Quick Webinars
Skill Building for NASA's Technical Workforce

Next-Gen Engineering: Model-Based Systems Engineering at NASA

An Overview of MBSE at NASA and APPEL KS's MBSE Courses

Date: September 26, 2024

Presented by:

Shira Nadile - MBSE Implementation Lead

NASA GRC, System Engineering and Architecture Division

Shira Nadile

- **Current Role/Title:** MBSE Implementation Lead at NASA GRC

- **Bio Description:**
  - Systems Engineering expertise in all phases of system development
  - MBSE and SysML expert with applied experience in NASA, Defense, Automotive and Medical industries
  - Supports NASA Digital Transformation and Digital Engineering efforts
  - A process improvement enthusiast with experience in ISO, CMMI and Six Sigma

  - **Education:**
    - Aeronautical and Astronautical Engineering degree from Purdue University
    - Graduate Certificate in Systems Engineering from University of Houston - Clear Lake
    - Certificate in Digital Transformation from MIT

Agenda

1. NASA's Digital Transformation Initiative
   - How Digital Engineering relates to NASA's Digital Transformation
   - How MBSE fits into Digital Engineering
2. Short intro to MBSE and how it relates to NASA SE
3. How MBSE models can connect to Multiple Disciplines and Tools
   - Examples of modeling and data exchange capabilities
4. Progression of MBSE within the Agency
5. Recap of Benefits of MBSE
6. MBSE Resources to Facilitate Adoption at NASA

Key Points

- MBSE helps to make Projects/Programs more efficient by enhancing the Systems Engineering and Project Management efforts
- MBSE resources are available to help with use of MBSE and to plan MBSE integration into projects
- APPEL Course are available to provide training

NASA's Digital Transformation (DT) Initiative

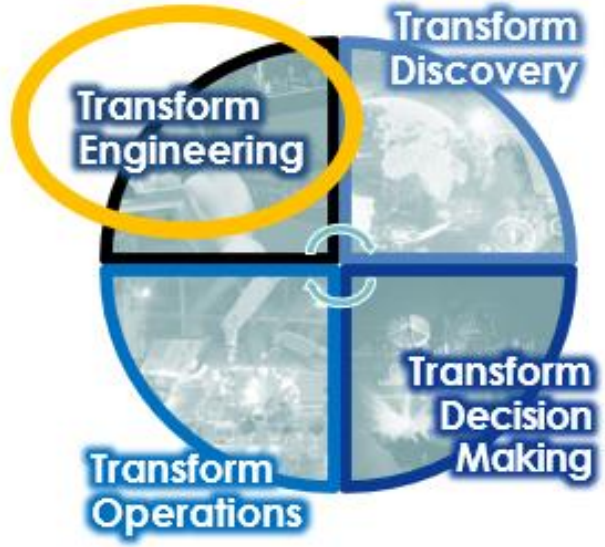
- NASA's Digital Transformation Initiative is a HQ led initiative to
  - Collectively acknowledge and support the Agency's need to transform the way we work, workforce and workplace (to meet the demands and challenges we face – complexity, adaptation)
  - Develop an overarching Enterprise vision and 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
  - NASA DT Homepage: https://nasa.sharepoint.com/sites/dt

How Does Digital Engineering Relate to NASA's Digital Transformation

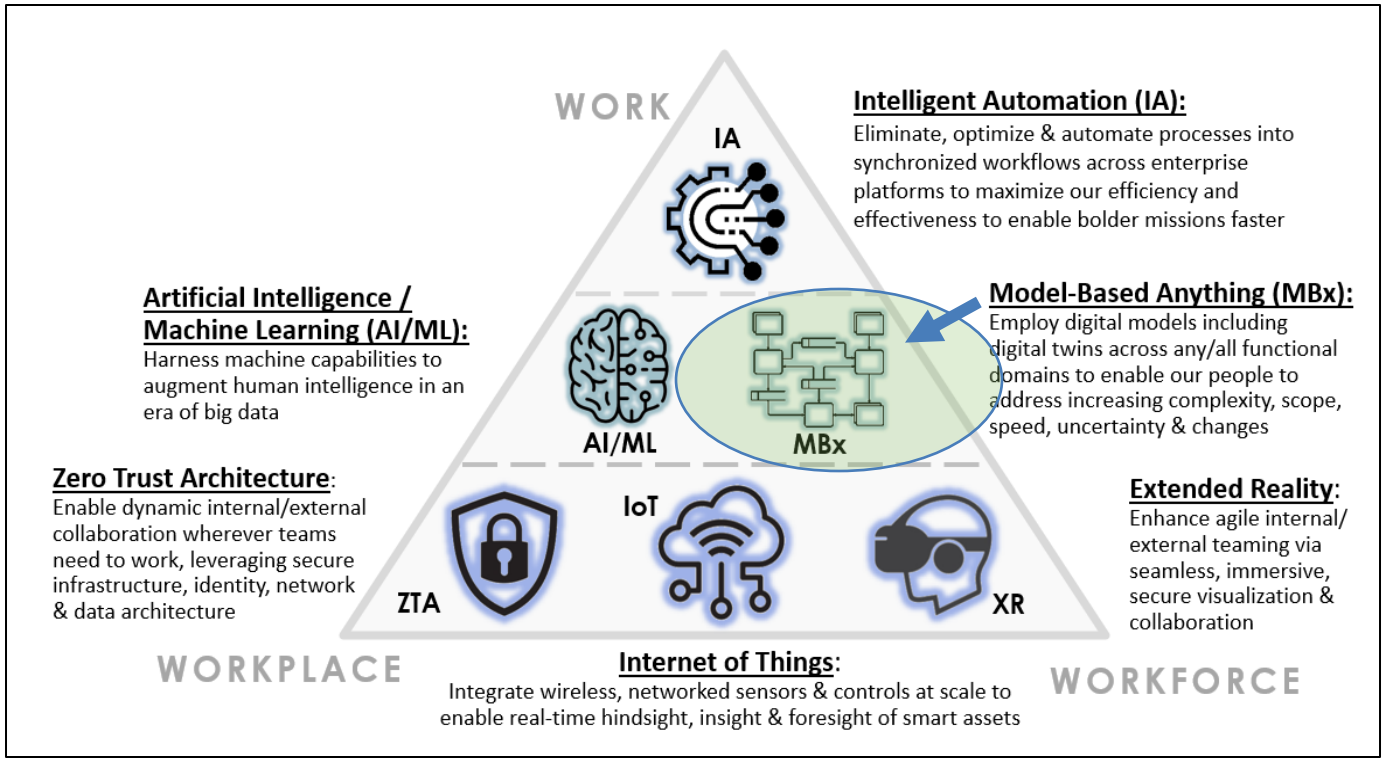
- **What is Digital Engineering?**
  - An integrated digital approach that uses authoritative sources of systems' data and models as a continuum across disciplines to support life cycle activities from concept through disposal. (DAU Glossary -Defense Acquisition Guidebook)

- A major target of the DT Strategic initiative is to **Transform Engineering**
- **Transforming Engineering requires and includes Digital Engineering,** specifically:
  - Data Centric (aka: 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



