# State of the Practice for MBSE at NASA GRC

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**Presented by:**

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**NASA GRC, System Engineering and Architecture Division**

# Agenda

1. NASA’s Digital Transformation Initiative
   - How Digital Engineering relates to NASA’s Digital Transformation
   - How MBSE fits into Digital Engineering
2. How MBSE models can connect to Multiple Disciplines and Tools
   - Examples of modeling and data exchange capabilities
3. Progression of MBSE within the Agency
4. How is MBSE being used today at GRC
5. MBSE Resources to Facilitate Adoption at NASA and GRC

# Experience with MBSE

- ***MBSE and SysML applied experience in NASA, Defense, Automotive and Medical industries***
- ***Developed SysML Models for Multiple NASA Projects:***
  - *Deep Space Habitat Models*
    - Requirements, Concept Operations, Functional Analysis, Design, Testing
  - *Spacecraft Life Support System Models*
    - Cascade Distiller System
    - Capillary Brine Residual in Containment System
  - *Testbed Models*
    - Human Exploration Testbed model for Integration and Analysis of Space Habitats
    - Integrated Power and Avionics System (IPAS)
  - *Power System Models*
- ***Modeled Solar Plant System using SysML***
  - Heliostat, Solar Panels, thermal loops, reliability analysis
- ***Used SysML for Medical Device Modeling***
  - Hardware and Software, and reliability analysis
- ***Developed SysML Library Repository***
  - Collection of SysML Models
- ***Current Role: MBSE Implementation Lead at NASA GRC***
  - *Developing shared MBSE resources*
  - *Identify MBSE activities and products to increase MBSE usage*
  - *Provide modeling and SE support to GRC projects*
  - *Worked with multiple NASA MBSE SMEs to concur on a modeling approach and message for the NASA Systems Modeling Handbook for Systems Engineering (NASA-HDBK-1009)*
  - *Actively support the GRC Digital Transformation (DT) team*

# NASA's Digital Transformation (DT) Initiative

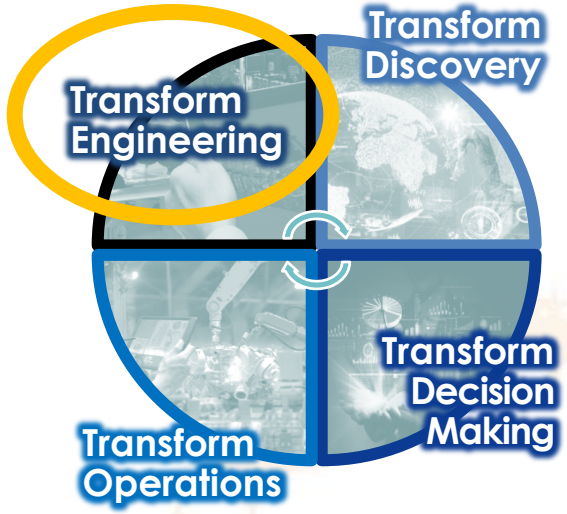
- NASA's Digital Transformation Initiative is a HQ led initiative to
  - Collectively acknowledge and support the Agency's need to transform the way we work, workforce and workplace (to meet the demands and challenges we face – complexity, adaptation)
  - Develop an overarching Enterprise vision and strategy for transformation
  - Focus, share and leverage the Agency's distributed efforts to apply new digital technologies and approaches in order to improve effectiveness at an enterprise level

- For more information about NASA's Digital Transformation
  - Reference: NASA/TM–20220018538
  - https://ntrs.nasa.gov/citations/20220018538

# How Does Digital Engineering Relate to NASA's Digital Transformation

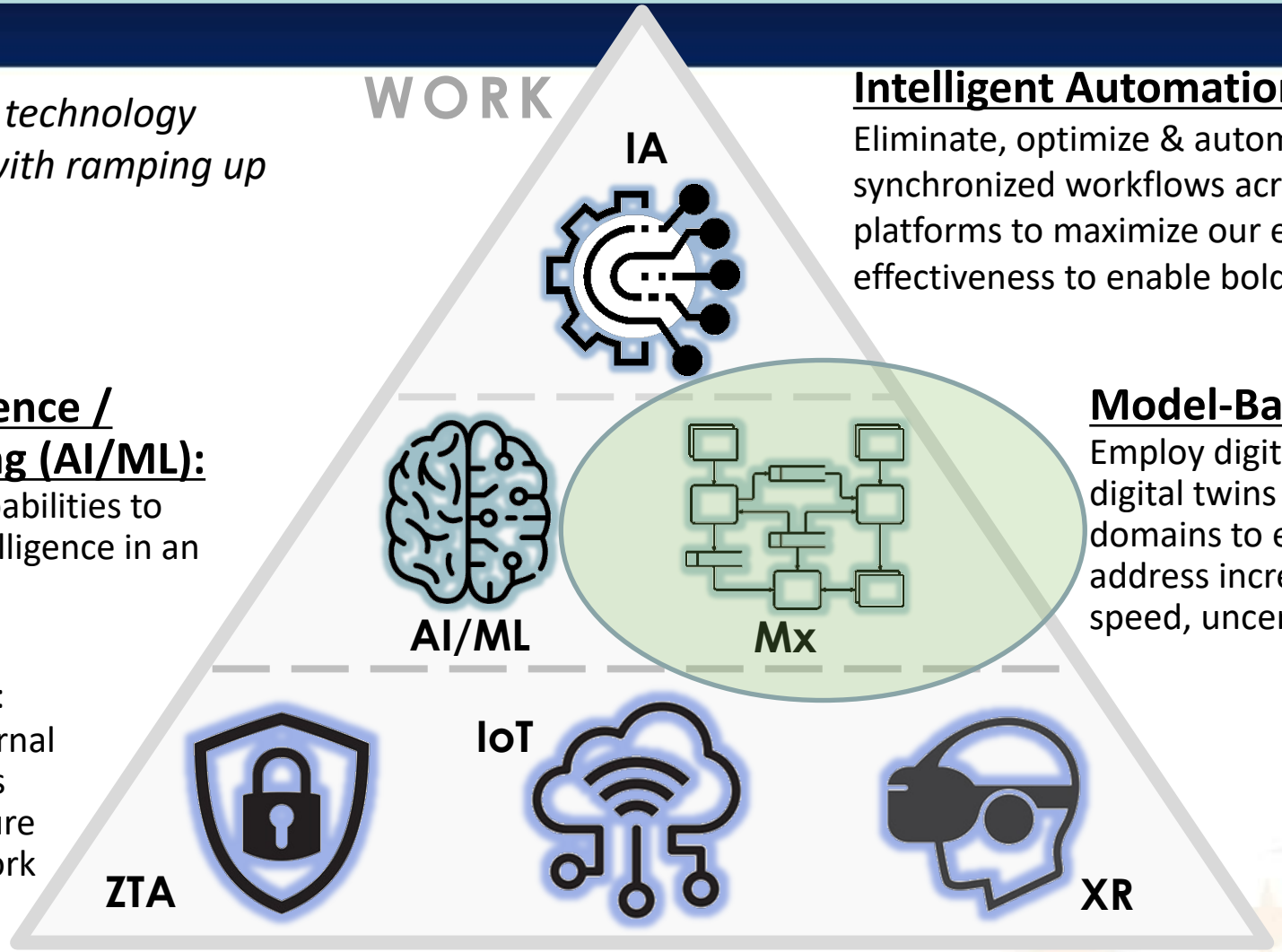
- **What is Digital Engineering?**
  - An integrated digital approach that uses authoritative sources of systems' data and models as a continuum across disciplines to support life cycle activities from concept through disposal. (DAU Glossary -Defense Acquisition Guidebook)

