NASA's Digital Transformation & Digital Engineering

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PLM Road Map™ & PDT North America 2024
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"It is not necessary to change. Survival is not mandatory."
(W. Edwards - Deming Institute, 2019)

Why Digitally Transform NASA?

Enduring
Bold
Mission...

...now in a Changing World

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

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NASA's DT Strategic Framework

3 FUTURE STATE GOALS
- Transform the way we Work
- Transform the experience of our Workforce
- Transform the agility of our Workplace

4 TRANSFORMATION TARGETS
- Transform Engineering
- Transform Discovery
- Transform Decision Making
- Transform Operations

5 DIGITAL LEVERS
- Establish Interoperable *Architectures*
- Transform Critical *Processes*
- Maximize the Impact of our *Data*
- Adopt Common *Tools*
- Strengthen Inclusive[3] *Teaming*

6 TECHNOLOGY FOUNDATIONS
- Intelligent Automation
- Artificial Intelligence/ Machine Learning
- Model-Based Anything
- Zero Trust Architecture
- Internet of Things
- Extended Reality

7+ MISSION OUTCOMES
- Bolder, More Complex Missions
- Faster, More Agile Processes
- Seamless Partner Teaming
- Inspire & Engage Citizens
- Affordable Sustainable Operations
- Attract & Retain Workforce
- Modern Future of Work

One Future NASA

[NASA TM 20220018538]

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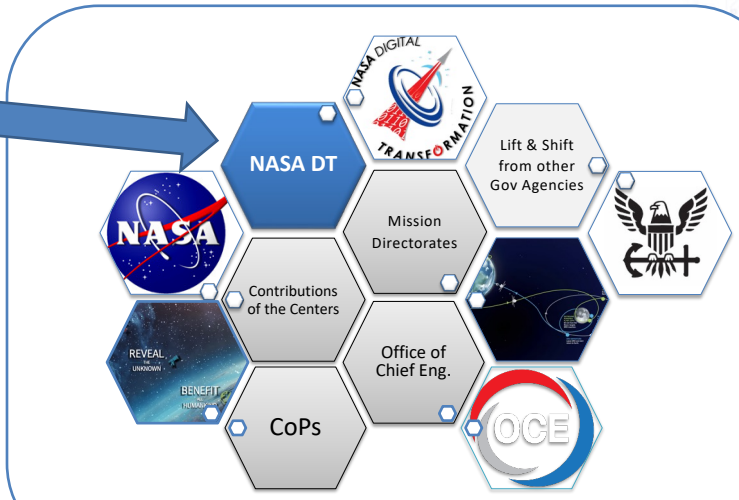
Transformation of Engineering – It Takes a Village



NASA's Digital Engineering Transformation Efforts

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NASA's Digital Engineering Need

…from Concept to Operations

Historically a change of Presidential administration or Congress means a change to our missions/priorities/budgets

Improve how the Agency Engineering Domain operates over the entire NASA lifecycle by effectively managing complexity, reducing cost and schedule, and improving product integrity via the integration of processes, digital tools, and techniques along with seamless flow of information throughout the engineering system development life-cycle (concept development, design, testing and validation, manufacturing and operations).

Updated

Digital Engineering Needs, Goals, & Objectives

Need

Improve how the Agency Engineering Domain operates over the entire NASA lifecycle by effectively managing complexity, reducing cost and schedule, and improving product integrity via the integration of processes, digital tools, and techniques along with seamless flow of information throughout the engineering system development life-cycle (concept development, design, testing and validation, manufacturing and operations).

Goals

- **G1 Interoperability:** Engineering artifacts and information are produced and consumed such that related engineering activities can be seamlessly integrated.
- **G2 Deployment:** Coordinated and collaborative adoption and implementation of DE methods and utilization of DE resources across NASA centers.
- **G3 Systems Engineering and DE Integration:** System engineering activities are driven by models and data extracted from the digital engineering environment and integrated across engineering disciplines.
- **G4 ASoT:** Authoritative sources of truth are integrated into digital engineering activities and managed such that control of the underlying data is secure and distributed properly.
- **G5 Configuration/Change Management:** Engineering data, models, and analysis within the digital engineering environment are integrated into configuration items with their associated attributes and are fully integrated into the configuration management process for the engineering lifecycle.
- **G6 Digital Threads:** Engineering data, models and analysis are organized such that related data is traceable and usable across engineering activities, decision evolutions, tools, teams, centers, agencies, and industry.
- **G7 Culture and Workforce:** NASA culture embraces digital engineering, and the NASA workforce is enabled through training opportunities and community support.

Objectives

- Capability Groups
- Capability Roll-Out
- Center DE Health and Status
- Implementation Guidance
- Minimum Capability
- ASoT Governance
- ASoT Legitimacy
- ASoT Usage
- Digital Thread Identification
- Digital Thread Integrity
- Digital Thread Ontology
- Engineering Ontology
- Model Development Best Practices
- Reusable Model Library
- Tool Interoperability
- Tool Procurement/Development
- Digital Acquisition
- Candidate Architecture Exploration
- Digital System Model / Twin Maturity
- Engineering Communication
- V&V
- CM Interoperability
- CM Justification
- CM Verification
- CM Version Management
- CM Workflow
- Life-cycle Baselines
- DE Community
- DE Outreach
- DE Roles and Responsibilities
- DE Training

Systems Engineering/MBSE Accomplishments as part of NASA Digital Engineering Efforts

Utilizing workforce volunteer time

FY20

- Feb. '20 - MBSE Leadership Team (MLT) established by the Engineering Management Board per action from APMC
- NASA released its NASA-HDBK-1004 NASA Digital Engineering Acquisition Framework Handbook and includes contractual language for statements of work and provided information referencing topics such as Data Requirements Descriptions, model-based data definition, collaboration, architecture, interoperability standards, and general guidance for model-based product/data acquisition requirements.
- CY19 Office of Chief Engineering piloted MagicDraw (SysML modeling tool) with Teamwork Cloud (model management)

FY21

- Continued to build MLT with reps. from most centers
- Piloted the INCOSE MBSE Capability assessment to determine usefulness to NASA
- Initiated the MBSE/SysML (Systems Engineering Modeling Language) Orion Digital Twin to address insight concerns by Orion Chief Eng.

