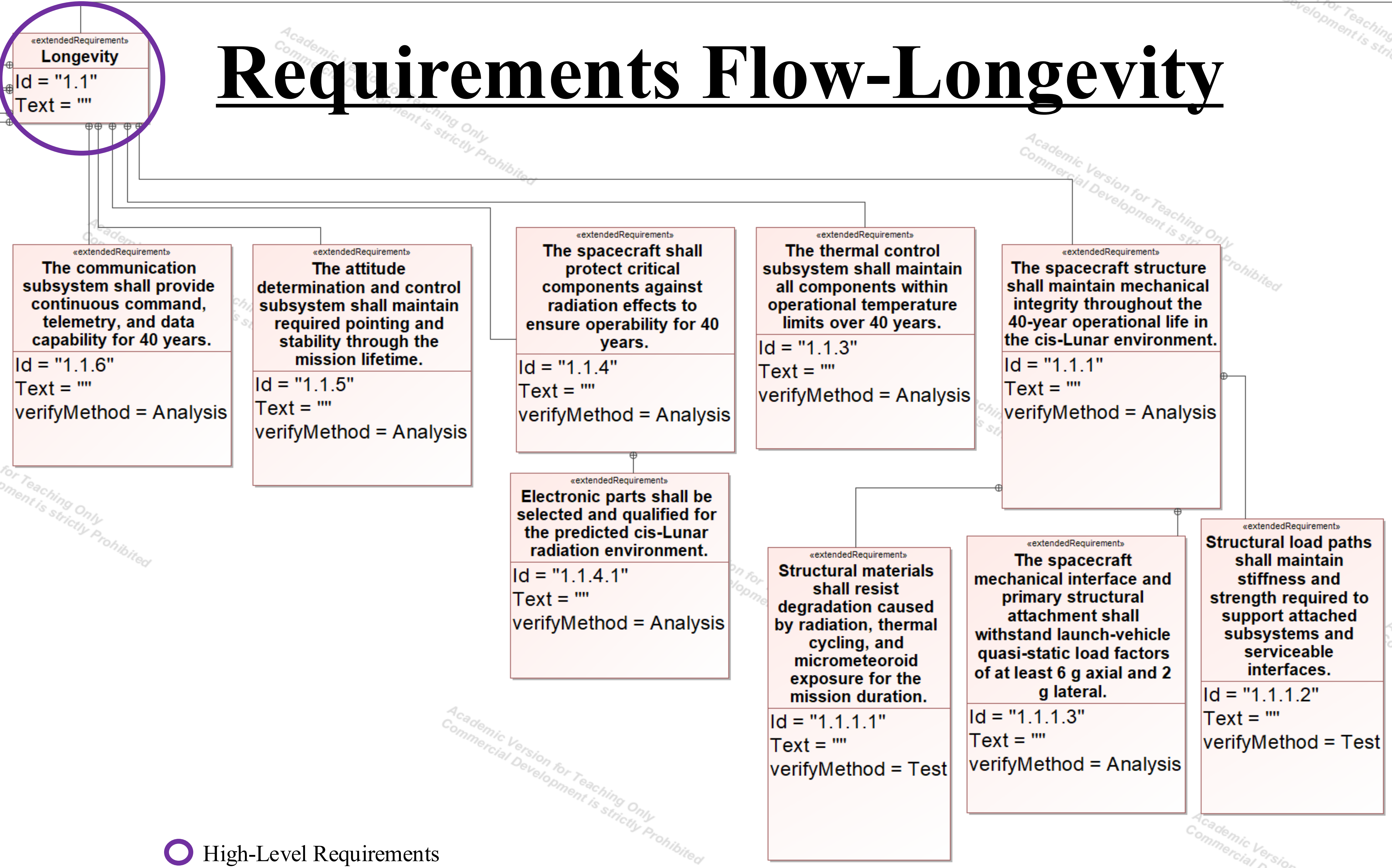
Requirement Overview



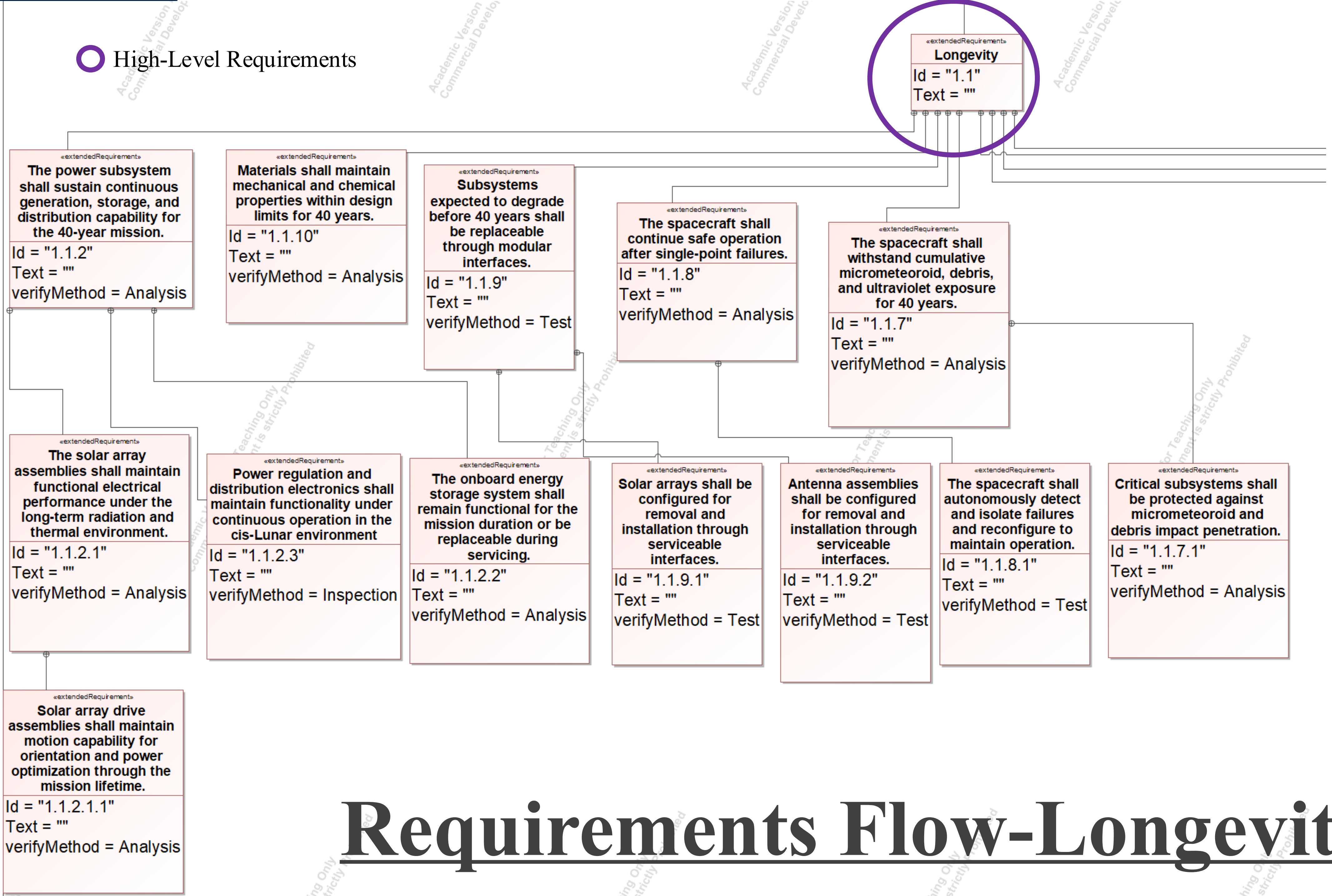
Requirements Flowdown



Requirements Flow-Longevity



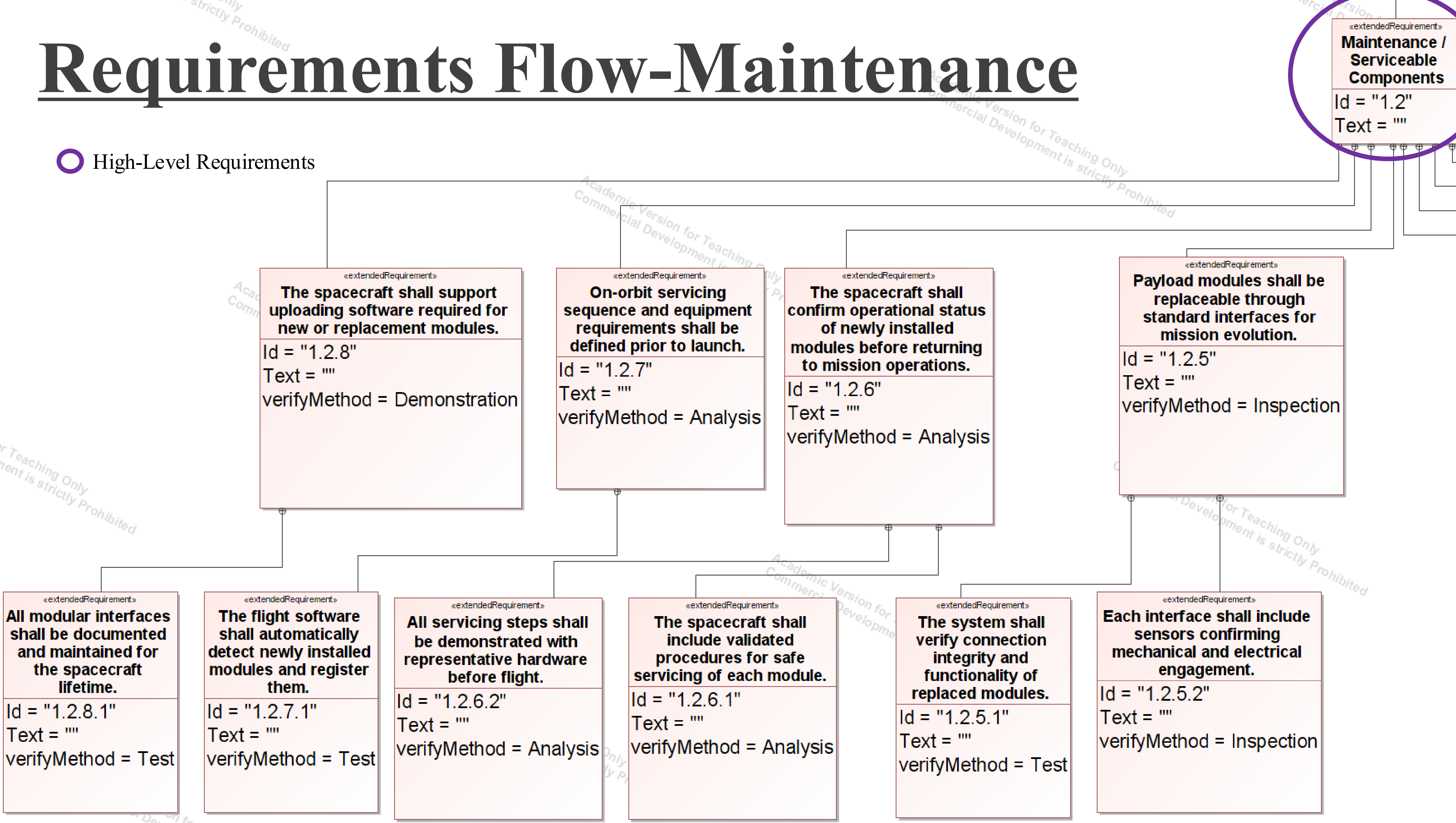
High-Level Requirements



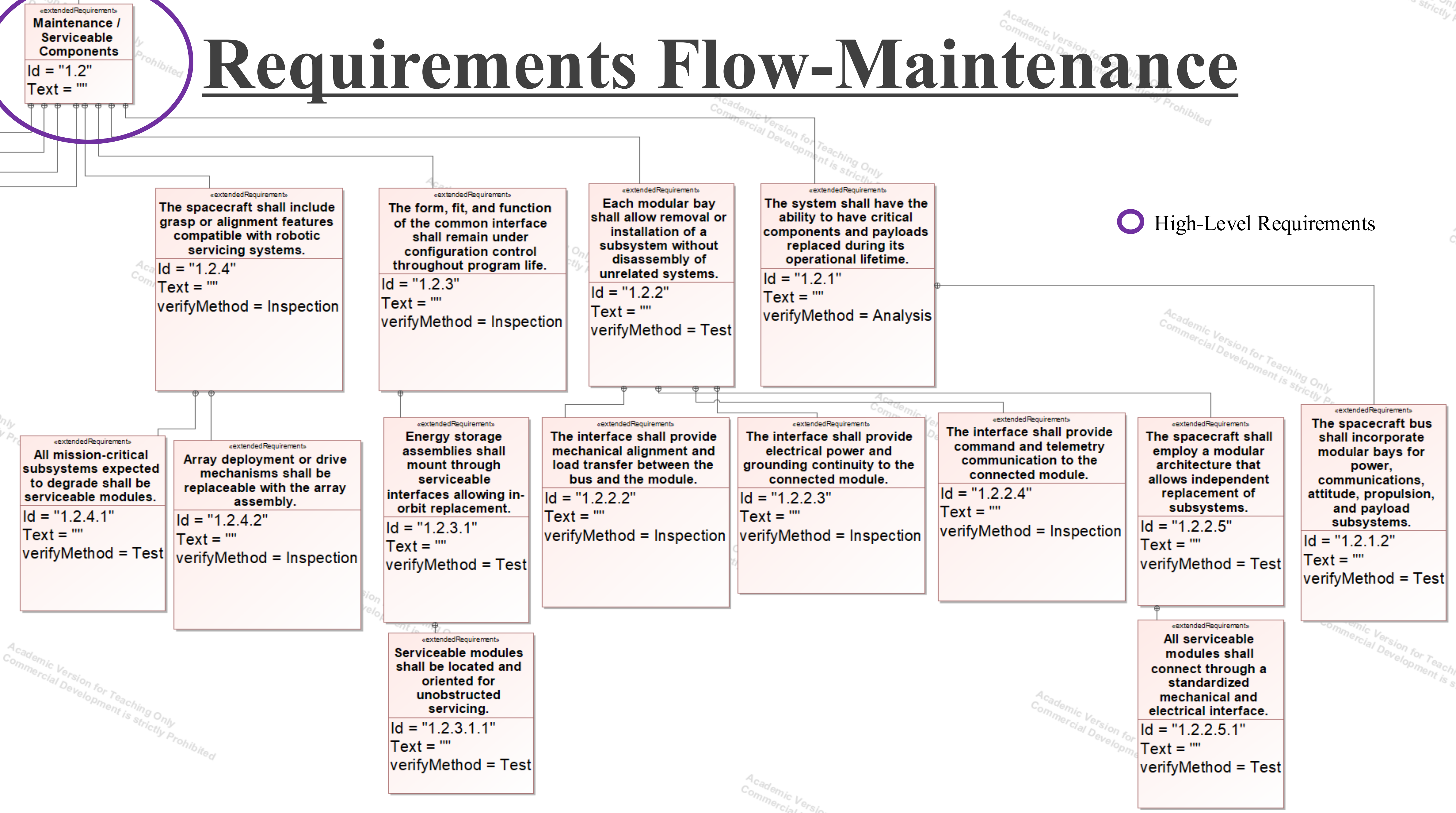
Requirements Flow-Longevity

Requirements Flow-Maintenance

High-Level Requirements

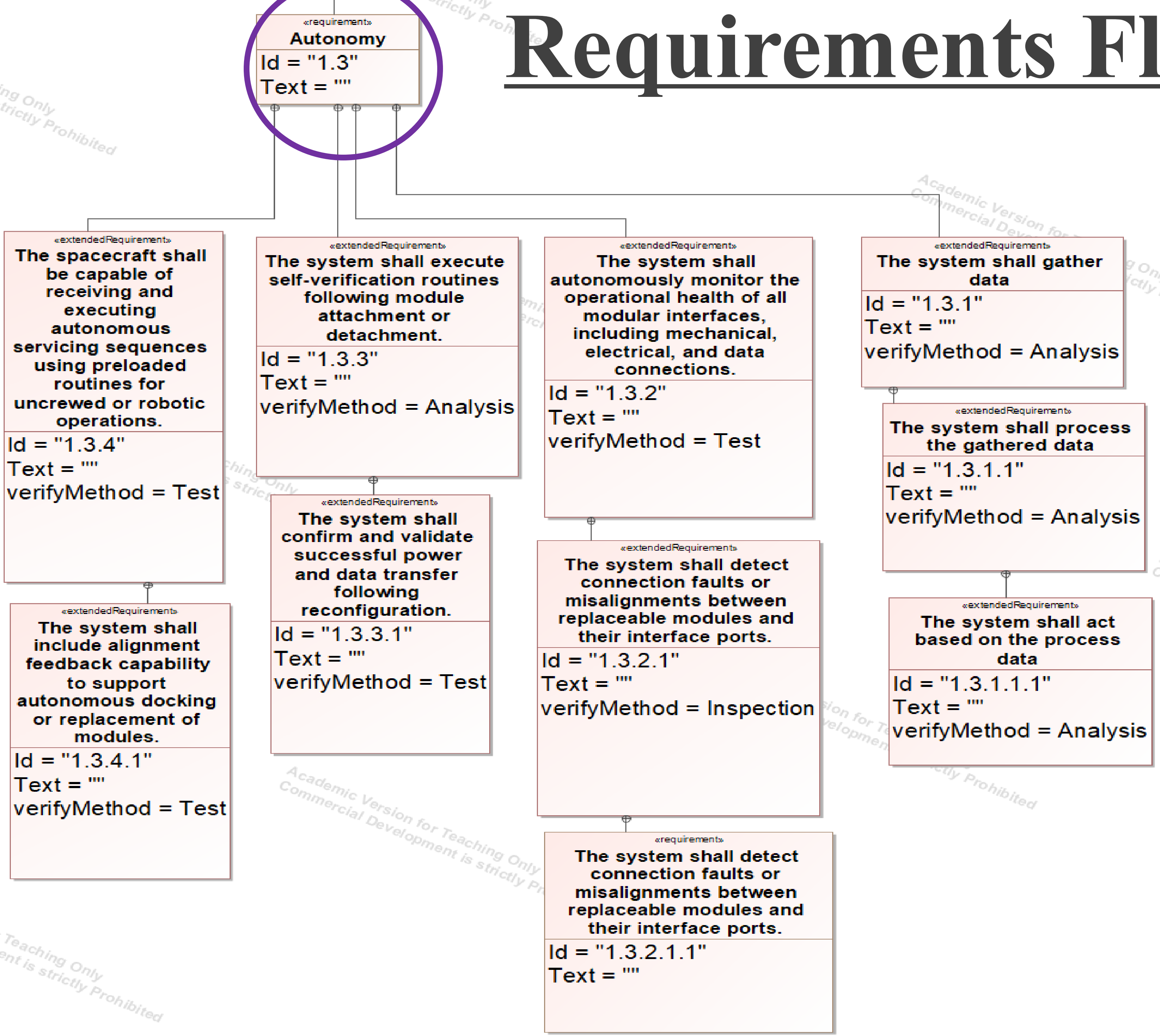


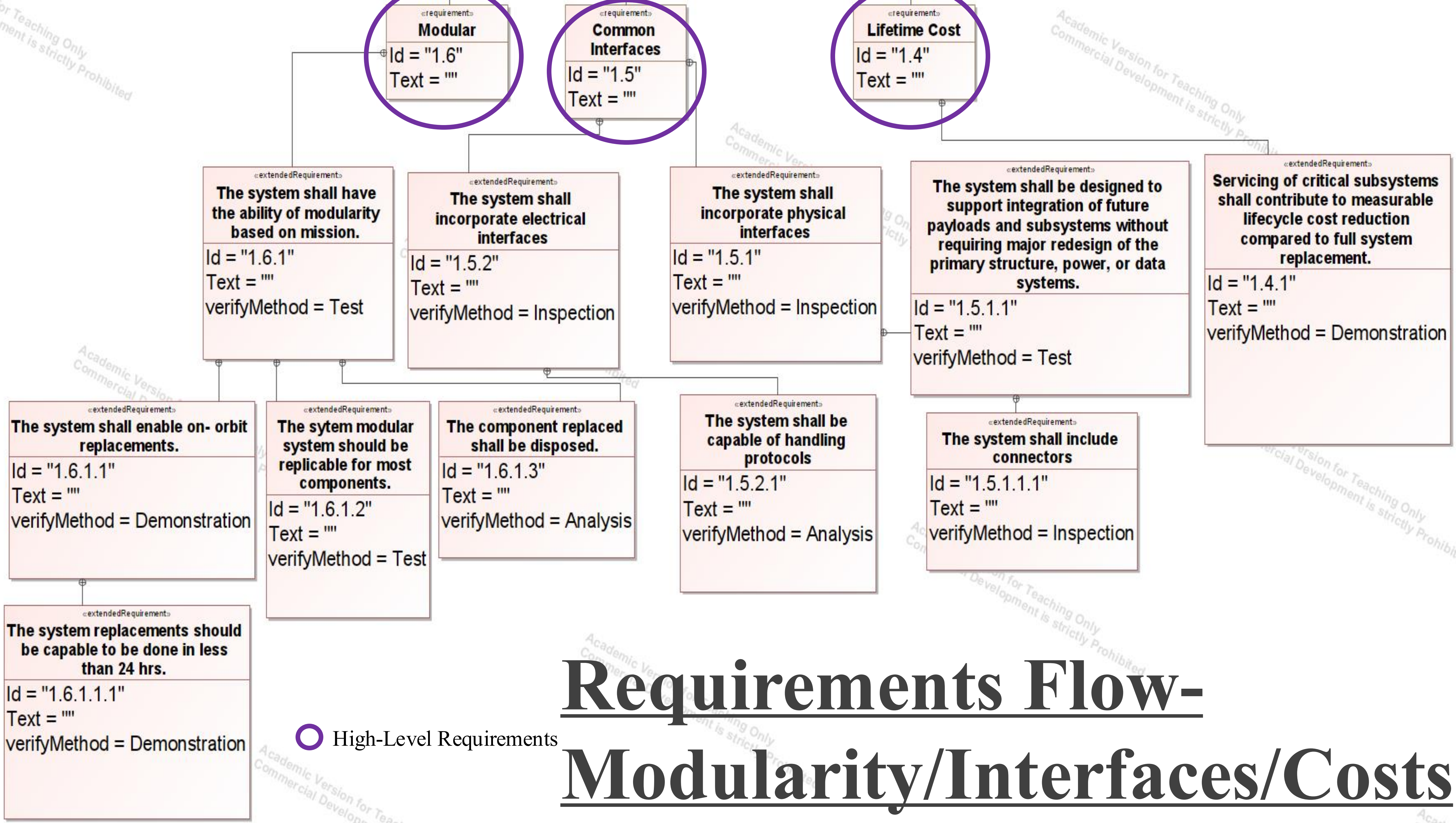
Requirements Flow-Maintenance



Requirements Flow-Autonomy

High-Level Requirements

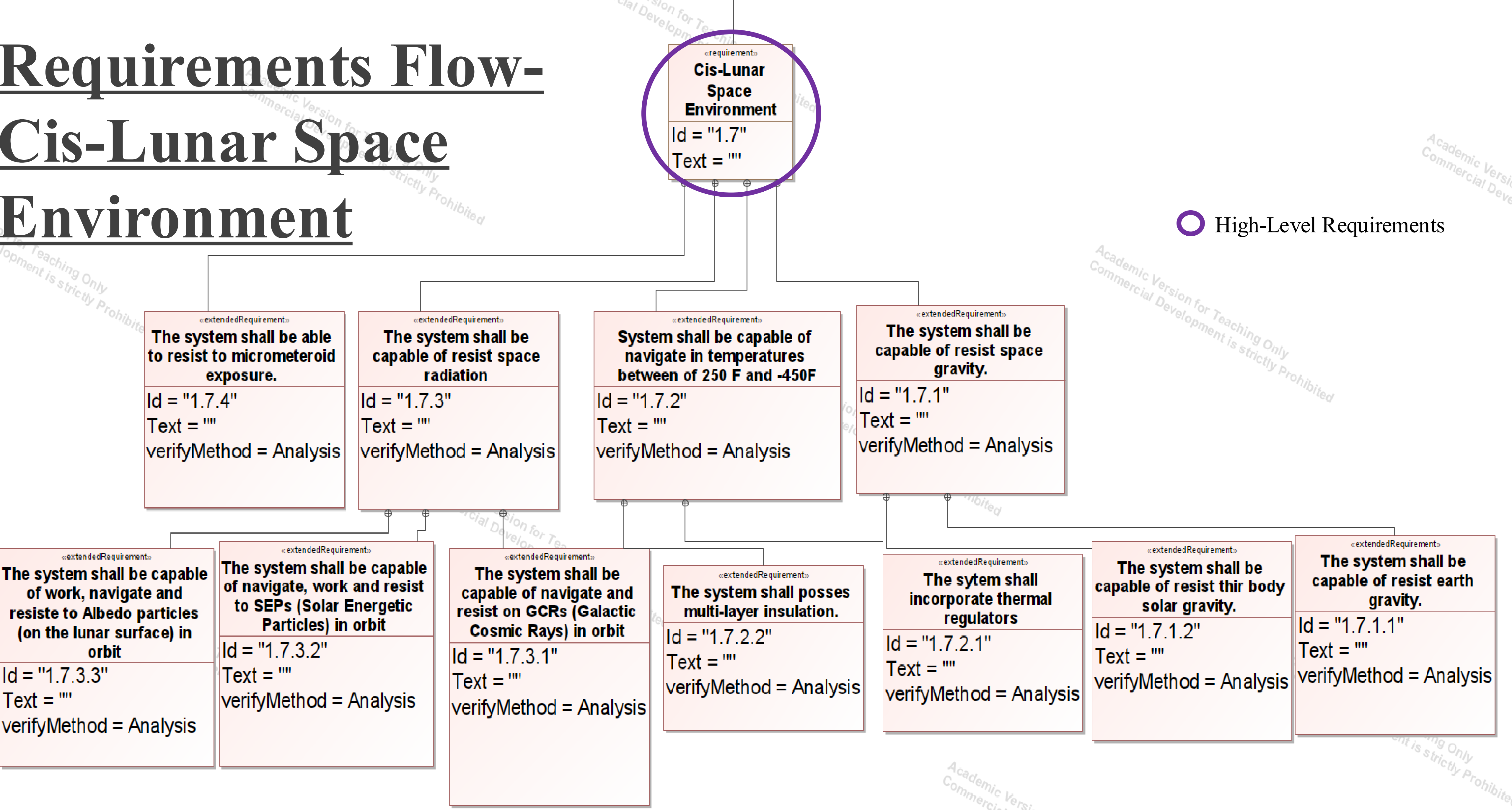




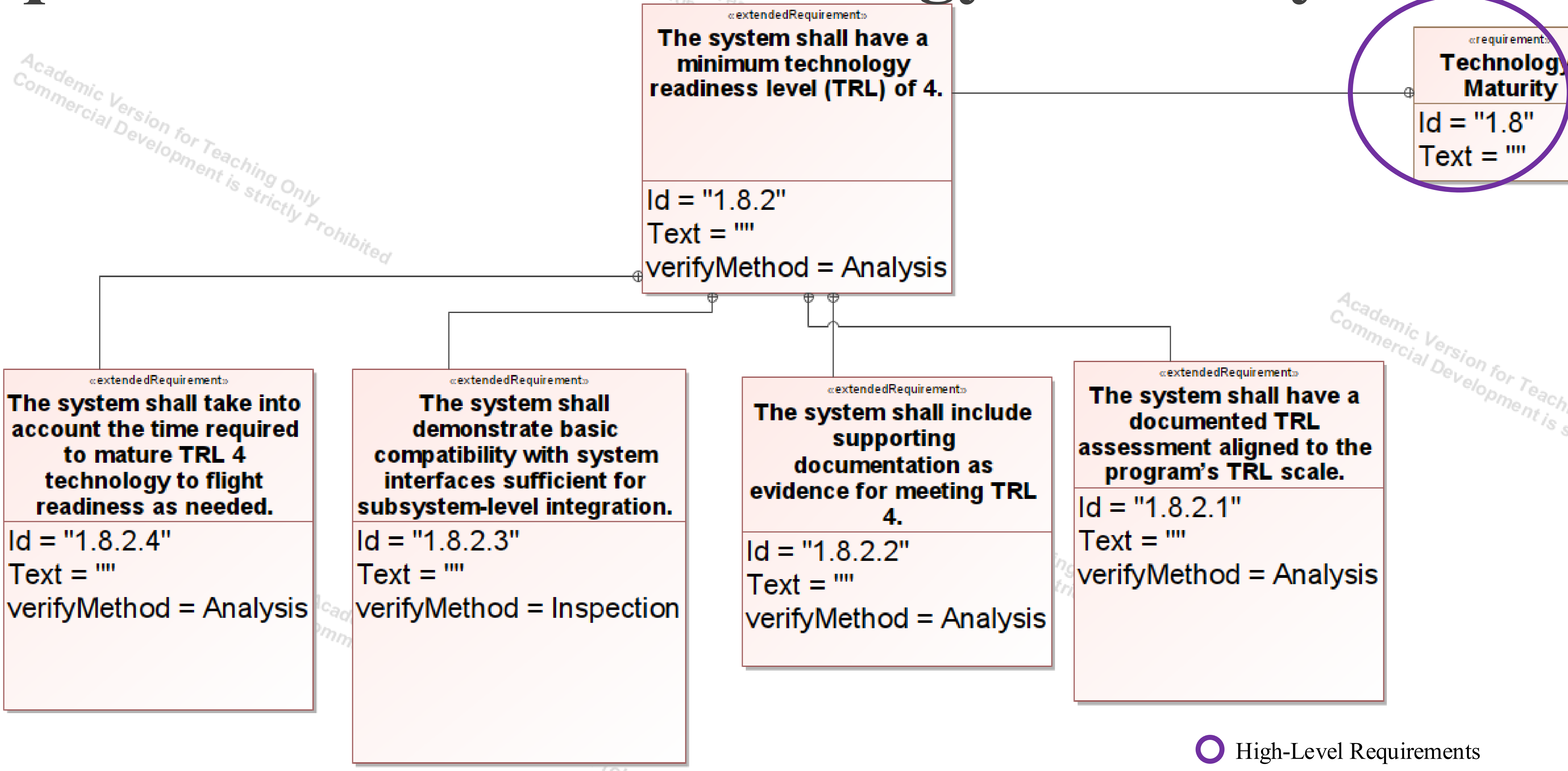
