MBSE for the Gateway Program

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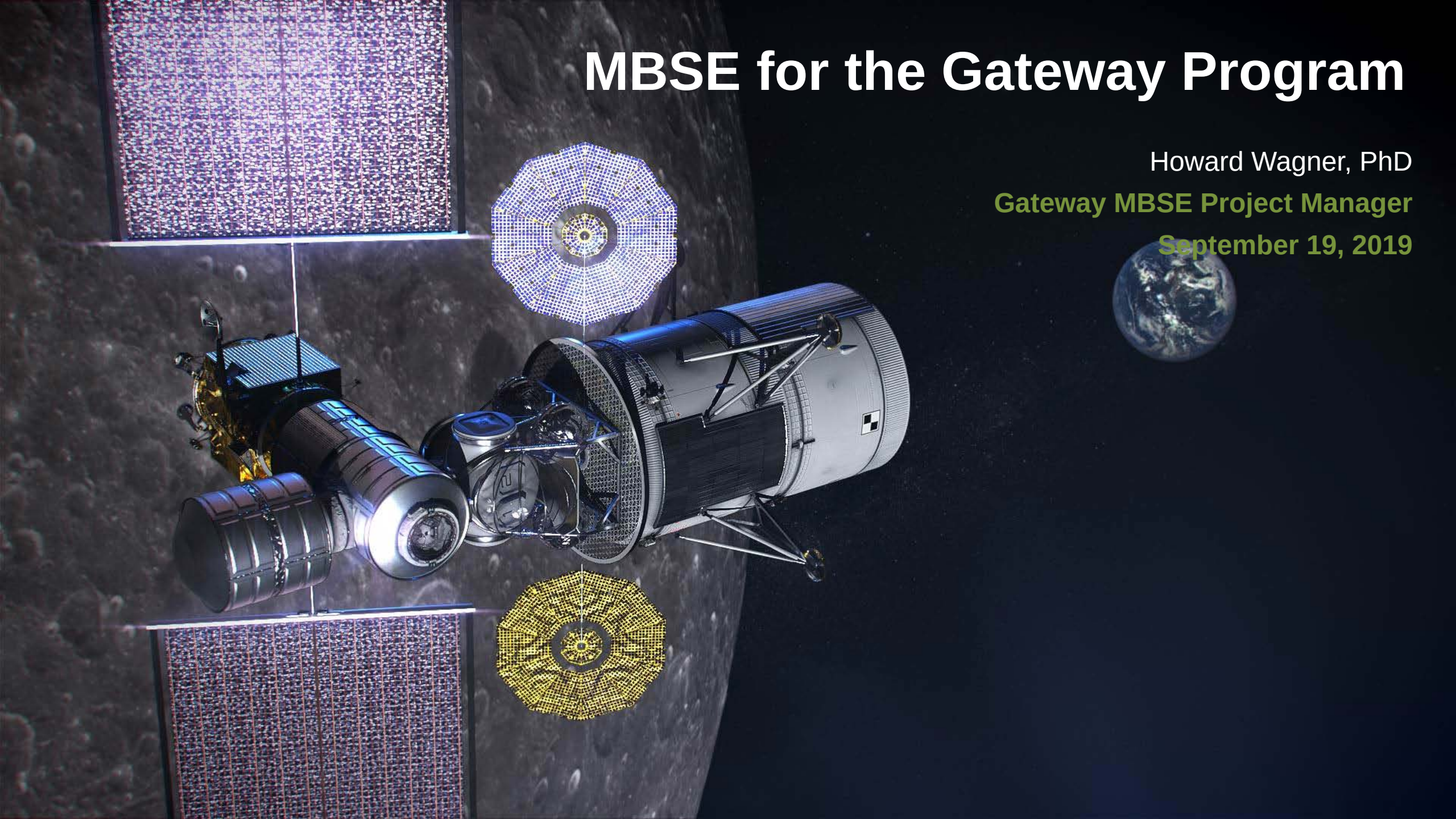


Executive Summary

- Gateway Program objectives
- Use of MBSE on the Gateway Program
- Integration issues with multiple MBSE models
- How to ensure commonality amongst these models

Background

- Worked at NASA since a co-op in 1983 until I retired in 2014
- Held various systems engineering positions
  - Subsystem Manager for Orbiter Fuel Cells/PRSD
  - Deputy Division Orbiter Chief Engineer, Power and Propulsion Division
  - Assistant Orbiter Project Chief Engineer
  - Assistant Space Shuttle Program Chief Engineer
  - Deep Space Habitat Chief Engineer
    - Used MBSE to track project requirements and design
- Retired January 2014 and formed my own aerospace consulting company
  - Primary focus has been on implementing MBSE on NASA fault management processes
  - Started with the NASA Fault Management Handbook and looked at where we could use MBSE to help with the required analyses
    - Fault Tree generation
    - Failure Modes and Effects Analysis (FMEA)
  - Was asked to help lead the MBSE efforts on the Gateway program