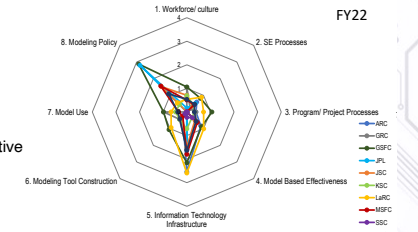
FY21

Model-Based Capability Categories	NASA Average	ARC	GRC	GSFC	JPL	JSC	KSC	LaRC	MSFC	SSC
1. Workforce/ culture	0.5	0.1	1.0	1.1	0.2	0.7	0.7	0.5	0.5	0.0
2. SE Processes	0.5	0.6	0.2	0.8	0.5	0.4	0.4	0.9	0.4	0.0
3. Program/ Project Processes	0.3	0.4	0.4	1.1	0.0	0.0	0.3	0.7	0.0	0.0
4. Model Based Effectiveness	0.6	0.8	0.5	0.9	0.0	0.5	0.3	1.0	0.6	0.3
5. Information Technology Infrastructure	1.6	2.5	1.6	2.2	1.5	1.5	0.7	2.6	1.8	0.2
6. Modeling Tool Construction	0.4	0.2	0.4	1.1	0.0	0.3	0.4	0.9	0.2	0.1
7. Model Use	0.4	0.0	1.0	1.0	0.0	0.0	0.5	0.7	0.3	0.0
8. Modeling Policy	1.1	0.0	0.0	2.9	2.8	1.5	0.4	0.6	1.6	0.0

FY22

- Incorporated the MLT into the larger NASA Digital Engineering (DE) Agency team.
- Performed initial high-rez MBSE Capability assessment & collected center priorities and vanguard examples.
- NASA Released NASA-HBK-1009 MBSE Modeling Handbook
- APPEL offered 4 of the 5-tiered MBSE Course from beginner to expert via requirements from MLT
- Completed the MBSE/SysML Orion Digital Twin
- Initiated the modeling of NPR 7123, 7120.5/.8 & 8705 in SysML to assess changes from a data-centric perspective
- Benchmarked 6 large industry partners in how they performed internal MBSE training.
- Began meeting monthly with the NRO MBSE team to share information.
- Using Systems Engineering principals, created the "Four Layered Cake" process to identify opportunities for investment for digital transformation given limited resources.

FY22



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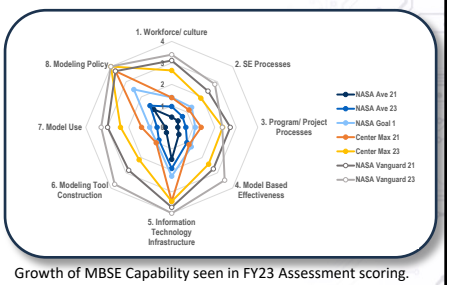
Systems Engineering Accomplishments as part of NASA Digital Engineering Efforts

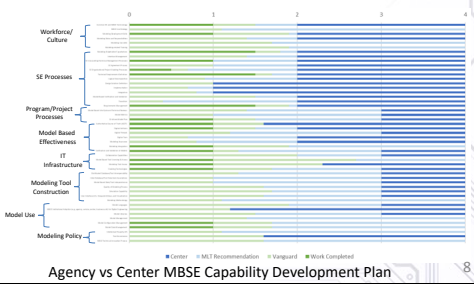
Utilizing workforce volunteer time

FY23

- Used standard SE approach to define what DE means for NASA: NGO's to Capabilities
- Aggressive engagement with DoD, DoE, Intelligence and FAA on DE and SE topics
- Modeling & Data-centric analysis of NPR 7123, 7120.5/.8 & 8705
- Agency benchmarking of toolchain capabilities concluded (included SE toolchains)
- RFI to Industry released which requested input from Industry as to how they want work, collaborated, and exchange info with NASA (Systems Engineering included)
- Added focus area of Interoperability / data exchange standards for engineering data thread which will create the backbone of digital SE.
- Tier 5 MBSE Training requirements defined and provided to APPEL – see backup chart
- Performed second high-rez MBSE Capability Assessment across the Agency. Used the INCOSE MBSE Assessment tool to create Agency / Center development plan
- MLT's INCOSE International Symposium paper on Orion MBSE Digital Twin won Best Paper in Model/Simulation category



Growth of MBSE Capability seen in FY23 Assessment scoring.



