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NASA's Use of MBSE and SysML Modeling to Architect the Future of Human Exploration

Why Digitally Transform NASA?

ENDURING

BOLD

MISSION...

REACH NEW HEIGHTS

BENEFIT ALL HUMANKIND

REVEAL THE UNKNOWN

...NOW IN A CHANGING WORLD

Increasingly bold & complex missions
Increasingly partnered
Increasingly fast
Increasingly affordable
Increasingly transparent
Increasingly inclusive

NASA DIGITAL TRANSFORMATION

NASA's DT Strategic Framework

3 FUTURE STATE GOALS

4 TRANSFORMATION TARGETS

5 DIGITAL LEVERS

6 TECHNOLOGY FOUNDATIONS

7+ MISSION OUTCOMES

Transform the way we **Work**

Transform the experience of our **Workforce**

Transform the agility of our **Workplace**

Transform Discovery

Transform Engineering

Transform Decision Making

Transform Operations

Establish Interoperable *Architectures*

Transform Critical *Processes*

Maximize the Impact of our *Data*

Adopt Common *Tools*

Strengthen Inclusive[3] *Teaming*

Intelligent Automation

Artificial Intelligence/ Machine Learning

Model-Based Anything

Zero Trust Architecture

Internet of Things

Extended Reality

Seamless Partner Teaming

Bolder, More Complex Missions

Faster, More Agile Processes

Inspire & Engage Citizens

Affordable Sustainable Operations

Attract & Retain Workforce

Modern Future of Work

One Future NASA

Chart cleared for public release Jan 9 2024

3

Retooling to Enable Bolder Missions

Overarching Goal of NASA:

- Mitigate the risk and lower expenses of space exploration, science, and discovery to the point where industry is willing and able to profitably take on these on.

NASA is transforming Human Exploration Campaign and Mission planning of the future and the present via:

- Model-Based Systems Engineering (MBSE) methodology and and associated models

- To link work groups from Headquarters to Programs to engineering teams at the field Centers

- **To enable mission feasibility, planning, and operations enabling feasible approaches to taking humanity to the Moon and on to Mars**

What NASA is asked to do in the future will only be harder and more complex

Coupled with flat or decreasing budgets, a driving need to go from concept to operations in less time, at reduced costs, all the while addressing with society's expectations of risk aversion for NASA

New ways of integrating, managing, sharing, and leveraging data and information is needed
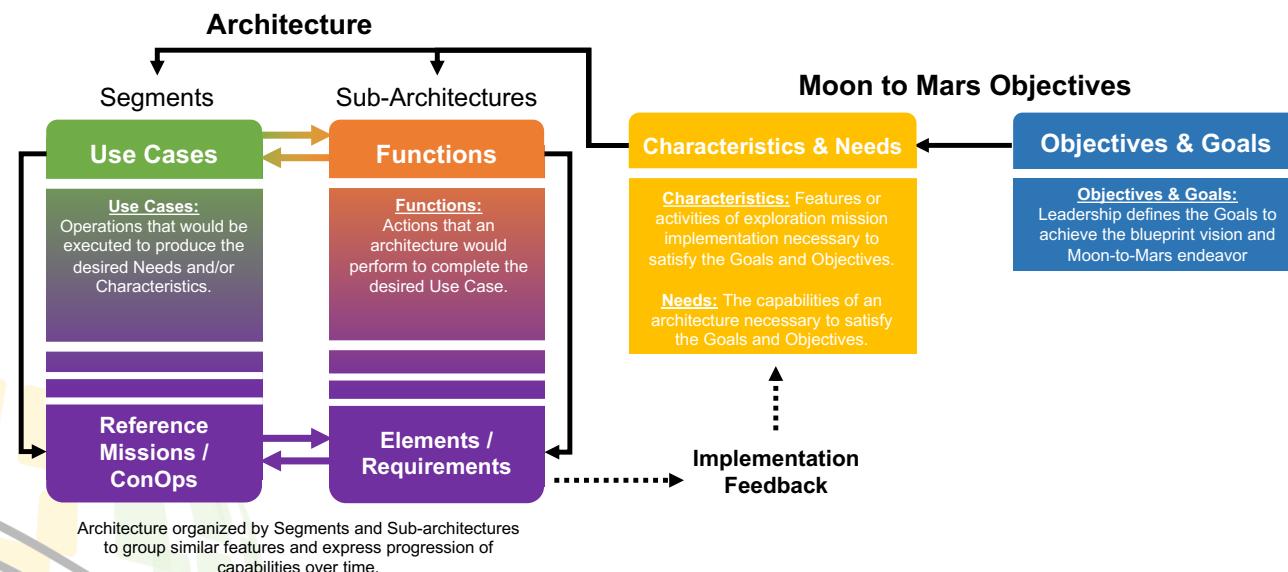
4