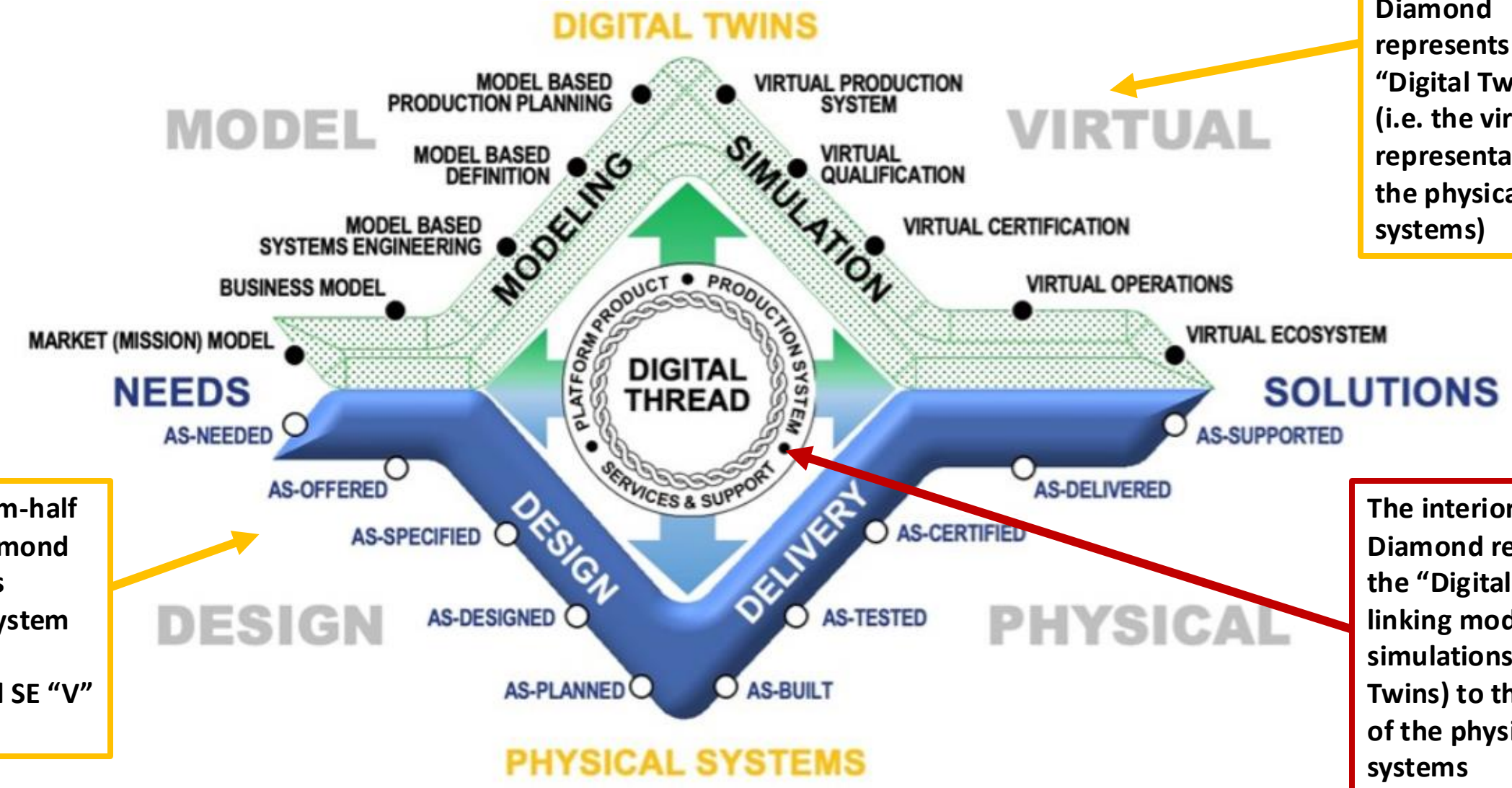
How Does MBSE fit into Digital Engineering?

- 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)
    - Can utilize 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

What is MBSE and How It Relates to SE

MBSE Definition

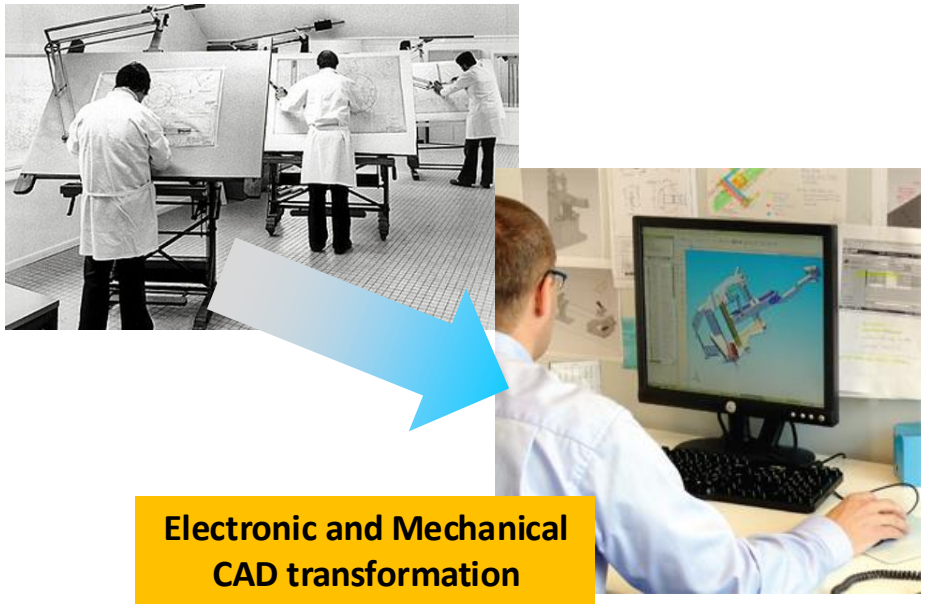
"Model-based systems engineering (MBSE) is the *formalized application of modeling* to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases."

INCOSE Initiatives (https://www.incose.org/incose-member-resources/initiatives)

INCOSE International Council on Systems Engineering

MBSE as it Relates to Systems Engineering

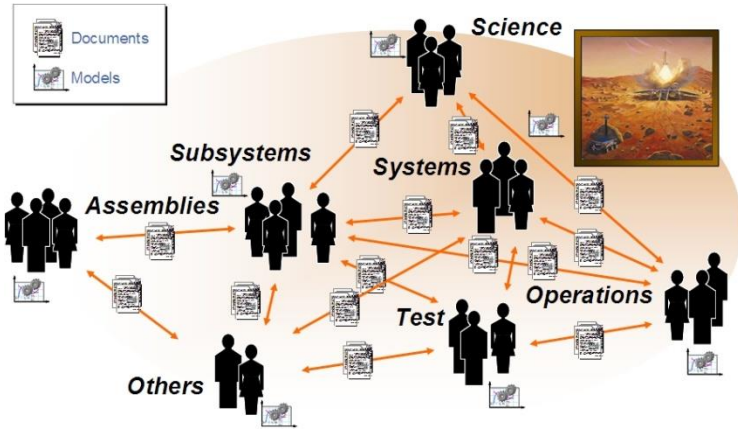
- MBSE *is* a tool for systems engineering, just as ECAD *is* a tool for electrical engineering.
- MBSE helps make SE more efficient; it doesn't replace SE.
- Documents are still important. What's different in MBSE is that some documents can be generated from an authoritative, integrated system model, and therefore be kept mutually consistent and up to date.



Electronic and Mechanical CAD transformation

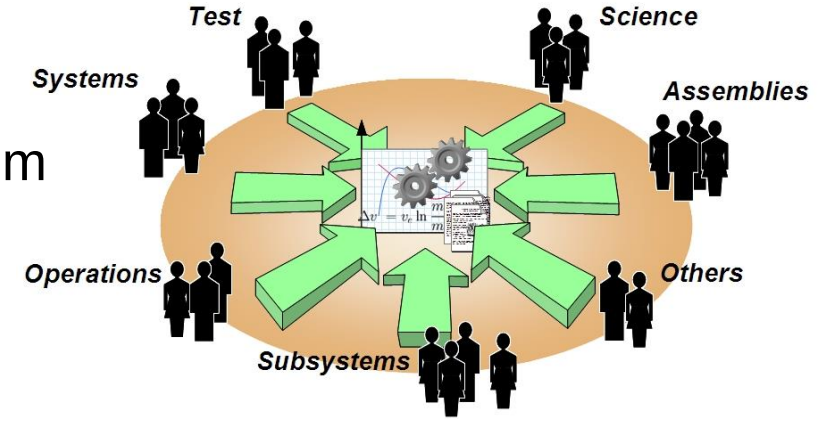
MBSE and How It Relates to SE

- Pre MBSE with **standalone and un-linked** models, documents, and other sources
  - Difficult to …
    - assess completeness and consistency of information spread across several documents
    - perform traceability
    - assess change impacts