Agency vs Center MBSE Capability Development Plan

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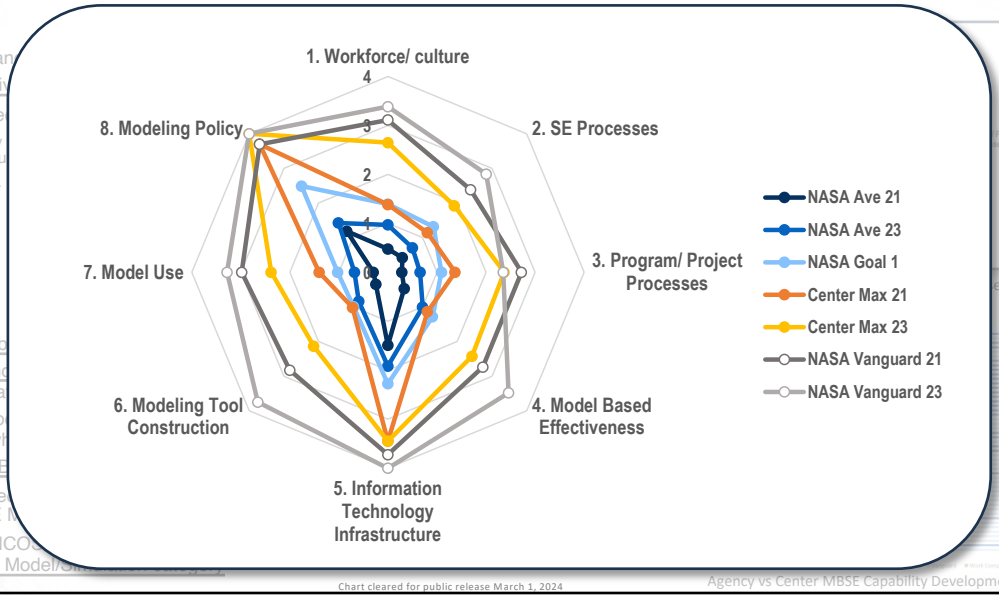
Systems Engineering Accomplishments as part of NASA Digital Engineering Efforts

Utilizing workforce volunteer time



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Agency vs Center MBSE Capability Development Plan

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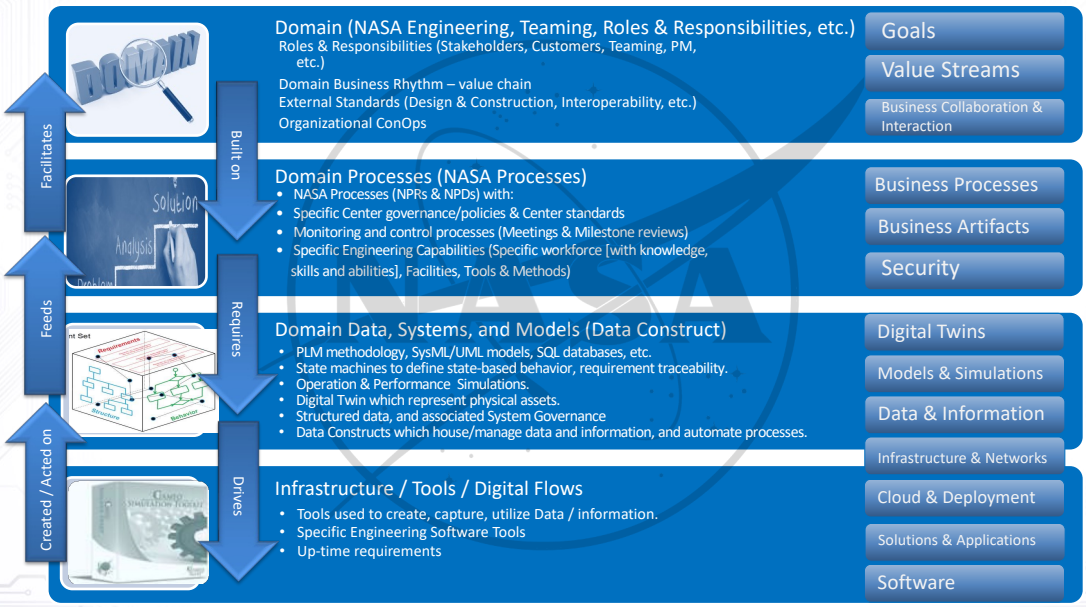
The "4-Layer Cake" Analysis for Identification of Digital Transformation Opportunities

Developed by the Office of Chief Engineer's Digital Engineering Leadership Team



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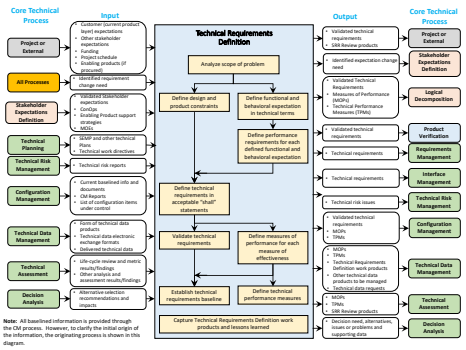
Engineering Project Lifecycle

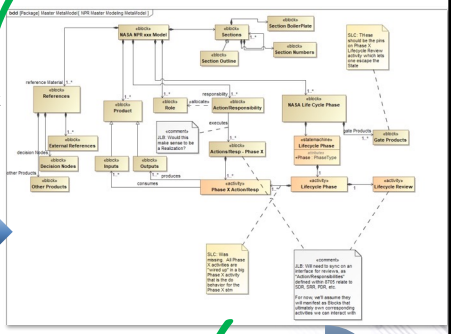
Engineering Domain

NPR's – provide Agency-wide requirements | NPR 7120.5/.8 | NPR 7123 | NPR 8705

Logically decomposed current NPR document to understand the intended processed flow



Created Common Document meta-model framework so all the NPR models would be structured consistently



Agency-wide peer review of the As-Is NPR modeling 'trifecta'.

Data-Centric analysis of the process models and provide recommendations for updates to the NPRs.

Support Centers as they update their derivative processes to be more data-centric as part of their transformation.