High-Level Requirements

Requirements Flow-Modularity/Interfaces/Costs

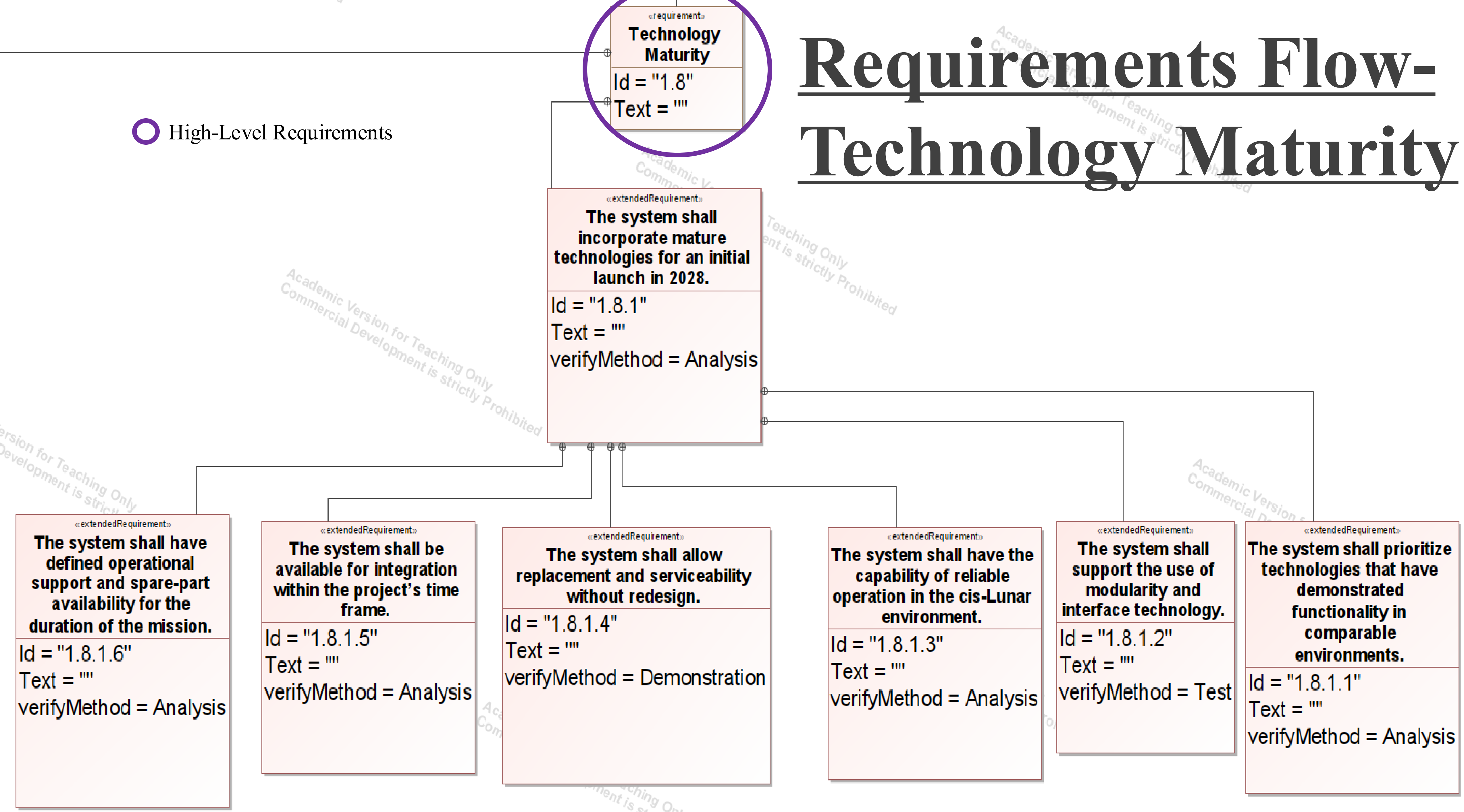
Requirements Flow- Cis-Lunar Space Environment



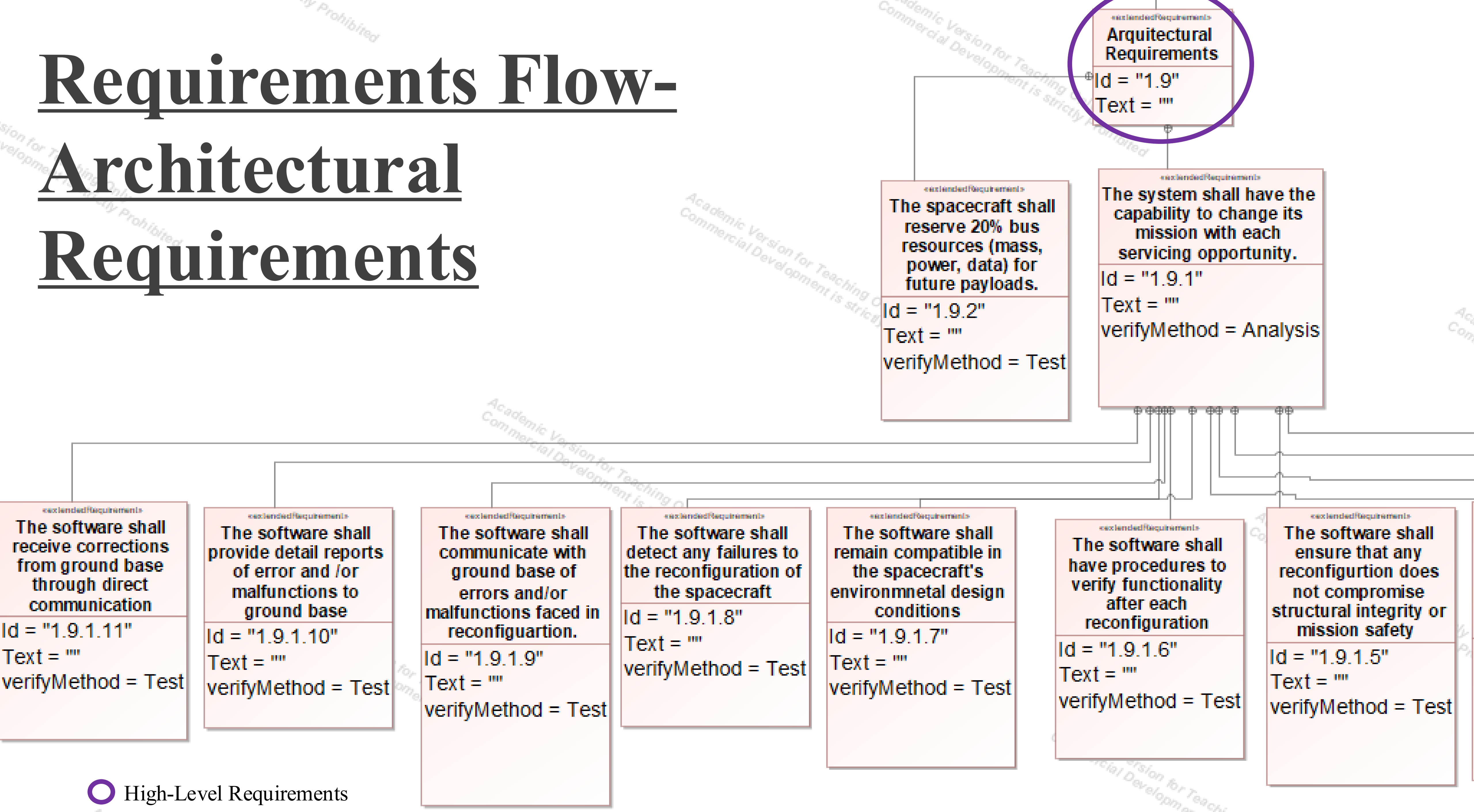
equirements Flow-Technology Maturity



Requirements Flow-Technology Maturity

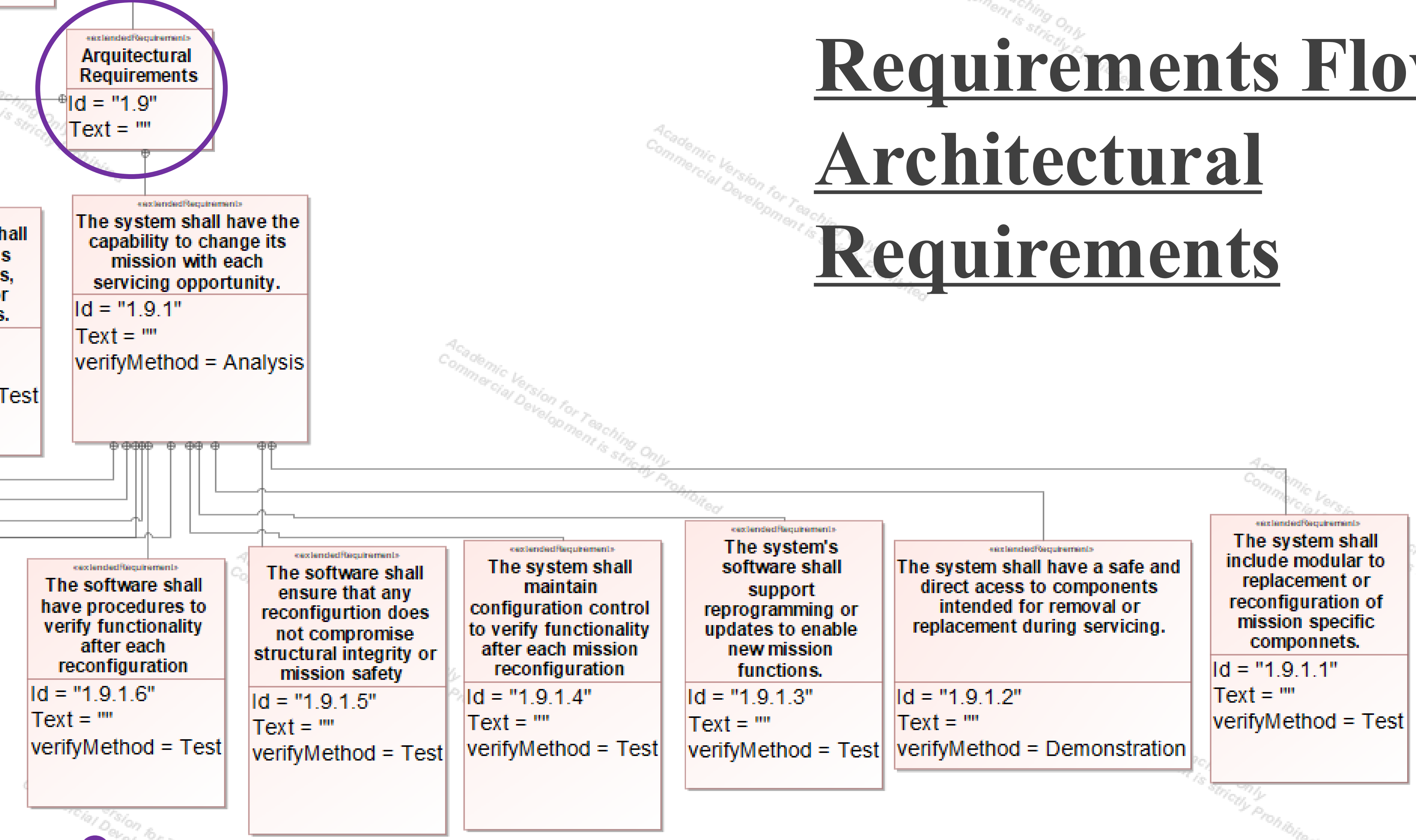


Requirements Flow-Architectural Requirements



High-Level Requirements

Requirements Flow- Architectural Requirements



High-Level Requirements

Key Requirements V&V Summary

Requirements	Verification	Validation
1.1 Longevity	Conducted through accelerated life-cycle testing, material fatigue analysis, and component endurance simulations to confirm design robustness over time.	Achieved by long-duration operational testing and environmental exposure trials to ensure sustained performance meets mission lifetime objectives.
1.2 Maintenance / Serviceable	Performed through design inspection, accessibility assessments, and interface compatibility checks to verify ease of servicing.	Conducted via maintenance procedure demonstrations and hands-on service simulations to validate the system can be efficiently repaired or maintained.