- A major target of the DT Strategic initiative is to **Transform Engineering**
- **Transforming Engineering requires and includes Digital Engineering**, specifically:
  - Model-Based Engineering: Design, Systems Engineering, Analysis, etc.
  - Leveraging new methods: Artificial Intelligence, Machine Learning, Virtual and Augmented Reality
  - Manipulating and leveraging data to understand and improve development and decision-making



# The 6 Key NASA Digital Technology Foundation Blocks

*Here are 6 key NASA digital technology foundation areas to assist with ramping up transformational areas*




**Intelligent Automation (IA):**
Eliminate, optimize & automate processes into synchronized workflows across enterprise platforms to maximize our efficiency and effectiveness to enable bolder missions faster

**Artificial Intelligence / Machine Learning (AI/ML):**
Harness machine capabilities to augment human intelligence in an era of big data

**Model-Based Anything (MBx):**
Employ digital models including digital twins across any/all functional domains to enable our people to address increasing complexity, scope, speed, uncertainty & changes

**Zero Trust Architecture**:
Enable dynamic internal/external collaboration wherever teams need to work, leveraging secure infrastructure, identity, network & data architecture

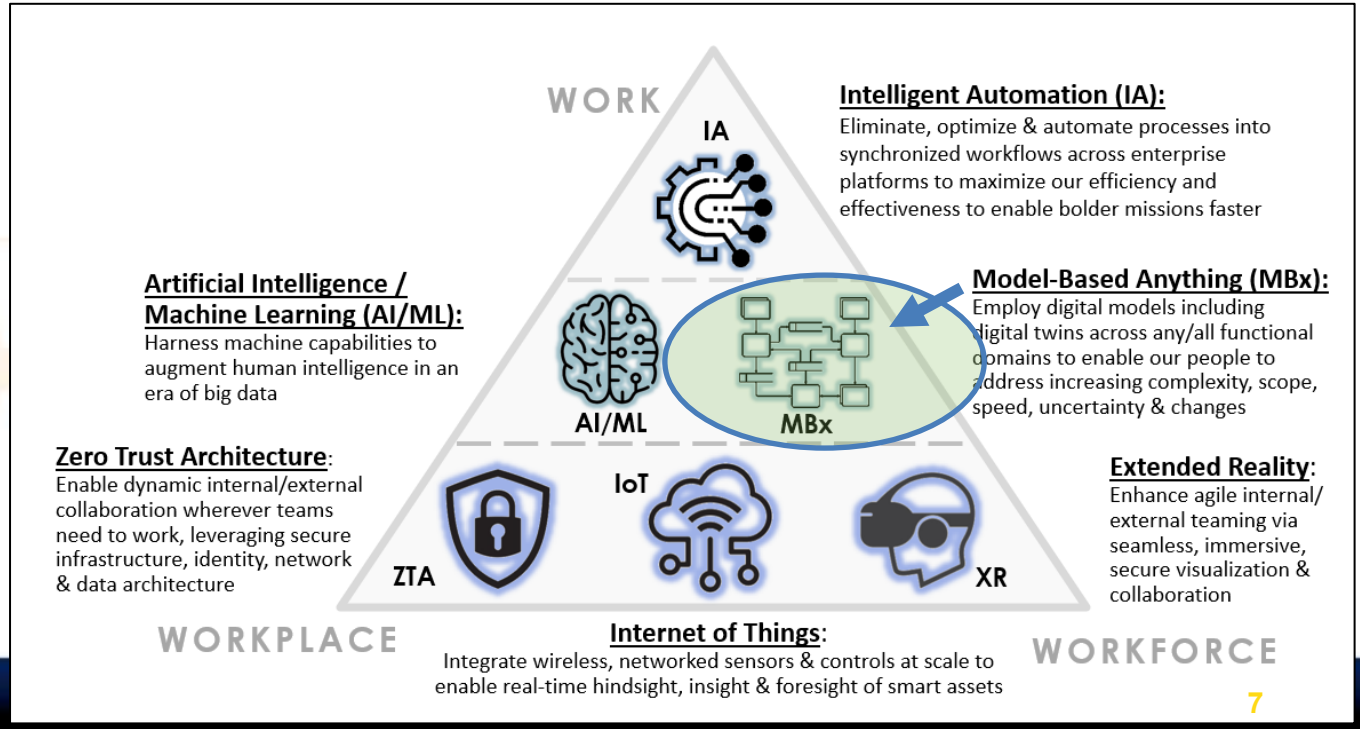
**Extended Reality**:
Enhance agile internal/ external teaming via seamless, immersive, secure visualization & collaboration

**Internet of Things**:
Integrate wireless, networked sensors & controls at scale to enable real-time hindsight, insight & foresight of smart assets