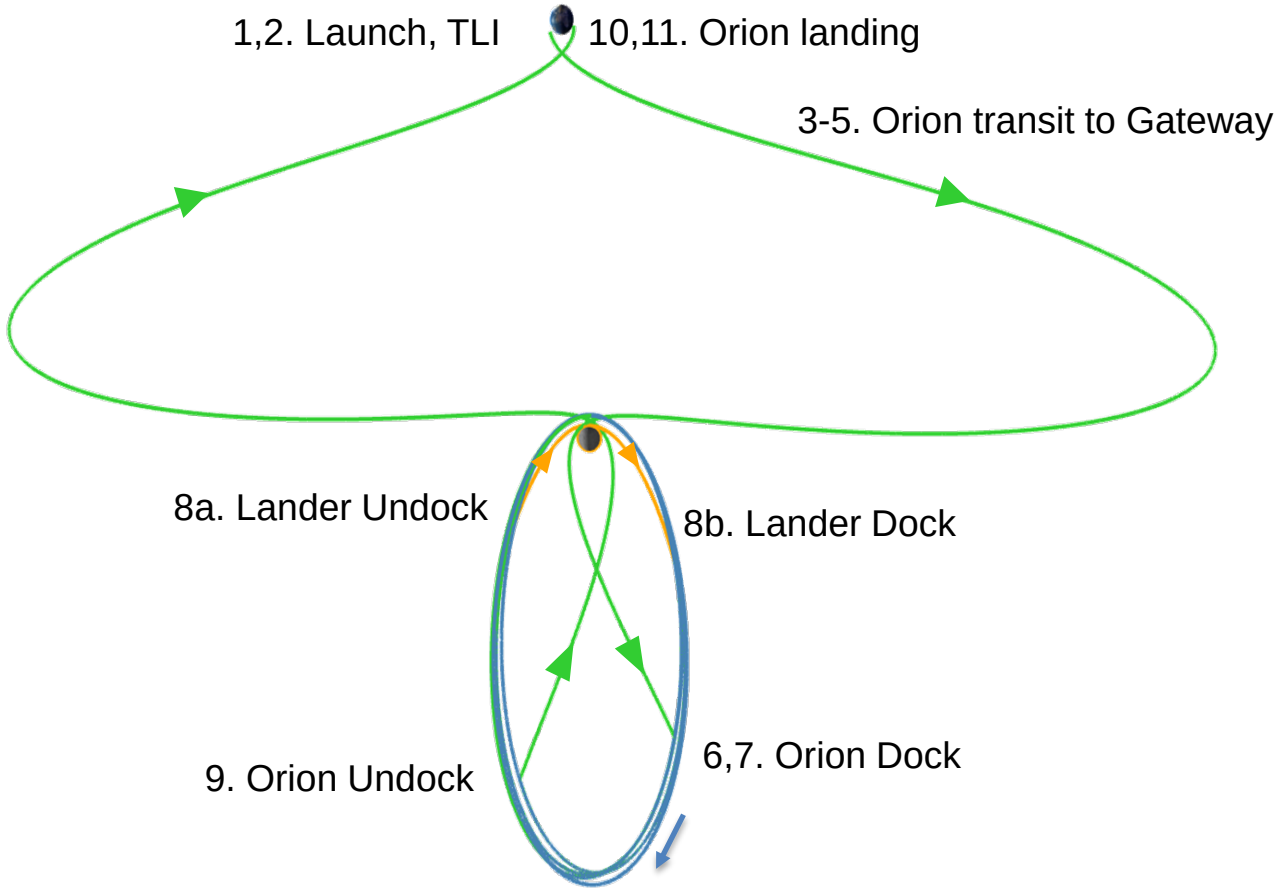
Gateway Program Objectives

- **Gateway Program created to provide a deep space research facility**
  - Operate in the cis-lunar environment so it is not protected by the earth's magnetic field
  - Allow for research into long term human and spacecraft exposure to galactic radiation
  - Develop the technologies and processes that would be used for a future crewed Mars mission
  - Recently tasked to support human return to the lunar surface

- **Gateway operates in a highly elliptical orbit about the moon**

Lunar Sortie Mission Through Gateway

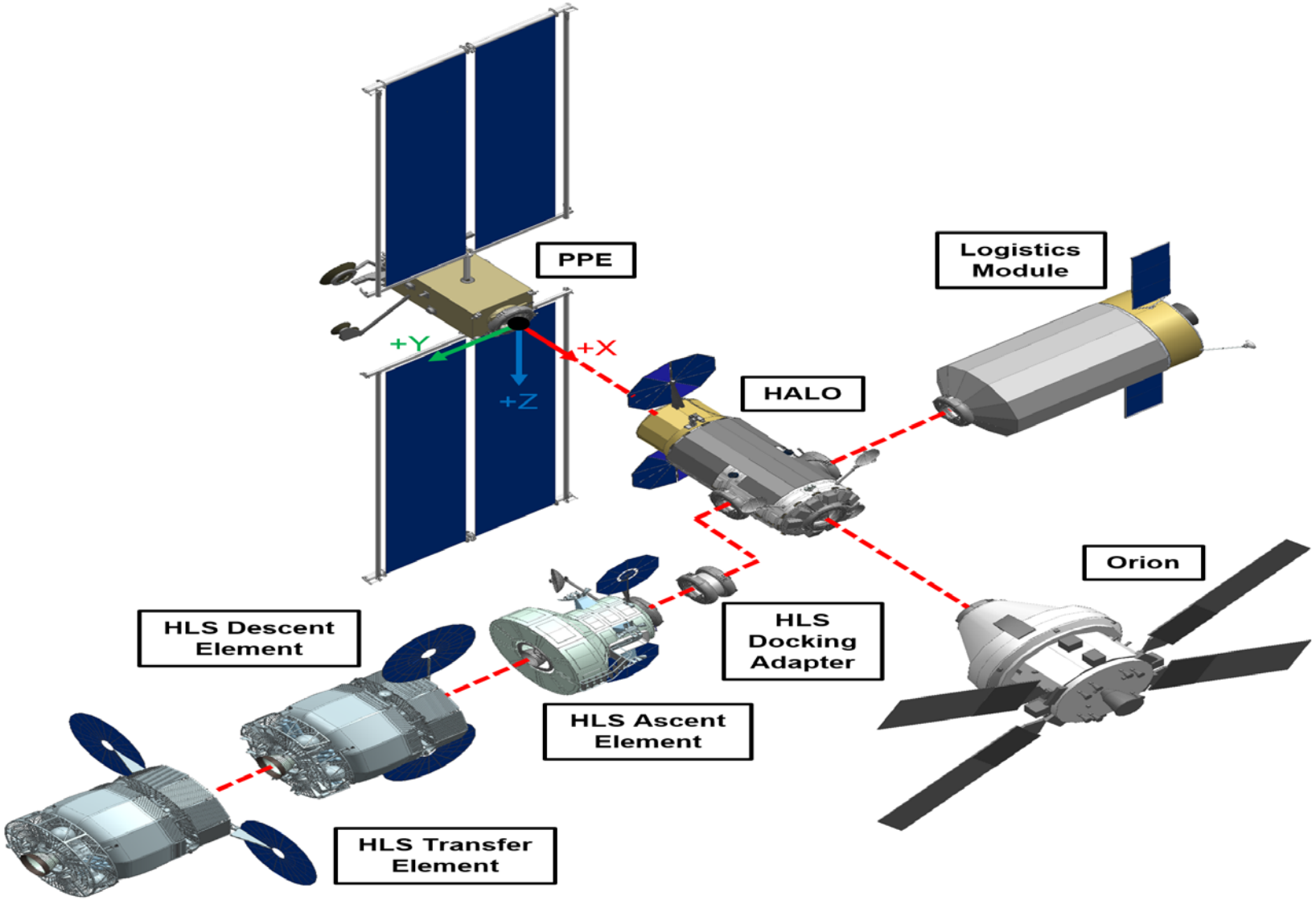
- **Pre-mission Assumption**
  - Lander Elements aggregated and docked with Gateway prior to crew launch
- **Crewed lunar orbit**
  - ~6 days (TBR): Orion TLI to Orion dock at Gateway in NRHO
  - ~5 days: Orion dock at Gateway to Lander depart Gateway
  - ~7.5 days: Lander depart Gateway to Lander return to Gateway
  - ~5 days: Lander return to Gateway to Orion undock from Gateway
  - ~6 days: Orion undock from Gateway to Orion Earth Return
  - Orion stay on Gateway ~17 days
  - Nominal Orion TLI to Orion Earth Return ~ 30 days
    - Protect for 1 contingency orbit ~ 7 additional days
  - 4 Crew Size (2 Crew down / 2 Crew stay)
- **Spacecraft configuration**
  - Gateway: PPE + HALO
  - Orion
  - Logistic Module (LM) (TBD)
  - Human Lander Systems



Gateway Objectives

- Support human exploration beyond Earth.
- Provide a staging point that can be used for multiple missions both to the Moon and beyond, enabling reusable in-space systems.
- Enable a regular cadence of human crewed missions to cislunar space including capabilities that enable lunar surface mission.
- Provide capabilities to meet scientific requirements for lunar discovery and exploration, as well as other science objectives, as appropriate.
- Demonstrate and validate technologies that are enabling for lunar missions and feed forward to Mars as well as other deep space destinations.
- Demonstrate the systems and operational capabilities required for crewed missions beyond the Earth-Moon system.