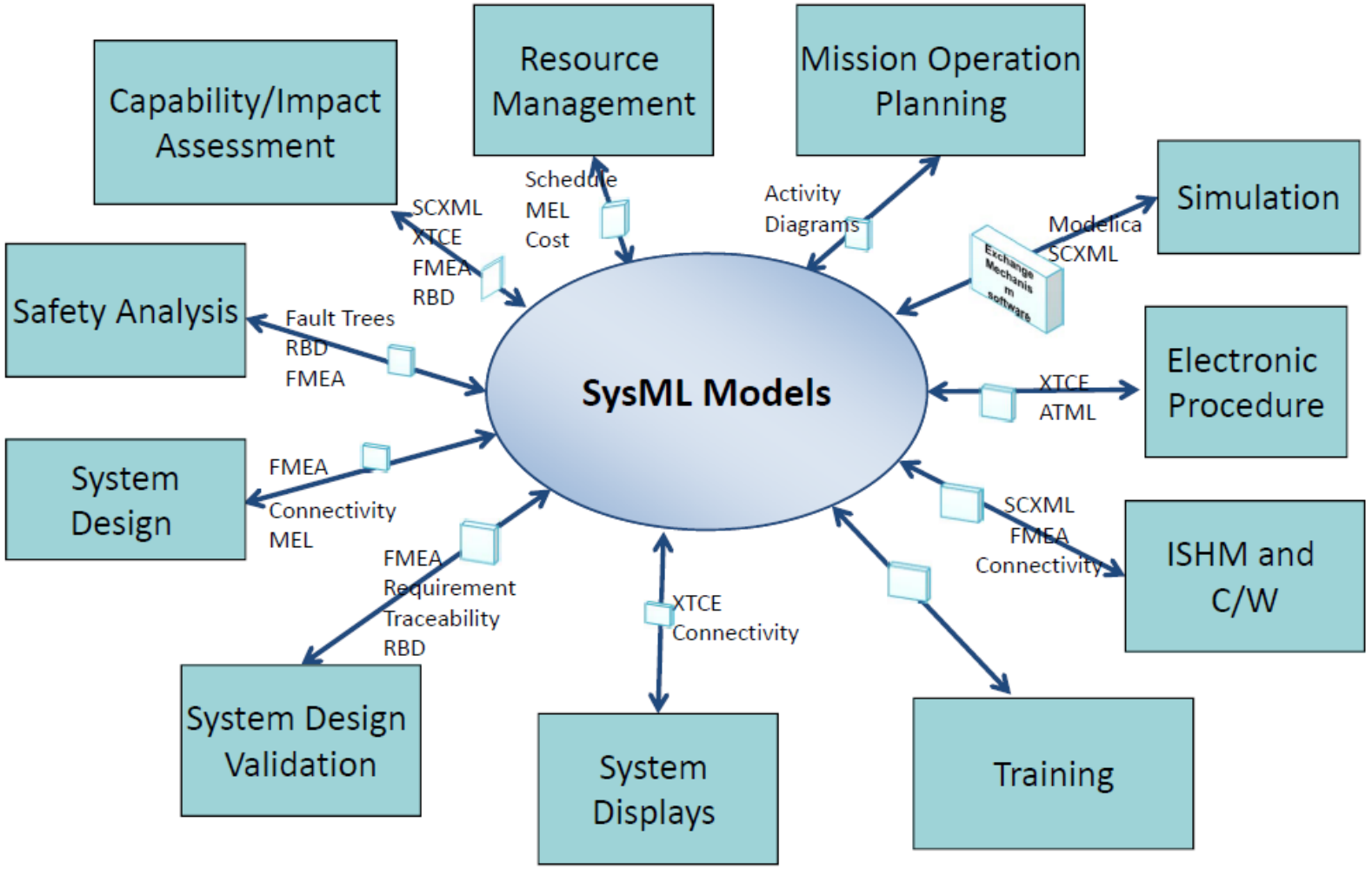
Pre MBSE: Standalone models and documents

- MBSE produces a system model **that can link** models, documents, and other sources
  - Provides a more complete, consistent and traceable system design
  - Facilitates traceability and change impact assessments



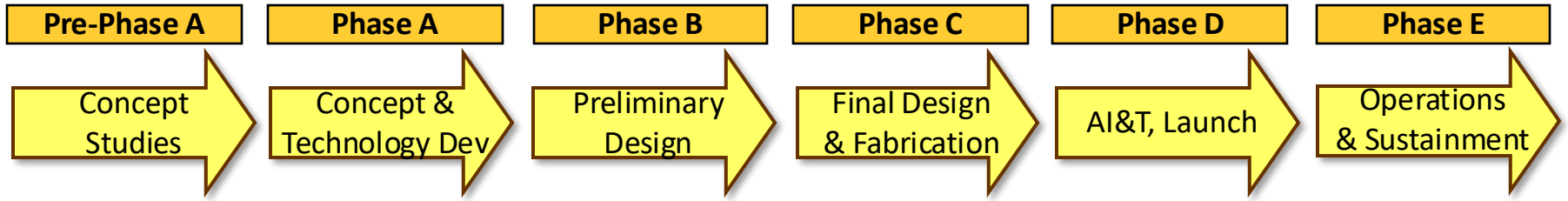
Model Based SE (MBSE)

Models Connected to Multiple Disciplines and Tools



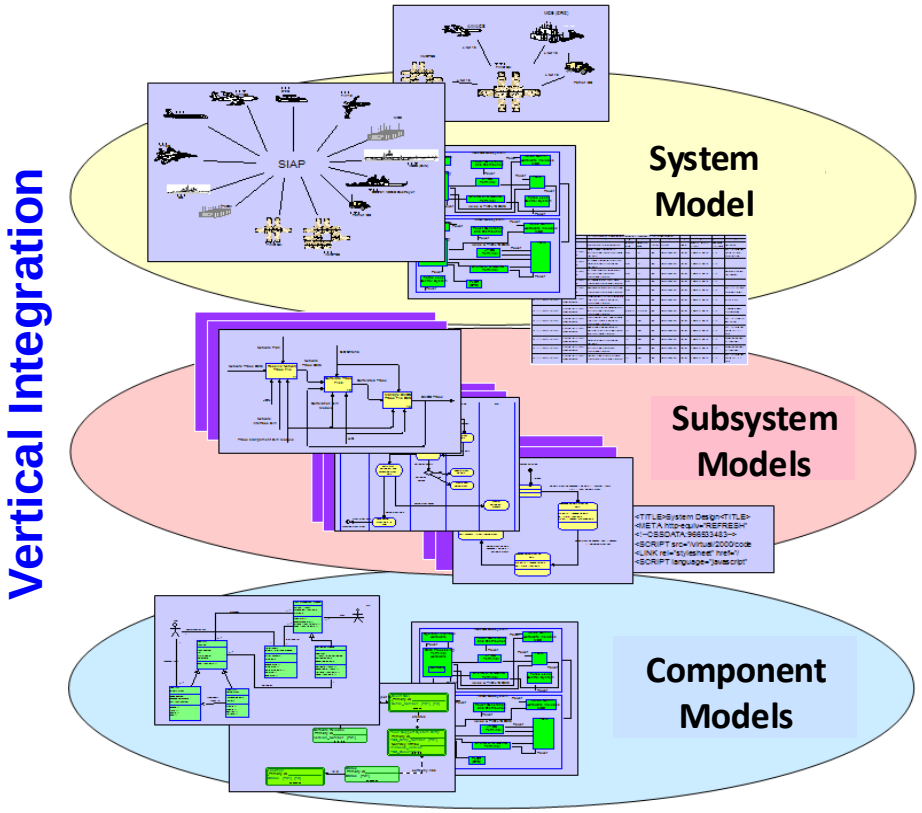
Source: Izygon, M., Wang, L., Okon, S., Wagner, H., and Garner, L., "Effort to Accelerate MBSE Adoption and Usage at JSC," AIAA SPACE 2016, Long Beach, CA, 2016.https://arc.aiaa.org/doi/pdf/10.2514/6.2016-5542