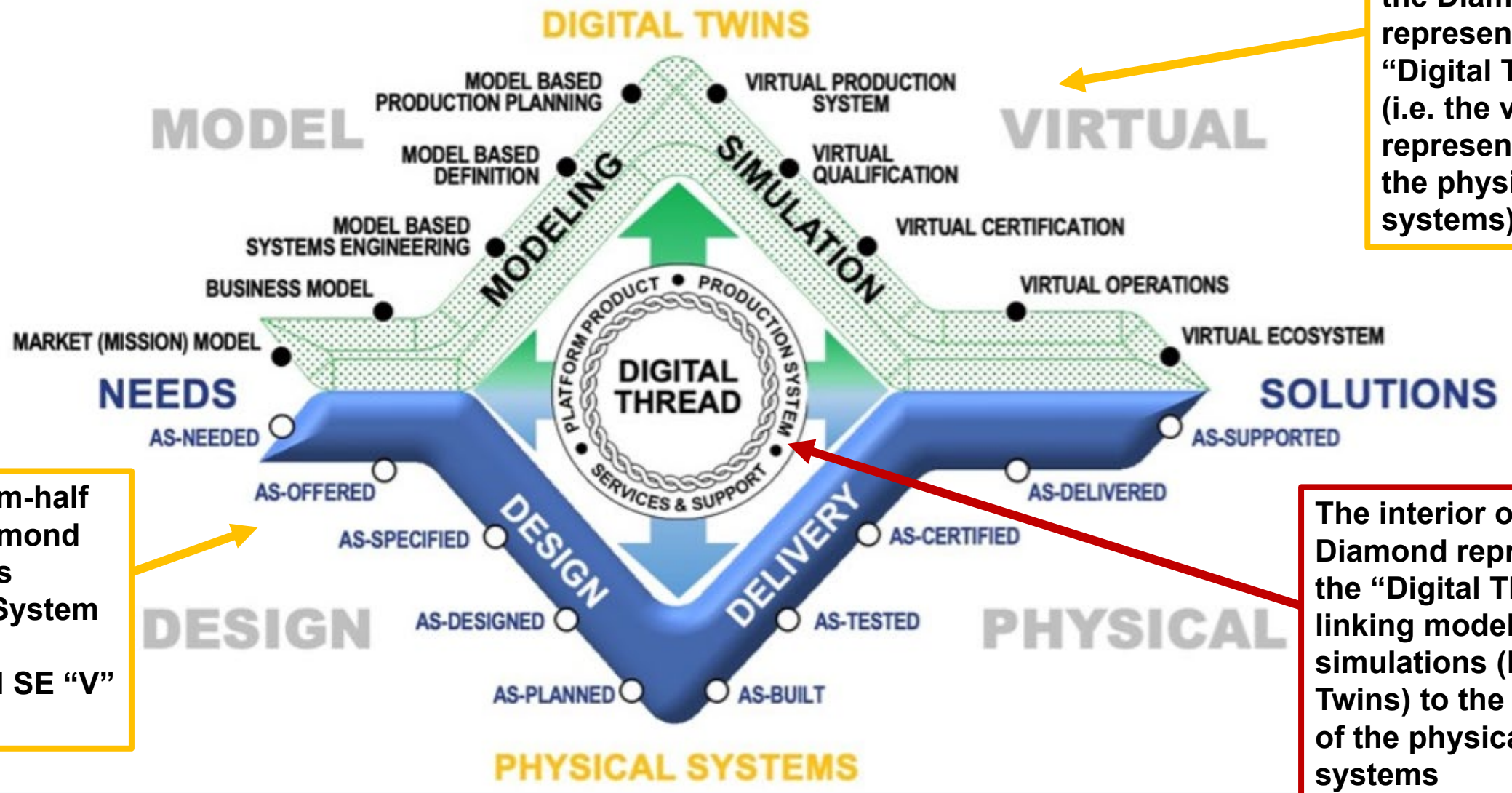

Reference: NASA/TM–20220018538 https://ntrs.nasa.gov/citations/20220018538

# How Does MBSE fit into Digital Engineering

- MBSE **is a part of Digital Engineering**
  - MBSE consists of **data and relationships with a graphical overlay** to support views of the data and relationships
- MBSE produces a system model **that can link to** models, documents, and additional digital engineering tools
  - Can be used to conduct analysis and reason on data for decisions
    - Can utilize Artificial Intelligence (to conduct analysis) and Machine Learning (to reason)
  - Can share data with third party tools to conduct analysis/ generate additional views



# The Relationship of Modeling and Simulation to Systems Engineering




The top-half of the Diamond represents the "Digital Twins" (i.e. the virtual representation of the physical systems)

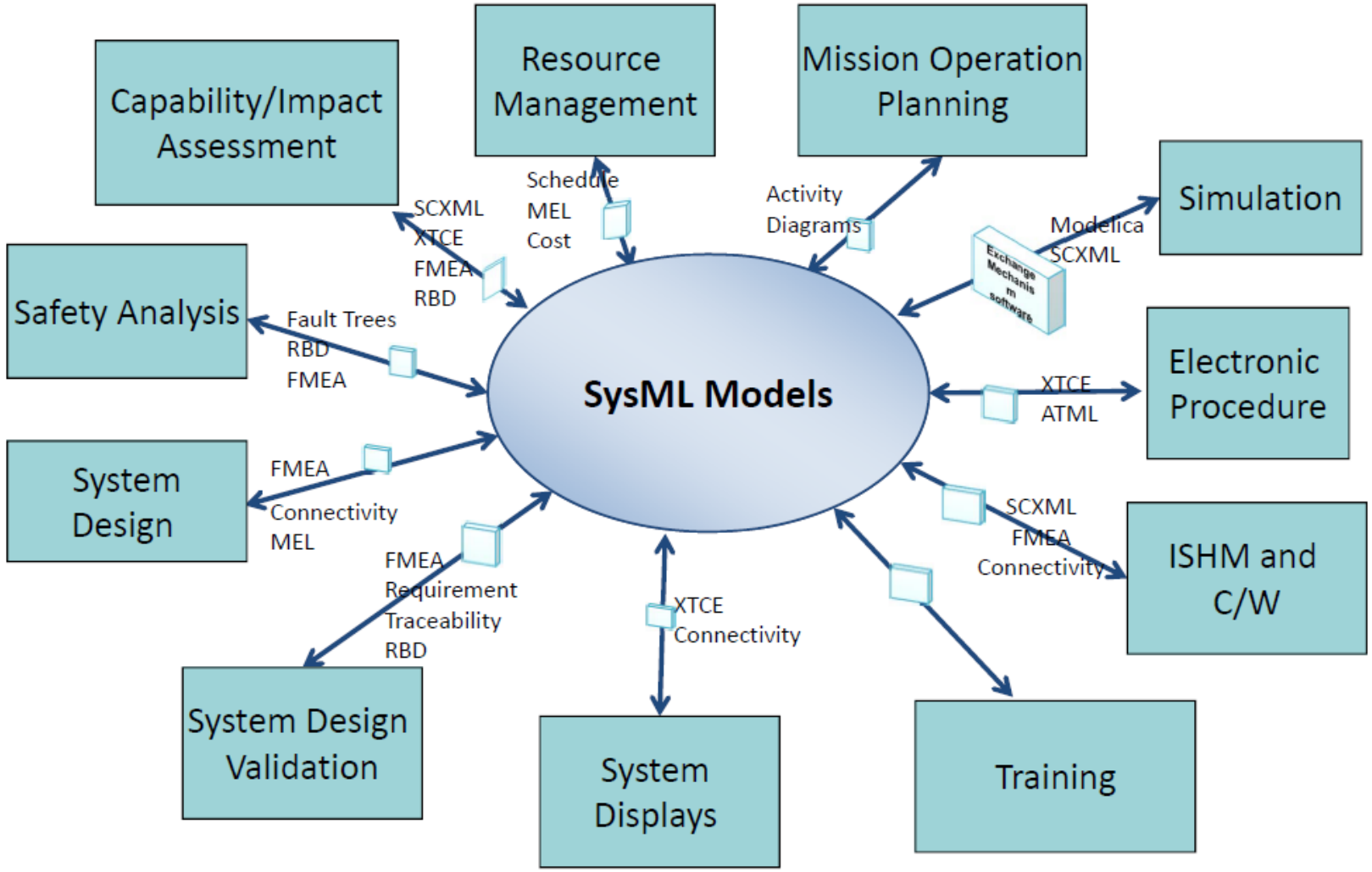
The bottom-half of the Diamond represents Physical System (retaining traditional SE "V" flow)