Gateway Phase 1 (Support Human Lunar Landing in 2024)



Gateway Elements

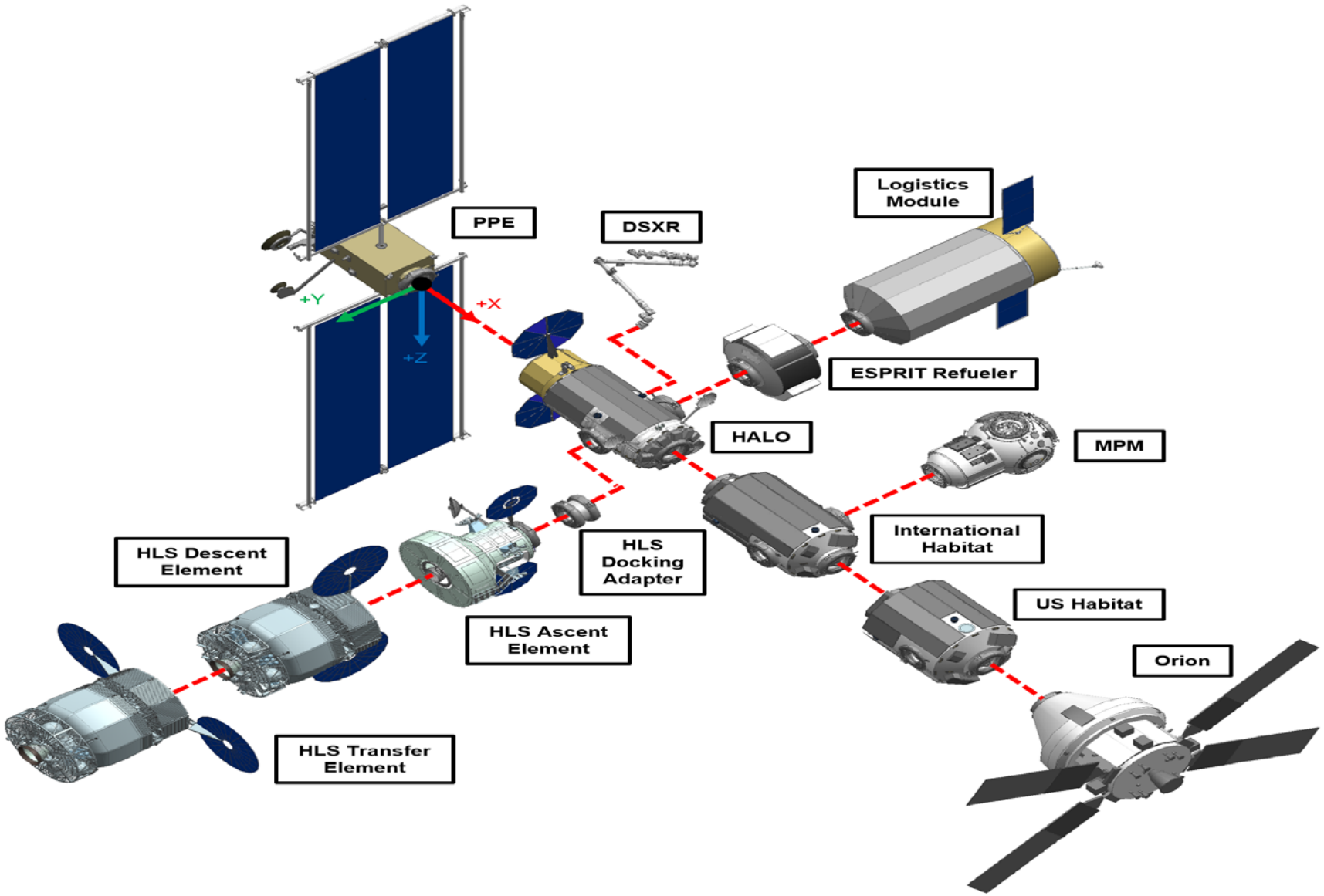
- **Power and Propulsion Element**
  - The PPE provides the capability to generate power, transport Gateway between cislunar orbits, perform orbital maintenance, provide attitude control, provide communication (to and from Earth, space to space communication, space to lunar communication, and relay EVA communication to Earth), and accommodations for external utilization.
- **Habitation And Logistics Outpost Element**
  - The HALO element provides the capabilities for early habitable utilization of the Gateway, initial support for HLS to the Lunar surface, internal and external payload accommodations, external robotic interfaces, power and thermal control, and logistics storage for crew consumables.
- **Logistics Module**
  - The Logistics Module provides the capability to deliver pressurized and unpressurized cargo to the Gateway enabling extended crew mission durations, science utilization, exploration technology demonstrations, potential commercial utilization, system outfitting and other necessary supplies.

Gateway Visiting Vehicles

- **Human Lander System**
  - The HLS is the crewed lunar lander to support human exploration of the lunar south pole
  - The HLS is outfitted at the Gateway prior to each HLS mission
  - The HLS returns the crew to the Gateway after each surface mission

- **Orion**
  - The Orion provides the crew transport to and from the earth to support each Gateway and HLS mission
  - During Phase 1 the Orion life support system is augmented to provide life support services for the early Gateway configuration

Gateway at Assembly Complete



Gateway Elements

- **International Habitat**
  - The International Habitation Module is an ESA contribution to the Gateway Program.
  - The I-Hab will provide a place for the astronauts will live and work while aboard the Gateway.
  - Provides a Gateway dedicated life support system
- **US Habitat**
  - The US-HAB will provide additional core capabilities to the Gateway
- **Extravehicular Robotics**
  - The Extravehicular Robotics (EVR) Deep Space Exploration Robot (DSXR) provides the capability to deploy and retrieve external utilization payloads, external inspection of the Gateway system, and support EVA crewmembers.
  - The EVR is provided by the Canadian Space Agency
- **Airlock**
  - The Airlock provides the capability to enable crewed EVAs, accommodate EVA suit/tool storage, accommodate pre-EVA checkout and preparations to include prebreathe protocols, accommodate post-EVA activities, as well as accommodate demonstration of future EVA technologies.

MBSE on the Gateway Program

- **Multiple MBSE models have been created for the Gateway**
- **Gateway SE&I MBSE model is responsible for the integrated Gateway system**
  - Development of the Functional breakdown
  - Functional allocation across elements
  - Requirements tracing to functions and Gateway elements
  - Gateway Concept of Operations
  - Visiting Vehicle Interfaces
  - Requirement Verifications
- **PPE MBSE model**
  - PPE Requirements
  - Further functional decomposition
  - Functional allocation to subsystems and components
  - PPE Requirement verifications
- **Logistics Module MBSE model**
  - LM Requirements
  - Further functional decomposition
  - Functional allocation to subsystems and components
  - LM Requirement verifications

MBSE on the Gateway Program

- **HALO MBSE model**
  - HALO Requirements
  - Further functional decomposition
  - Functional allocation to subsystems and components
  - HALO Requirement verifications
- **Canadian Space Agency developing MBSE model for the Robotic Arm**
  - Robotic Arm Requirements
  - Further functional decomposition
  - Functional allocation to subsystems and components
  - Robotic Arm Requirement verifications
- **European Space Agency developing MBSE model for the International Habitat**
  - I-Hab Requirements
  - Further functional decomposition
  - Functional allocation to subsystems and components
  - I-Hab Requirement verifications
- **Additional MBSE models planned**
  - US Habitat
  - Airlock