MBSE in Two Dimensions



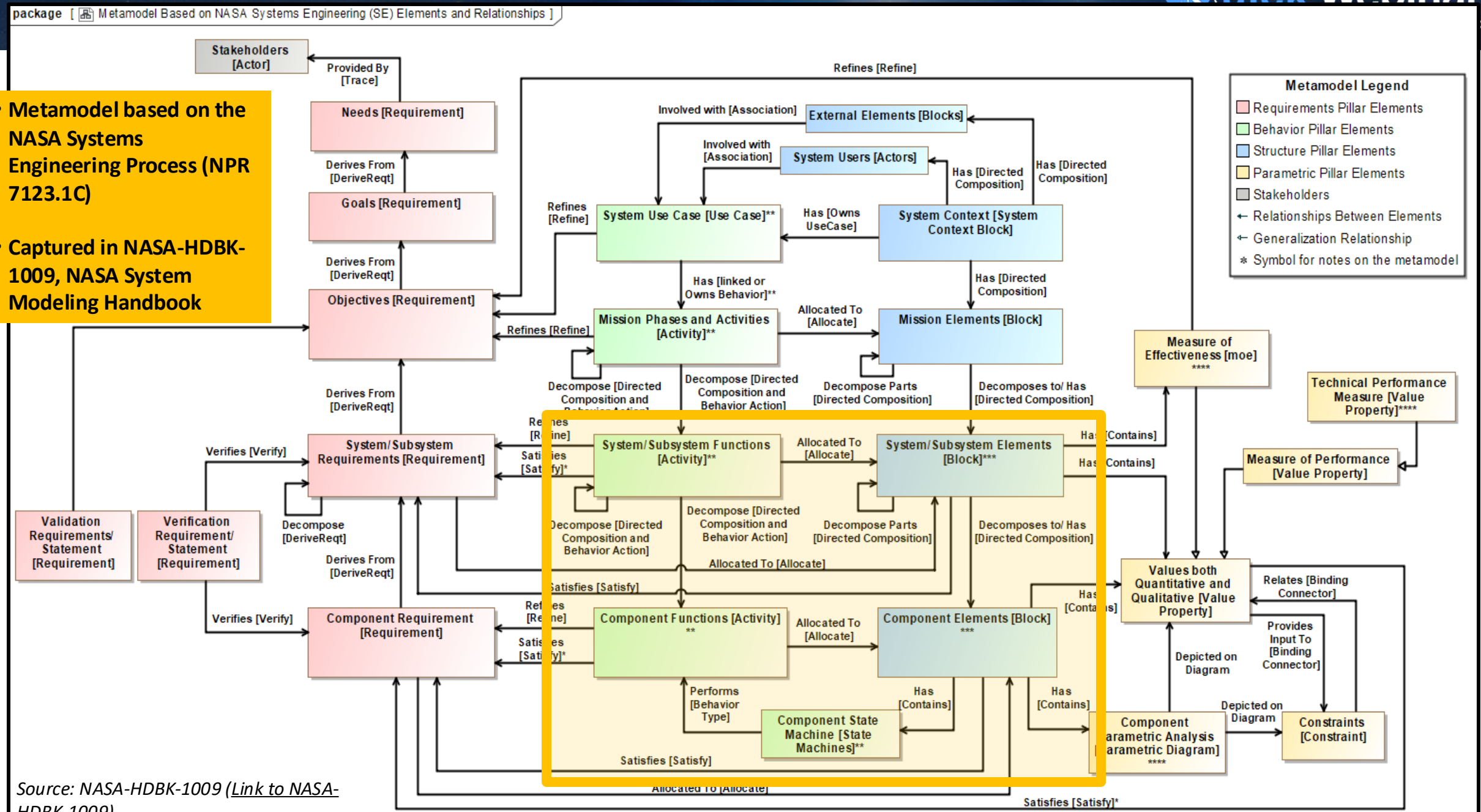
MBSE (and SE) …

- Applies across the engineering life-cycle
- Integrates vertically with multiple engineering disciplines
- MBSE can depict the following at any level:
  - Structure
  - Behavior
  - Requirements
  - Parametrics/ Engineering Analysis



How Systems and Subsystems Fit into the MBSE Domain

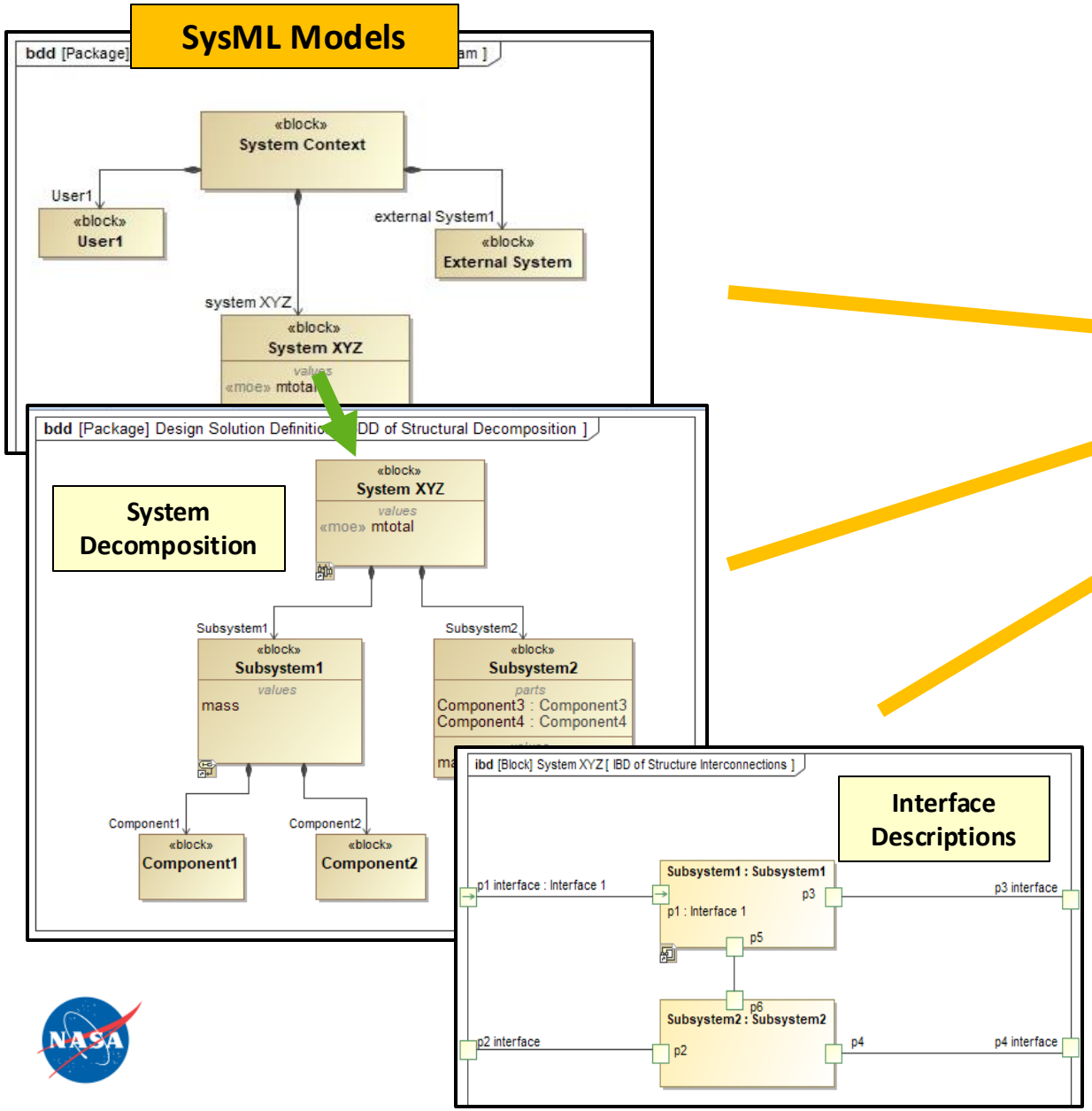
- **Metamodel based on the NASA Systems Engineering Process (NPR 7123.1C)**
- **Captured in NASA-HDBK-1009, NASA System Modeling Handbook**