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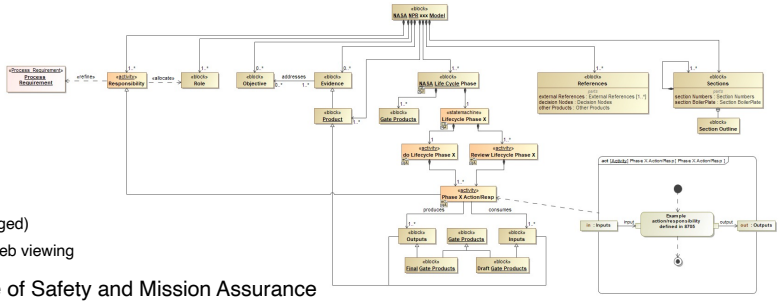
NPR SysML Modeling

- Processes form the foundation of all Engineering Products and services, and for Eng Domain, NPR 7123, 7120.5 and 8705 are the core driving processes.
  - Understanding our processes from a data-centric perspective is foundational to NASA DE transformation.
- Jointly, DE modeled NPRs 7120.5/.8, 7123.1, NPD 7120.4, and OSMA modeled NPR 8705.2 and 8705.4
  - Cross-Center effort (KSC, JPL, GSFC, with support from GRC and LaRC)
- Created common meta model so that each NPR/NPD were modeled consistently to ensure appropriate integration.
- Data-Centric Analysis Results
  - Found common elements:
    - 860 Blocks (various Data, Role, type, etc.),
    - 126 Activities (part of Lifecycle Reviews),
    - 460 Terms Terms, Roles, Data Products, Lifecycle, Organizations, Operational Areas, Program-Project Types
  - Identified discrepancies (49)
  - Classified integrated content with (25) tags (e.g., Cost, Schedule, Requirements, etc. - over 2900 elements tagged)
  - Can produce modeled documents in Word/PDF or for Web viewing



- Joint modeling partnership with NASA's Office of Safety and Mission Assurance

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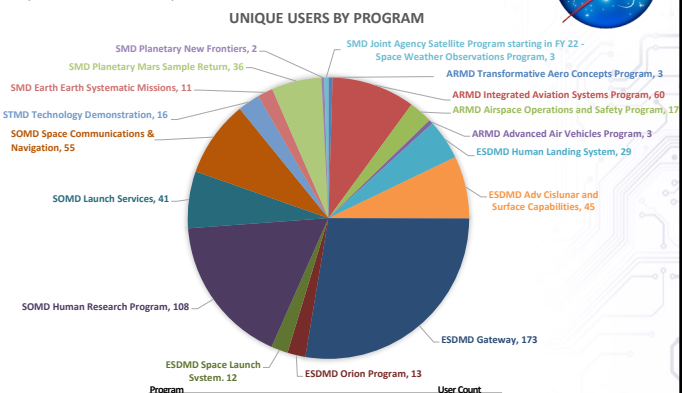
OCE Agency-level MagicDraw license server and Teamwork Cloud (model management)

Number of Models & Users by Mission Directorate and Program (at end of FY23)

- After three years of development and support from NASA's Office of Chief Engineer MBSE methodologies /SysML modeling are used across five mission directorates on most all of the large programs and projects.
- Used by almost 700 unique users from across all Centers in FY23.
- Over 1.3k models created and managed on the OCE Teamwork Cloud



Program	User Count
ARMD Transformative Aero Concepts Program	3
ARMD Integrated Aviation Systems Program	60
ARMD Airspace Operations and Safety Program	17
ARMD Advanced Air Vehicles Program	3
ESDMD Human Landing System	29
ESDMD Adv Cislunar and Surface Capabilities	45
ESDMD Gateway	173
ESDMD Orion Program	13
ESDMD Space Launch System	12
SOMD Human Research Program	108
SOMD Launch Services	41
SOMD Space Communications & Navigation	55
STMD Technology Demonstration	16
SMD Earth Earth Systematic Missions	11
SMD Planetary Mars Sample Return	36
SMD Planetary New Frontiers	2
SMD Joint Agency Satellite Program starting in FY 22 - Space Weather Observations Program	3
Unknown	65
Total	692

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NASA MBSE Tiered Capability Training Requirements

Skill Acquired	Tier 1: Manager / Reviewer	Tier 2: LSE Tech Lead	Tier 3: Modeler	Tier 4: Modeling Lead	Tier 5: Expert Modeler	Additional Description
Understand concept of MBSE	x	x	x	x	x	What is MBSE and why could it be useful? When should I use it?
Aware of Different Languages		x	x	x	x	SysML vs LML vs AML vs frameworks like DoDAF and UPDM
Being able to read a diagram	x	x	x	x	x	Need to read a diagram in the tool the project uses. Usually SysML.
Advise on Infrastructure				x	x	What servers, tools, libraries, personnel, etc. are needed to support the project's MBSE implementation?
Scripting					x	Use languages like Python, Matlab, Java, Jython, etc. to program features into the tools that they do not currently have. This is for both internal analysis and sending data out (and the subsequent return of that data) for other tools to analyse.
Integrating Models				x	x	MBSE and other discipline models should be able to send information between each other. This may be accomplished through scripting, other tools like ModelCenter, or through data standards.
SysML Literate		x	x	x	x	Read the SysML language.
Able to Model basic elements / diagrams in a MBSE tool			x	x	x	Model behavior/operations, structure/architecture, requirements, and simple parametric calculations.
Able to open someone else's model and navigate, add to		x	x	x	x	Use another model to gain the information that you need. Add some more detail to a pre-existing model within the model.
Create Patterns / Templates				x	x	Create templates for others to base their models off of. This is more like copying and editing.
Create Profiles / Metamodels				x	x	Create basic starter models for others to immediately build from. This is more like general instructions and structures for people to expand.
Develop Modeling Plan / Strategies				x	x	Includes model CM and processes for adding or deleting information.
Use / Integrate other models			x	x	x	Use info pulled in or taken out from other models. This is less about doing the connecting and more about sending information back and forth in pre established channels.
Use MBSE for SE	x	x	x	x	x	You cannot have MBSE without SE. Everyone should learn what a ConOps or a requirements verification matrix (for instance) look like in a model. Modelers should know how to actually create these artifacts.
Follow Modeling Plan / Strategies		x	x	x	x	Follow CM and other processes already laid out for the model. This may include using tools like Teamwork Cloud, Jira, or Git.
Show/"surface" information from the model			x	x	x	