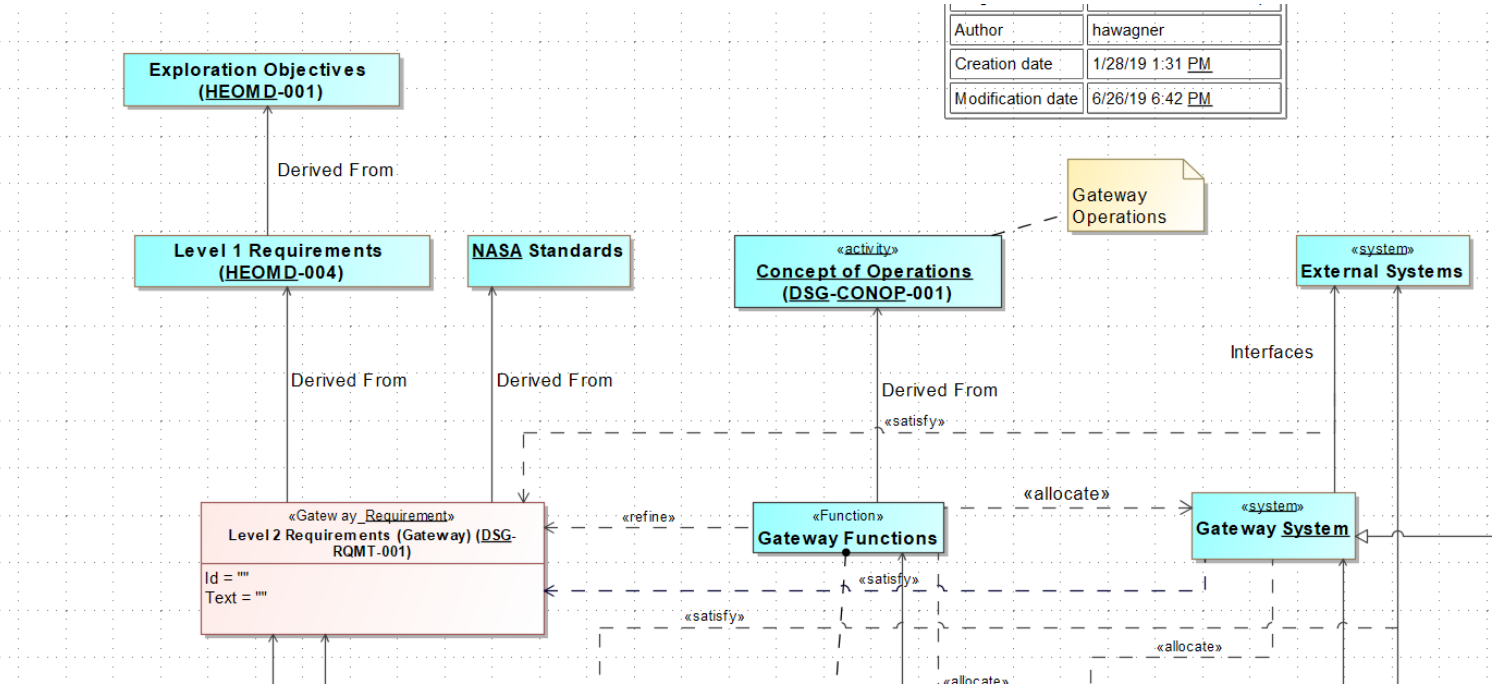
MBSE Model Integration

- **How do we ensure that all these MBSE models developed by different groups across the US and International Partners can share data?**

- **Needed to early on develop a description of the model structure and elements**
  - Created a metamodel to document the MBSE elements utilized and the relationships between the elements

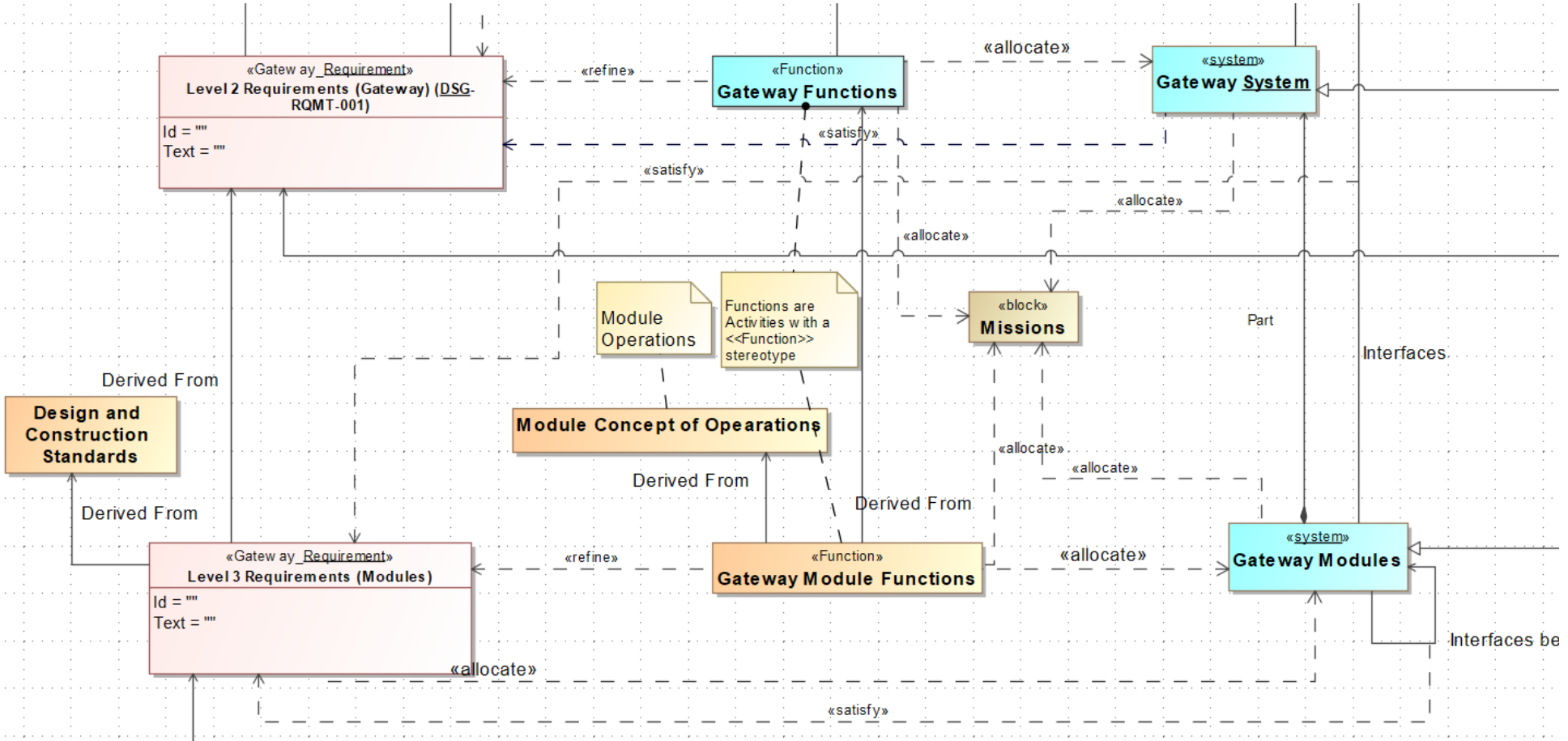
Metamodel Structure

- Defined model elements and relationships between elements
- Functions were modeled as Activities with a <<Function>> stereotype
- Gateway systems was modeled using System or Subsystem blocks
- Functions were allocated to the System block that would perform that function
- Requirements are refined by functions (Functions help identify the need for a functional requirement)
- Requirements are satisfied by a System



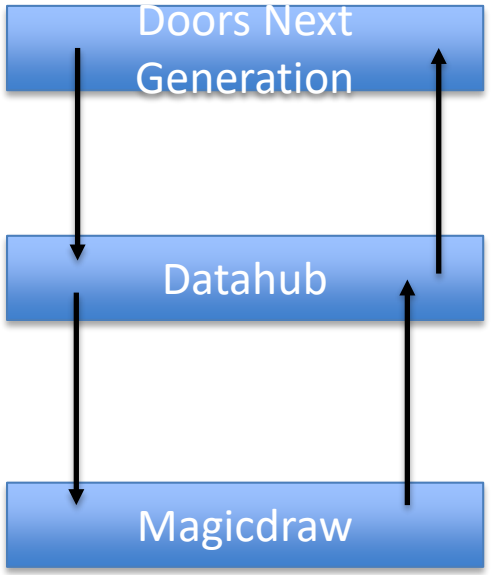
Metamodel Structure

- The same elements and relationships are used in the Module models
- Module level requirements are derived from the Gateway level requirements
- Module level functions are derived from the Gateway level functions
  - The functional breakdown is available in the Gateway SEI model



