Digital Engineering at Goddard

Evolving Process by Revolutionizing Collaboration

NASA Goddard Space Flight Center (GSFC)

Engineering and Technology Directorate (ETD)

Presenter: Aaron Comis, ETD/Chief Digital Engineer

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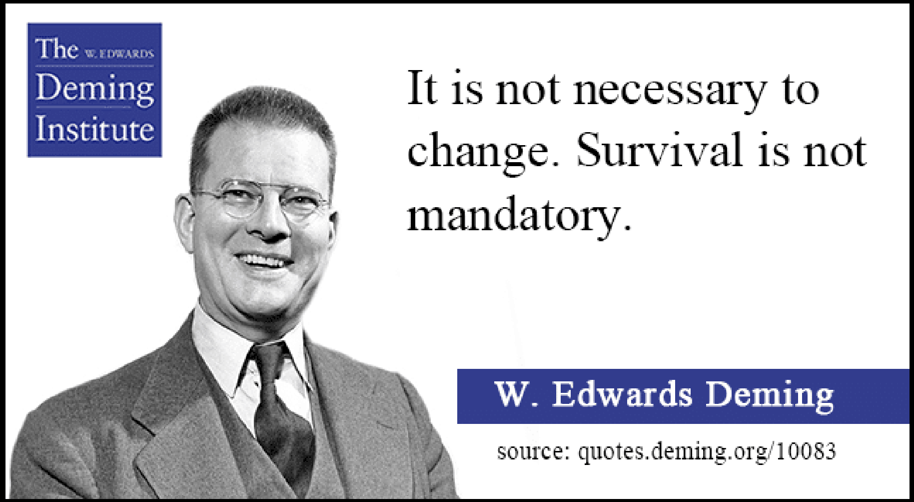
August 2023

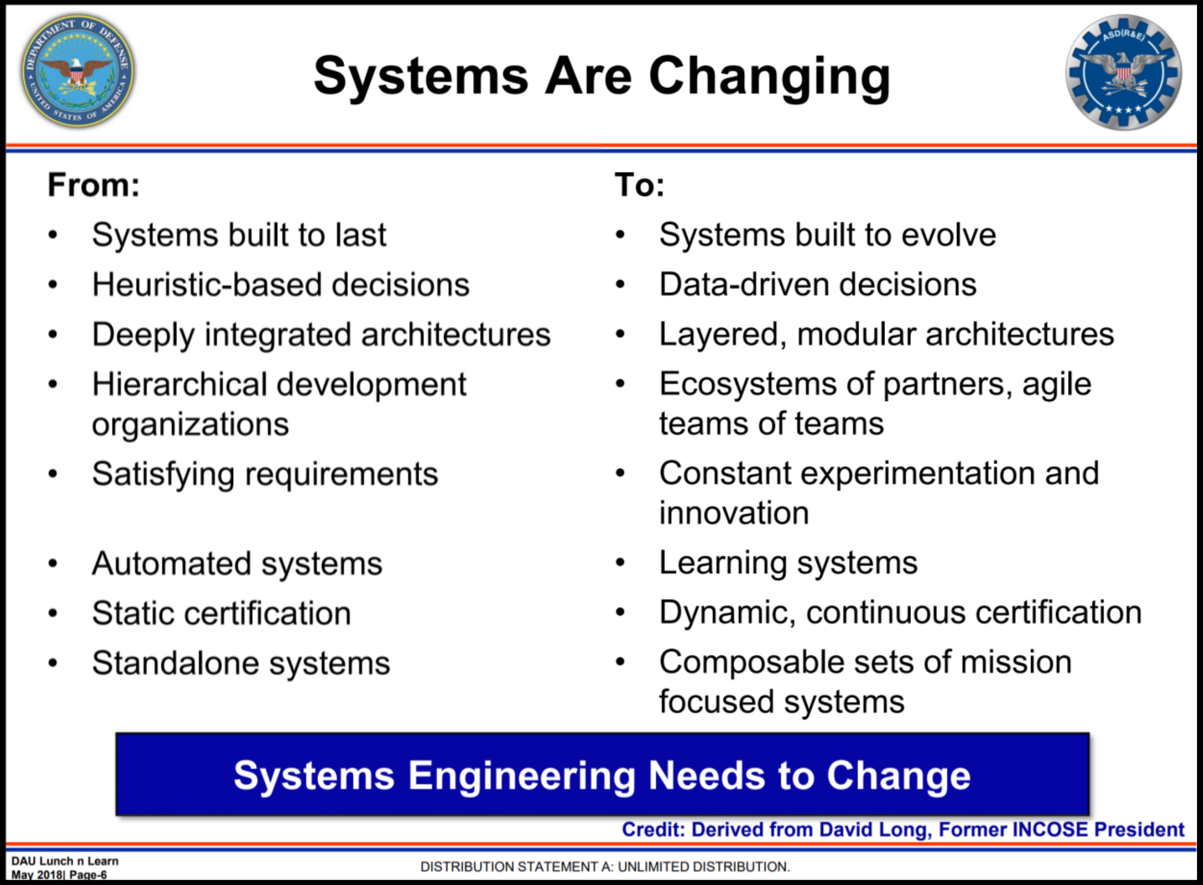
Agenda

- Goddard Approach to Digital Engineering *(Our Place?)*
- Identification of Existing Governance *(Alignment)*
- Using Existing Governance to Define a Need *(Defined)*
- Using a Need to Derive Key Goals *(Derived)*
- Digital Engineering Roadmap *(Roadmap)*
- Pyramid of Digital Success *(Pyramid)*
- Shift roles between government and industry *(Industry)*
- Digital Engineering: Potential Gains & Pitfalls *(Case Studies)*
- Takeaway

What are we doing here?

- Systems are becoming increasingly complicated and interconnected
  - Includes missions across NASA
- Resources are decreasing
  - Funding, schedule, personnel, etc.
- Project complexity is increasing
  - Mission, partnership, competition, etc.
- Current practices are not sustainable
  - Goddard at increasing risk of falling behind





Systems Are Changing

From:	To:
Systems built to last	Systems built to evolve
Heuristic-based decisions	Data-driven decisions
Deeply integrated architectures	Layered, modular architectures
Hierarchical development organizations	Ecosystems of partners, agile teams of teams
Satisfying requirements	Constant experimentation and innovation
Automated systems	Learning systems
Static certification	Dynamic, continuous certification
Standalone systems	Composable sets of mission focused systems