The interior of the Diamond represents the "Digital Thread" linking models/ simulations (Digital Twins) to the design of the physical systems



Reference: https://www.incose.org/docs/default-source/midwest-gateway/events/incose-mg_2018-11-13_scheurer_presentation.pdf

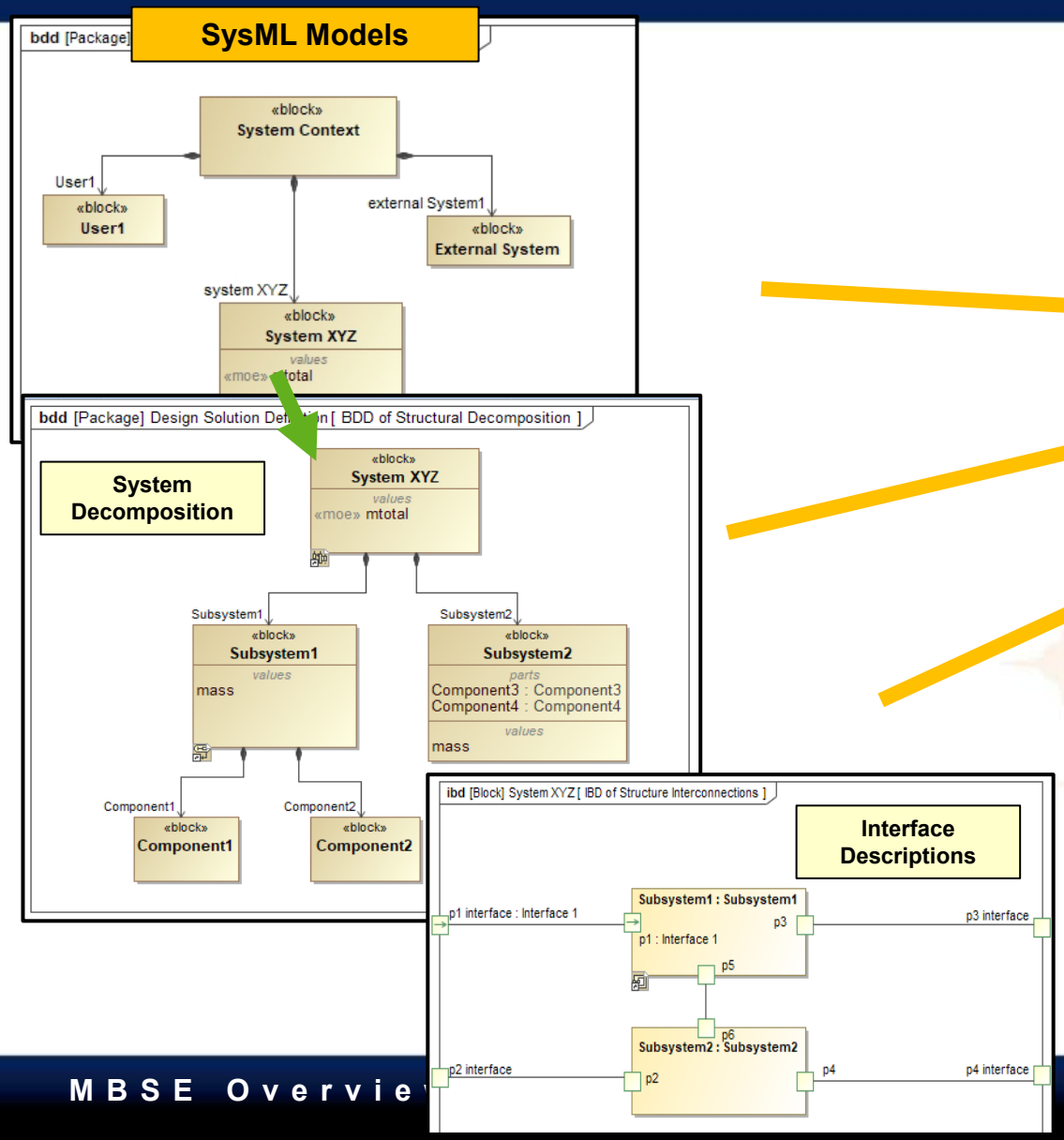
# Models Connected to Multiple Disciplines and Tools






Source: Izygon, M., Wang, L., Okon, S., Wagner, H., and Garner, L., "Effort to Accelerate MBSE Adoption and Usage at JSC," AIAA SPACE 2016, Long Beach, CA, 2016. https://arc.aiaa.org/doi/pdf/10.2514/6.2016-5542