Missions

to Campaigns
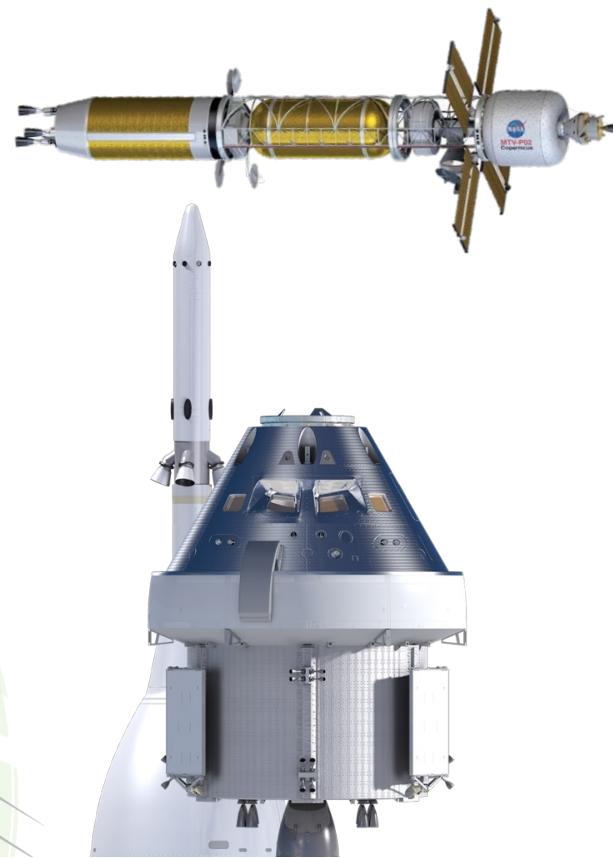
to Capabilities

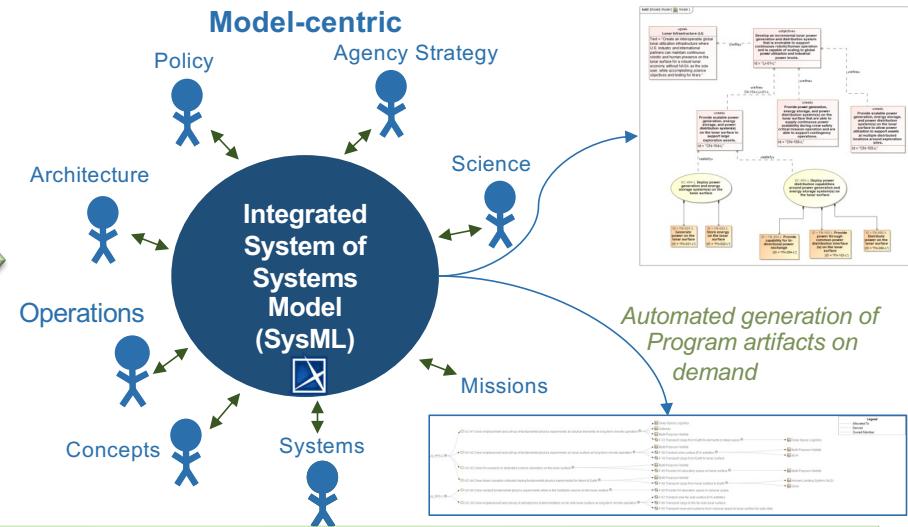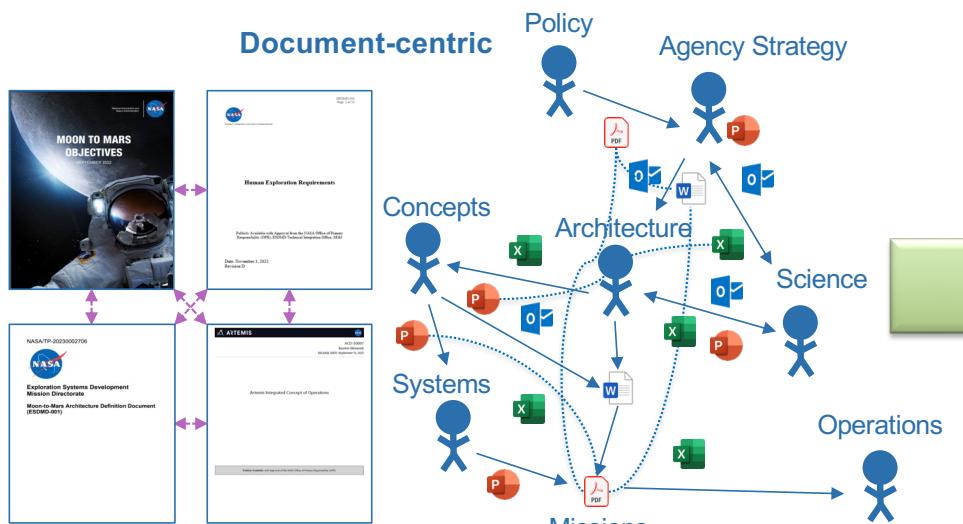# Architecting from the Right, Engineering from the Left

- NASA is leading a global, innovative, and sustainable space exploration initiative with the goal of returning humans to the Moon, achieve long-term surface presence, and continue to Mars

- In 2022 senior leaders, industry, international partners, and academia developed a set of Moon to Mars goals and objectives

- A new process referred to as "architecting from the right, engineering from the left" distills the objectives to architecture components

Architecture

Segments	Sub-Architectures		**Moon to Mars Objectives**	
Use Cases	**Functions**		**Characteristics & Needs**	**Objectives & Goals**
Use Cases: Operations that would be executed to produce the desired Needs and/or Characteristics.	**Functions:** Actions that an architecture would perform to complete the desired Use Case.		**Characteristics:** Features or activities of exploration mission implementation necessary to satisfy the Goals and Objectives. **Needs:** The capabilities of an architecture necessary to satisfy the Goals and Objectives.	**Objectives & Goals:** Leadership defines the Goals to achieve the blueprint vision and Moon-to-Mars endeavor
Reference Missions / ConOps	**Elements / Requirements**			

Implementation Feedback

Architecture organized by Segments and Sub-architectures to group similar features and express progression of capabilities over time.