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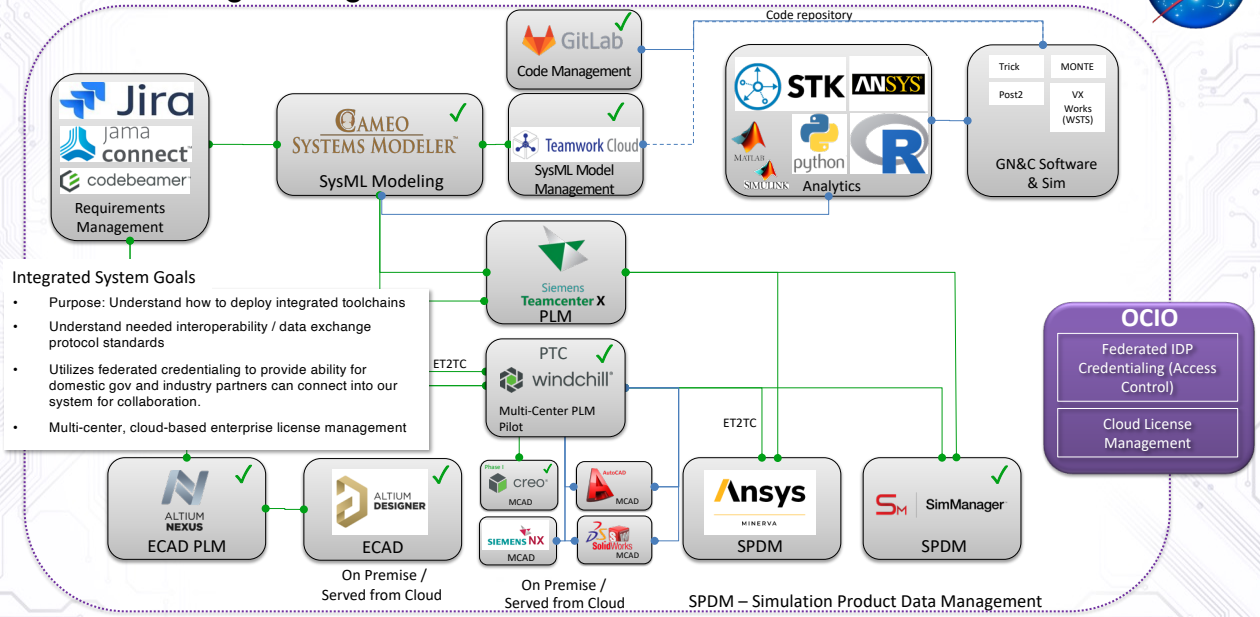
NASA DE Training Development To Date

- In the first quarter of CY24 the NASA DE Leadership Team will make available approximately **840 online digital engineering training modules and digital books**
  - Aligned with the NASA definition of digital engineering mapping of desired skill capabilities
  - Via COTS training platform
- Content area Managers identify and curate digital engineering resources from Agency training courses, other government learning providers, and private sector off-the-shelf courses and training videos
- Collecting these resources in one location provides a helpful entry point for personnel learning basic skills as well as those with more DE experience who need support to understand a particular tool or practice.
- **In the first four months of being available without any internal communication there have been 464 topic sessions used across 212 DE topic courses.**

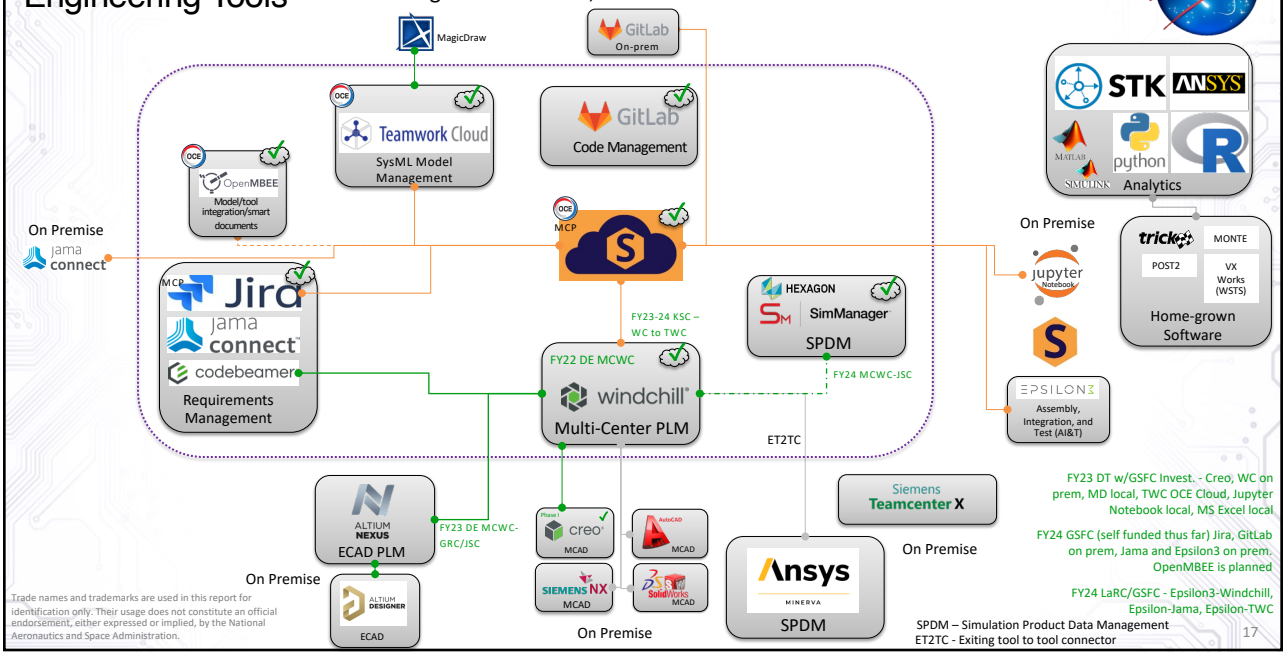
Toolchain Pilot: Phased Integration of Commonly Used Engineering Tools w/in NASA Engineering Domain