Systems Engineering Needs to Change

Credit: Derived from David Long, Former INCOSE President

DAU Lunch n Learn May 2018| Page-6

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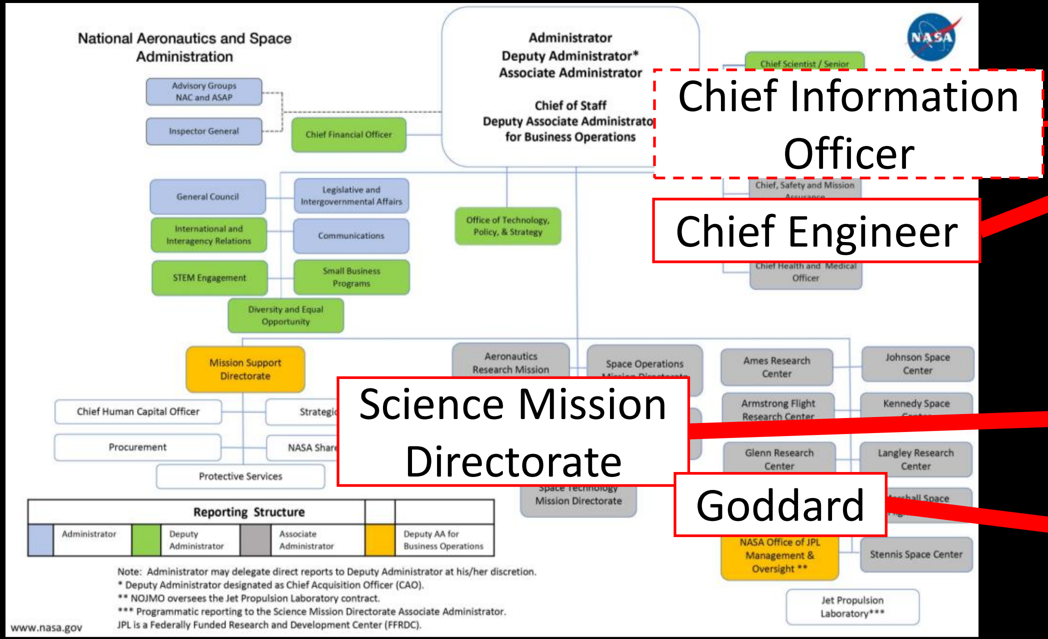
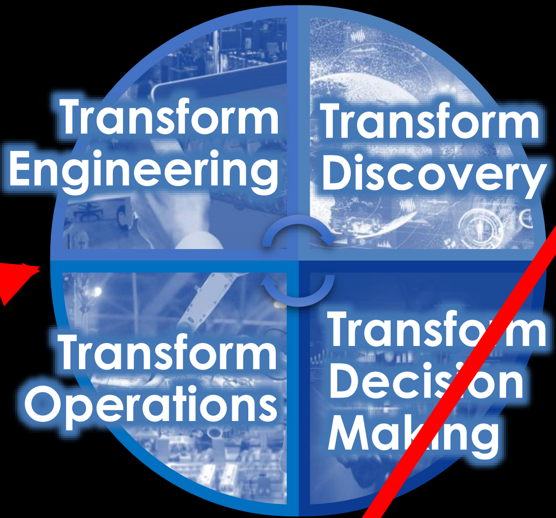
What is ***our place*** in a changing industry?

Our Place Alignment

- Sources of guidance inform *our place*



NASA Organization Structure – Not intended to be legible



SMD Tiers
Long-Term Capability Strategy

ASIG-23
Annual Strategic Investment Guidelines

Our place is defined **internally** and **externally**

Our Place Defined

- Map *our place* to a top-level Need

Draft

«businessRequirement»
«Need»
Need

Id = "N"
Text = "Inform timely data-driven decision making across the lifecycle with increasingly complex missions and decreasing resources and timeframes to achieve GSFC 2040 vision"

Practice what you preach

SMD Tiers
Long-Term Capability Strategy

ASIG-23
Annual Strategic Investment Guidelines

Need maps all inputs into common vision supporting *our place*

Yes, all governance is modeled

Our Place Derived

Transform culture
Transform technology

- Derive goals from Need

Draft

«businessRequirement»
«Need»
Need

Id = "N"
Text = "Inform timely data-driven decision making across the lifecycle with increasingly complex missions and decreasing resources and timeframes to achieve GSFC 2040 vision"

Practice what you preach

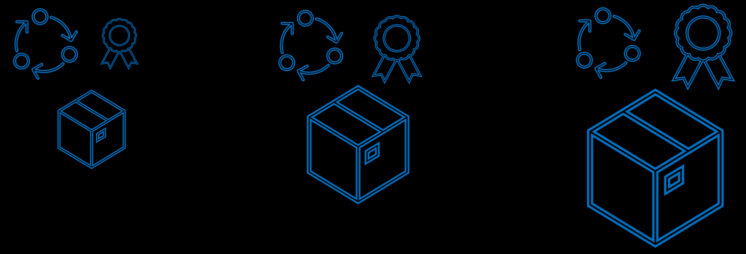
3 draft goals

- **Goal 1: Break down barriers through education**

- **Goal 2: Enable cross-team dynamic collaboration**

- **Goal 3: Advance incrementally across disciplines**

Modified from SAFe 5.x portrayal of incremental DDTE



Culture poses the *most significant challenge* to **Digital Engineering** Transformation

Roadmap Overview

- Definition of Digital Engineering *(per ETD)*
  - *A **cross-disciplinary field** that leverages **digital tools** and **processes** for the design, development, and production of engineering products across the project lifecycle towards improved efficiency and accuracy of the engineering process, along with reduced project risk*

Phase 0: Align and Advance Enabling Capabilities
Prove locally, interconnect globally

Phase 1: Implement Digital Thread
Foundational data-focused ecosystem linkage of technical information throughout the mission lifecycle

Phase 2: Assess Cross-Disciplinary Trades
Science-informed trade study analysis and optimization with manufacturing workflow modernization

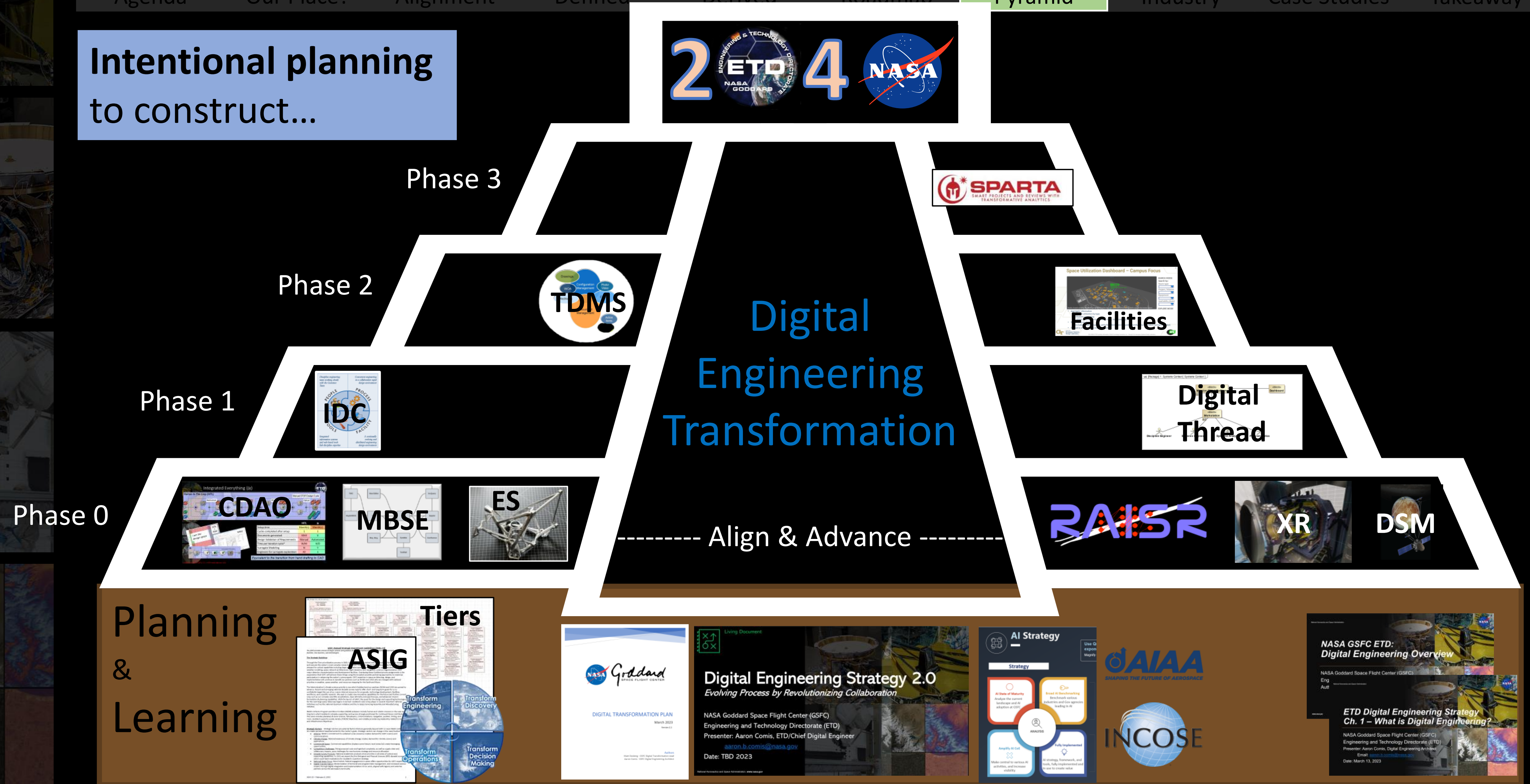
Phase 3: Interconnect Programmatics
Scalable coupling of technical information with cost, schedule, risk, safety, etc.