The decomposition of objectives is just the beginning of a web of data that continues to grow as the architecture evolves and systems are defined

Document-centric to Model-centric Architecture Data Management

Document-centric

Policy · Agency Strategy · Concepts · Architecture · Science · Systems · Operations · Missions

Model-centric

Policy · Agency Strategy · Architecture · Science · Operations · Concepts · Systems · Missions

Integrated System of Systems Model (SysML)

Automated generation of Program artifacts on demand

- Many documents that describe the M2M architecture and associated data are managed by different teams
- Info in these docs all relate to each other, but aren't directly connected in any way or updated in sync
- Causes discrepancies, redundancies, gaps in info

Importing data into a model allows for
- Traceability
- Gap analysis
- Propagated updates of data
- Consistency
- Reduces human error and overall risk
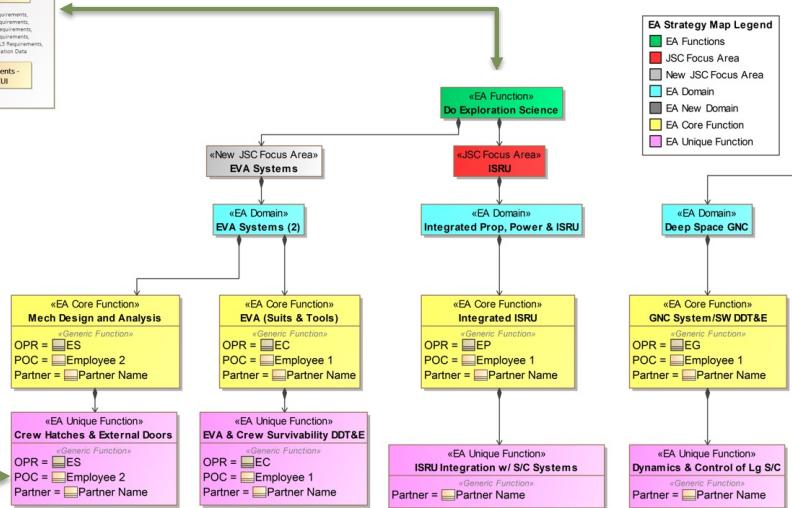- Allows for easy exportability and shareability

Missions

to Campaigns
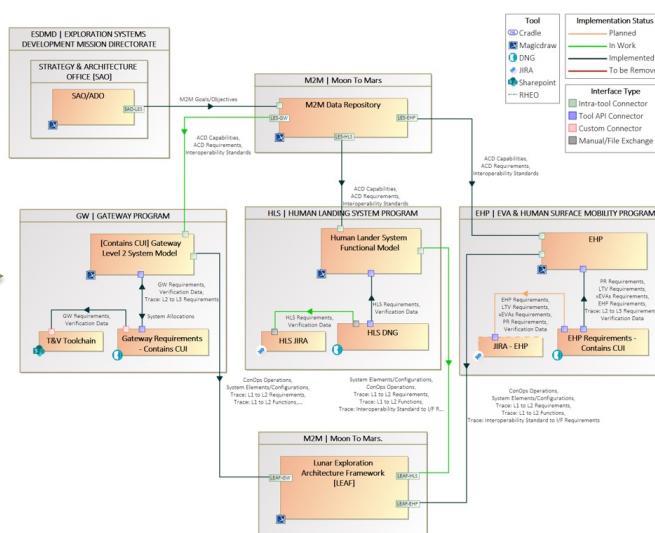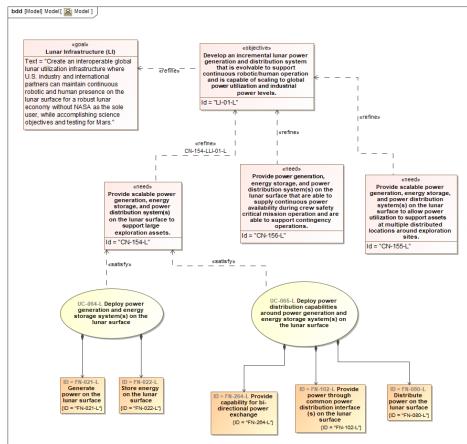
to Capabilities