# System Decomposition and System Interface Modeling and Data Exchange Capabilities




**Example Data Exchange Capabilities**

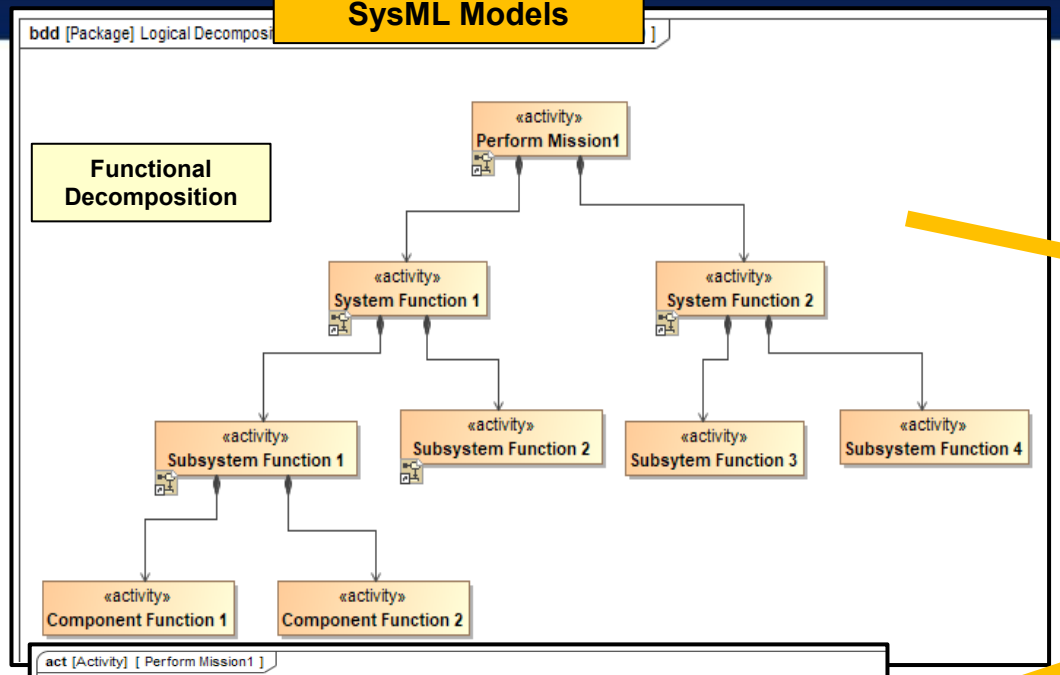
- Can Extract Master Equipment Lists (MELs)
- Architecture Documents/Reports
- Can send structural decomposition data and relationships and interface descriptions to other System Support and Analysis tools
  - System Displays
  - Resource Management
  - Safety Analysis
  - Discipline Engineering Tools

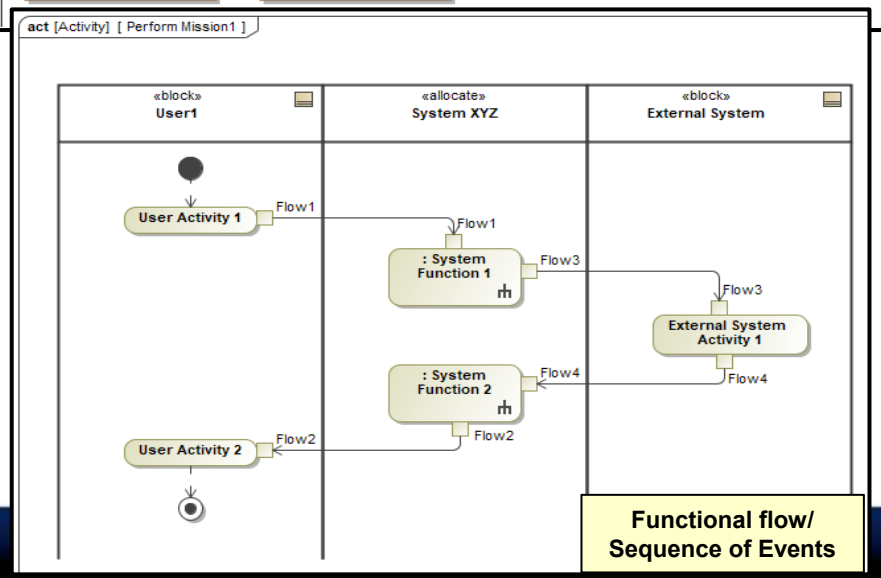


*Image Source: NASA-HDBK-1009 (Link to NASA-HDBK-1009)*

# Functional Decomposition and Interface Modeling and Data Exchange Capabilities

**SysML Models**



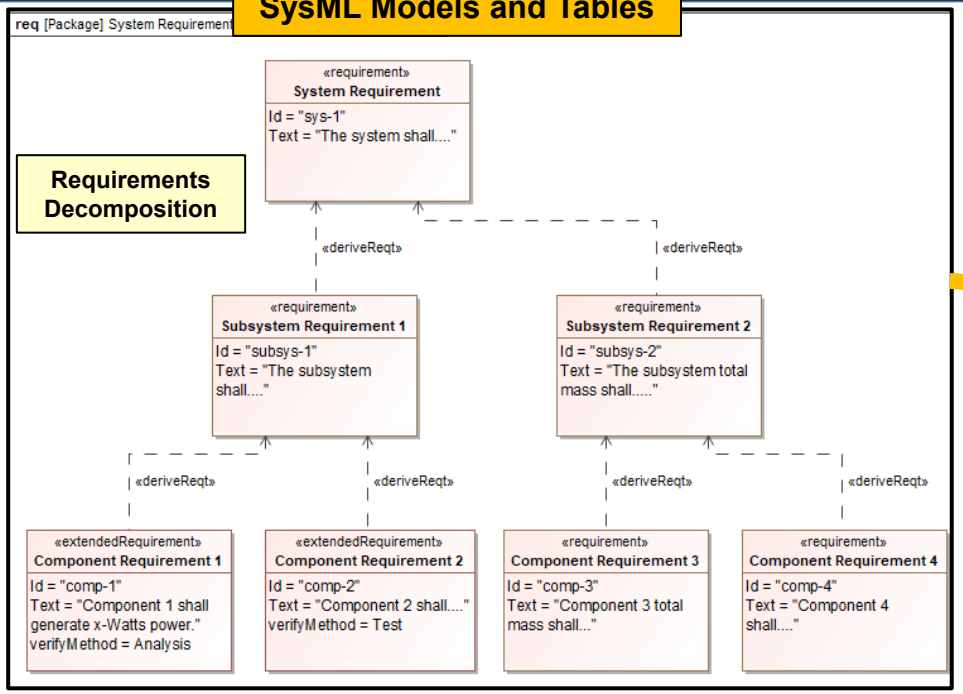

**Example Data Exchange Capabilities**

- Together with the System Architecture Description can be used to autogenerate a ConOps Report
- Can send Functional decomposition data and relationships and interface descriptions to other System Support and Analysis tools
  - Mission Operation Planning
  - Electronic Procedures
  - Safety Analysis

*Image Source: NASA-HDBK-1009 (Link to NASA-HDBK-1009)*

# System Requirements Modeling and Data Exchange Capabilities

**SysML Models and Tables**




**Example Data Exchange Capabilities**

- Can be used to auto-generate spreadsheet reports or System Specifications Document
  - Can facilitate customer/vendor specification discrepancies
- Can send data and relationships to other System Support and Analysis tools
  - System Design Validation
  - Impact Assessments