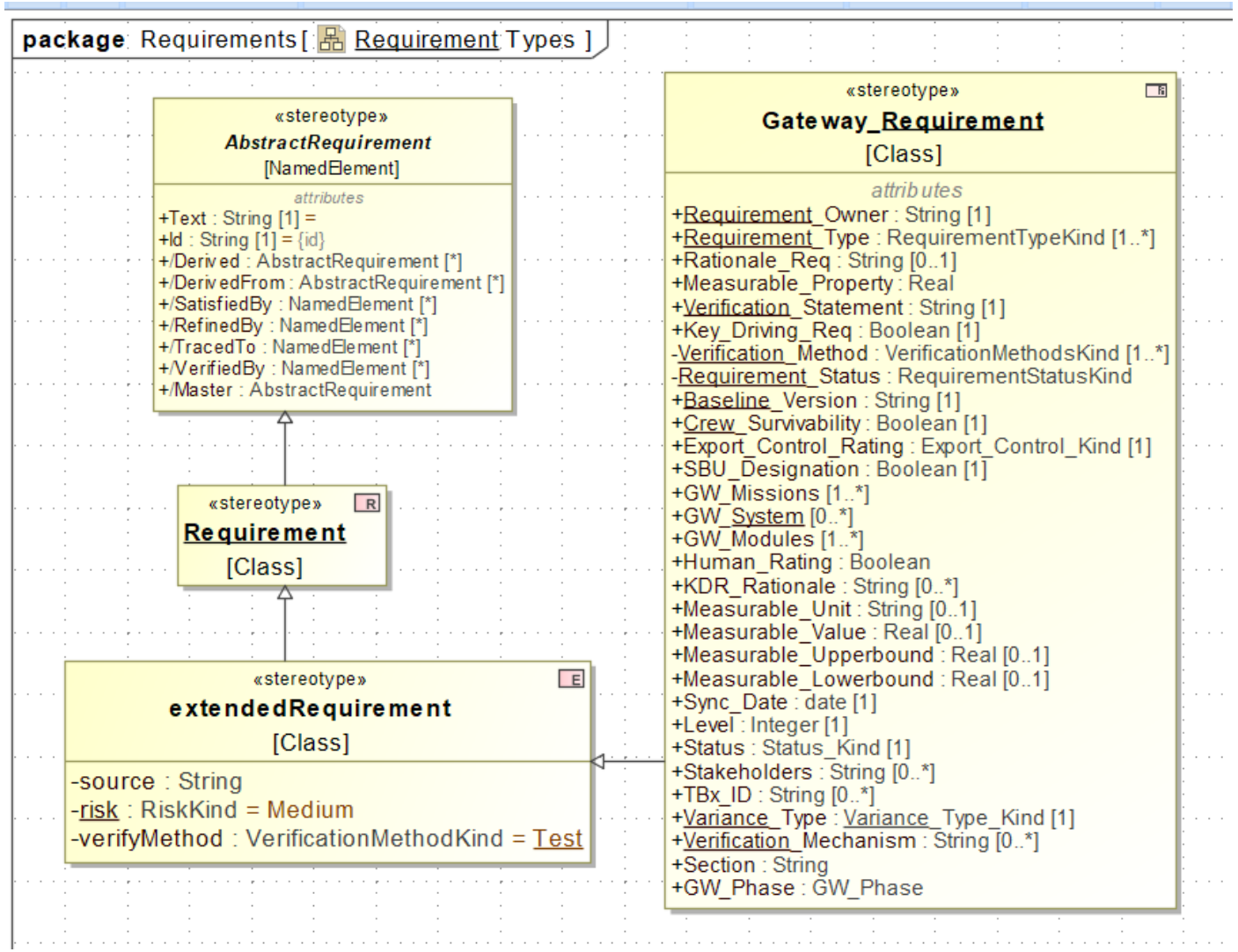
Requirements

- Requirements are officially maintained in the Doors NG database
- Requirements are brought into MagicDraw using the Datahub interface
- In MagicDraw relationships are created between requirements and other requirements, functions, and components
- Any new requirements created in MagicDraw are pushed back into Doors NG
- The relationships between requirements are pushed into Doors NG
- Needed to define a new requirement type to assist in the synchronization with Doors NG



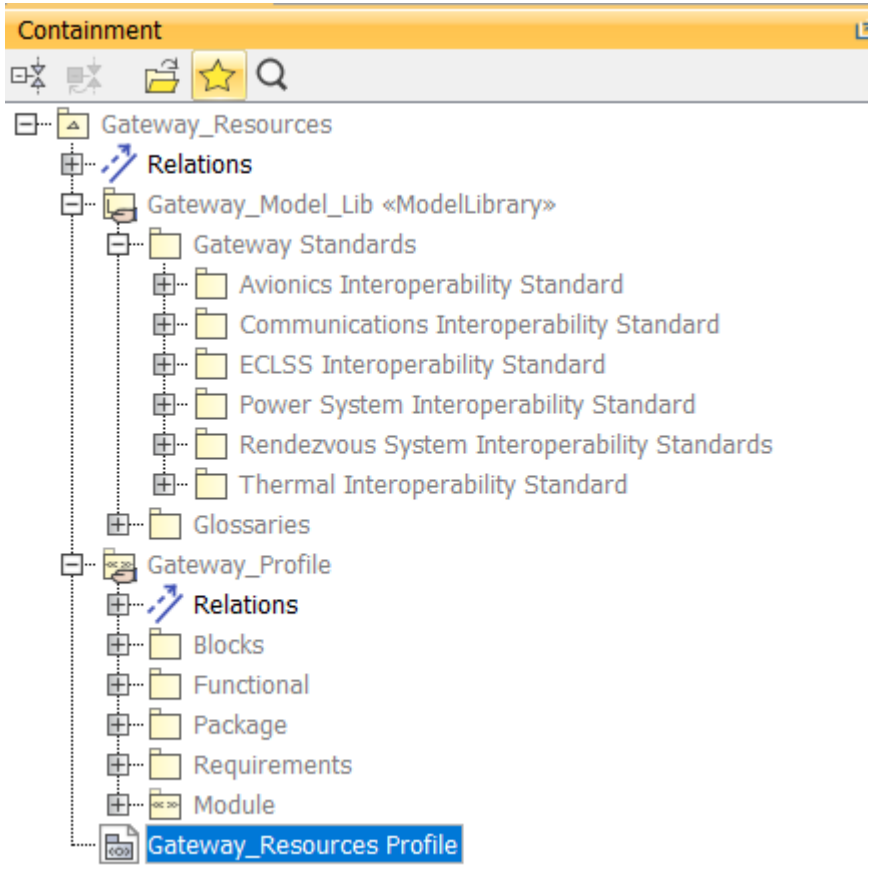
Gateway Requirement

- Doors NG uses several attributes that are not present in the native MagicDraw environment
- In order to properly synchronize the data we needed to add those attributes into a MagicDraw Requirement type
- This allows us to populate the Doors NG attribute fields when we push a requirement from MagicDraw into Doors NG
- Created the Gateway Profile to house these specific profile elements