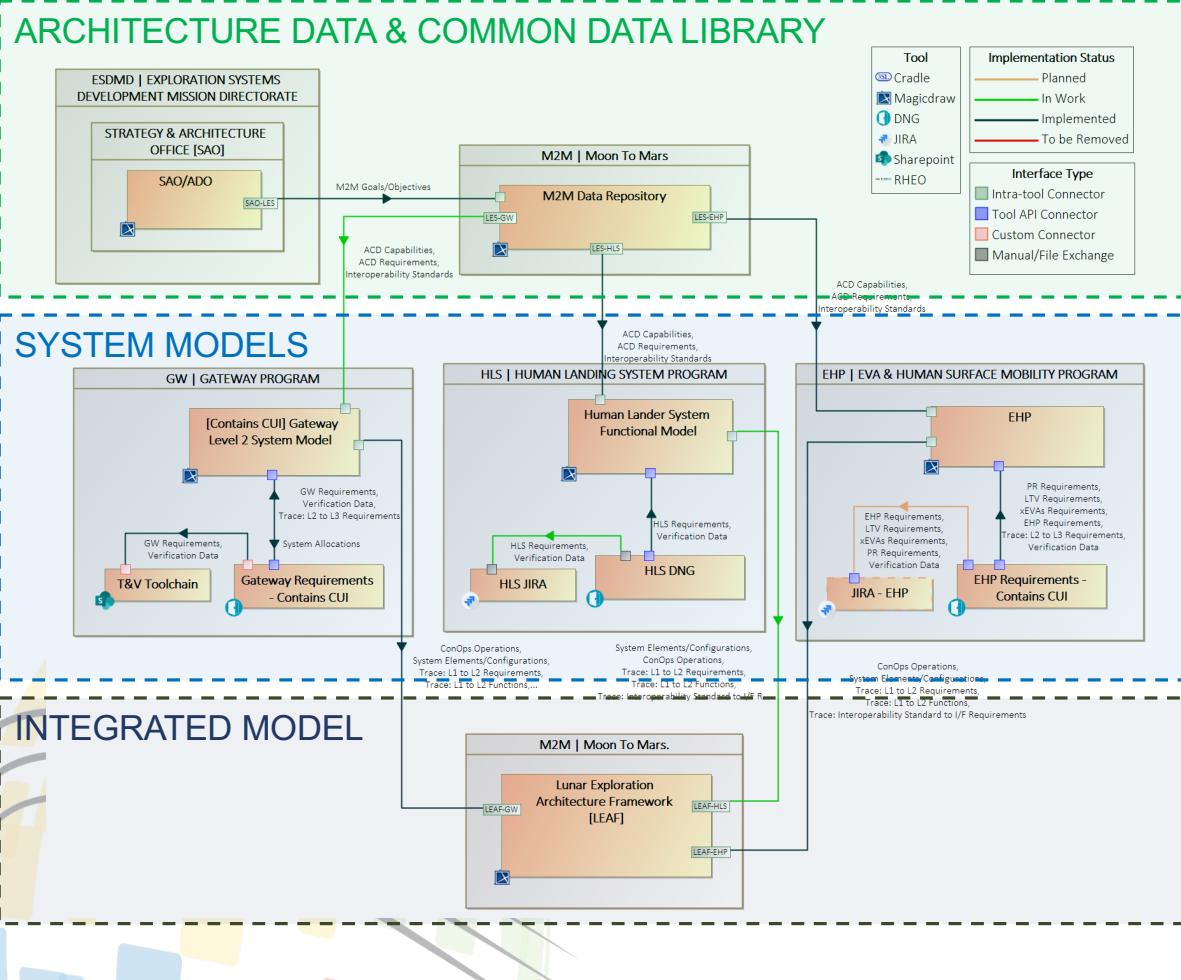# Integration Across the Artemis Campaign

The Moon to Mars Program Office (M2M PO) was established to support hardware development, mission integration, and risk management for the six Programs to the NASA Artemis campaign: the Space Launch System (SLS) rocket, Orion spacecraft, Exploration Ground Systems (EGS), Human Landing System (HLS), Gateway Space Station, and Extravehicular Activity and Human Surface Mobility.