FY23 | FY24 | FY25 | FY26 | FY27 | FY28 | FY29+

Intentional planning and ***strategic use of pilots*** will enable the smoothest transition (***technical*** and ***cultural***) from ‘***why***’ to ‘***how***’

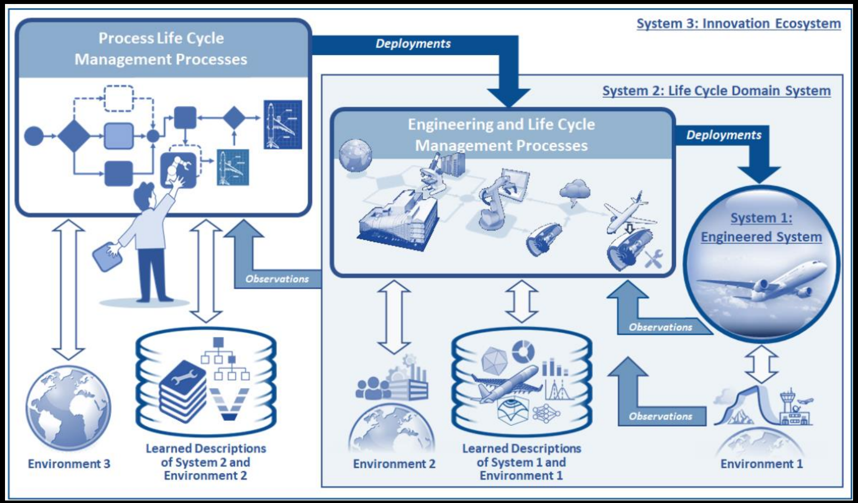
Pyramid of Digital Success

Intentional planning
to construct…



Industry Alignment

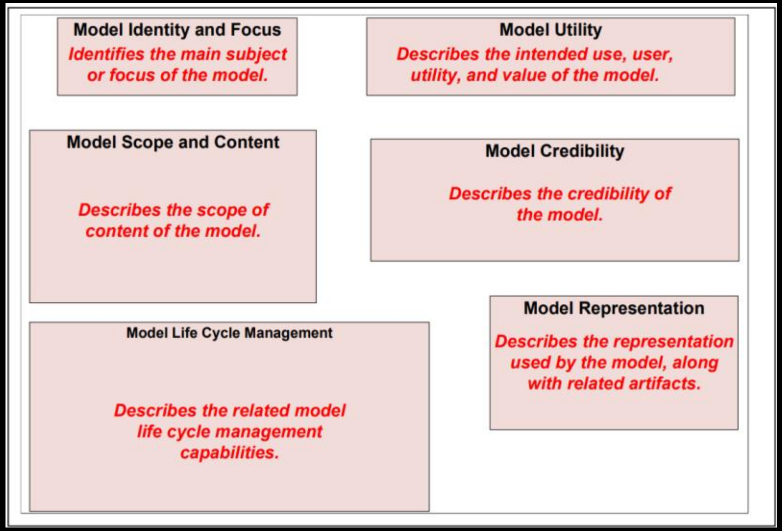
- Previous decade(s) show missions slowly shifting towards a partner-centric model



ASELCM Level 1

INCOSE ASELCM Pattern (left)
Agile Systems Engineering
Lifecycle Management
Reference Pattern

OMG MCP (below)
Model Characterization Pattern



Intentional alignment with industry **enables expanded future partnerships**

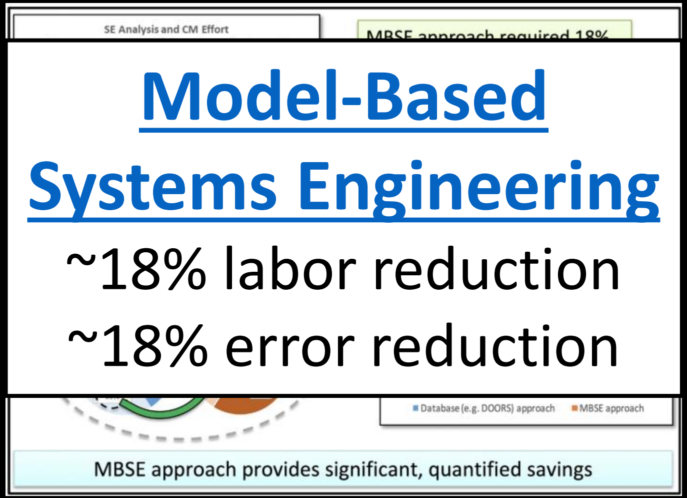
OMG Wiki, "*The Model Characterization Pattern (MCP): A Universal Characterization & Labeling S*Pattern for All Computational Models*"
W. Schindel, "*Realizing the Promise of Digital Engineering: Planning, Implementing, and Evolving the Ecosystem*"

Digital Engineering: Potential Gains & Pitfalls

- Ongoing market research of relevant, available case studies to constructively inform
  - Searching for good *and* bad

Digital Thread
~$700M savings

Cross-Disciplinary Analysis & Optimization
>50% labor reduction



Model-Based Systems Engineering
~18% labor reduction
~18% error reduction

T-7A DE Pitfalls

DE Over-Hype

Industry experience is mixed, but indicates ***potential for gains***

Digital Twin
*TBD savings
(operations and sustainment)

*Not publicly quantified

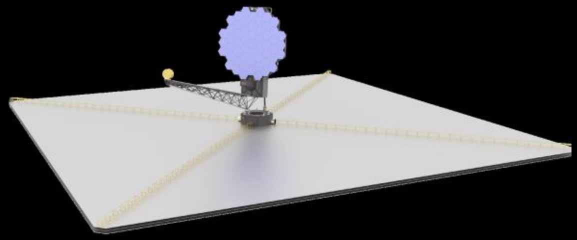
Takeaway

- Digital Engineering transformation of Goddard is a **HUGE** and **impactful** undertaking
- Focus is on understanding the '*why*' BEFORE shifting focus to the '*how*'
  - Market is saturated with cure-all solutions

    …but what is the question being asked?

Ref. Deep Thought, Hitch Hikers Guide to the Galaxy

- Goddard is heavily involved in Agency efforts (DE and MBSE) and increasing involvement with professional societies



Digital Engineering will enable Goddard to achieve more ***science per dollar***

Backup

- Acronyms
- Overview of Digital Transformation at NASA
- Goddard Digital Engineering Transformation Risk
- Shallow Dive: Digital Engineering + Model-Based Systems Engineering
- Steppingstones of Cross-Disciplinary Collaboration
- Existing Enabling Technologies

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Acronyms

- CDAO: Cross-Disciplinary Analysis and Optimization
- MBSE: Model-Based Systems Engineering
- ETD: Engineering and Technology Directorate
- GSFC: Goddard Space Flight Center

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Digital Transformation at NASA

- Digital Transformation: Employment of digital technologies to change a process, product, or capability so dramatically that it's unrecognizable compared to its traditional form
- Brief History of NASA DT
  - FY18: NASA's Digital Transformation (DT) officially kicked off
    - Formulation effort identified increased industry focus on DT
    - Led to internal assessment of the current state of 'digital' at NASA centers and major projects
    - Found many examples already underway at various levels of maturity – termed 'Silos of Curiosity'
  - FY20: Agency DT mandate, which focused effort in FY21 to define the DT vision and strategy
    - Included mobilization of early adopters – termed 'Coalitions of Willing'
  - FY22+ (**we are here**): Development of an agency-level plan, in the form of DT Targets, Levers, and Foundations
- Agency DT vision involves fully leveraging evolving digital technologies to advance missions, enhance efficiency, and encourage a culture of innovation
  - Digital Transformation is now officially housed within OCIO (Office of the Chief Information Officer) with OCE (Office of the Chief Engineer) as a primary stakeholder

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Digital Engineering Transformation – Risk

- ETD Digital Engineering Transformation has been operating *extremely* lean
- Current ETD Digital Engineering Transformation risk is 3x4
- Risk is on the verge of increasing to 4x4 if mitigation steps are not taken
  - Includes, but is not limited to dedicated Science Mission Directorate funding within PPBE cycle, dedicated Goddard resource investment (across TCC and IRAD), and more

Given that: The aerospace industry is amid a Digital Transformation, which is being framed, defined, and explored simultaneously

It is possible that: ETD will take longer than industry partners to realize digital engineering benefits

Resulting in: Degraded ability to formulate and execute complex research missions, including maintaining systems engineering excellence (Tier 1 capability) due to an inability to leverage digital engineering efficiencies limiting the ability to attract and retain the next generation NASA workforce, and an inability to collaborate with industry and academia.