Key Requirements V&V Summary

Requirements	Verification	Validation
1.3 Autonomy	Achieved using software code analysis, control logic simulation, and algorithm testing under nominal and off-nominalconditions	Performed through full-system autonomous operationtrials and fault-response demonstrations to confirm independent decision-making reliability.
1.4 Lifetime Cost	Based on analytical calculation of production,maintenance, and operational costs compared to requirements andhistorical benchmarks.	Assessing actual prototype performance, integrationeffort, and overall life-cycle savings to confirm the design trulyreduces long-term cost

Key Requirements V&V Summary

Requirements	Verification	Validation
1.5 Common Interfaces	Done by reviewing the interface control documents,checking that the mechanical and electrical interfaces physically fit,and ensuring the data protocols match	Is performed through subsystem integration testing,where we confirm the interfaces actually allow seamless power,structural attachment, and communication across Bus, SADA,UMIM, and the solar array.
1.6 Modular	Achieved through inspection of modular design documentation, interface verification between modules, and independent functional testing.	Conducted by physical module integration and reconfiguration testing to demonstrate system adaptability and ease of replacement or upgrade.

Key Requirements V&V Summary

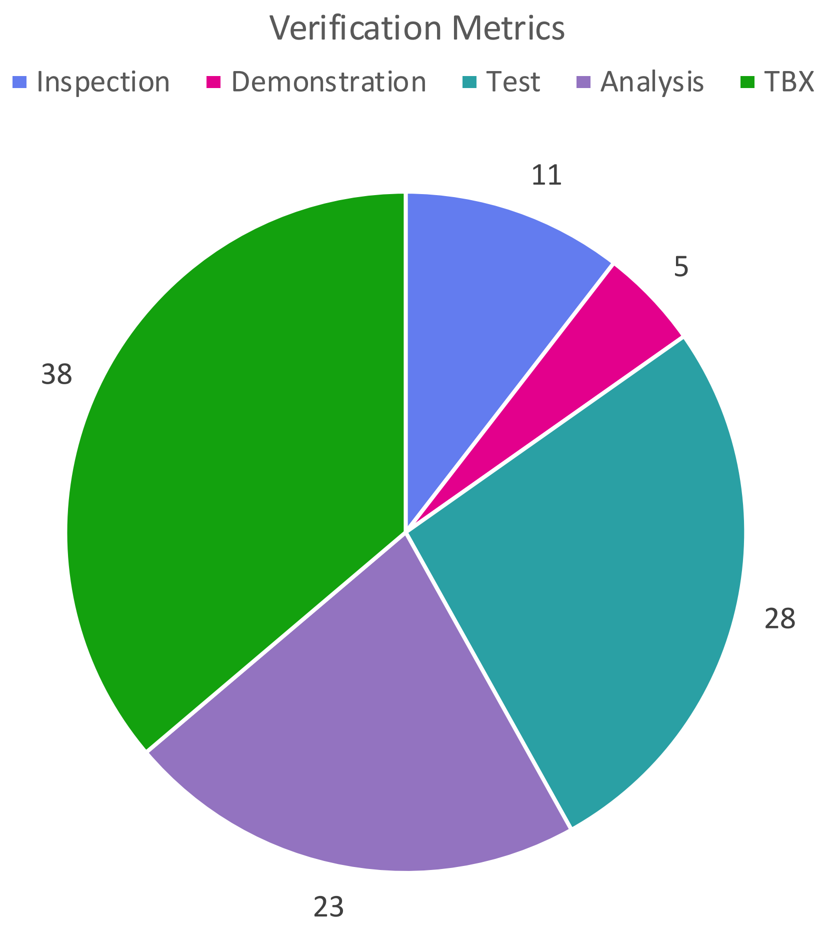
Requirements	Verification	Validation
1.7 Cis-Lunar Space Environment	Completed through environmental simulation, including thermal-vacuum, radiation, and vibration analysis representative of cis-lunar conditions.	Performed using environmental chamber testing and mission analog trials to validate system performance under expected operational extremes.
1.8 Technology Maturity	Carried out through technology readiness assessments (TRL analysis), component qualification reviews, and prototype evaluation reports.	Achieved by subsystem and system-level demonstration testing to confirm all technologies meet readiness requirements prior to deployment.

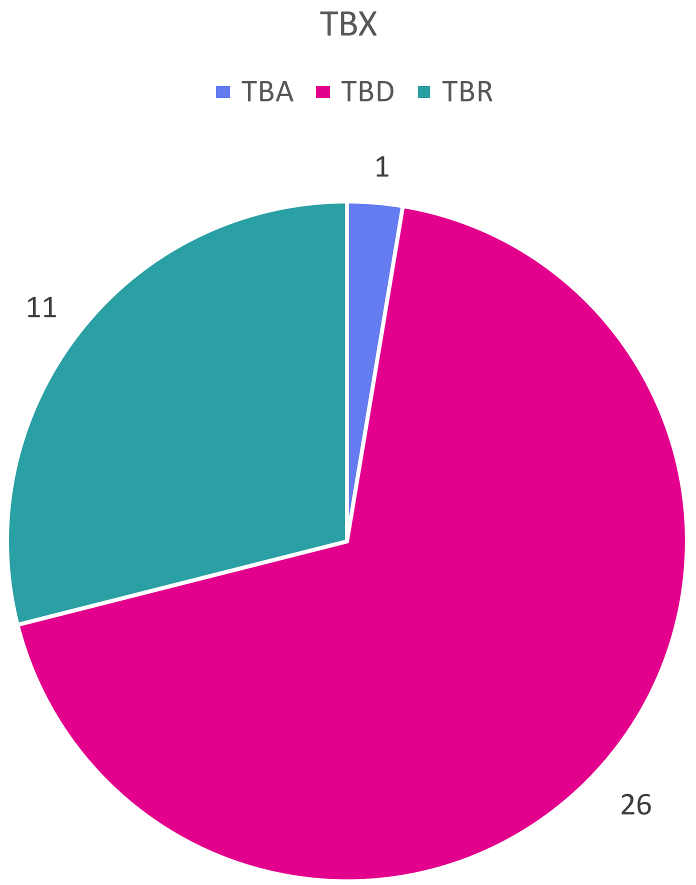
Key Requirements V&V Summary

Requirements	Verification	Validation
1.9 Architectural	Conducted through system modeling, trade studies, and architecture traceability analysis to ensure all functions align with design intent.	Performed by end-to-end system integration testing and operational simulations demonstrating that the architecture satisfies mission-level objectives.

Link to Complete V&V Activities:
Full V&V Activities for Requirements

Verification Metrics





TBA: To be announced
TBD: To be determined
TBR: To be revised

Design Concept

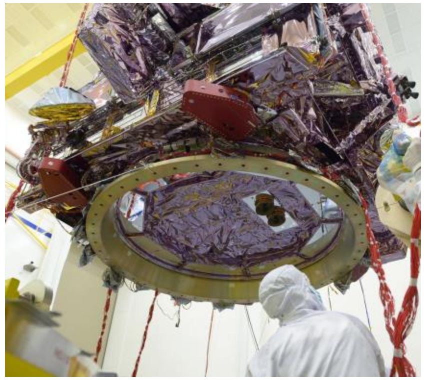
Proposed System Solution: Modular Structural Interface for Satellite Components

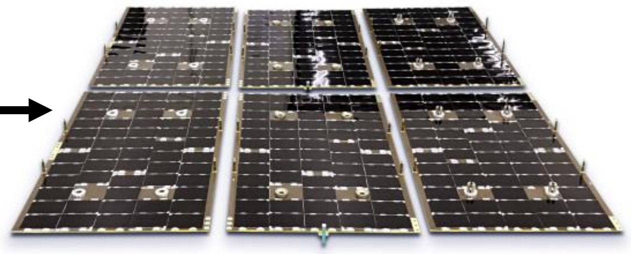
System Concept: Universal Mechanical Interface Module **(UMIM)**

Concept Definition: Modular Replaceable Interface for Spacecraft Assemblies

Design Concept Flow

Spacecraft Bus → Solar Array Drive Assembly → Universal Mechanical Interface Module → Solar Array





Trade Study 1: Attachment Method

Trade Study 1: Attachment Method							
Connector Type	**Structural Integrity**	**Serviceability**	**Reliability**	**Mass / Volume Efficiency**	**Technology Maturity (TRL ≥ 4)**	**Integration Complexity**	**Weighted Score (Trade Score)**
Docking / Blind-Mate Connector	4- Strong; guided pins and alignment features	5- Instant alignment; optimal for robotic or manual servicing	4- High; reliable with calibration	4- Guide frames lighter than expected	4-TRL 6-7 (OSAM-1 heritage)	4- Better fit with UMIM modular bay geometry	**4.35 / 5 = 87%**
Circular Connector	5- Excellent; robust retention under launch vibration	4- Requires twist-lock alignment; slower servicing	5- Excellent; redundant contacts	4- Compact	5- TRL 9 (flight heritage)	3- Added alignment steps during integration	**4.25 / 5 = 85%**
Rectangular Connector	4 - Good; adequate load transfer and vibration resistance	3 - Medium; manual alignment required	4 - High; reliable if strain-relieved	4 - Compact; high contact density	4 - TRL 8–9 (used in aerospace systems)	4 - Moderate; allows easy bench testing	**3.95 / 5 = 79%**
Ruggedized Connector	4 - Good; sealed housing resists vibration and dust	4 - High; simple manual connect and disconnect	4 - High; reliable in harsh environments	4 - Compact; moderate weight	5 - TRL 9 (space-qualified design)	4 - Moderate; straightforward qualification	**4.10 / 5 = 82%**
CRS (Connector Retention System)	5 - Excellent; rigid structural attachment and vibration resistance	2 - Low; non-serviceable after integration	5 - Excellent; zero motion and high load tolerance	2 - Heavy; reinforced flange adds mass	5 - TRL 9 (fielded on GEO buses)	2 - Difficult; requires structural verification for each integration	**4.05 / 5 = 81%**
D-Sub Connector	4 - Good; proven structural integrity in spacecraft heritage designs	1 - Very low; jackpost screws limit quick servicing	4 - High; reliable electrical contacts when secured	5 - Very compact; space efficient	5 - TRL 9 (flight avionics heritage)	4 - Easy; standard bench qualification	**3.80 / 5 = 76%**
Umbilical Harness (Cords)	2 - Weak; provides limited structural support	5 - Excellent; flexible and easy to replace	3 - Moderate; exposed to environmental degradation	2 - Bulky; requires strain relief	4 - TRL 8 (used in ground systems)	3 - Moderate; requires manual inspection	**3.20 / 5 = 64%**
Weight ->	**0.25**	**0.2**	**0.2**	**0.1**	**0.15**	**0.1**	

Trade Study 1: Attachment Method

Objective:

Identify the attachment method that best balances correct alignment, structural reliability, and fast servicing for UMIM modules.

Result Summary:

- Top candidate: Docking / Blind-Mate Connector
  - Highest updated score (87%).
  - Instant alignment; no twist-lock required.
  - Supports robotic and autonomous servicing with minimal risk of misalignment.
  - Compatible with UMIM modular bay geometry; smooth blind docking demonstrated.

- Second candidate: Circular Connector
  - Updated score (85%).
  - Proven flight heritage and strong structural reliability.
  - Requires rotational alignment and twist-lock, increasing servicing time.
  - Still a robust option, but less favorable for fast-swap UMIM operations.

Trade Study 2: Electrical Connector Standard

Objective:
Select the electrical connector standard for the UMIM that best balances reliability, compactness, mass, and ease of servicing over the 40-year cis-lunar mission.