This set of loosely-coupled Programs form a systems of systems (SoS) which must be integrated together to deliver a tightly-coupled SoS architecture under the Campaign.

The Integrated Technical Baseline using Model-Based Systems Engineering methodologies enables:

- Simplified Data Sharing/Access across Programmatic boundaries

- Streamlined delivery of Integrated Campaign-level SE&I Products

- A digital thread to understand architecture objectives & impacts from changes/updates

- Isolation of sensitive data across Systems/Program

- Standardization of model customizations, data schemas, modeling processes, etc.

Campaign System of Systems Model Federation

ARCHITECTURE DATA & COMMON DATA LIBRARY

ESDMD | EXPLORATION SYSTEMS DEVELOPMENT MISSION DIRECTORATE

STRATEGY & ARCHITECTURE OFFICE [SAO]

SAO/ADO
SAO-LES

M2M | Moon To Mars
M2M Data Repository
LES-GW
LES-HLS
LES-EHP

M2M Goals/Objectives

ACD Capabilities, ACD Requirements, Interoperability Standards

ACD Capabilities, ACD Requirements, Interoperability Standards

Tool
- Cradle
- Magicdraw
- DNG
- JIRA
- Sharepoint
- RHEO

Implementation Status
- Planned
- In Work
- Implemented
- To be Removed

Interface Type
- Intra-tool Connector
- Tool API Connector
- Custom Connector
- Manual/File Exchange

SYSTEM MODELS

GW | GATEWAY PROGRAM
[Contains CUI] Gateway Level 2 System Model
T&V Toolchain
Gateway Requirements – Contains CUI
GW Requirements, Verification Data, Trace: L2 to L3 Requirements
GW Requirements, Verification Data
System Allocations

HLS | HUMAN LANDING SYSTEM PROGRAM
Human Lander System Functional Model
HLS JIRA
HLS DNG
HLS Requirements, Verification Data
HLS Requirements, Verification Data

EHP | EVA & HUMAN SURFACE MOBILITY PROGRAM
EHP
JIRA - EHP
EHP Requirements – Contains CUI
EHP Requirements, LTV Requirements, xEVAs Requirements, PR Requirements, Verification Data
PR Requirements, LTV Requirements, xEVAs Requirements, EHP Requirements, Trace: L2 to L3 Requirements, Verification Data

ConOps Operations, System Elements/Configurations, Trace: L1 to L2 Requirements, Trace: L1 to L2 Functions,...

System Elements/Configurations, ConOps Operations, Trace: L1 to L2 Requirements, Trace: L1 to L2 Functions, Trace: Interoperability Standard to I/F R...

ConOps Operations, System Elements/Configurations, Trace: L1 to L2 Requirements, Trace: L1 to L2 Functions, Trace: Interoperability Standard to I/F Requirements

INTEGRATED MODEL

M2M | Moon To Mars.
Lunar Exploration Architecture Framework [LEAF]
LEAF-GW
LEAF-HLS
LEAF-EHP

The Model Federation Architecture enables integration across the system of systems.

- **Architecture Data & Common Data Library**: *Enterprise Data Library including level 1 requirements baseline, design reference mission definition, and capability architecture*

- **System Models:** *System description model for systems in the architecture. This includes system requirements, functional, and structural architecture*

- **Integrated Model:** *Artemis campaign model leveraged to support integrated product development. Allows for both isolation & integration of system information*