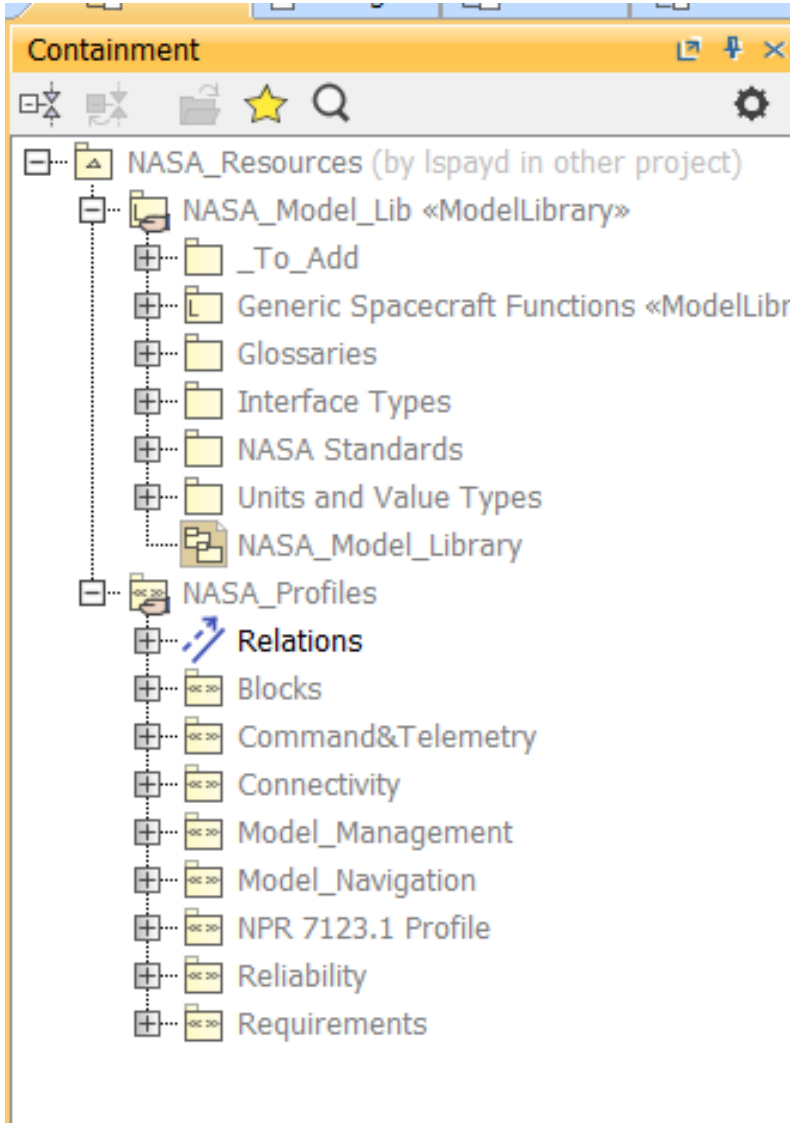
Gateway MBSE Resources

- The Gateway Resources mdzip file provides access to the Gateway tailored standards
  - More standards are being added to the library
- Provides access to the Gateway unique stereotypes used in the MBSE model



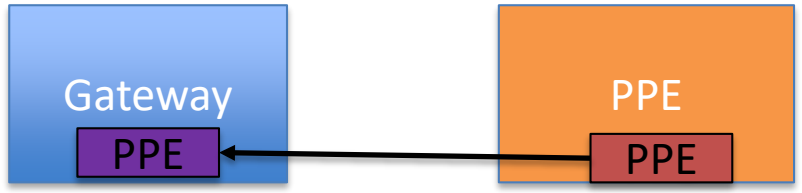
Metamodel Structure

- The NASA Resources mdzip file provides access to the NASA standards
  - More standards are being added to the library
- Provides access to the stereotypes that can be used in any NASA MBSE model
- Access to the Gateway Resources also provides access to the NASA Resources

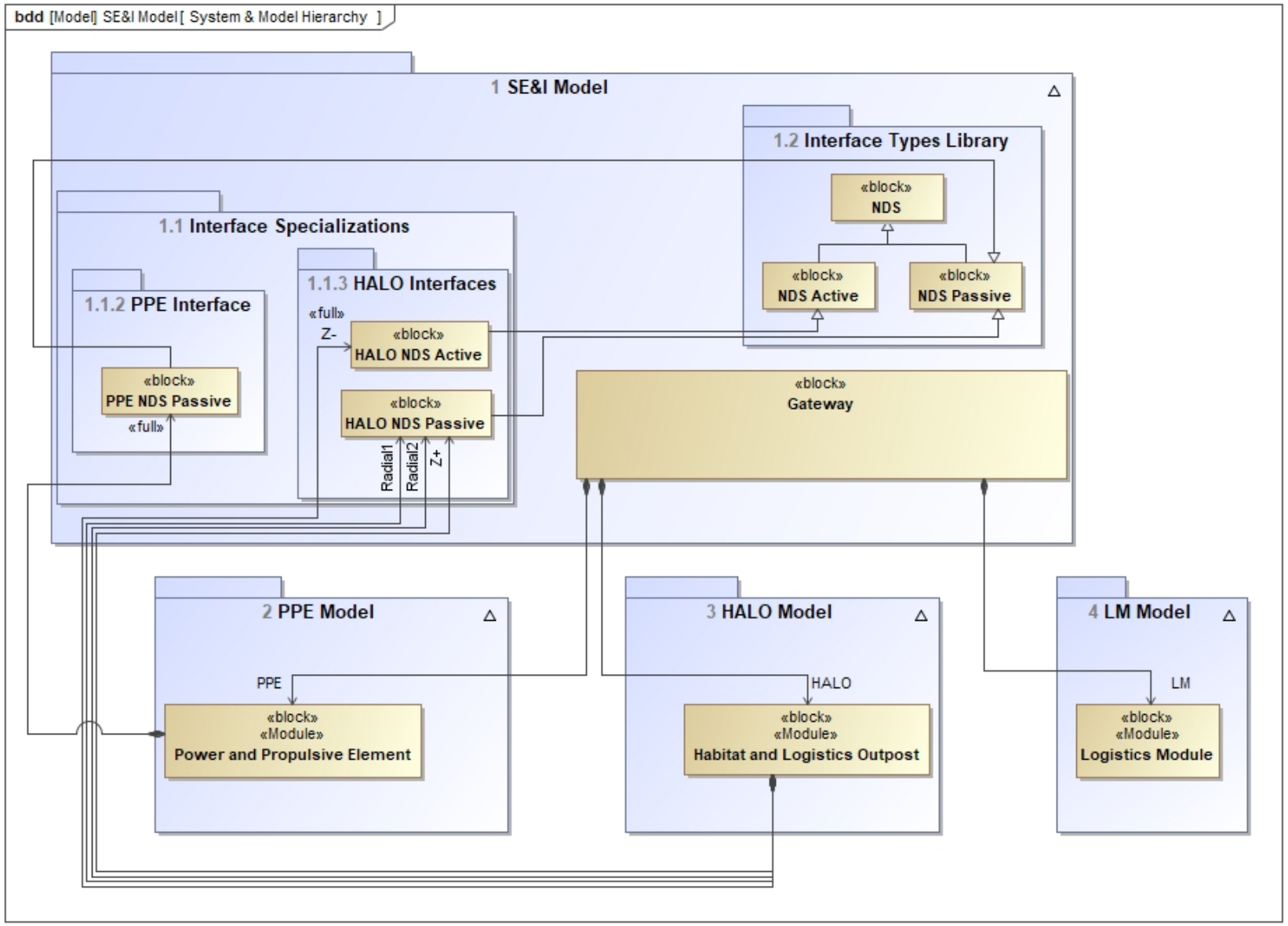


Gateway MBSE Model Integration

- Started with each MBSE model having an element (Block) to represent the Module
- The PPE MBSE model would establish a generalization relationship to the PPE element in the Gateway model
  - PPE can see all requirements, functions, interfaces allocated to the PPE
  - Gateway cannot see the details of the PPE model
- Decided a better approach would be to have the Gateway MBSE model use the PPE block from the PPE model
  - Gateway can now see the details in the PPE model



Gateway MBSE Model Integration



Gateway Concept of Operations Generated from MBSE Model

- Details for the Concept of Operations captured using the documentations field for MagicDraw elements, diagrams, and packages
- Velocity template extracts the details in the proper sequence to generate a typical looking Word document for the ConOps
- The MBSE model uses activity diagrams to document the assembly sequence operations to deploy each module to the Gateway
- The following example shows how we modeled the first docking sequence (HALO to PPE) in the MBSE model