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

System Decomposition and System Interface Modeling and Data Exchange Capabilities

SysML Models



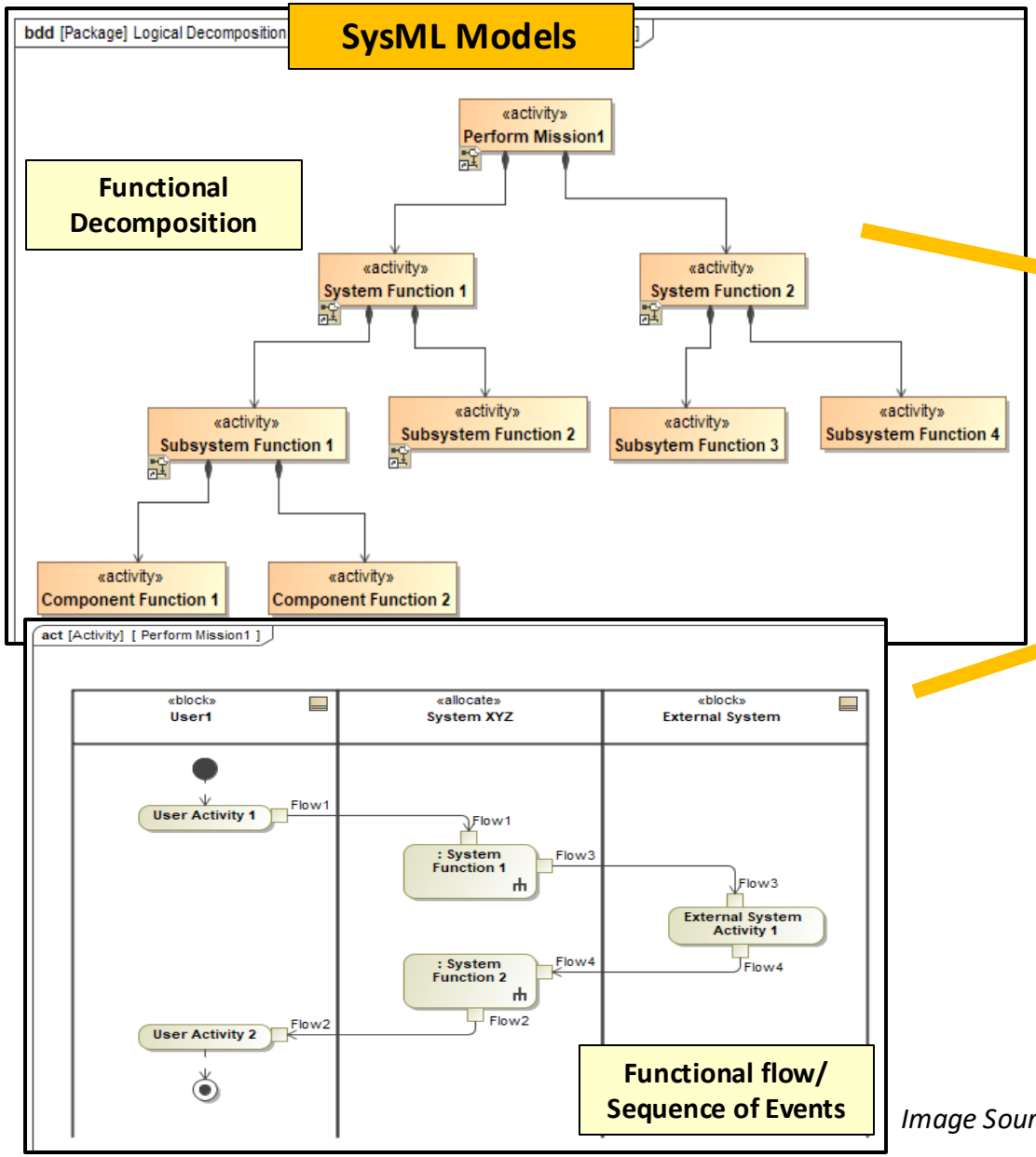
Example Data Exchange Capabilities

- 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

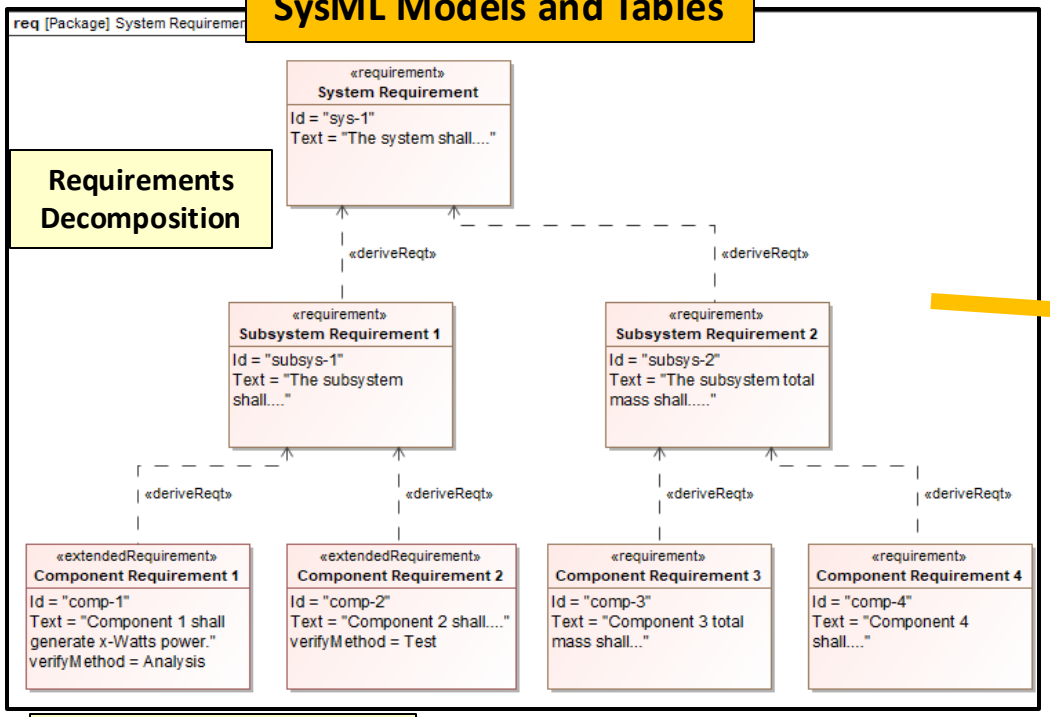
- Together with the System Architecture Description can be used to autogenerate a ConOps Report
- Can send Functional decomposition data and relationships and interface descriptions to other System Support and Analysis tools
  - Mission Operation Planning
  - Electronic Procedures
  - Safety Analysis

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

System Requirements Modeling and Data Exchange Capabilities

SysML Models and Tables

Requirements Decomposition



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 Subsystem Function 4(con	sys-1 System Requirement			/mtotal
3	subsys-1	Subsystem Requirement 1	The subsystem shall....	Subsystem Function 1(con 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