ET2TC - Exiting tool to tool connector

Phased Integration Activities to Date of Commonly Used Engineering Tools

Not a single environment, but could be if the demand is there



SPDM – Simulation Product Data Management
ET2TC - Exiting tool to tool connector

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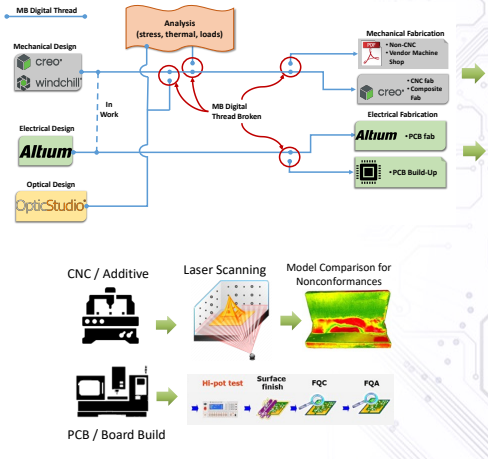
Design, Manufacturing & Inspection: Capability Definitions

Agreed-to Capabilities	Definitions
Integrated PDM Tool	Repository for collecting on-going data package where all project plans, requirements & technical models are accessible by Reviewers/Approvers/Stakeholders; Seamless integration with Reviewer's Tools, such as Analysis & Manufacturing Tools; Capable of review/approve workflows; Maintains traceability via numbering & versioning control through lifecycle of all product models
MB/PDM CM	Configuration Management is built in to the PDM Tools because CM requirements on the tools will be adopted by the tools; Traceability maintained during the full lifecycle; Provides release and revision aspects of MB workflow
MB ICD	Paperless Documentation. Interfaces captured in a model instead of 2D document. Model-based ICD can be linked directly to CAD models for interface control.
MB Design	Standalone 3D CAD Model*, full Model-Based Definition; Compliant with ANSI Y14.41 Compliant; Seamless Export/Import of 3D CAD to/from Discipline Integrated PDM Tool; Seamless Export/Import to/of FEA Tools and Other Discipline Tools for Review/Comments/Markups. (Downstream users (generally non-CAD users) need varying viewing formats.)
MB Analysis	Seamless Retrieval of latest 3D CAD Model from Integrated PDM Tool; No need to create a copy of 3D CAD Model; Can build FEA directly off 3D CAD Model; Can Export space saving FEA model digitally and seamlessly to PDM. Leverages direct interoperability between CAD and FEA enabling near automated updates upon revision.
MBD Review/Approve	Integrated PDM capable of review and approve workflows of the MBD; automatic routing and notifications to reviewers; 3D mark up capabilities.
MB Mfg.	Seamless Retrieval of 3D CAD Model; Paperless manufacturing; Monitors/computers/network access at needed equipment, mobile devices such as iPads or laptops for viewing/reviewing models and work orders; Fully digital work orders; Digital stamping; Automated generation of customer number and work order; Automated
MB Inspection	Seamless Retrieval of as-built product information, digital and physical as needed; Product scanning capable; Automated comparison to as-designed product information with capability to digitally output discrepancies; Seamless exchange of information from Inspection to manufacturing to design