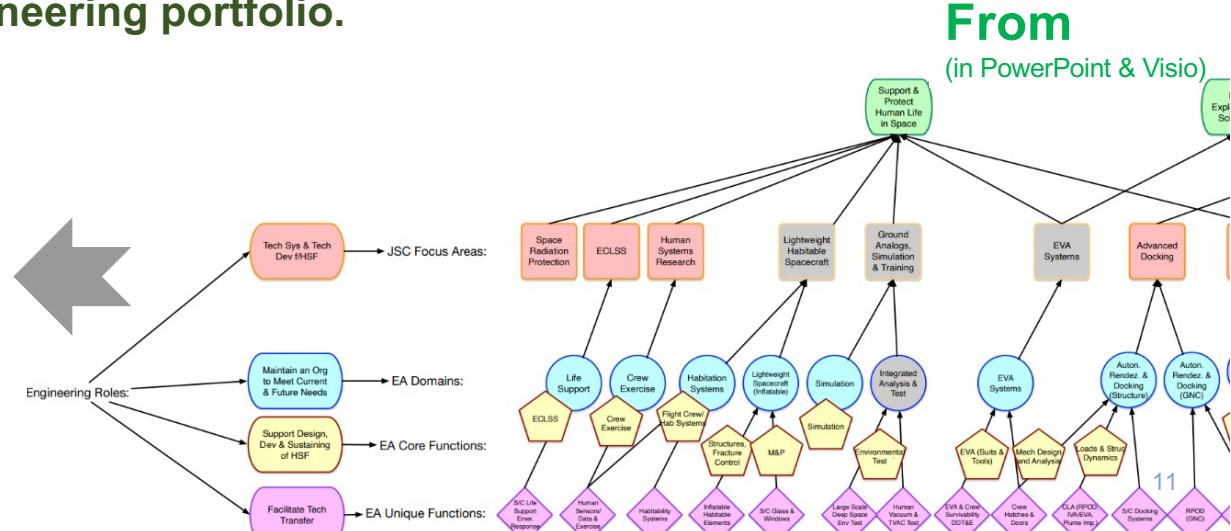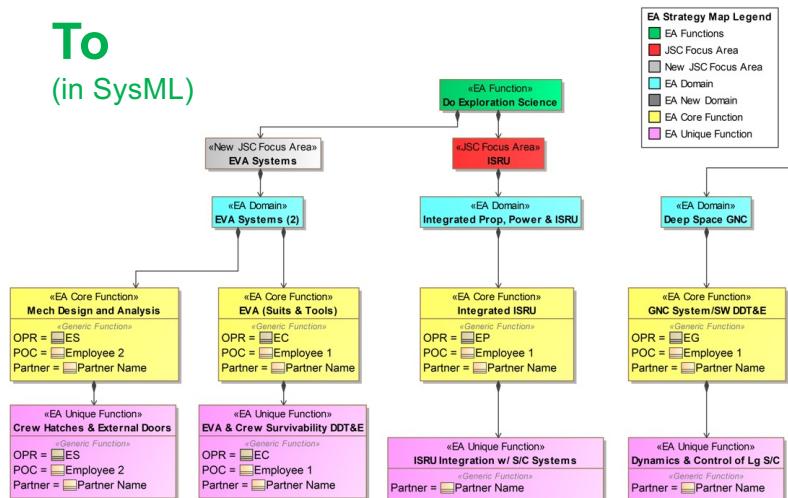# Mission Feasibility and Capability Portfolio Management – The Challenge

Challenge: Keeping program mission architects synced with Operations, Engineering, and R&D

Challenge: Difficult to devise strategic capability development and plan resources without clear linkage to mission objectives

Solution: Model-centric approach enables parametric linkage updates and shows clear traceability to mission objectives, functions, needs, and technology gaps to help strategically plan and manage engineering portfolio.

Mission Feasibility and Capability Portfolio Management - Solution

- SysML model to create a database to manage Engineering capability portfolio

- Can manage significantly more information
  - Traceability to Agency objectives/program contacts, funding

- Acts as an ASoT, increasing maintainability and reuse

- Multiple methods of model reviewing/ updating
  - Web-based, spreadsheet syncing, report generation (on right respectively), sync to higher-level models
  - Automation in both directions (i.e., updating model and updating artifacts)
  - Low entry barrier, don't need modeling software to benefit