Example Data Exchange Capabilities

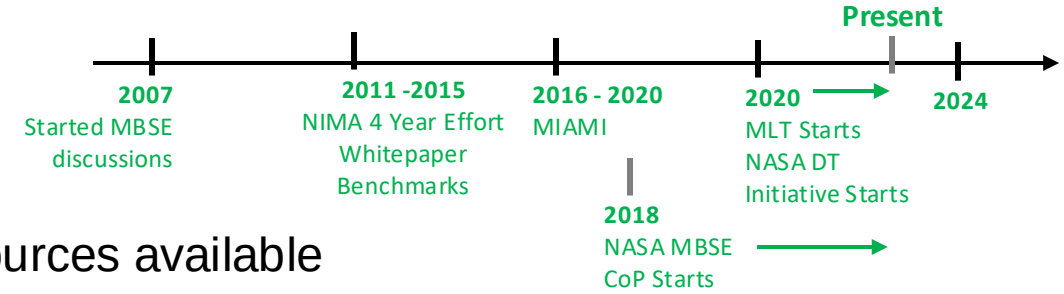
- Can be used to auto-generate spreadsheet reports or System Specifications Document
  - Can facilitate customer/vendor specification discrepancies
- Can send data and relationships to other System Support and Analysis tools
  - System Design Validation
  - Impact Assessments

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
  - Applying INCOSE MBSE Capability Assessment to gauge current state and future state goals
- **NASA MBSE Community of Practice** (~2018 – Present) (Link to Teams Channel)
- **NASA Digital Transformation (DT) Initiative** (2020 – Present) (Link to DT homepage)
- There are approximately **145 multi-center collaborations** utilizing MBSE with about 300 modelers (as of FY24)
- NASA **published a NASA System Modeling Handbook** for Systems Engineering (Dec 2022; Rev A in work)

NASA Projects Using MBSE and Application Areas

- **Some NASA projects applying MBSE include:**
  - Artemis/ Moon to Mars/ Gateway Programs and Project models
  - Advance Air Mobility projects (includes unmanned aerial systems)
  - Exploration Medical Capabilities project
  - Lunar Surface Architecture projects
  - Fission Surface Power project
  - Space Communications and Navigation (SCaN)
  - Orion Digital Twin
  - And more…

- **Application Areas where MBSE is being used include:**
  - in support of Concept of Operations development
  - for Requirements and Requirements Analysis
  - 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
  - Simulation and Engineering Analysis

NASA Mission Directorates*

- Cuts across the majority of NASA Mission Directorates

- Space Operations
- Aeronautics Research
- Exploration Systems Development
- Space Technology
- Science

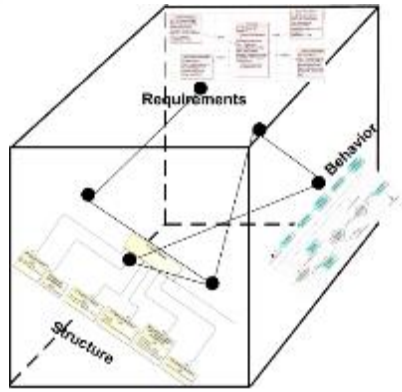
*Source: https://www.nasa.gov/about/org_index.html

Benefits of MBSE

- **It Enhances Communication**
  - Can support use of a single, authoritative source of information; keeps team on same page
  - Documents are kept consistent and up-to-date by generating them *from* the model

- **It Improves Productivity**
  - Supports automated generation of gate products; Reduces time "wasted" on making slides for gate reviews
  - Changes are automatically traced and implemented across all products
  - Less time spent looking for information

- **It Improves Quality**
  - Industry-standard notation reduces misunderstanding
  - Earlier detection of inconsistencies due to clearer semantics
  - Model is analyzable, unlike PowerPoint/Visio, so it can support many kinds of checks (completeness, consistency, correctness)
  - Facilitates traceability and change impact assessments (ex: between requirements, design and verification)



- **It Helps Manage Complexity**
  - Different views address the concerns of different stakeholders; and all views refer to the same model elements.

MBSE Resources to Facilitate Adoption at NASA

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Skill Building for NASA's Technical Workforce

1. **Agency MBSE NEN Site** (https://nen.nasa.gov/web/mbse) - Common area to share knowledge and resources
2. Agency MBSE Support Personnel / Agency and Center MBSE working groups
   - For **Center MBSE POCs/Working groups**: Link to NEN for MBSE POCs
   - **Agency MBSE CoP** meets weekly at Thursday's 11am EST (NASA MBSE CoP Microsoft Teams)
3. Digital Engineering Homepage (DE Homepage Link) – Info on enterprise tools and DE contacts
4. Tools available: MagicDraw as an Enterprise tool
   - Multi-center PLM and Analysis Integration tools (Contact Trish Nicoli from MLT for more info)
   - Exploring enterprise solutions to create a tool suite that can be leveraged by all project sizes
5. Resources available to make use of modeling easier:
   1. The **NASA System Modeling Handbook** for Systems Engineering (NASA-HDBK-1009)
   2. **Companion Model** to the NASA-HDBK-1009 (A Template Model); Agency Teamwork Cloud Server (All members have access)
   3. Additional **Center Specific Starter Models/Template Models** (Contact Trish Nicoli from MLT for more info)
   4. Guidelines that trace **Technical Review Products** (SRR, PDR, CDR, etc.) **to MBSE Practices and Products and Tools** to support (Contact Shira Nadile for more info)
   5. NASA **Document Generation Tools** – that support extracting Word documents from MagicDraw models (used to extract ConOps document, Requirements Reports, and More!); Generic Document Generation Tool Resources
   6. NASA Systems Engineering **Modeling Plan Template** and Supporting Resources (Link to NEN Website with Modeling Plan Template and Resources)
   7. **APPEL Courses** developed using a **Skills Matrix** targeted to MBSE roles/levels (Link to Skills Matrix)
   8. Model Based **Capability Assessment Results** from all Centers: MBCA Assessments


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Skill Building for NASA's Technical Workforce
Introducing the NASA MBSE Program
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Meet The MBSE Training Team

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CASEY MEDINA
Founder
Systems Engineer

KRISTINA CARROLL
Product Development
Systems Process Engineer

ALLISON LYLE
Principal Trainer
Systems Engineer

Russ Rydin
Senior Engineer
Systems Engineer

NASA

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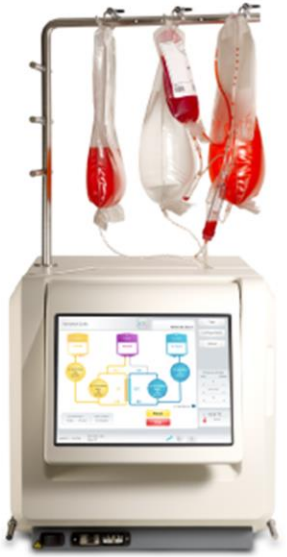
Casey Medina