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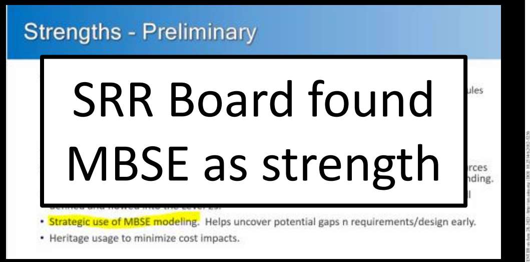
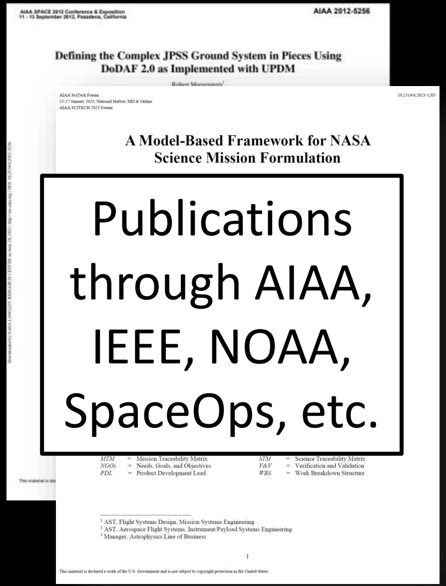
MBSE at Goddard (Greenbelt, Wallops, IV&V)

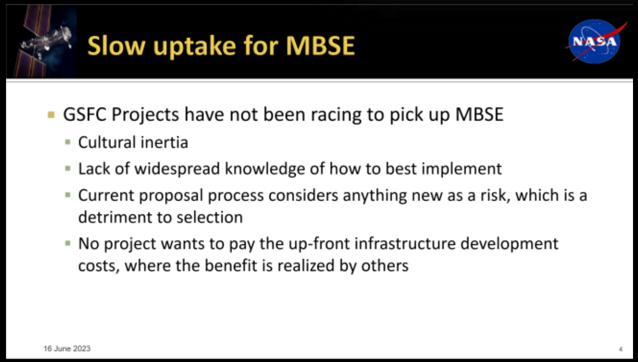
- Goddard involved with MBSE work for some time now
- Rob Morgenstern is leading Goddard MBSE strategy

- Accomplishments
  - Multitude of published papers with MBSE use-cases
  - Flight project usage with JPSS, DAVINCI, etc.



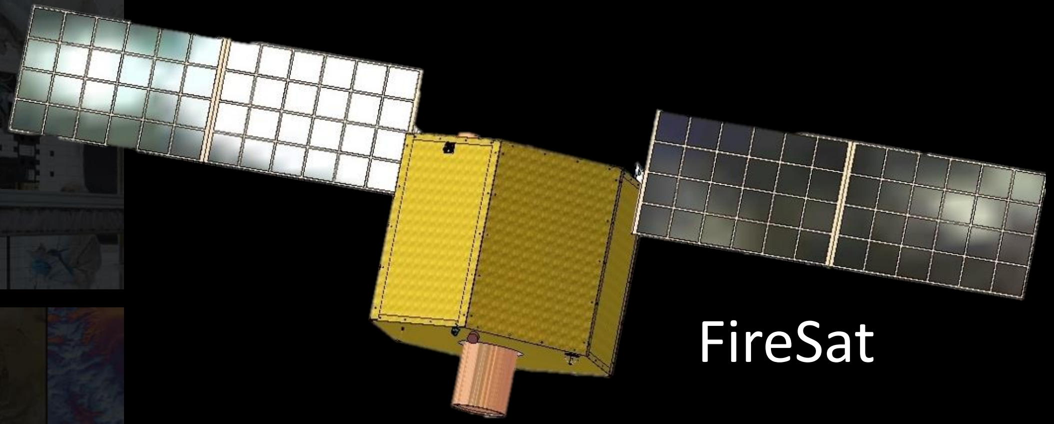


- Ongoing effort to reduce barrier to entry with starter models
  - Multiple complementary ongoing efforts focused on streamlining import and new project initiation with templates
    - POCs include GSFC/Rob Morgenstern, GSFC/Henock Legesse, WFF/Dave Kotsifakis
    - Growing list of capabilities (demonstrated and future) in backup
  - Model-Based Mission Assurance
    - IVV/Frank Huy and GSFC/Nancy Lindsey
- Supporting HQ DT NPR modeling effort