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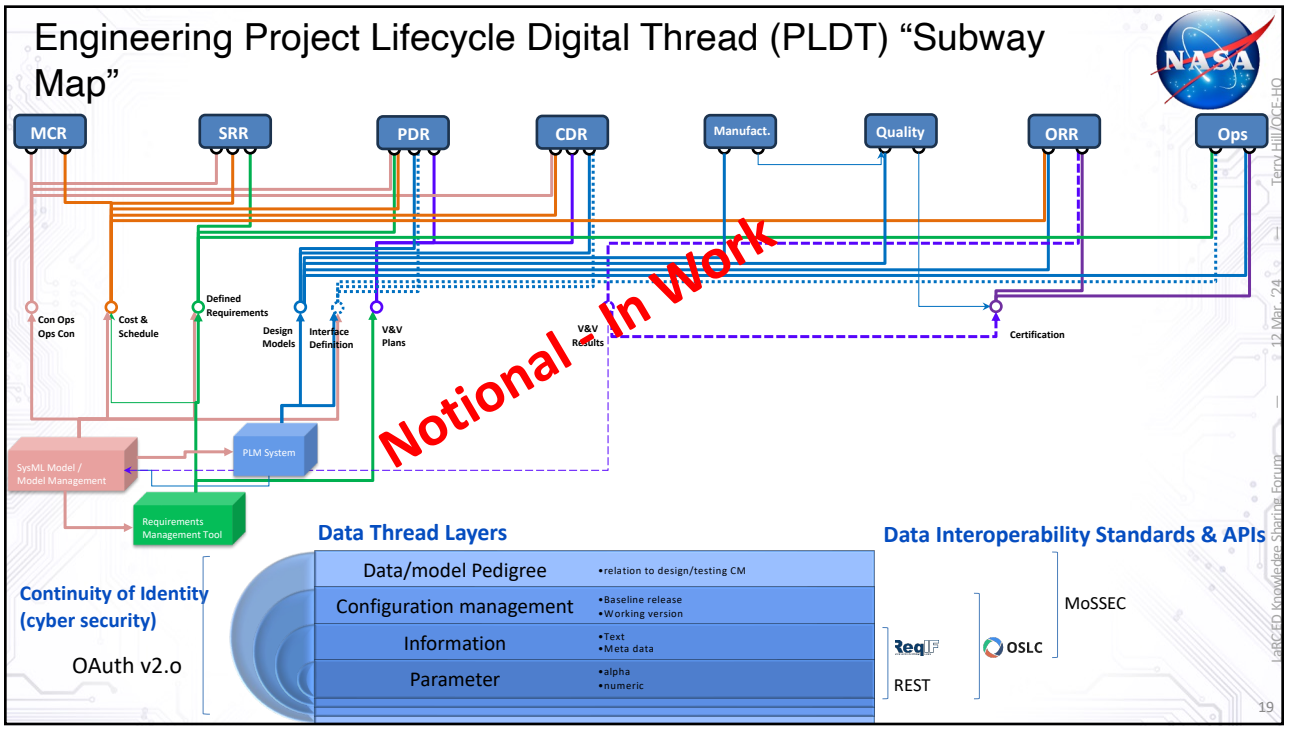
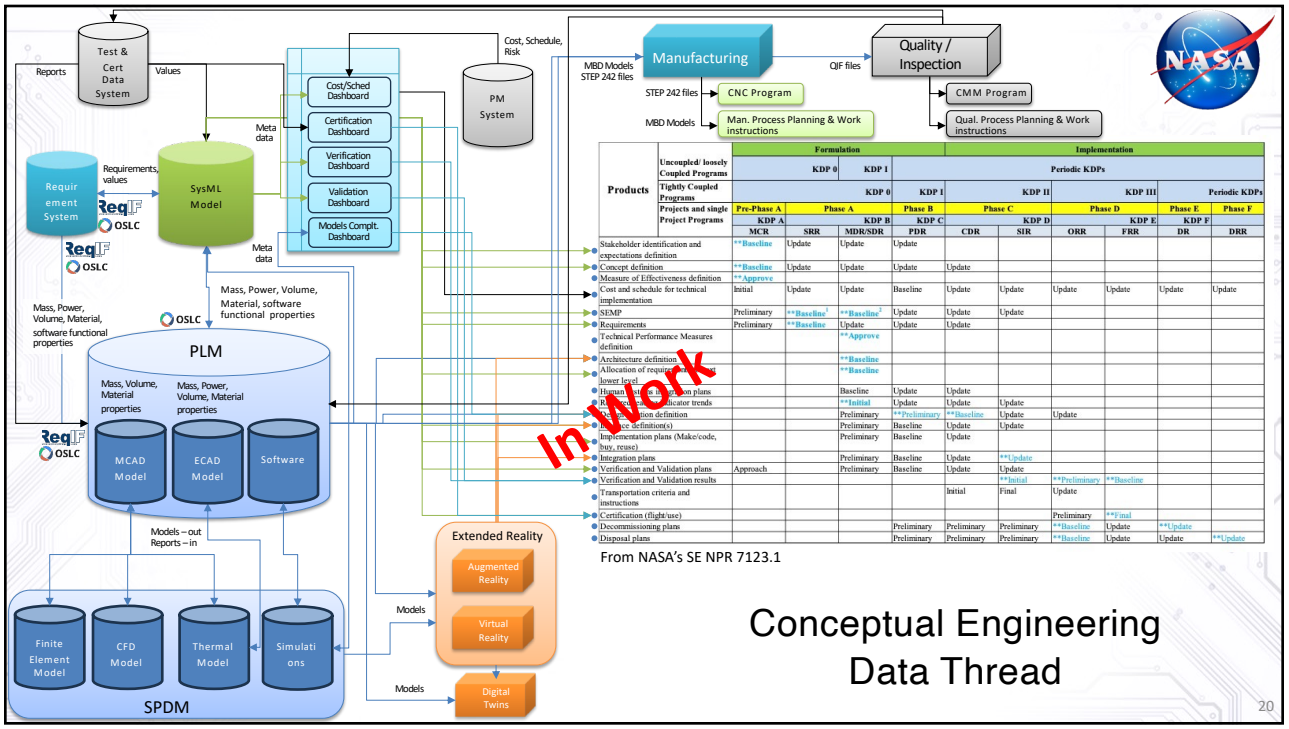

Engineering Project Lifecycle Digital Thread (PLDT) "Subway Map"
MCR
SRR
PDR
CDR
Manufact.
Quality
ORR
Ops
Con Ops
Ops Con
Cost & Schedule
Defined Requirements
Design Models
Interface Definition
V&V Plans
V&V Results
Certification
Notional In Work
SysML Model / Model Management
PLM System
Requirements Management Tool
Data Thread Layers
Data/model Pedigree
•relation to design/testing CM
Configuration management
•Baseline release
•Working version
Information
•Text
•Meta data
Parameter
•alpha
•numeric
Data Interoperability Standards & APIs
ReqIF
OSLC
MoSSEC
REST
Continuity of Identity (cyber security)
OAuth v2.o
19