How We Work

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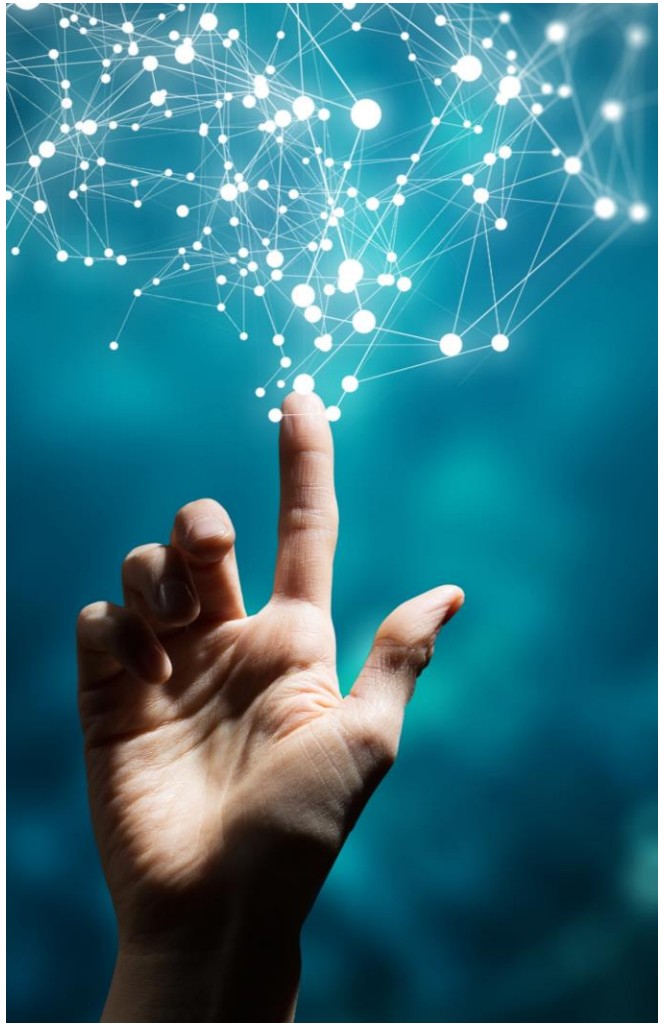
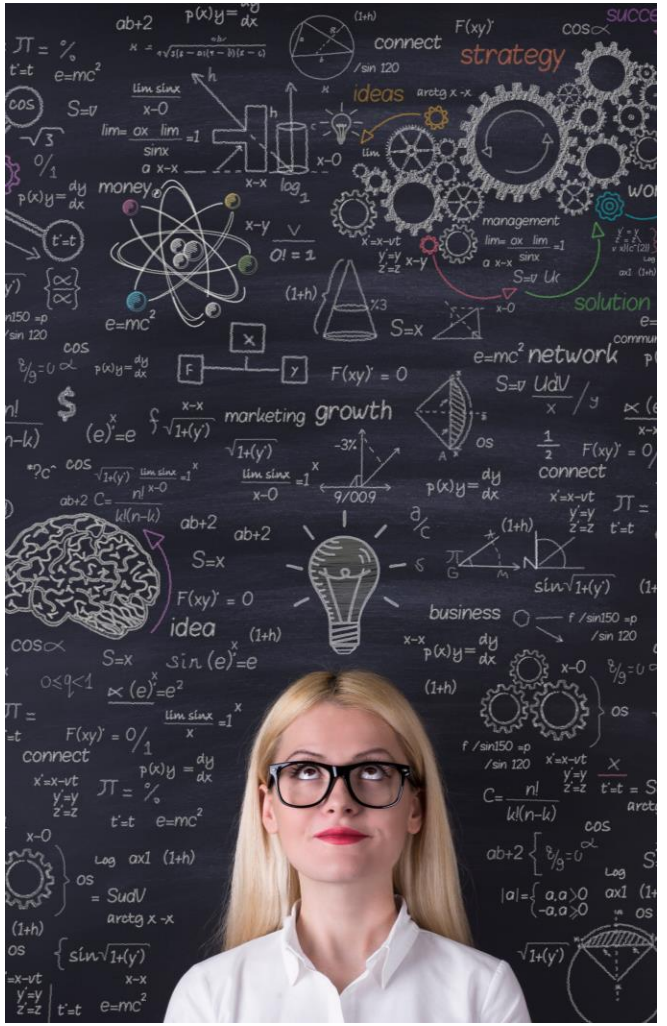
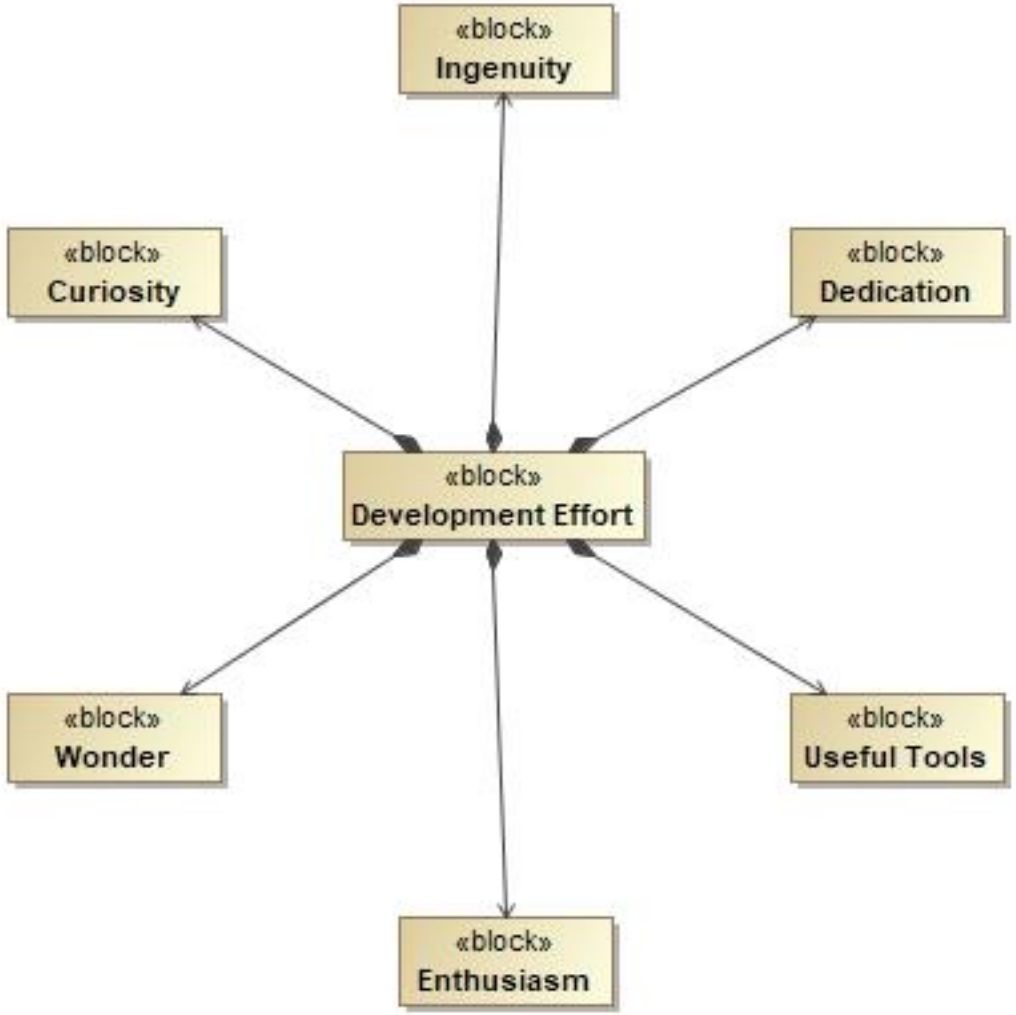
Learn **Practice** **Do!**

What We Believe





What We Infuse



What We Inspire

The NASA MBSE Experience

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	AWARENESS	DISCOVERY	PROFICIENCY	COMMUNICATE	PROCESS	ANALYSIS	APPLICATION
OBJECTIVE	MBSE for Managers – Learn key considerations in leading an MBSE effort.	MBSE for Tech Leaders – Learn key concepts in navigating models and guiding your MBSE team.	MBSE Foundations – Gain proficiency in the deployment of MBSE with SysML.	AMBSE 1 – Reinforce foundational concepts in MBSE with SysML and deploy on a representative system.	AMBSE 2 – Learn to customize the SysML language and create reusable elements to support good process.	AMBSE 3 – Learn how to leverage simulation capabilities to solve problems using SysML.	AMBSE 4- Put all your skills together and deploy MBSE with SysML on a NASA specific example.
COMPETENCY	Champion	Guide	Contribute	Lead	Plot the Course	Simulate	Deploy

Each class includes access to a rich collection of references and resources to aid in your MBSE journey!

APPEL KNOWLEDGE SERVICES

Questions

Back up

Screenshots from Center MBSE POCs/Working Group

Armstrong Flight Research Center

POC: Christopher Acuff

Community of Practice/Working Group: TBD

Ames Research Center MBSE Working Group

POC: Chris Barreras

For Ames employees: contact the POCs to be added to the mailing list for ad hoc meeting invitations

Glenn Research Center MBSE Working Group

POC: Edith Parrott, Shira Nadile

Goddard Space Flight Center MBSE Practitioners

POC: Ioana Rus, Rob Morgenstern

The purpose of this group is to give GSFC MBSE practitioners a forum to develop their models, r
grow their modeling capability, and learn to design models which can display answers to engine

Generated Beginner and Intermediate guides for MBSE.