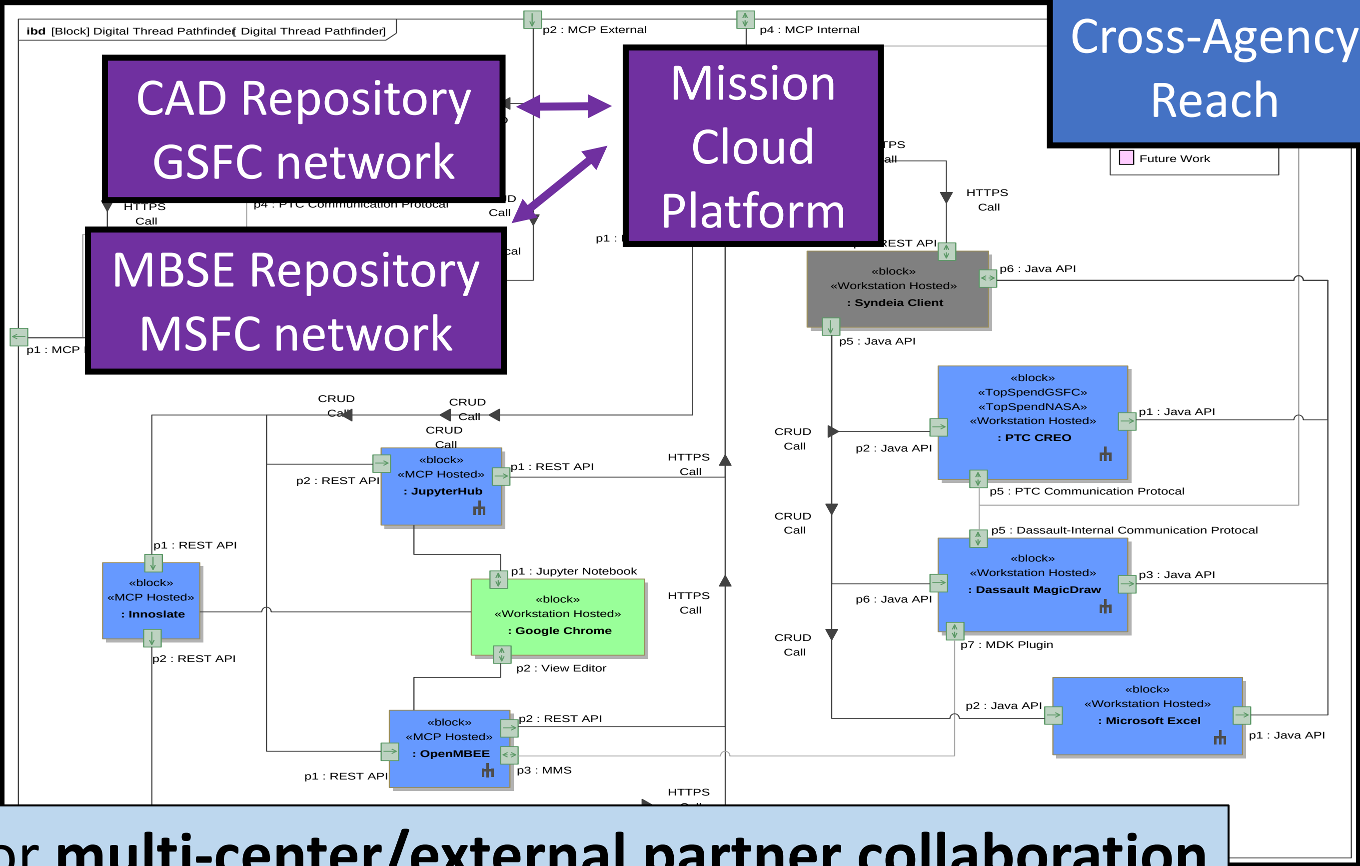


Cross-Agency Digital Thread Pathfinder

- Digital Thread will be the foundation for improved project coordination, asynchronous collaboration, and consistency management
- Multi-sourced funding from Goddard investment and HQ proposal award
- Cross-agency collaboration
  - Goddard: Engineering and OCIO
  - HQ: OCE and OCIO
  - Marshall (others in-work)



FireSat



Cross-Agency Reach

Pathfinder MVP paves the way for **multi-center/external partner collaboration**

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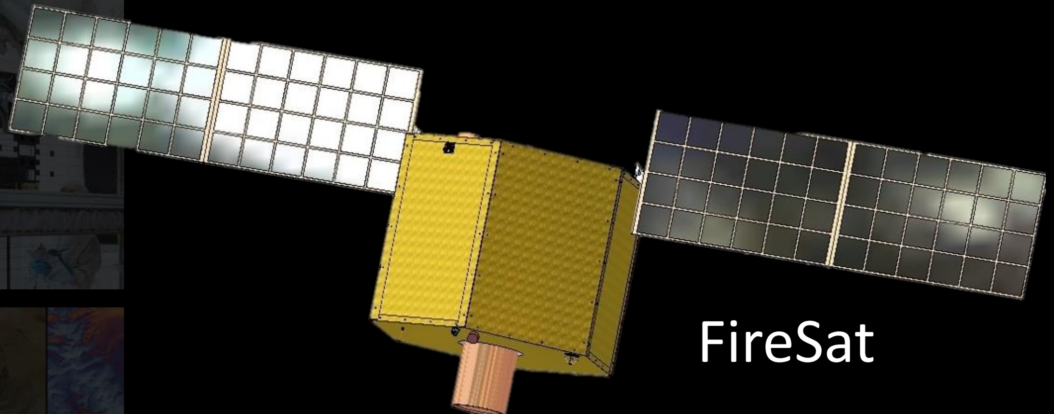

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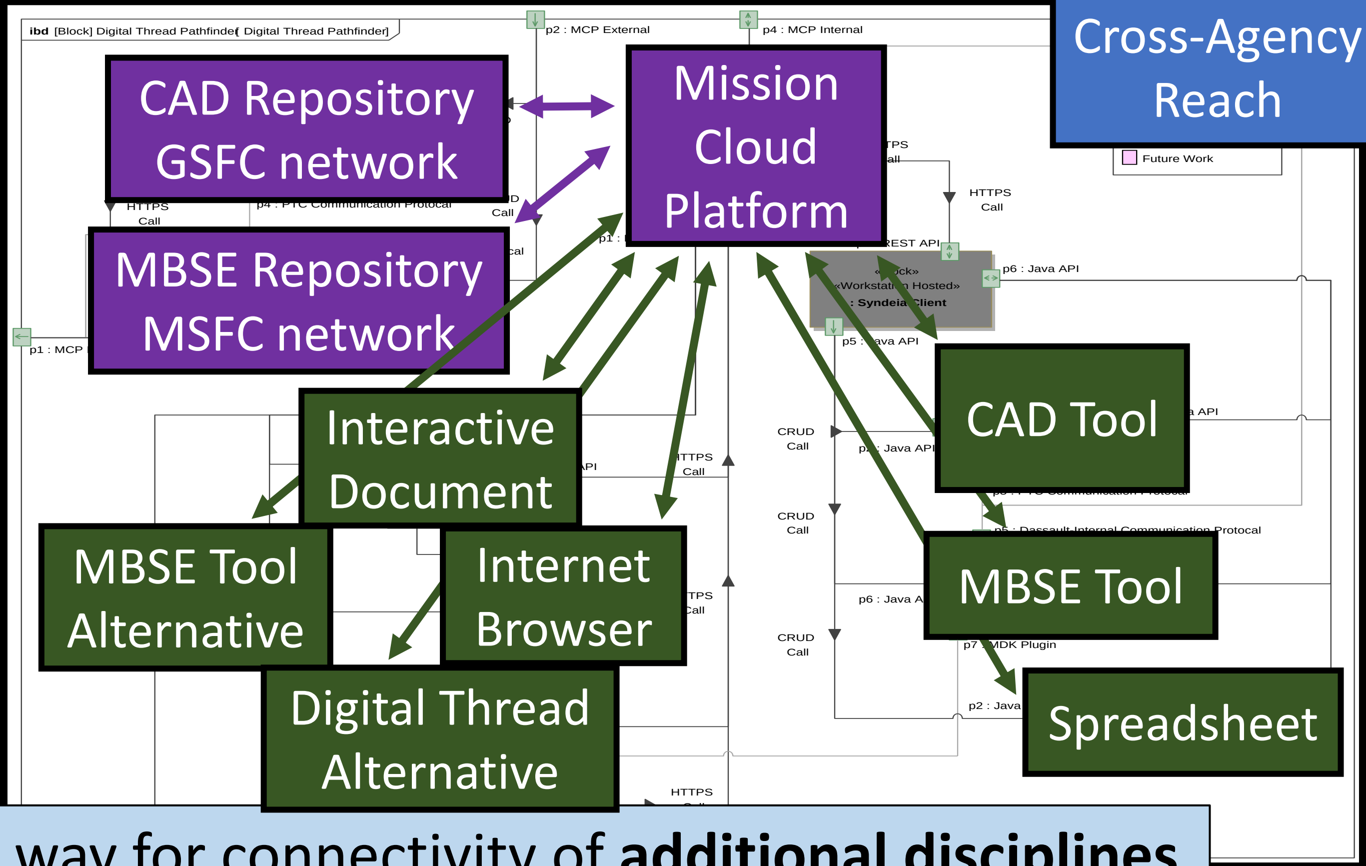
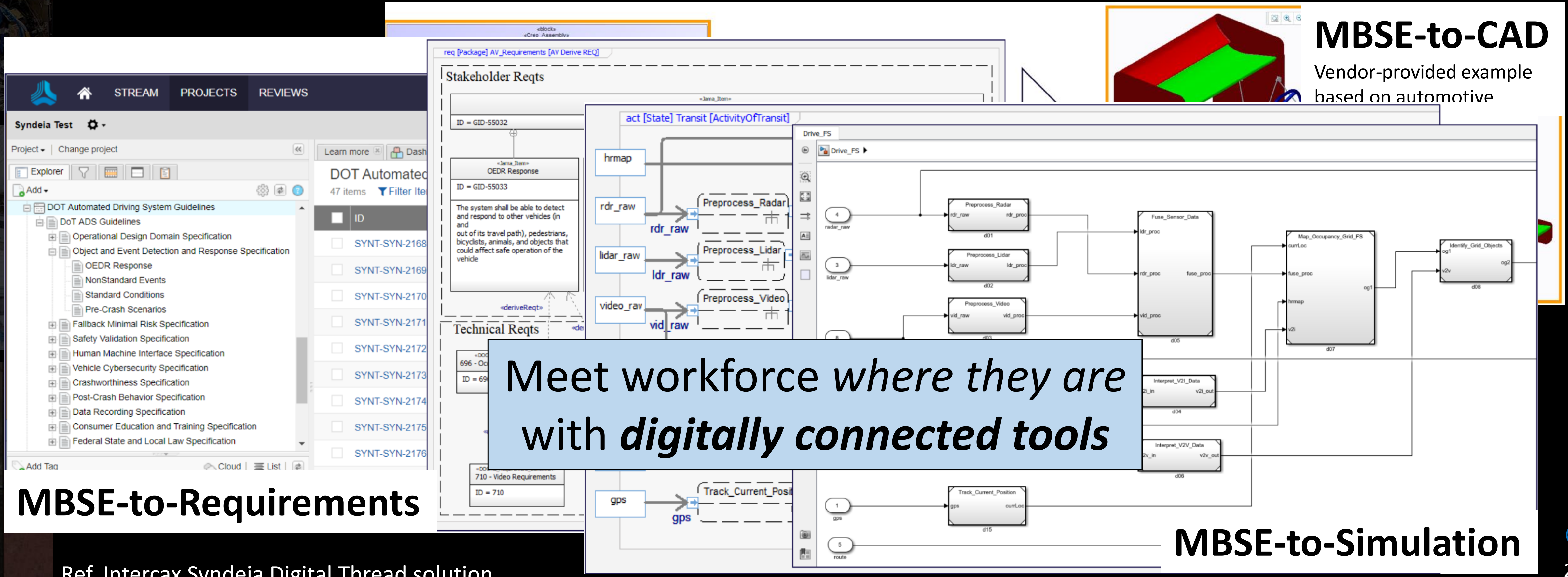