Result Summary:

- **Top candidate: Micro-D (MIL-DTL-83513)**
  - Highest updated score (**92%**).
  - Excellent reliability with extensive CubeSat and payload avionics heritage.
  - Very compact and lightweight—optimal fit for UMIM's small modular bays.
  - Supports quick servicing and modular subsystem replacement.
- **Second candidate: MIL-DTL-38999 / MS27XXX / D38999 Series I-IV**
  - Updated score (**87%**).
  - Strong mechanical robustness and proven flight qualification.
  - Requires torque-tool servicing and has higher mass, making it less ideal for UMIM's miniaturized architecture.
  - Still a viable legacy option for high-load or externally mounted subsystems.

Trade Study 3: Mechanical Connector

Objective: Select the mechanical connector that provides secure, launch-survivable attachment of UMIM modules to the spacecraft while still enabling reliable modular replacement and servicing.

Result Summary

• Top Candidate: Bolted Flange (90%)

•Highest score; proven under 1500 g launch vibration.

•Zero-motion, highly reliable joint.

•Straightforward integration with UMIM structure.

•Slight mass penalty but best overall performance.

• Second Candidates (85%): Quick-Release Clamp & Single-Point Latching

•Quick-Release: Fast servicing, compact, reliable; requires verification testing.

•Single-Point Latch: Excellent robotic alignment; moderate integration complexity.

Trade Study 4: Connector Material

Objective:
Determine the most suitable connector material for UMIM by comparing candidates on radiation tolerance, strength, complexity, and serviceability to ensure long-term reliability in cis-lunar operations.

Result Summary

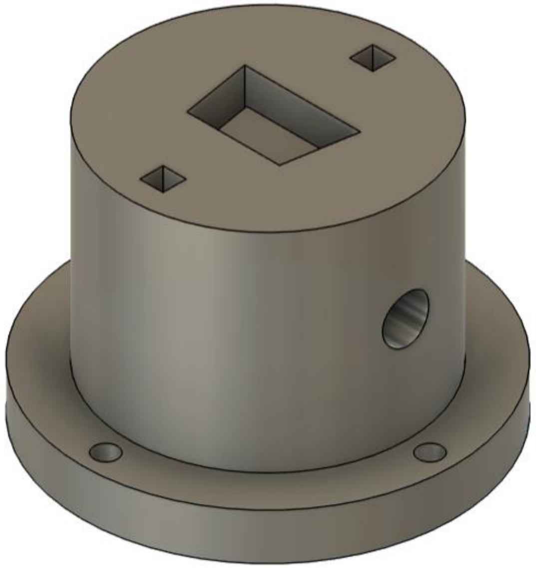
Top Candidate

- **Titanium Ti-6Al-4V - 4.50 / 5 (90%)**
- Radiation: High
- Complexity: Medium
- Serviceability: High
- Note: Very strong/stable; matches CFRP well.

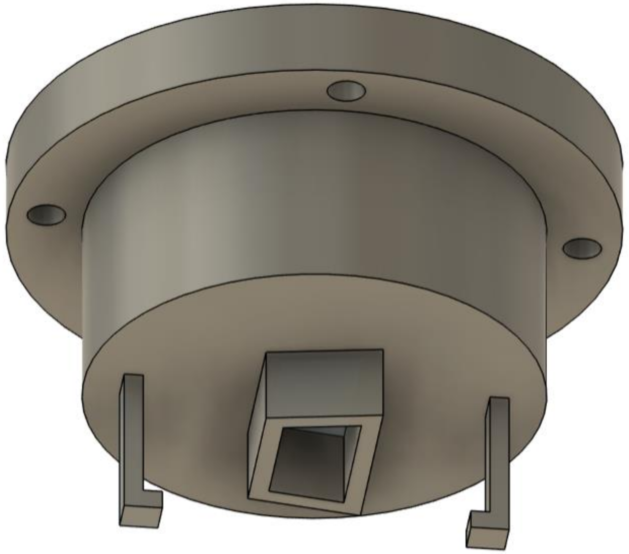
Second candidate

- **BeCu with Au/Ni (contacts) - 4.50 / 5 (90%)**
- Radiation: High
- Complexity: Medium
- Serviceability: High
- Note: Aerospace standard; low contact resistance.

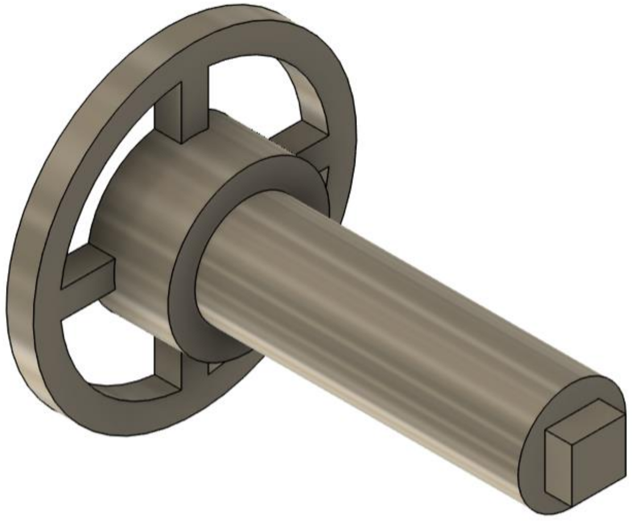
Proposed Design Configuration



Part A: Connected to the Solar Array Drive Assembly (SADA)

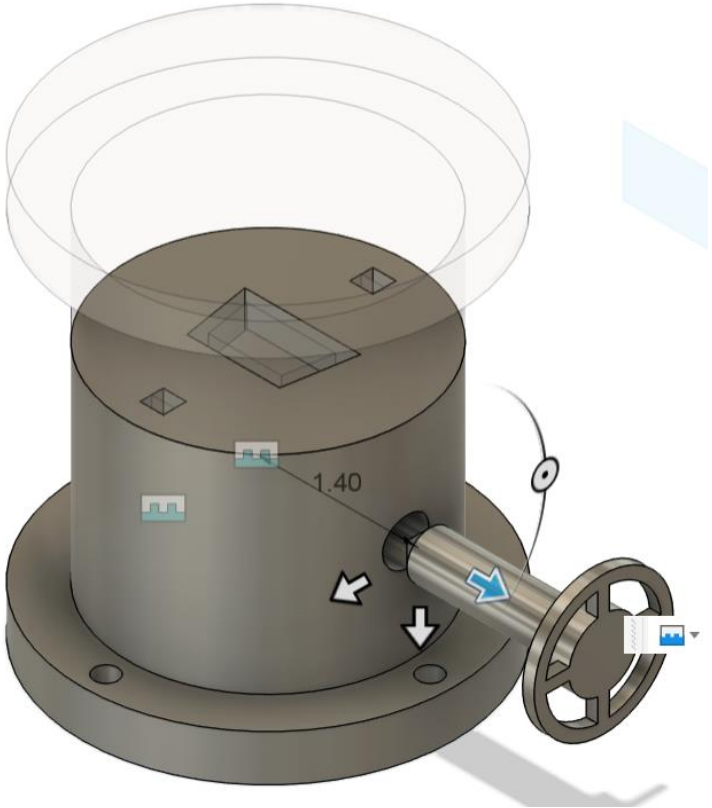


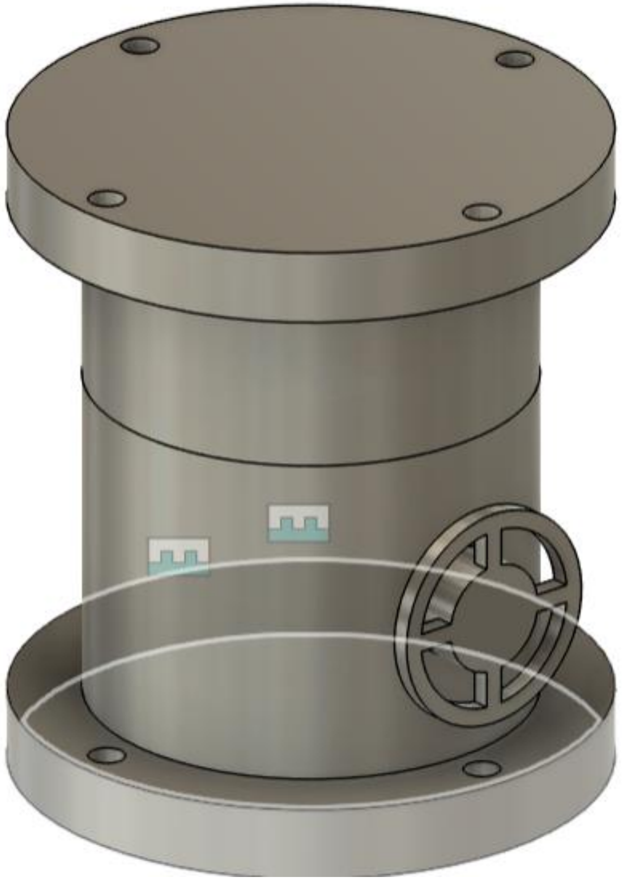
Part B: Connected to the Solar Array.

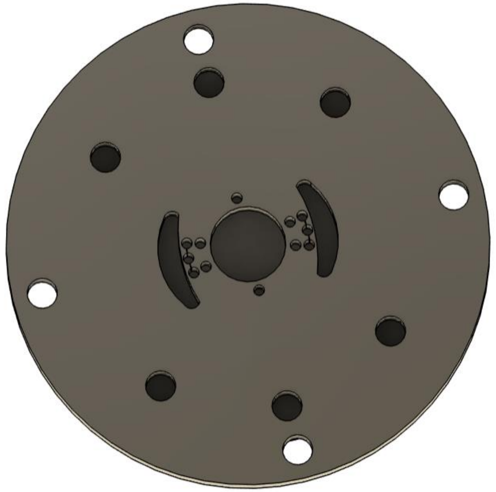


Key: Activates the clamping mechanism.