**Requirements Traceability**

| # | Id | Name | Text | Refined By | Derived From | Verify Method | Verified By | Satisfied By |
|---|---|---|---|---|---|---|---|---|
| 1 | sys-1 | System Requirement | The system shall.... | System Function 1(contex | | | verif-1 Verification Requirement 1 | System XYZ |
| 2 | subsys-2 | Subsystem Requirement 2 | The subsystem total mass shall..... | Subsytem Function 3(cont<br>Subsystem Function 4(con | sys-1 System Requirement | | | /mtotal |
| 3 | subsys-1 | Subsystem Requirement 1 | The subsystem shall.... | Subsystem Function 1(con<br>Subsystem Function 2(con | sys-1 System Requirement | | verif-3 Verification Requirement 3 | Subsystem1 |
| 4 | comp-4 | Component Requirement 4 | Component 4 shall.... | | subsys-2 Subsystem Requirement 2 | | | |
| 5 | comp-3 | Component Requirement 3 | Component 3 total mass shall... | | subsys-2 Subsystem Requirement 2 | | | mtotal |
| 6 | comp-2 | Component Requirement 2 | Component 2 shall.... | Component Function 2 | subsys-1 Subsystem Requirement 1 | Test | | Component2 |
| 7 | comp-1 | Component Requirement 1 | Component 1 shall generate x-Watts power. | Component Function 1 | subsys-1 Subsystem Requirement 1 | Analysis | verif-2 Verification Requirement 2 | power value |

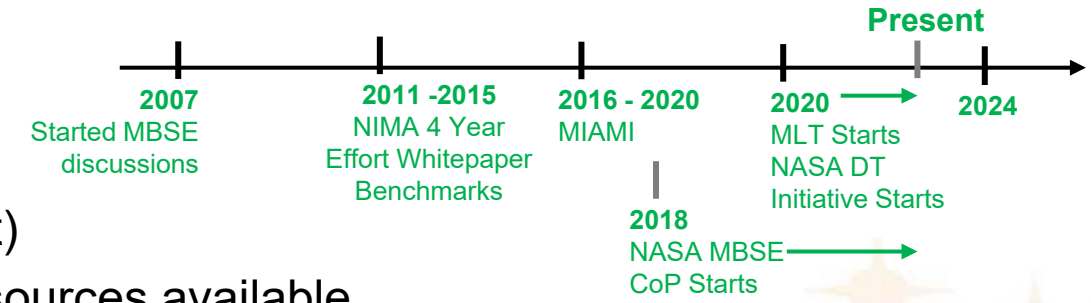


*Image Source: NASA-HDBK-1009 (Link to NASA-HDBK-1009)*

# Progression of MBSE within The Agency

## History of MBSE Activity at the Agency Level:

- **NASA Systems Engineering Working Group (SEWG)** began MBSE discussions (2007)
  - Sub-team to investigate MBSE formed (2009)
- **NASA Integrated Model-Based Centric Architecture (NIMA)** (2011 – 2015)
- **MBSE Infusion and Modernization Initiative (MIAMI)** effort (2016 – 2020)

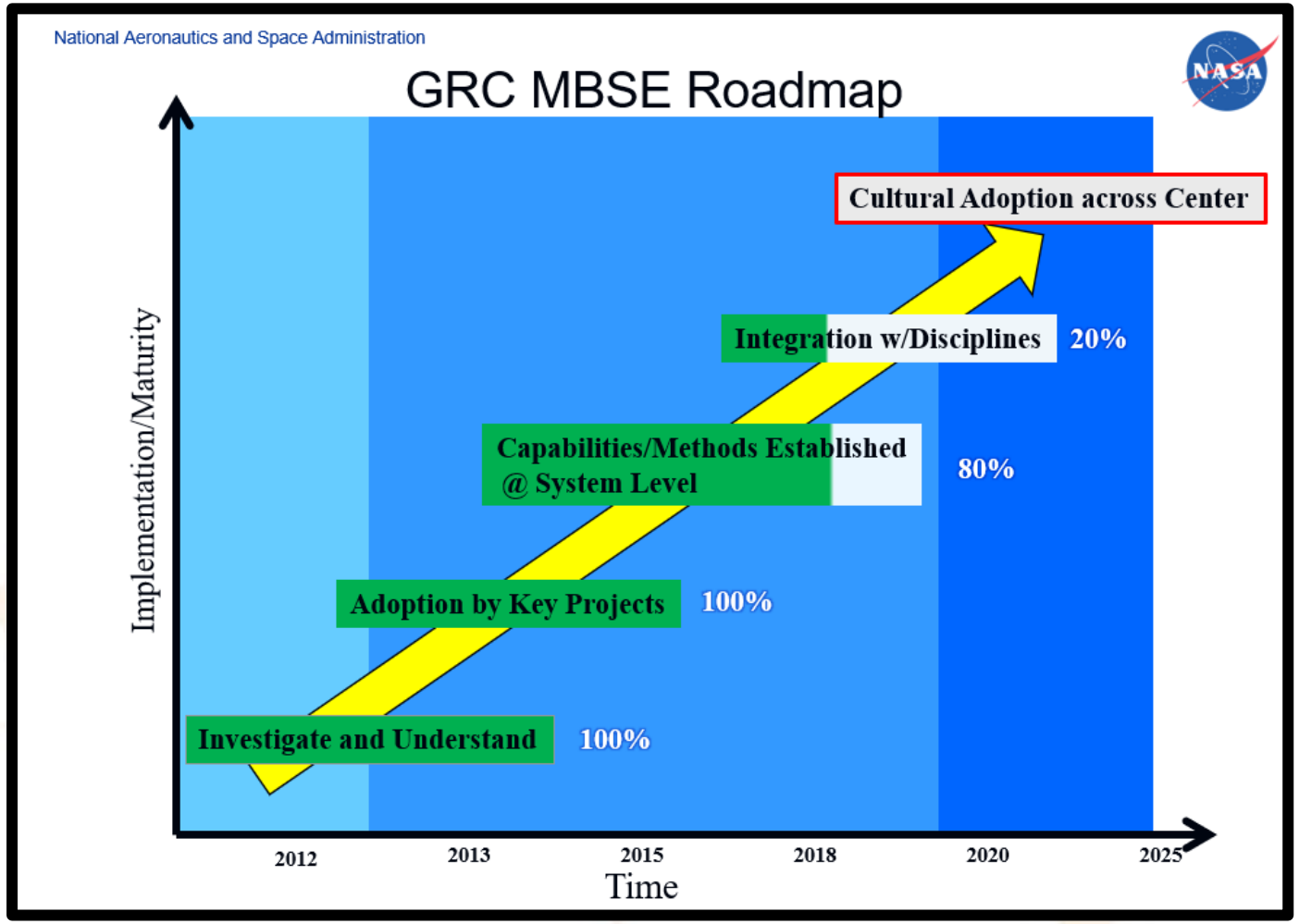



## Today at the Agency:

- **NASA MBSE Leadership Team (MLT)** (2020 – Present)
  - Making a consolidated effort to get Agency MBSE resources available
  - Every center has MLT representatives
- **NASA MBSE Community of Practice** (~2018 – Present)
- **NASA Digital Transformation (DT) Initiative** (2020 – Present)
- There are approximately 89 multi-center collaborations utilizing MBSE with about 350 modelers
- NASA **published a NASA System Modeling Handbook** for Systems Engineering (Dec 2022)