First Docking Event

- **Developed details on docking of the HALO element to the PPE element**
  - Extracted RPOD operations from the International Rendezvous System Interoperability Standard (IRSIS)
  - These details will be repeated for any Visiting Vehicle or Gateway element to dock to the Gateway

- **Content was modeled in the MBSE model (MagicDraw)**
  - Activity diagrams showing the functions that will be performed during the RPOD operations
  - Diagrams and associated text are used to generate details in the ConOps document

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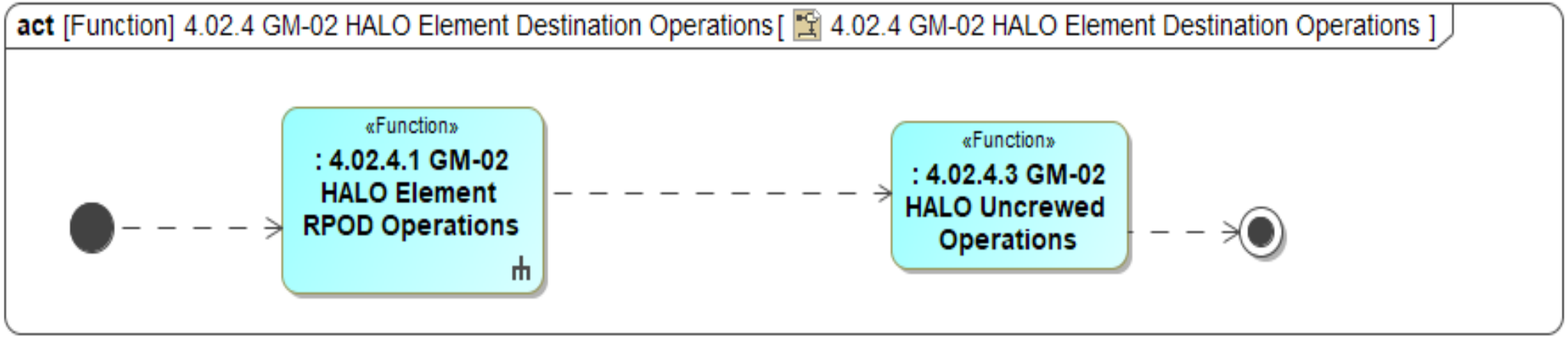
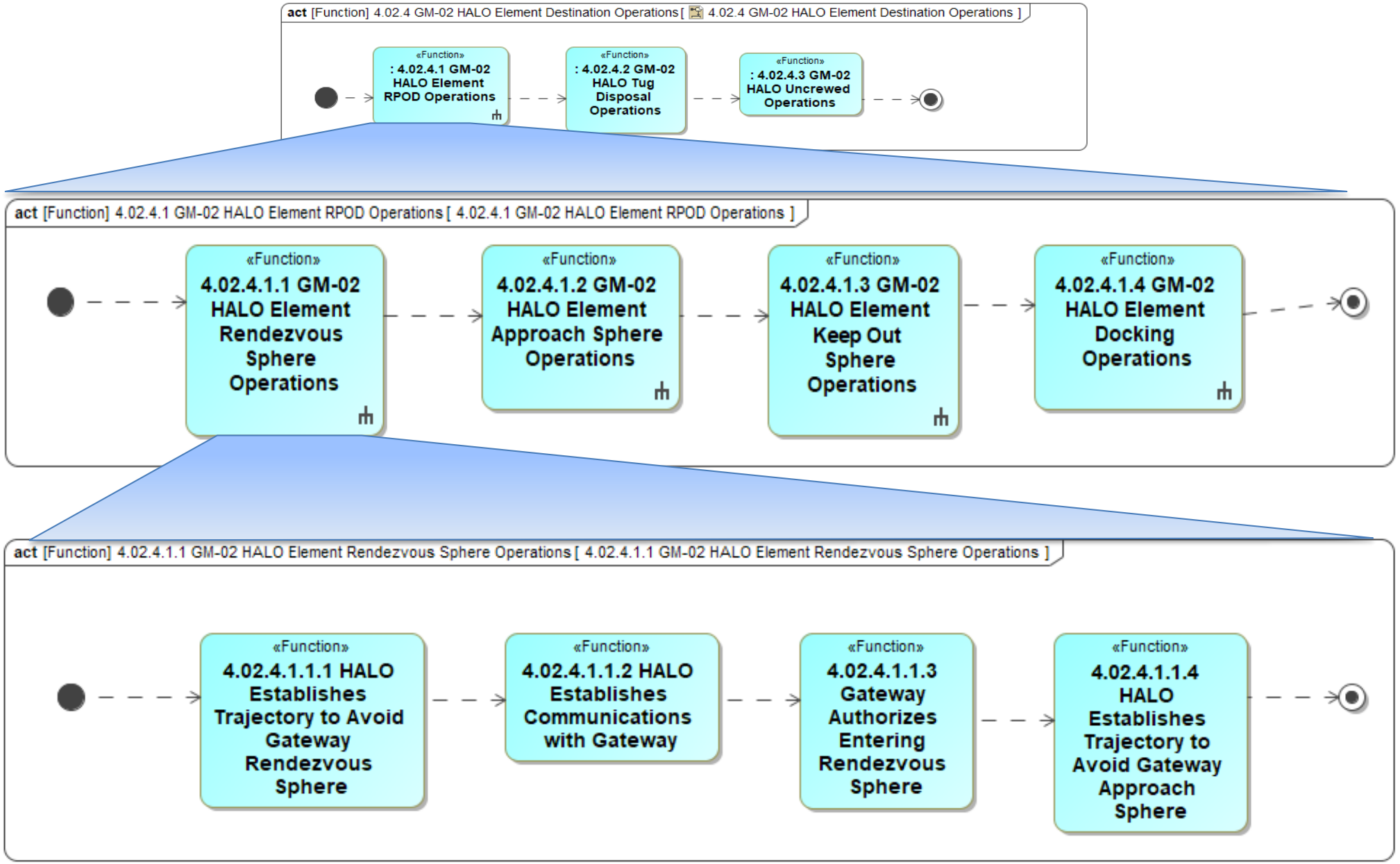
First Docking Event



- **GM-02 HALO Element RPOD Operations**
  - This section describes the docking operations of the HALO to the Gateway. Docking will be in compliance with the International Rendezvous System Interoperability Standard (IRSIS). During rendezvous and proximity operations, Gateway will continue its nominal trajectory (no jet firings or orbit changes).

- **GM-02 HALO Uncrewed Operations**
  - The HALO powers up and checks out subsystems. The HALO then performs operations while awaiting the next vehicle in the launch sequence.