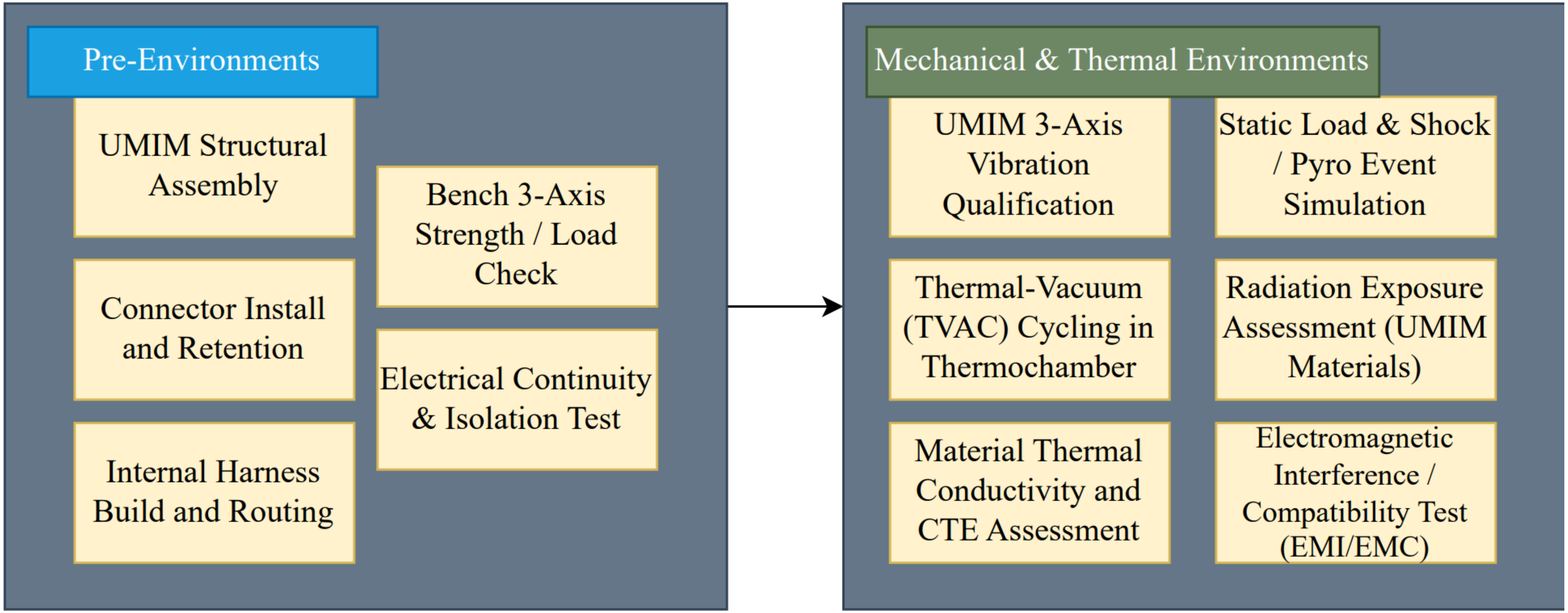
Proposed Design Configuration



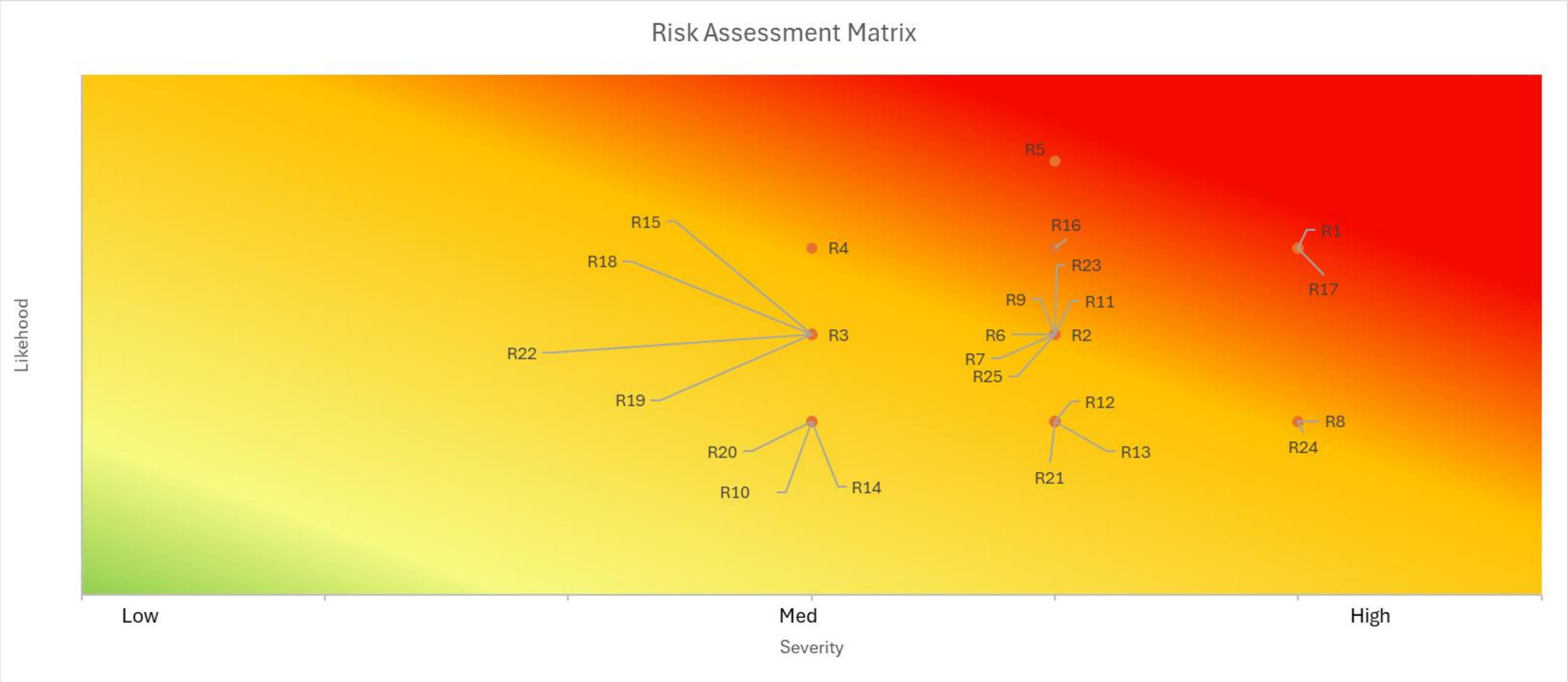




Integration and Test Flow Diagram



Risk Assessment



The following risk matrix illustrates the distribution and range of potential risks identified during the development of our design concept. Each orange point represents a specific risk (labeled as RX), corresponding to the calculated value of *Likelihood* × *Severity* as defined in the risk assessment table.

Risk Assessment

Risk ID	Description	Response Strategy	Preventative Actions	Likehood(1-5)	Severity(A-E)	Risk Level
R1	Failure in modular attachment mechanism during assembly	Mitigation	Perform mechanical load testing on all attachment mechanisms before assembly.	4	5	20
R5	Human error during integration and testing	Mitigation	Create detailed integration checklists and cross-verification steps for testing.	5	4	20
R17	Schedule compression causing reduced testing time	Mitigation	Add project buffers and enforce test readiness reviews before timeline shifts.	4	5	20
R16	Budget overrun delaying project schedule	Acceptance	Set up budget tracking dashboards and pre-approve milestone spending.	4	4	16

This table outlines the primary project risks, their response strategies, and corresponding – likelihood-severity ratings. Each risk includes preventative actions to reduce potential impacts on design, integration, and schedule.

Contingency Plan Summary

Response to high-impact risks across mechanical, electrical, thermal, software, and schedule domains. For each risk category, predefined backup actions ensure mission continuity.

Mechanical & Structural Risks

- Backup attachment method (bolted flange) ready if UMIM interface fails
  - Add damping / stiffening material if vibration resonance appears

Electrical & Data Risks

- Redundant data channel available
  - Backup power routing if load balancing fails

Thermal & Environmental Risks

- Increase sink size if thermal thresholds exceeded or reduce internal power load

Software, Documentation & Integration Risks

- Roll back to last stable build if integration fails
  - Rapid documentation correction session for missing requirements

Schedule, Staffing & Budget Risks

- Activate cross-trained backups if team member unavailable
  - Add recovery shifts
  - Prioritize core UMIM tasks if budget tightens

Activation Plan:

- Risk level ≥12
- Preventative action fails during integration or testing
- Schedule delay >2 days
- Critical-path item impacted
- Safety/certification requirement not met

Proposed Future Work

- Complete all requirement maturation.
- Develop a functional 3D-printed UMIM prototype to validate alignment, fit, connector placement, and serviceability.
- Define how the spacecraft subsystems will be interchanged in-orbit.
- Expand autonomy development in simulation, focusing on module detection, fault management, and safe-mode logic.
- Build detailed integration and test documentation using the UMIM prototype for sequencing and procedure definition.
- Refine analytical models (thermal, mass, cost) and update risk assessment using prototype-based findings.

ABET Outcome 2: Engineering Design

During our Long-Duration Spacecraft capstone, we applied engineering design to turn stakeholder needs into a practical concept (the UMIM modular interface) by building requirements, running trade studies, and planning verification/testing to make sure the solution was realistic and measurable.

Safety and welfare were a constant focus, since our design decisions aimed to reduce the chance of on-orbit failures (and potential debris) while still supporting long-term, autonomous servicing in a harsh cis-lunar environment. We also considered environmental and economic factors by prioritizing serviceability and extended life to reduce waste, lower the need for repeated launches, and minimize lifetime cost over a 40+ year mission timeline.

ABET Outcome 3: Communication

For ABET 3 (effective communication with a range of audiences), our project pushed us to explain the same technical work in different ways depending on who was listening. In our NG/UTEP final presentation, we organized the story from mission goals to requirements, V&V, trade studies, and risk, so sponsors and instructors could quickly see the logic behind our design choices.

We also communicated in writing through the final report, where we summarized our systems engineering approach (requirements, trade studies, V&V planning, integration/testing, and risk management) in a clear executive-level format. Finally, our risk/contingency communication plan made us practice professional updates (notify sponsor/instructor fast, send a short email summary, document the issue, and report it at the next review meeting).

ABET Outcome 4: Ethics

For ABET 4 (Ethics), this project made us think beyond just “does it work” and focus on what is responsible engineering. Since space systems can’t be easily repaired, we treated safety and reliability as ethical priorities by designing in a way that reduces the chance of failures that could create hazards like mission loss or space debris.

We also tried to be honest and realistic in our decisions by documenting assumptions, limits, and trade-offs instead of overpromising performance. On the team side, we practiced ethical collaboration by giving credit for contributions, keeping our work traceable in the report/presentations, and making decisions based on data and requirements rather than personal preference.

ABET Outcome 5: Teamwork

For ABET 5 teamwork and leadership, this project showed us what it takes to work effectively as a team with a real deadline. We divided the work based on each person's strengths, set clear roles, and stayed coordinated so our subsystems and documents matched. We planned tasks week by week, set goals for each milestone, and adjusted when something took longer than expected. Communication was a big part of it too. We kept meetings productive, followed up on action items, and made sure everyone's input was included so we stayed collaborative and respectful while still getting the work done.

ABET Outcome 7: Applying New Knowledge

The Senior Design Capstone has helped developed new knowledge such as creating Contingency Plan, 3D printing protypes,TRL assessment andvocabulary, Cameo, autonomous servicing concepts and Verification Metrics etc. This new integrated knowledge will allow us to move forward in our careers and navigate with ease. The new acquired vocabulary gained from the Senior Design Capstone will allow us to broadcast for future career proposals in a professional manner and not lose translation when communicating proposal ideas. We have also developed new organizational habits to be able to fulfill these ideas in a well-established time and have structure in our presentations.

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Q&A

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Backup

Requirements: Part 1

#	Name	Verify Method
1	1 Modular Serviceable Autonomous Spacecraft	
2	1.1 Longevity	
3	1.1.1 The spacecraft structure shall maintain mechanical integrity throughout the 40-year operational life in the cis-Lunar environment.	Analysis
4	1.1.1.1 Structural materials shall resist degradation caused by radiation, thermal cycling, and micrometeoroid exposure for the mission duration.	Test
5	1.1.1.2 Structural load paths shall maintain stiffness and strength required to support attached subsystems and serviceable interfaces.	Test
6	1.1.1.3 The spacecraft mechanical interface and primary structural attachment shall withstand launch-vehicle quasi-static load factors of at least 6 g	Analysis
7	1.1.2 The power subsystem shall sustain continuous generation, storage, and distribution capability for the 40-year mission.	Analysis
8	1.1.2.1 The solar array assemblies shall maintain functional electrical performance under the long-term radiation and thermal environment.	Analysis
9	1.1.2.1.1 Solar array drive assemblies shall maintain motion capability for orientation and power optimization through the mission lifetime.	Analysis
10	1.1.2.2 The onboard energy storage system shall remain functional for the mission duration or be replaceable during servicing.	Analysis
11	1.1.2.3 Power regulation and distribution electronics shall maintain functionality under continuous operation in the cis-Lunar environment	Inspection
12	1.1.3 The thermal control subsystem shall maintain all components within operational temperature limits over 40 years.	Analysis
13	1.1.4 The spacecraft shall protect critical components against radiation effects to ensure operability for 40 years.	Analysis
14	1.1.4.1 Electronic parts shall be selected and qualified for the predicted cis-Lunar radiation environment.	Analysis
15	1.1.5 The attitude determination and control subsystem shall maintain required pointing and stability through the mission lifetime.	Analysis
16	1.1.6 The communication subsystem shall provide continuous command, telemetry, and data capability for 40 years.	Analysis
17	1.1.7 The spacecraft shall withstand cumulative micrometeoroid, debris, and ultraviolet exposure for 40 years.	Analysis
18	1.1.7.1 Critical subsystems shall be protected against micrometeoroid and debris impact penetration.	Analysis
19	1.1.8 The spacecraft shall continue safe operation after single-point failures.	Analysis
20	1.1.8.1 The spacecraft shall autonomously detect and isolate failures and reconfigure to maintain operation.	Test
21	1.1.9 Subsystems expected to degrade before 40 years shall be replaceable through modular interfaces.	Test
22	1.1.9.1 Solar arrays shall be configured for removal and installation through serviceable interfaces.	Test
23	1.1.9.2 Antenna assemblies shall be configured for removal and installation through serviceable interfaces.	Test
24	1.1.10 Materials shall maintain mechanical and chemical properties within design limits for 40 years.	Analysis

Requirements: Part 2

#	Name	Verify Method
25	1.2 Maintenance / Serviceable Components	
26	1.2.1 The system shall have the ability to have critical components and payloads replaced during its operational lifetime.	Analysis
27	1.2.1.1 The spacecraft shall employ a modular architecture that allows independent replacement of subsystems.	Test
28	1.2.1.2 The spacecraft bus shall incorporate modular bays for power, communications, attitude, propulsion, and payload subsystems.	Test
29	1.2.2 Each modular bay shall allow removal or installation of a subsystem without disassembly of unrelated systems.	Test
30	1.2.2.1 All serviceable modules shall connect through a standardized mechanical and electrical interface.	Test
31	1.2.2.2 The interface shall provide mechanical alignment and load transfer between the bus and the module.	Inspection
32	1.2.2.3 The interface shall provide electrical power and grounding continuity to the connected module.	Inspection
33	1.2.2.4 The interface shall provide command and telemetry communication to the connected module.	Inspection
34	1.2.3 The form, fit, and function of the common interface shall remain under configuration control throughout program life.	Inspection
35	1.2.3.1 Serviceable modules shall be located and oriented for unobstructed servicing.	Test
36	1.2.4 The spacecraft shall include grasp or alignment features compatible with robotic servicing systems.	Inspection
37	1.2.4.1 All mission-critical subsystems expected to degrade shall be serviceable modules.	Test
38	1.2.4.2 Array deployment or drive mechanisms shall be replaceable with the array assembly.	Inspection
39	1.2.4.3 Energy storage assemblies shall mount through serviceable interfaces allowing in-orbit replacement.	Test
40	1.2.5 Payload modules shall be replaceable through standard interfaces for mission evolution.	Inspection
41	1.2.5.1 The system shall verify connection integrity and functionality of replaced modules.	Test
42	1.2.5.2 Each interface shall include sensors confirming mechanical and electrical engagement.	Inspection
43	1.2.6 The spacecraft shall confirm operational status of newly installed modules before returning to mission operations.	Analysis
44	1.2.6.1 The spacecraft shall include validated procedures for safe servicing of each module.	Analysis
45	1.2.6.2 All servicing steps shall be demonstrated with representative hardware before flight.	Analysis
46	1.2.7 On-orbit servicing sequence and equipment requirements shall be defined prior to launch.	Analysis
47	1.2.7.1 The flight software shall automatically detect newly installed modules and register them.	Test
48	1.2.8 The spacecraft shall support uploading software required for new or replacement modules.	Demonstration
49	1.2.8.1 All modular interfaces shall be documented and maintained for the spacecraft lifetime.	Test