# How has MBSE Adoption Progressed at GRC

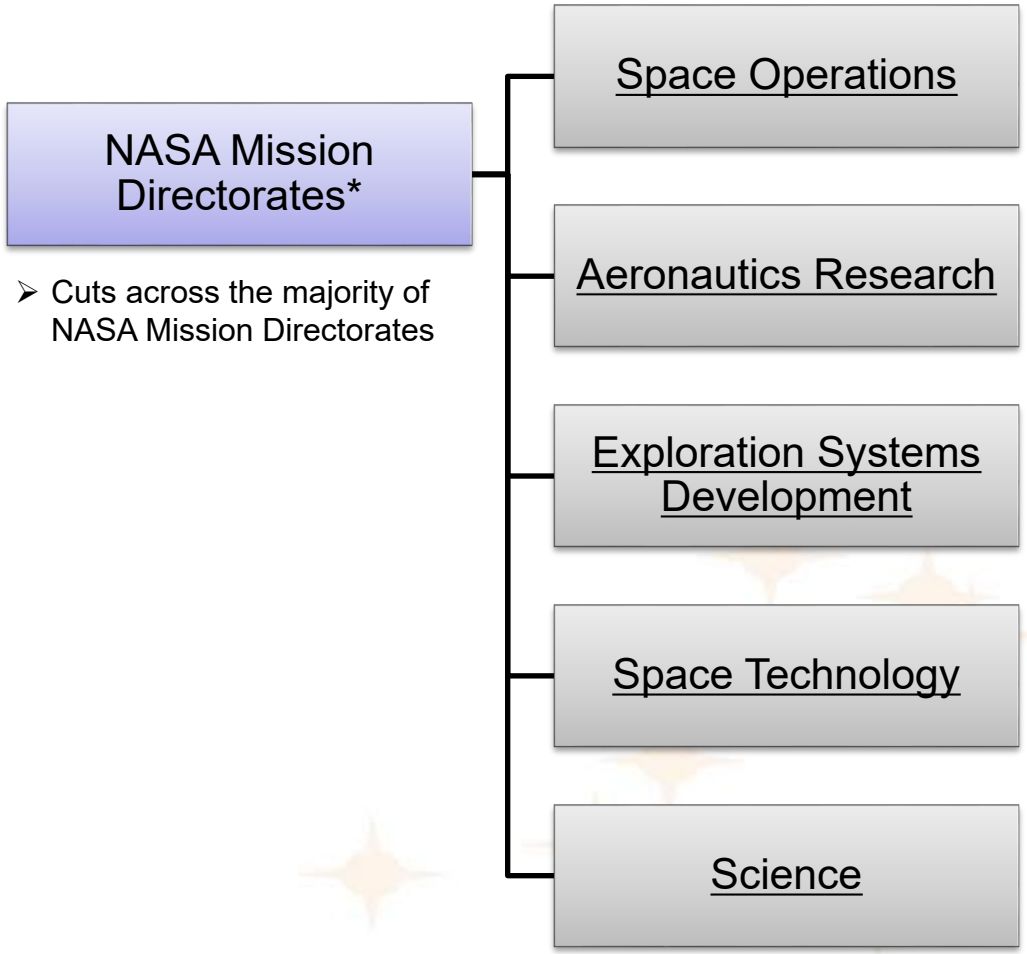
- **2011: Started a MBSE GRC Working Group**
  - Developed a MBSE Roadmap
- **2011-Present: Applying MBSE to projects at GRC**
- **2021-Present: Maturing GRC's MBSE capability**
  - Agency has applied the **INCOSE MBSE Capability Assessment (MBCA)** as a yardstick
  - GRC uses the MBCA together with our roadmap to gauge our current state and future state
  - Defines tasks and products to support future state goals
  - Laid out plans to mature our MBSE capability
  - Increased engagement at the Agency Level and cross-centers to collaborate and share/ leverage resources



# GRC Projects Using MBSE and Application Areas

- **Some GRC projects applying MBSE include:**
  - Advance Air Mobility projects (includes unmanned aerial systems)
  - Power Propulsion Element (PPE), a Gateway/Artemis system
  - Exploration Medical Capabilities project
  - Lunar Surface Architecture projects
  - Fission Surface Power project
  - Space Communications and Navigation (SCaN)
  - High-Rate Delay Tolerant Networking

- **Application Areas where MBSE is being used include:**
  - in support of Concept of Operations development
  - for Requirements
  - for Architecture and Interface definitions
  - in support of Verification and Validation activities
  - to support Safety Mission Assurance applications (ex: FMEAs)
  - to support Security Engineering analysis and products




➢ Cuts across the majority of NASA Mission Directorates



*Source: https://www.nasa.gov/about/org_index.html

# MBSE Resources to Facilitate Adoption at NASA and GRC

- A GRC MBSE SharePoint
  - Common area to share knowledge and resources
- Starter Template Models
- Report Templates for extracting Word documents from the model
- Modeling guidelines that trace Technical Review Products to MBSE Products
- Revamping MBSE Training
- Agency and Center MBSE working groups
- The NASA System Modeling Handbook for Systems Engineering (NASA-HDBK-1009) – *Public Resource*
- A Companion Model to the NASA-HDBK-1009 (A Template Model) – *Public Resource*