First Docking Event



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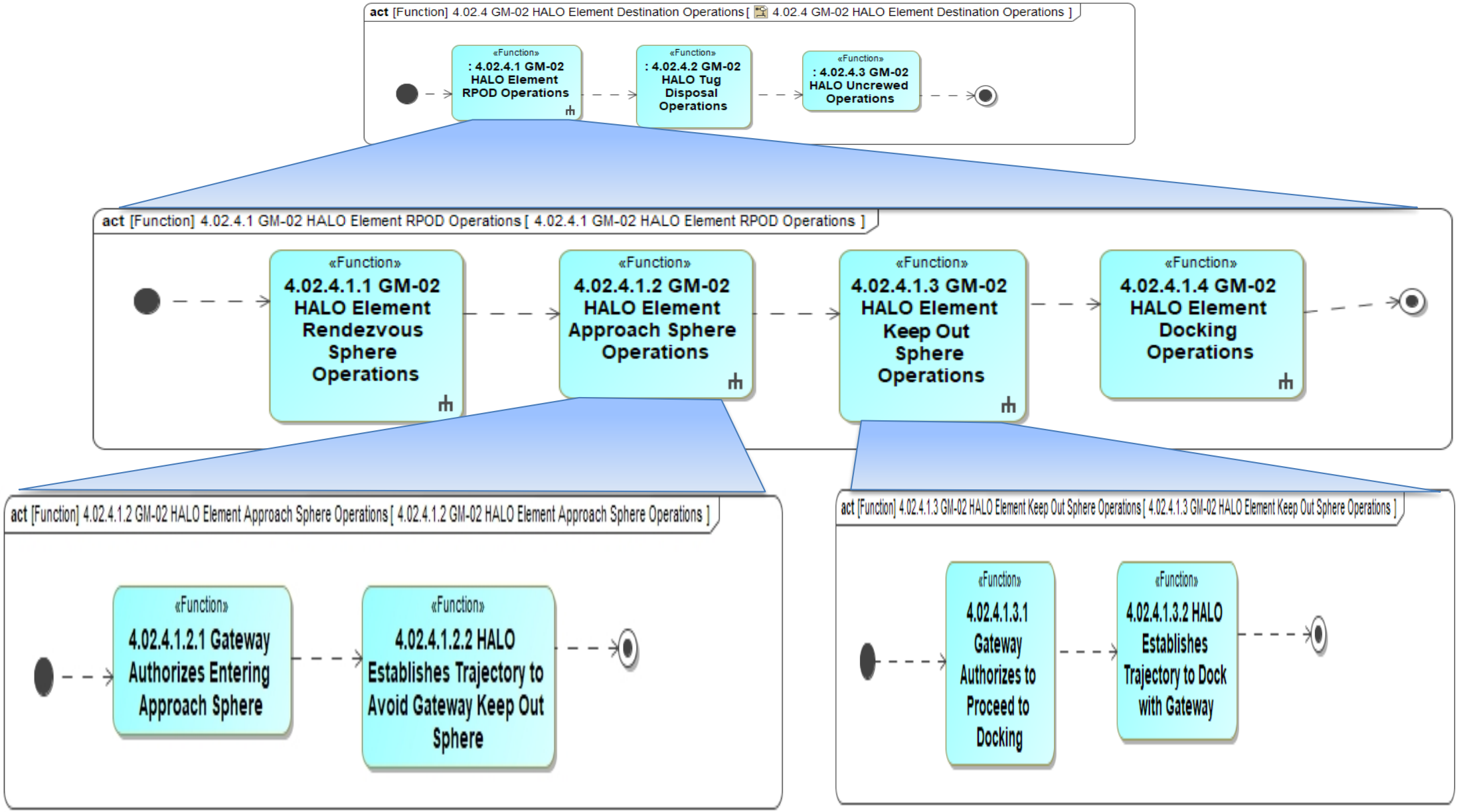

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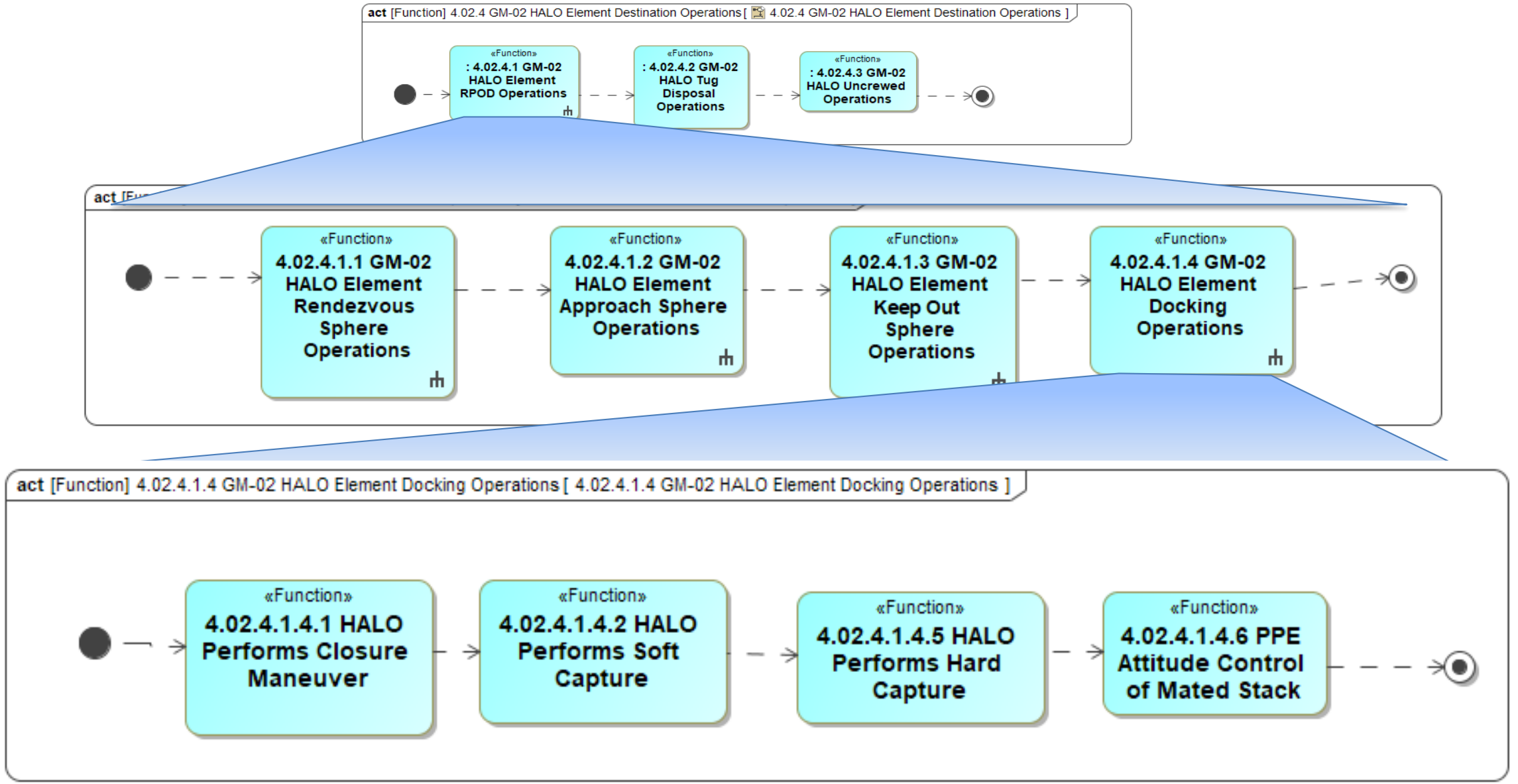

Future Work

- **Visiting Vehicle Interfaces**
  - Held a recent TIM to discuss how to model the interfaces between Gateway and Visiting Vehicles
  - Same interfaces would apply between Gateway modules
  - How to capture levels of abstraction
    - Top level (Level 1) shows item flows between vehicles without using ports
    - Next lower level (Level 2) includes interfaces (connectors, fluid disconnects) modeled as ports
    - Third level (Level 3) includes pin assignments within connectors
  - Mirrored interface requirements
    - A shall provide to B
    - B shall receive from A

Future Work

- **Verification Requirements**
  - Doors Next Generation will be used to host the verification requirements
    - Feed data to the Rational Team Center for Verification Closure Notice generation and tracking
  - Verification Requirements will be proposed by NASA for the Gateway system
    - Traced to Gateway Requirements
  - Gateway Requirements flowed down to the modules
    - Module design contractor will generate Verification Requirements to document how they propose to satisfy the Gateway Requirements
  - Module Verification Requirements and associated proof will be supplied to Gateway SE&I model
    - Will be compared to NASA Verification Requirements to determine if sufficient proof is provided
  - NASA would then generate the Verification Closure Notice for the associated Gateway Requirement

Questions and Answers

- ???