Requirements: Part 3

#	Name	Verify Method
50	1.3 Autonomy	
51	1.3.1 The system shall gather data	Analysis
52	1.3.1.1 The system shall process the gathered data	Analysis
53	1.3.1.1.1 The system shall act based on the process data	Analysis
54	1.3.2 The system shall autonomously monitor the operational health of all modular interfaces, including mechanical, electrical, and data connections.	Test
55	1.3.2.1 The system shall detect connection faults or misalignments between replaceable modules and their interface ports.	Inspection
57	1.3.3 The system shall execute self-verification routines following module attachment or detachment.	Analysis
58	1.3.3.1 The system shall confirm and validate successful power and data transfer following reconfiguration.	Test
59	1.3.4 The spacecraft shall be capable of receiving and executing autonomous servicing sequences using preloaded routines for uncrewed or robotic op	Test
60	1.3.4.1 The system shall include alignment feedback capability to support autonomous docking or replacement of modules.	Test
61	1.4 Lifetime Cost	
62	1.4.1 Servicing of critical subsystems shall contribute to measurable lifecycle cost reduction compared to full system replacement.	Demonstration
63	1.4.2 The system shall be designed to support integration of future payloads and subsystems without requiring major redesign of the primary structure	Test
64	1.5 Common Interfaces	
65	1.5.1 The system shall incorporate physical interfaces	Inspection
66	1.5.1.1 The system shall include connectors	Inspection
67	1.5.2 The system shall incorporate electrical interfaces	Inspection
68	1.5.2.1 The system shall be capable of handling protocols	Analysis
69	1.6 Modular	
70	1.6.1 The system shall have the ability of modularity based on mission.	Test
71	1.6.1.1 The system shall enable on- orbit replacements.	Demonstration
72	1.6.1.1.1 The system replacements should be capable to be done in less than 24 hrs.	Demonstration
73	1.6.1.2 The sytem modular system should be replicable for most components.	Test
74	1.6.1.3 The component replaced shall be disposed.	Analysis

Requirements: Part 4

#	Name	Verify Method
75	1.7 Cis-Lunar Space Environment	
76	1.7.1 The system shall be capable of resist space gravity.	Analysis
77	1.7.1.1 The system shall be capable of resist earth gravity.	Analysis
78	1.7.1.2 The system shall be capable of resist thir body solar gravity.	Analysis
79	1.7.2 System shall be capable of navigate in temperatures between of 250 F and -450F	Analysis
80	1.7.2.1 The sytem shall incorporate thermal regulators	Analysis
81	1.7.2.2 The system shall posses multi-layer insulation.	Analysis
82	1.7.3 The system shall be capable of resist space radiation	Analysis
83	1.7.3.1 The system shall be capable of navigate and resist on GCRs (Galactic Cosmic Rays) in orbit	Analysis
84	1.7.3.2 The system shall be capable of navigate, work and resist to SEPs (Solar Energetic Particles) in orbit	Analysis
85	1.7.3.3 The system shall be capable of work, navigate and resiste to Albedo particles (on the lunar surface) in orbit	Analysis
86	1.7.4 The system shall be able to resist to micrometeroid exposure.	Analysis
87	1.8 Technology Maturity	
88	1.8.1 The system shall incorporate mature technologies for an initial launch in 2028.	Analysis
89	1.8.1.1 The system shall prioritize technologies that have demonstrated functionality in comparable environments.	Analysis
90	1.8.1.2 The system shall support the use of modularity and interface technology.	Test
91	1.8.1.3 The system shall have the capability of reliable operation in the cis-Lunar environment.	Analysis
92	1.8.1.4 The system shall allow replacement and serviceability without redesign.	Demonstration
93	1.8.1.5 The system shall be available for integration within the project's time frame.	Analysis
94	1.8.1.6 The system shall have defined operational support and spare-part availability for the duration of the mission.	Analysis
95	1.8.2 The system shall have a minimum technology readiness level (TRL) of 4.	Analysis
96	1.8.2.1 The system shall have a documented TRL assessment aligned to the program's TRL scale.	Analysis
97	1.8.2.2 The system shall include supporting documentation as evidence for meeting TRL 4.	Analysis
98	1.8.2.3 The system shall demonstrate basic compatibility with system interfaces sufficient for subsystem-level integration.	Inspection
99	1.8.2.4 The system shall take into account the time required to mature TRL 4 technology to flight readiness as needed.	Analysis

Requirements: Part 5

#	Name	Verify Method
100	1.9 Arquitectural Requirements	
101	1.9.1 The system shall have the capability to change its mission with each servicing opportunity.	Analysis
102	1.9.1.1 The system shall include modular to replacement or reconfiguration of mission specific componnets.	Test
103	1.9.1.2 The system shall have a safe and direct acess to components intended for removal or replacement during servicing.	Demonstration
104	1.9.1.3 The system's software shall support reprogramming or updates to enable new mission functions.	Test
105	1.9.1.4 The system shall maintain configuration control to verify functionality after each mission reconfiguration	Test
106	1.9.1.5 The software shall ensure that any reconfigurtion does not compromise structural integrity or mission safety	Test
107	1.9.1.6 The software shall have procedures to verify functionality after each reconfiguration	Test
108	1.9.1.7 The software shall remain compatible in the spacecraft's environmnetal design conditions	Test
109	1.9.1.8 The software shall detect any failures to the reconfiguration of the spacecraft	Test
110	1.9.1.9 The software shall communicate with ground base of errors and/or malfunctions faced in reconfiguartion.	Test
111	1.9.1.10 The software shall provide detail reports of error and /or malfunctions to ground base	Test
112	1.9.1.11 The software shall receive corrections from ground base through direct communication	Test
113	1.9.2 The spacecraft shall reserve 20% bus resources (mass, power, data) for future payloads.	Test

Docking/Blind-Mate Connector

Overview:
- Auto-connects power/data/fluids during docking (e.g. ISS, Orbital Express).
- Part of NASA IDSS; enables robotic servicing.

Applications:
- Docking ports, stage separation, payload swaps, LRUs.

Pros:
- Hands-free, fast, EVA-free servicing.
- Tolerates minor misalignment.
- Flight-proven (TRL 8-9).

Cons:
- Alignment-sensitive; risk of failure.
- Complex, adds mass.
- Limited mating cycles.

TRL:
- TRL 8-9 **-** Flight-proven; new designs require validation.

Trade Study 2: Connector Standard

Trade Study 2: Connector Standard							
Connector Standard (Family)	Structural Integrity	Serviceability	Reliability	Mass / Volume Efficiency	Technology Maturity (TRL ≥ 4)	Integration Complexity	Weighted Score (Trade Score)
Micro-D (MIL-DTL-83513)	4 - Good; 100 g shock	5 -Excellent; modular	5 -Excellent; heritage	**5 - Ultra-low mass, compact**	5 - TRL 9	3 - Moderate; precision alignment	4.60 / 5 = 92%
MIL-DTL-38999 / MS27XXX / D38999 Series I-IV	5- Excellent	4-High; torque tool	5 -Excellent	4 - Compact	5 -TRL 9	4 -Moderate; tooling	4.35 / 5 = 87%
MIL-DTL-38999 Series IV	5 - Excellent; breech-lock and hermetic options for high vacuum (Glenair)	4 - High; supports blind-mate operation	5 - Excellent; space-grade variants available	3 - Minor mass increase from hermetic seal	4 - TRL 8 to 9; used in launch and payload interfaces	3 - Higher integration complexity (hermetic qualification)	4.35 / 5 = 87 %
MIL-DTL-38999 Series II	4 - Very good; bayonet coupling for moderate vibration (Amphenol Aerospace)	5 - Excellent; low-profile design simplifies service	4 - High; heritage in aircraft and satellites	4 - Compact and lightweight	4 - TRL 8; current aerospace production	3 - Requires specific tooling	4.15 / 5 = 83 %
Weight ->	**0.25**	**0.2**	**0.2**	**0.1**	**0.15**	**0.1**	

Micro-D (MIL-DTL-83513)

Overview:

Miniature rectangular connector with twist-pin contacts on 0.050" pitch.

Very compact; rated to 3A/contact; TRL 9 with space-grade versions.

Applications:

Used in CubeSats, avionics, instruments, and space payloads.

Common for high-density signal interfaces in tight spaces.

Pros:

High density; excellent SWaP performance.

Reliable under vibration; widely QPL-qualified.

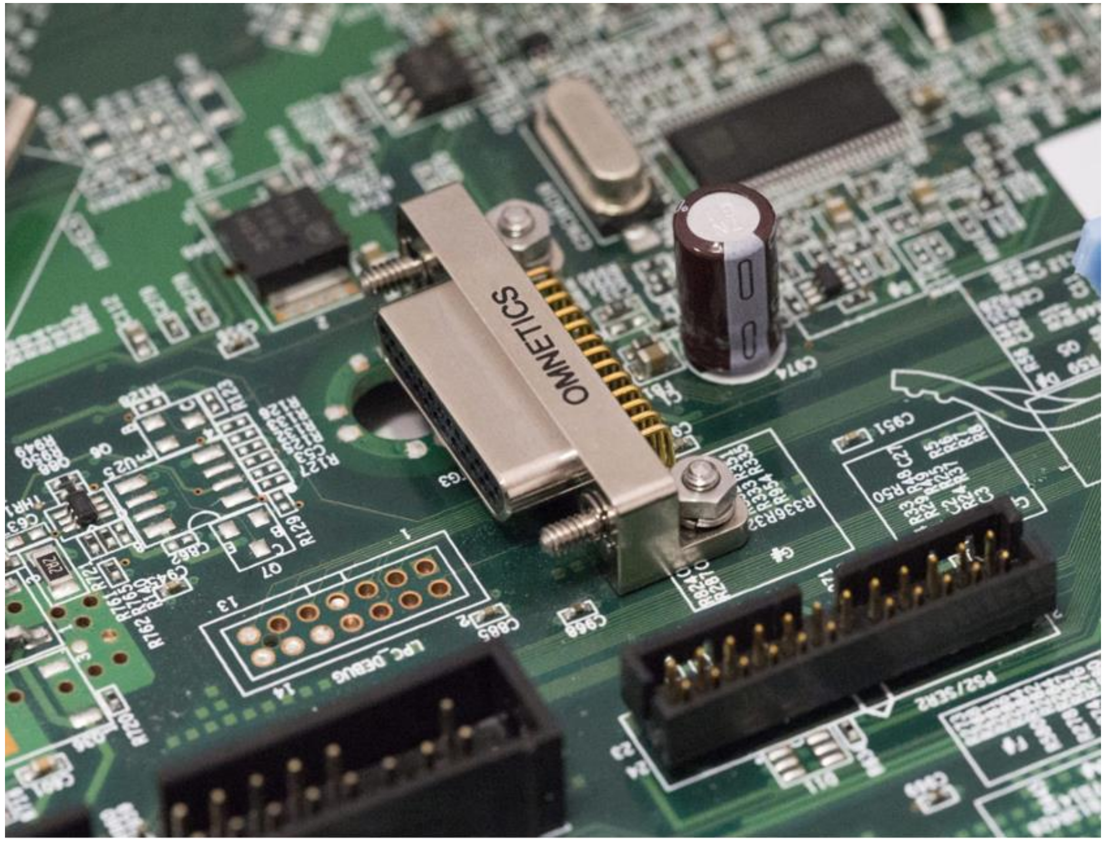
Cons:

Non-removable contacts; field repairs difficult.

Limited current per pin; small hardware can be hard to handle.

TRL:

TRL 9 - Proven in space and defense systems worldwide.