# NASA-HDBK 1009 Background and Scope

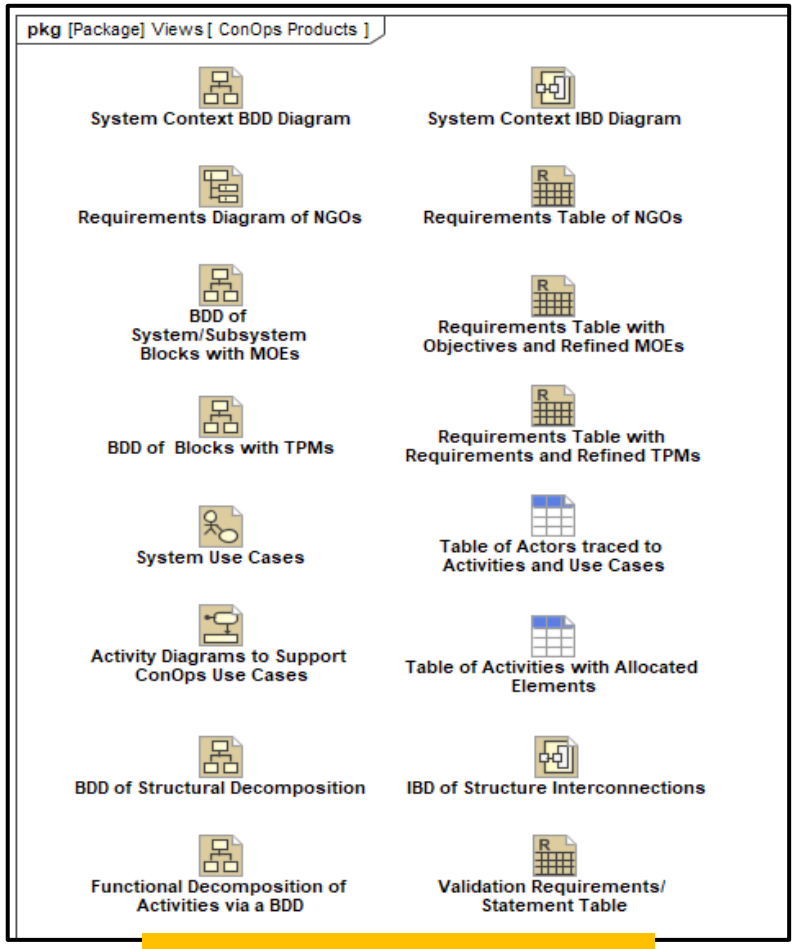
**Background:**

- Handbook development sponsored by the NASA Office of Chief Engineer (OCE)
  - Based on a need from practitioners for a system modeling handbook
- The handbook development and approval adhered to the NASA Technical Standards Development Process
  - Consensus based
  - Formally concurred by the Engineering Management Board (EMB) members from all NASA centers and signed by the NASA Chief Engineer

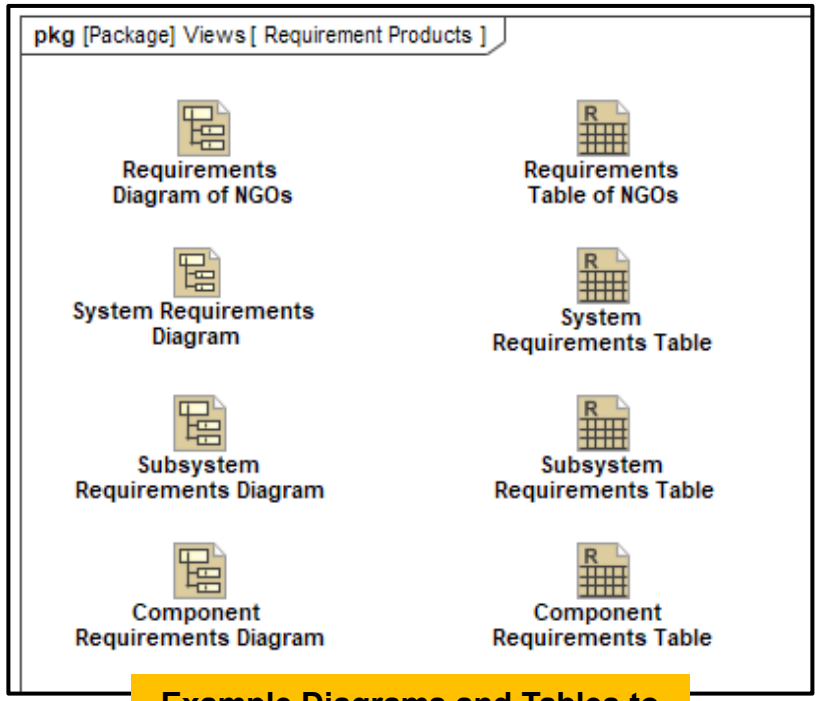
**Scope:**

- Shows how system modeling using SysML® can be integrated with the NASA Systems Engineering processes in NPR 7123.1
  - The SE products covered are Concept of Operations (ConOps), Requirements, and Verification and Validation (V&V).
    - Based on feedback from the NASA Agency MBSE CoP

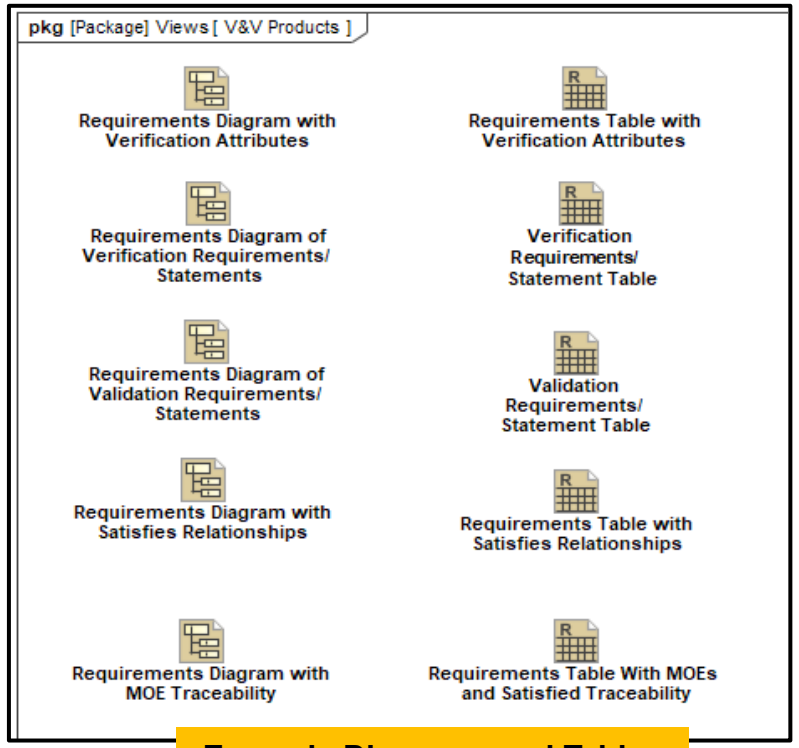
# Example Product Views to Support Systems Engineering




**Example Diagrams and Tables to Support ConOps Products**




**Example Diagrams and Tables to Support Requirements Products**




**Example Diagrams and Tables to Support V&V Products**



*Source: NASA-HDBK-1009 (Link to NASA-HDBK-1009)*

# Questions