Jet Propulsion Laboratory

POC: Alex (AJ) Jimenez, Integrated Model-Centric Engineering (IMCE) Project Manager

For JPL employees: Contact Alex Jimenez to access IMCE Community of Practice

- Dave Wagner: IMCE CAESAR Product Development Manager, David.A.Wagner@jpl.nasa.g
  - CAESAR Integrated Systems Engineering Tool Suite.
- Maged Elaasar: Open-CAESAR Architect, Maged.E.Elaasar@jpl.nasa.gov

Johnson Space Center MBSE Community of Practice

POC: Greg Pierce

Re-starting a CoP

Kennedy Space Center

POC: Brian Kryszczynski; Deep Space Logistics - Gateway Logistics Module; LSP

Community of Practice/Working Group: TBD

Langley Research Center Model-Based Engineering

POC: Trevor Grondin

Marshall Space Flight Center

POC: Mark Mitchell and Paul Gill

Community of Practice/Working Group: Kristina Rodgers for MSFC Systems Engineering Community (MSEC)

Source: Center-based MBSE Communities

Benefits of MBSE - INCOSE

- The International Council on Systems Engineering (INCOSE) defined 5 benefits of MBSE [1,2]:
  1. Improved communications
  2. Increased ability to manage system complexity
  3. Improved product quality
  4. Enhanced knowledge capture
  5. Improved ability to teach and learn SE fundamentals

- They also recognized the challenges in [2]:
  - process change and how information is conveyed
  - the front-loaded aspect of MBSE
    - requiring a financial investment for training and tooling
    - an MBSE approach can change the labor distribution curve; emphasizing a greater use of SE resources early in the life cycle

Source:

1. Friedenthal, S.; Griego, R.; Sampson, M. "INCOSE Model-based Systems Engineering (MBSE) Initiative." INCOSE 2007 Symposium, San Diego, CA, USA, 2007. https://www.researchgate.net/profile/Mark-Sampson/publication/267687693_INCOSE_Model_Based_Systems_Engineering_MBSE_Initiative/links/54ca7c290cf22f98631b167e/INCOSE-Model-Based-Systems-Engineering-MBSE-Initiative.pdf
2. Sandia Report, "Systematic Literature Review: How is Model-Based Systems Engineering Justified?", E. Carroll, R. Malins, SAND2016-2607, Mar 2016. https://www.incose.org/docs/default-source/enchantment/161109-carrolled-howismodel-basedsystemsengineeringjustified-researchreport.pdf?sfvrsn=2%26sfvrsn=2

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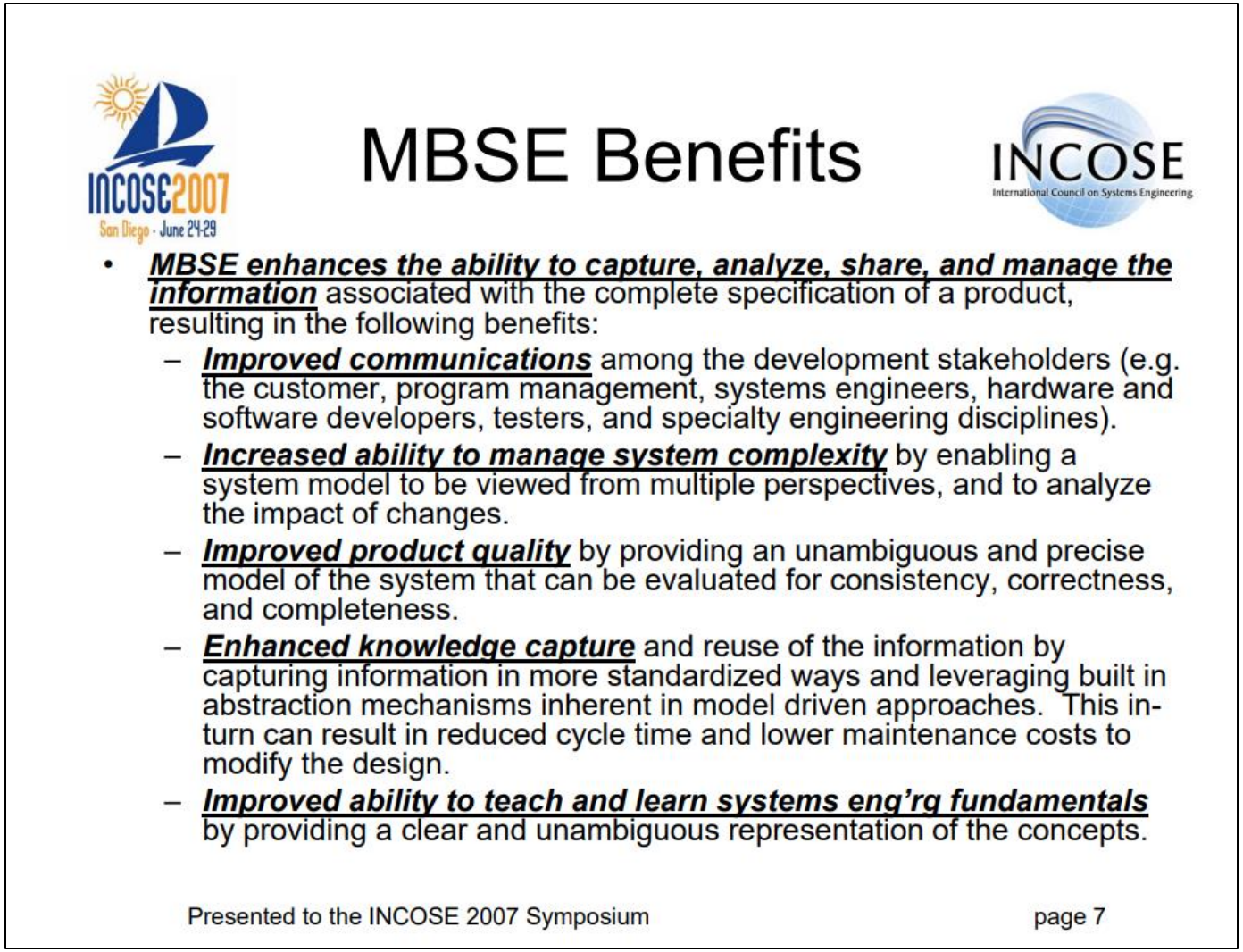
Details on the 5 MBSE Benefits from INCOSE



INCOSE2007 San Diego · June 24-29

MBSE Benefits

INCOSE International Council on Systems Engineering

- ***MBSE enhances the ability to capture, analyze, share, and manage the information*** associated with the complete specification of a product, resulting in the following benefits:
  - ***Improved communications*** among the development stakeholders (e.g. the customer, program management, systems engineers, hardware and software developers, testers, and specialty engineering disciplines).
  - ***Increased ability to manage system complexity*** by enabling a system model to be viewed from multiple perspectives, and to analyze the impact of changes.
  - ***Improved product quality*** by providing an unambiguous and precise model of the system that can be evaluated for consistency, correctness, and completeness.
  - ***Enhanced knowledge capture*** and reuse of the information by capturing information in more standardized ways and leveraging built in abstraction mechanisms inherent in model driven approaches. This in-turn can result in reduced cycle time and lower maintenance costs to modify the design.
  - ***Improved ability to teach and learn systems eng'rg fundamentals*** by providing a clear and unambiguous representation of the concepts.

Presented to the INCOSE 2007 Symposium page 7

Source: Friedenthal, S.; Griego, R.; Sampson, M. "INCOSE Model-based Systems Engineering (MBSE) Initiative." INCOSE 2007 Symposium, San Diego, CA, USA, 2007. https://www.researchgate.net/profile/Mark-Sampson/publication/267687693_INCOSE_Model_Based_Systems_Engineering_MBSE_Initiative/links/54ca7c290cf22f98631b167e/INCOSE-Model-Based-Systems-Engineering-MBSE-Initiative.pdf

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