Test & Cert Data System
Reports
Values
Cost/Sched Dashboard
Certification Dashboard
Verification Dashboard
Validation Dashboard
Models Compl. Dashboard
Cost, Schedule, Risk
PM System
Meta data
Requir ement System
Requirements, values
SysML Model
ReqIF
OSLC
Mass, Power, Volume, Material, software functional properties
PLM
Mass, Volume, Material properties
Mass, Power, Volume, Material properties
MCAD Model
ECAD Model
Software
Models – out
Reports – in
Finite Element Model
CFD Model
Thermal Model
Simulati ons
SPDM
Extended Reality
Augmented Reality
Virtual Reality
Digital Twins
Models
MBD Models
STEP 242 files
Manufacturing
QIF files
Quality / Inspection
CNC Program
CMM Program
Man. Process Planning & Work instructions
Qual. Process Planning & Work instructions
In Work
From NASA's SE NPR 7123.1
Conceptual Engineering Data Thread
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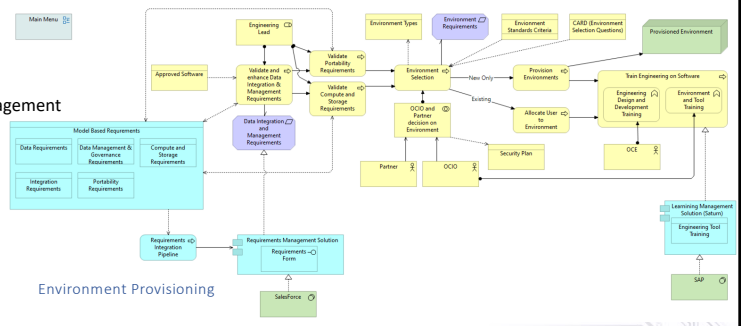
OCIO-DE Collaborative Strategic Planning

- Met with OCIO Architecture team for 4-day TIM Aug 1-4 and a second TIM on Nov. 14 & 17, 2023
- Mapped out DE needs on many fronts of which would/could/should involve OICO to realize identified capability.
- **DE participants felt these were extremely valuable** as a communication tool with OCIO and helped think through many use cases. OCIO felt it was very helpful because Eng. use cases will likely be similar to other customers/mission directorates and will cut down the time required when working with them in the future.
- EMB IT Working Group was engaged in this effort and was identified as a needed participant in these planning efforts going forward along with associated use cases that involve them.
- The following DE Use Cases were modeled as part of these TIMs:
  - Engineering Roles
  - Engineering Value Stream & Data Principals
  - Requirement Modelling and Logical Decomposition
  - Digital Acquisition Strategy
  - Software Approval Process
    - New Software Requests
  - Software Administration & Reporting
    - Initial Software Candidates for Cloud License Management
  - License Use (Accessing Licenses)
    - Thermal Desktop & associated software
  - OCE Cloud MagicDraw/Teamwork cloud
  - Environment Provisioning
  - Access Control / External Collaboration
  - Integration Provisioning
  - Integration Preparation Service
  - Security Development Operations



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DE RFI to Industry Summary

Recommended for Future EMB Special Topic

RFI 1: Approach to RFPs, proposals, and contracts per traditional, or model-based acquisitions. If your preferred or recommended approach is via a model-based approaches, please provide:

- Objective measures as to the value and/or return on investment or increased capabilities the approach provides over the traditional,
- Past, sharable, examples of success stories and associated models/metamodels in native formats if applicable
- Past government customers (POCs) who can attest to the benefit and would be willing to share their perspective and lessons learned with NASA

RFI 2: Approach for future contractual engineering, quality, and safety data/informational deliverables, model assurance and assurance requirements to provide insight and inform critical decisions to support certification, operations support, operational anomalies, program, architecture, or mission integrations when elements, products, or services may be provided my numerous industry partners.

RFI 3: Approach to NASA/industry partner collaborative environments, collaborative engineering/integration/simulation/ digital twin environments. Please indicate the nature of engagement and/or lifecycle phases of a program/project you would typically value collaborating/integrating designs with NASA.

RFI 4: Approach to integration of engineering toolchain to form digital thread(s) from concept to operations. Recommendations on appropriate/recommended interfaces between models, systems, etc. when providing contract required data/information and/or collaboration with NASA.

RFI 5: Recommended commercial off-the-shelf solution(s) (COTS) for integration of your toolchain(s) with pros and cons.

RFI 6: Recommended industry data interoperability standards (or non-baselined "needed" standards) per engineering subdomain (e.g. ReqIF for requirement management software) and why.

RFI 7: Recommendations of what you would like to see common/consistent across the US government when it comes to digital engineering, procurement/acquisitions supporting engineering deliverables, and safety.

Summary:

- 42 Responses – 27 met minimum expectations
- 1 company responded via SysML models
- 4-5 considered very informative

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DE RFI to Industry Summary

Recommended for Future EMB Special Topic

- Majority indicate MB Acquisition save time and increases quality of all aspects of the process.
- Significant experience with integration of tools, forming the digital thread, and needed interoperability protocol standards.
- DoD, and industry in turn, are emphasizing the use of MOSA (Modular Open Systems Approach) and it is required by United States law Title 10 U.S.C. 4401(b), states all major defense acquisition programs (MDAP) are to be designed and developed using a MOSA (https://www.dsp.dla.mil/Programs/MOSA/):
  - Employs a modular design that uses modular system interfaces between major systems, major system components and modular systems;
  - Is subjected to verification to ensure that relevant modular system interfaces comply with widely supported and consensus-based standards; or are delivered pursuant to the requirements established in FY21 National Defense Authorization Act Section 804 (a)(2)(B)
- Toolchain: proposed COTS digital backbone solutions with bidirectional interoperability, extensibility and cross-project connectivity (including non-engineering needs), and with diverse vendor toolset (avoid vendor lock) for robust and customizable COTS toolchain
- Gov. should:
  - Establish standardized digital engineering frameworks and guidelines that can be adopted across government agencies.
  - Develop a unified procurement framework for government projects that integrates digital engineering principles.
  - Promote cross-agency collaboration and information sharing to facilitate the adoption of common digital engineering standards and procurement practices.