Cross-Agency Reach

Pathfinder extension paves the way for connectivity of **additional disciplines**

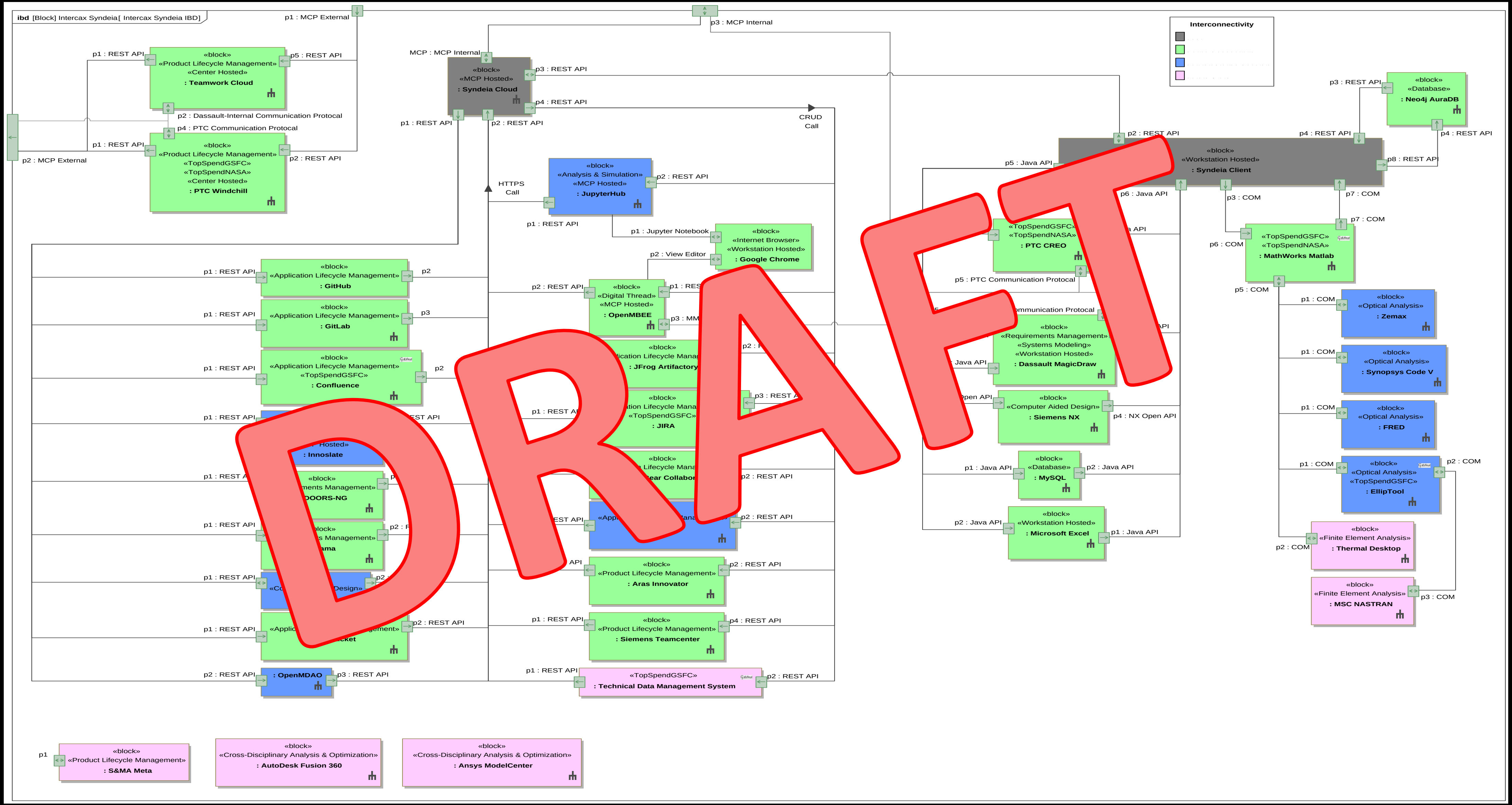
Digital Engineering enabled by Digital Thread

- Digital Thread provides out-of-the-box synergy with MBSE
  - **Reference Connection**: Connects anything-to-anything
  - **Model Transform Connection**: Take elements from one tool and create new elements in another tool *(bi-directional)*



Ref. Intercax Syndeia Digital Thread solution

Digital Thread Architecture Expansion *(in-work)*



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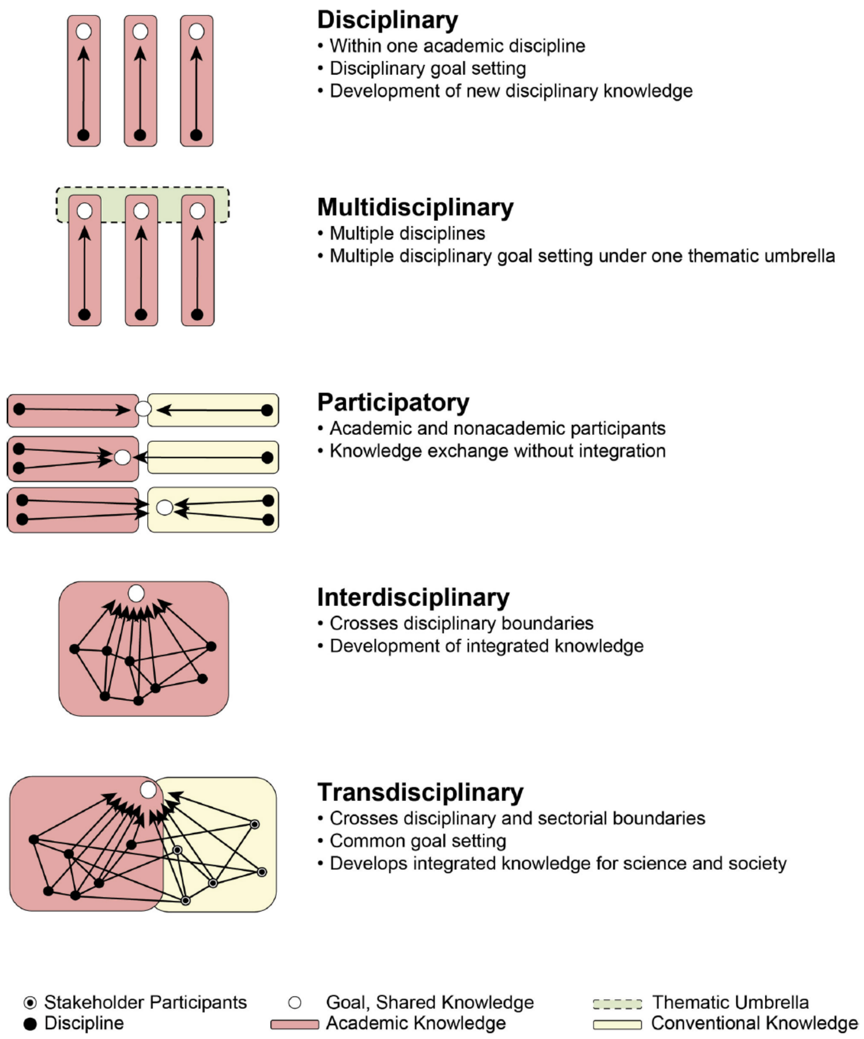
Steppingstones of Cross-Disciplinary Collaboration