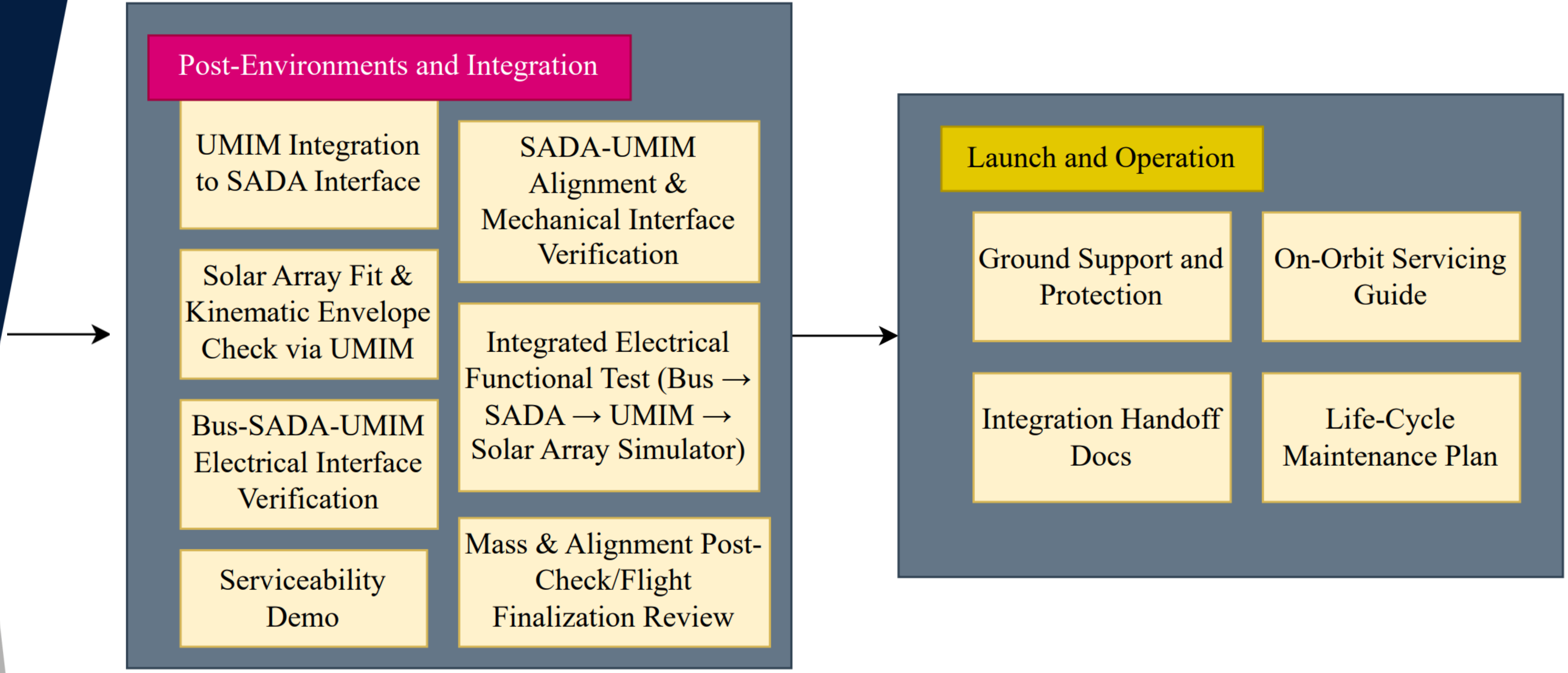
Trade Study 3: Mechanical Connector

Trade Study 3: Mechanical Connector							
Connector / Interface Option	Structural Integrity	Serviceability	Reliability	Mass / Volume Efficiency	Technology Maturity (TRL ≥4)	Integration Complexity	Weighted Score (Trade Score)
Bolted Flange	5 - Excellent high-stiffness joint; proven under 1500 g launch vibration	3 - Manual torque and tool access needed	5 - Highly reliable, zero-motion retention	4 - Compact, strong joint density	9 – Flight heritage TRL 9 (ISS, ESPA, GEO)	4 - Straightforward bench integration	4.50 / 5 = 90 %
Rotary Clamp Ring (Bayonet / Latch)	4 - Strong radial preload; reliable under dynamic load	5 - Fast twist-lock enables robotic or manual servicing	4 - Used on OSAM prototypes; periodic calibration	3 - Bulky ring housing	7-8 - Prototype maturity	3 - Requires docking-verification testing	4.20 / 5 = 84 %
Quick-Release Clamp (Band / Lever)	4 - Moderate stiffness; limited torsional support	5 - Excellent for manual or robotic swap	4 - Redundant locking; low wear	4 – Compact and efficient	7–8 – Used in OSAM demonstrations	3 - Requires verification tests	4.25 / 5 = 85 %
Single-Point Latching (Blind-Mate)	4 - Guided latch pins; supports preload	5 - Excellent robotic / autonomous servicing	4 - Reliable with periodic recalibration	3 - Moderate volume, capture ring required	6–7 – OSAM-1 demo heritage	3 – Moderate integration complexity	4.25 / 5 = 85 %
Docking Collar (Androgynous)	5 - Robust axial retention >100 kN (NASA NDS heritage)	4 - Semi-serviceable, actuated	5 – Proven on ISS / Orion systems	3 – Bulky, adds mass	9 – TRL 9 flight-proven	2 – Complex integration, docking cycles	4.35 / 5 = 87 %
Magnetic-Assisted Latch	3 - Limited stiffness < 500 N shear	5 – Excellent robotic alignment	3 – Sensitive to field decay	4 - Very compact	6 – Prototype-level maturity	3 – Requires control electronics	3.90 / 5 = 78 %
Dovetail Rail + Lock Pin	3 - Moderate load transfer; vibration-sensitive	4 - Easy slide-and-lock	3 - Prone to thermal play	4 - Low-mass, compact	6 – Lab-level demonstration	3 – Moderate manual alignment	3.45 / 5 = 69 %
Weight	0.25	0.2	0.2	0.1	0.15	0.1	

Trade Study 4: Connector Material

Trade Study: Material					
Material	Typical use	Radiation*	Complexity	Serviceability	Trade Score
Titanium Ti-6Al-4V	Connector insulators	High	Low-Med	High	4.7 / 5 = 94%
Aluminum 6061/7075	Latches, premium body	High	Medium	High	4.4 / 5 = 88%
PEEK / PPS	Electrical contacts	High	Medium	High	4.4 / 5 = 88%
BeCu with Au/Ni	Hermetic connectors	High	Medium	Med-High	4.1 / 5 = 82%
Hermetic glass	O-rings, seals	Medium	Medium	High	3.6 / 5 = 72%
Stainless 316L / 17-4PH	Precision bases/alignment	High	Medâ€“High	Medium	3.5 / 5 = 70%
CFRP + Al honeycomb	Thermal blankets	Medium	Medium	Medium	3.0 / 5 = 60%
Low-outgassing silicone	Hermetic feedthroughs	High	High	Med-Low	2.9 / 5 = 58%
Kapton/Mylar (MLI)	Bus sandwich panels	Medium	High	Medium	2.4 / 5 = 48%

Integration and Test Flow Diagram



Integration and Test Standards

Test Type	Applicable Standards	Relevance / Application
Functional Tests (Electrical & Data Interfaces)	NASA-STD-7002B; ECSS-E-ST-10-03C; MIL-STD-1540E; ISO 15864	Verifies all power and data interfaces meet performance requirements in every operating mode, before and after environmental testing.
Mechanical Fit & Alignment Checks (Interface Mating)	NASA-STD-7002B; ECSS-E-ST-10-03C; MIL-STD-1540E	Confirms modules mate, latch, and align correctly; checks critical dimensions and tolerances pre- and post-environmental tests.
Environmental Testing – Vibration & Thermal Vacuum	MIL-STD-1540E / SMC-S-016; NASA GEVS (e.g., GSFC-STD-7000, NASA-STD-7001/7002); ECSS-E-ST-10-03C; ISO 23670; ISO 24412	Qualifies for launch loads (sine/random, shock/acoustic) and verifies operation under vacuum and thermal extremes via TVAC cycling.
EMI/EMC Testing (Electromagnetic Compatibility)	MIL-STD-461 (e.g., RE102/CE102); ECSS-E-ST-20-07C	Controls radiated/conducted emissions and susceptibility so the interface neither interferes with nor is affected by spacecraft electronics.
Cleanroom Facility (Assembly & Test Environment)	ISO 14644-1; ECSS-Q-ST-70-01C	Defines airborne cleanliness (e.g., ISO Class 7) and contamination control for assembly and testing to protect sensitive parts.
Vibration Test Table (Shaker Facility & Controls)	ISO 23670:2021; NASA-STD-7001B; MIL-STD-810H (Method 514)	Sets shaker control tolerances, input spectra, axes, and durations; enables safe, repeatable vibration tests aligned to flight environments.
Thermal Vacuum Chamber (Environmental Chamber)	ISO 24412:2023; ECSS-E-ST-10-03C; MIL-STD-1540E	Specifies chamber performance and TVAC procedures (cycles, soaks, operating points) to validate function in space-like conditions.
Power/Data Test Stand (EGSE for Interface Validation)	NASA-STD-7002B; ECSS-E-ST-10-03C; Interface specs (e.g., MIL-STD-1553, SpaceWire)	Ensures EGSE correctly emulates spacecraft power/data buses (e.g., LISN on power lines) for end-to-end compatibility tests.

Risk Assesment: Part 1

Risk ID	Description	Response Strategy	Preventative Actions	Likehood(1-5)	Severity(A-E)	Risk Level
R1	Failure in modular attachment mechanism during assembly	Mitigation	Perform mechanical load testing on all attachment mechanisms before assembly.	4	5	20
R2	Electrical interface malfunction due to connector misalignment	Mitigation	Incorporate alignment guides and automated vision systems for connector placement.	3	4	12
R3	Thermal control inefficiency affecting module stability	Mitigation	Add thermal sensors to monitor module heat levels and improve heat sink design.	3	3	9
R4	Delayed delivery of modular components from suppliers	Transfer	Develop supplier agreements with strict delivery schedules and secondary sourcing.	4	3	12
R5	Human error during integration and testing	Mitigation	Create detailed integration checklists and cross-verification steps for testing.	5	4	20
R6	Software malfunction in modular control system	Mitigation	Implement continuous software integration and code review before system updates.	3	4	12
R7	Inadequate quality assurance during manufacturing	Mitigation	Add extra quality control checkpoints and automated defect detection systems.	3	4	12
R8	Unexpected vibration resonance during launch	Mitigation	Run vibration profile simulations and physical damping tests pre-launch.	2	5	10
R9	Material fatigue or structural weakness in connectors	Mitigation	Use high-strength materials and perform fatigue cycle analysis on connectors.	3	4	12
R10	Interface contamination causing poor signal transmission	Mitigation	Establish clean-room procedures and contamination inspections before assembly.	2	3	6
R11	Power distribution inconsistency across modular systems	Avoidance	Design redundant power buses and perform load balancing simulations.	3	4	12
R12	Data communication failure between subsystems	Mitigation	Add redundant data channels and real-time transmission error monitoring.	2	4	8

Risk Assesment: Part 2

R13	**Sensor calibration drift impacting accuracy**	**Mitigation**	**Schedule regular calibration cycles with sensor performance tracking logs.**	**2**	**4**	**8**
R14	Environmental test chamber malfunction	Mitigation	Inspect and calibrate environmental test chambers before every testing phase.	2	3	6
R15	Unclear documentation causing design confusion	Mitigation	Create a shared design repository with clear documentation versioning.	3	3	9
R16	Budget overrun delaying project schedule	Acceptance	Set up budget tracking dashboards and pre-approve milestone spending.	4	4	16
R17	Schedule compression causing reduced testing time	Mitigation	Add project buffers and enforce test readiness reviews before timeline shifts.	4	5	20
R18	Inadequate risk communication between teams	Mitigation	Hold weekly cross-functional meetings and track risk communication logs.	3	3	9
R19	Improper configuration management of module versions	Mitigation	Implement configuration management software with change history tracking.	3	3	9
R20	Inconsistent design standard across suppliers	Transfer	Use a unified design guideline and supplier training on tolerance requirements.	2	3	6
R21	Thermal expansion mismatch between modules	Mitigation	Test material compatibility under thermal cycling conditions in simulation tools.	2	4	8
R22	Incompatible mounting due to tolerance deviation	Avoidance	Perform tolerance checks using 3D scanning and assembly mockups.	3	3	9
R23	Loss of skilled personnel mid-project	Acceptance	Develop a cross-training plan and maintain backup staffing options.	3	4	12
R24	Failure to meet safety certification requirements	Mitigation	Schedule safety audits throughout design and testing stages.	2	5	10
R25	Inaccurate simulation results causing design flaws	Mitigation	Verify simulation models with small-scale prototype testing and comparison.	3	4	12

General FMEA

Subsystem / Component	Failure Mode	Effect(s)	Severity (1–10)	Occurrence (1–10)	Detection (1–10)	RPN (S × O × D)	Corrective / Preventive Action(s)	Responsible / Owner	Reference(s)
Power / Solar Arrays	Degradation from dust, radiation, age	Lower power margin; mission shortened; inability to support subsystems	8	7	6	336	Regular health monitoring; dust mitigation surfaces/coatings; redundant solar strings; oversizing initial power budget	Power Systems Lead	Finckenor (2016); Mazarico et al. (2018)
Communications/ High-Gain Antenna	Gimbal stall/mispoint or RF feed degradation causing pointing loss	Link margin collapse; intermittent or total loss of downlink/uplink	9	6	6	324	Dual-antenna geometry; autonomous switchover to backup L/S-band TT&C; periodic pointing calibration; make antenna module serviceable with quick-disconnects	Communications Lead	NASA SCaN link budgeting; NASA-HDBK-1002 Fault Management; Northrop Grumman MRV servicing concept
Communications	Loss of link in lunar farside or L2 relay point	Loss of telemetry/command; mission interruption	9	6	5	270	Use relay satellites; multiple comm paths; robust pointing control; fault detection & switching	Communications Lead	Zhang et al. (2019); NASA Communications guidance
Environment / Charging	Differential surface charging / plasma charging	Arcing; damage to electronics; potential system failure	9	6	5	270	Use conductive coatings; grounding routes; shielding; design to limit charge accumulation; regular diagnostics	Electrical / EMC Lead	NASA-HDBK-4002B (2022)
Materials / Structure	Micrometeoroid / Orbital Debris (MMOD) Impact	Hull breach; damage to instruments / critical surfaces; loss of function	10	4	6	240	Add MMOD shielding; select tougher outer material; redundant critical systems	Structural Lead / Materials Engineer	Finckenor (2016)
Thermal Control / Coatings	Degradation of thermal coatings / multilayer insulation (MLI) over time	Poor thermal control; overheating or freezing of components; increased power draw for temperature control	8	6	5	240	Use improved coating materials; redundancy; periodic thermal performance testing; robust mounting design	Thermal Systems Lead	Finckenor (2016); LRO studies
Materials / Structure	Radiation-induced embrittlement & thermal cycling cracks	Loss of structural integrity, warping, leaks, reduced thermal performance	9	5	5	225	Use radiation-resistant alloys/composites; apply thermal cycling testing; coatings that mitigate radiation damage	Materials Test Engineer	Finckenor (2016)
Attitude / Control	Reaction wheel failure or saturation	Loss of attitude control; pointing errors; loss of scientific data or solar exposure	9	5	5	225	Active fault tolerant control; spare actuators; torque control distributed; periodic wheel off-load or calibration	Attitude Control Lead	Active FTC study
Navigation / Orbit	Orbit insertion error or drift from desired cis-lunar orbit	Mission loss; inability to maintain communication or thermal constraints	10	3	6	180	High precision navigation; use of gravity assists; redundant navigation sensors; onboard autonomy	Navigation Lead	ARTEMIS (Angelopoulos, 2010); Holzinger et al. (2021)
Power / Energy Storage	Battery thermal runaway (e.g. Li-ion)	Fire; loss of power; potential cascading failures	10	4	4	160	Use battery management system; thermal sensors; use safer battery chemistries; robust fault isolation	Power Systems Lead	Sharma & Santasalo-Aarnio (2025)