- Disciplinary
  - Single discipline applying discipline processes towards a relevant problem
  - Example: Designing a structural beam
- Multidisciplinary (most common)
  - Individual disciplines work independently towards a common goal; results are supplementary.
  - Example: Designing an aircraft wing per wing budget allocation
- Interdisciplinary
  - Synthesis of multiple disciplines using integrated-discipline specific approaches in the collaborative pursuit of shared knowledge and multi-functional solutions
  - Example: Designing an aircraft lift solution per overall aircraft budget allocation
- Transdisciplinary
  - Larger scale interdisciplinary approach, which integrates processes from historically distinct disciplines
    1. Processes are deeply collaborative (i.e., deep integration)
    2. Results in a positive holistic impact
  - Example: Designing a holistic aircraft lift solution based on project-level merit function (i.e., cost, schedule, reuse, etc.)

Fig. 1. Graphical representation of the concepts of disciplinary, multidisciplinary, participatory, interdisciplinary, and transdisciplinary research. Redrawn from Tress et al. (2004).



References
- [The Difference Between Multidisciplinary, Interdisciplinary, and Convergence Research | Research Development Office (ncsu.edu)]
- [Architectures of adaptive integration in large collaborative projects]

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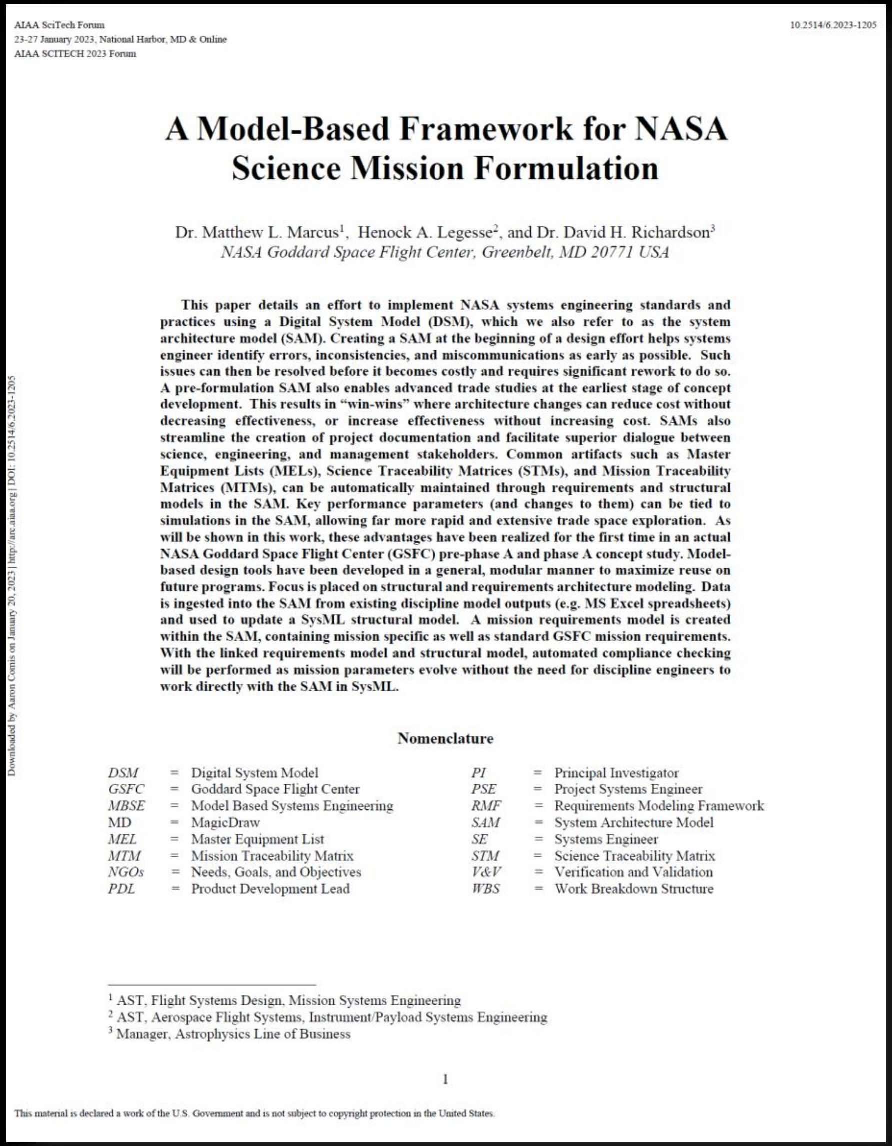
DAVINCI

- Khary Parker completed a model-based review for a ConOps EPR
  - Used success tree diagram in MagicDraw tool
  - Received high praise from the review panel
- Khary Parker and Kahni Pr’Out referenced MBSE benefits during a Requirements Review Outbrief
  - *“Strategic use of MBSE modeling. Helps uncover potential gaps in requirements/design early.”*
- Exploring opportunities for integrated modeling of RF performance vs aerodynamics during descent phase

AIAA Publication at SciTech 2023

- Title: A Model-Based Framework for NASA Science Mission Formulation (6.2023-1205)
  - Covered systems architecture modeling of observatory structure (spacecraft + payloads MEL), ConOps simulation, science requirements validation with parametrics, etc.
- Authors: Dr. Matthew Marcus, Henock Legesse, and Dr. David Richardson
- Dates: January 23-27, 2023
- Referenced Mission(s): Leveraged content from Pre-Phase A STAR-X proposal



AIAA SciTech Forum
23-27 January 2023, National Harbor, MD & Online
AIAA SCITECH 2023 Forum
10.2514/6.2023-1205

A Model-Based Framework for NASA Science Mission Formulation

Dr. Matthew L. Marcus[1], Henock A. Legesse[2], and Dr. David H. Richardson[3]
NASA Goddard Space Flight Center, Greenbelt, MD 20771 USA

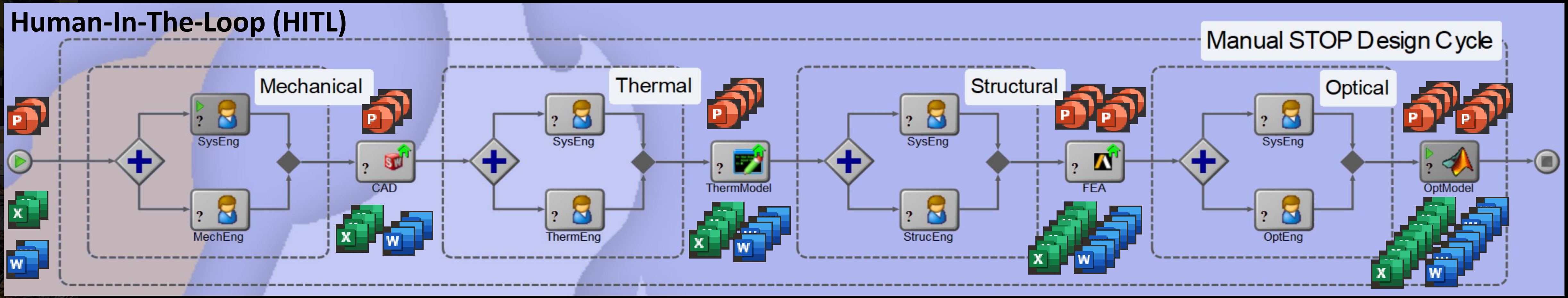
This paper details an effort to implement NASA systems engineering standards and practices using a Digital System Model (DSM), which we also refer to as the system architecture model (SAM). Creating a SAM at the beginning of a design effort helps systems engineer identify errors, inconsistencies, and miscommunications as early as possible. Such issues can then be resolved before it becomes costly and requires significant rework to do so. A pre-formulation SAM also enables advanced trade studies at the earliest stage of concept development. This results in "win-wins" where architecture changes can reduce cost without decreasing effectiveness, or increase effectiveness without increasing cost. SAMs also streamline the creation of project documentation and facilitate superior dialogue between science, engineering, and management stakeholders. Common artifacts such as Master Equipment Lists (MELs), Science Traceability Matrices (STMs), and Mission Traceability Matrices (MTMs), can be automatically maintained through requirements and structural models in the SAM. Key performance parameters (and changes to them) can be tied to simulations in the SAM, allowing far more rapid and extensive trade space exploration. As will be shown in this work, these advantages have been realized for the first time in an actual NASA Goddard Space Flight Center (GSFC) pre-phase A and phase A concept study. Model-based design tools have been developed in a general, modular manner to maximize reuse on future programs. Focus is placed on structural and requirements architecture modeling. Data is ingested into the SAM from existing discipline model outputs (e.g. MS Excel spreadsheets) and used to update a SysML structural model. A mission requirements model is created within the SAM, containing mission specific as well as standard GSFC mission requirements. With the linked requirements model and structural model, automated compliance checking will be performed as mission parameters evolve without the need for discipline engineers to work directly with the SAM in SysML.

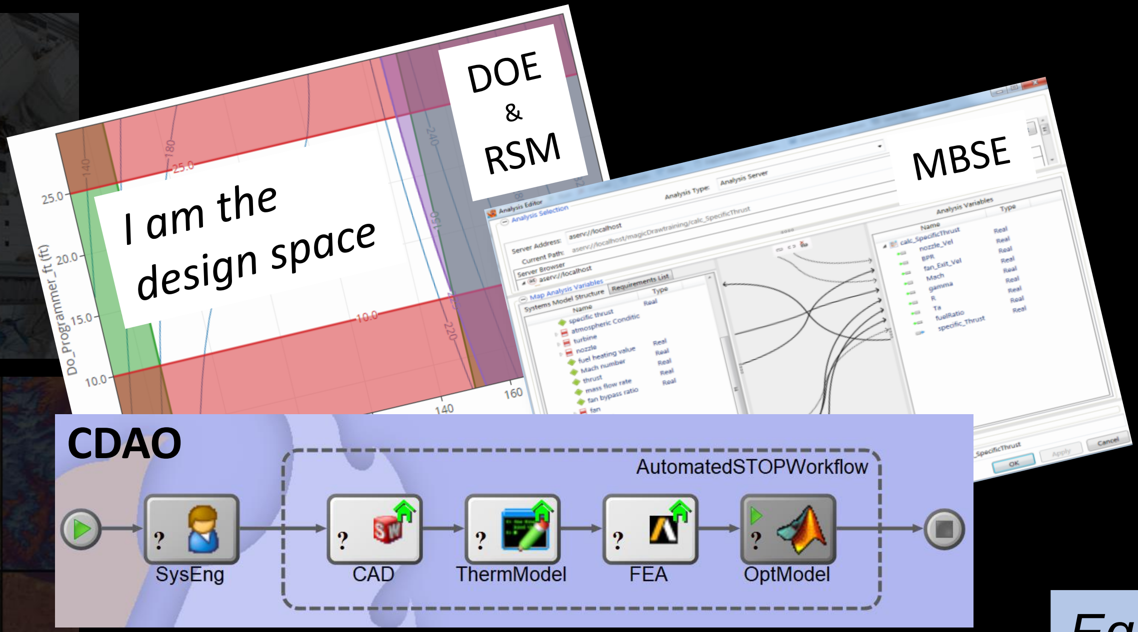
Nomenclature

DSM	=	Digital System Model	*PI*	=	Principal Investigator
GSFC	=	Goddard Space Flight Center	*PSE*	=	Project Systems Engineer
MBSE	=	Model Based Systems Engineering	*RMF*	=	Requirements Modeling Framework
MD	=	MagicDraw	*SAM*	=	System Architecture Model
MEL	=	Master Equipment List	*SE*	=	Systems Engineer
MTM	=	Mission Traceability Matrix	*STM*	=	Science Traceability Matrix
NGOs	=	Needs, Goals, and Objectives	*V&V*	=	Verification and Validation
PDL	=	Product Development Lead	*WBS*	=	Work Breakdown Structure

[1] AST, Flight Systems Design, Mission Systems Engineering
[2] AST, Aerospace Flight Systems, Instrument/Payload Systems Engineering
[3] Manager, Astrophysics Line of Business

Cross-Disciplinary Analysis and Optimization (CDAO)





	HITL	Ix
Setup time	Month(s)	Month(s)
Cycles completed after setup	1	1
Documents generated	XXXX	X
Design Validation of Requirements	Manual	Automated
Time per iteration cycle*	W/M	H/D
Surrogate Modeling	N	Y
Engineers for surrogate exploration	All	1

Equivalent to the transition from hand drafting to CAD

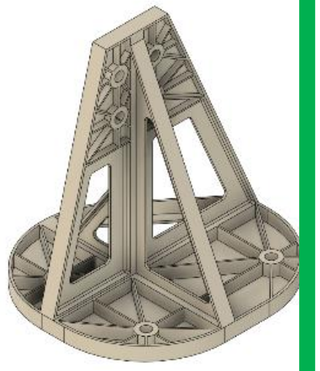
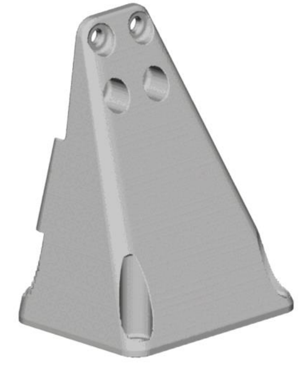
POC: Aaron Comis

Ref. Ansys ModelCenter tool

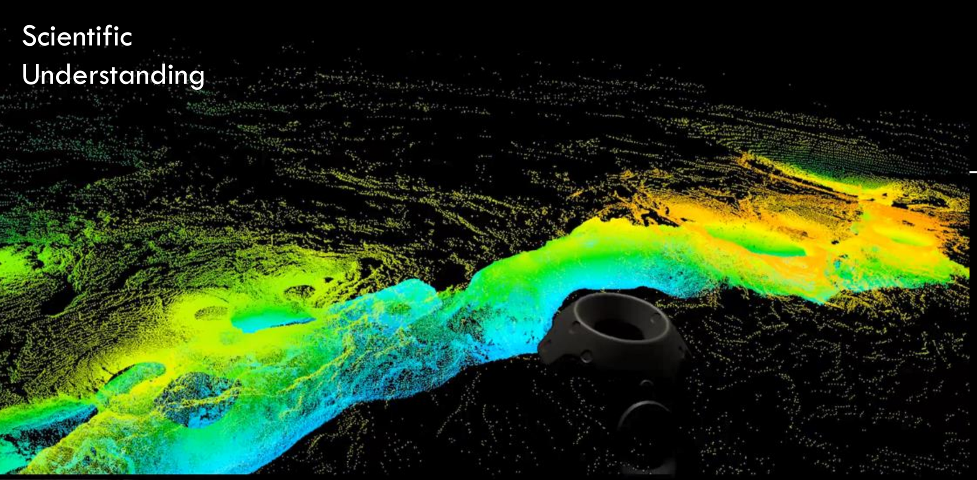
Evolved Structures Overview

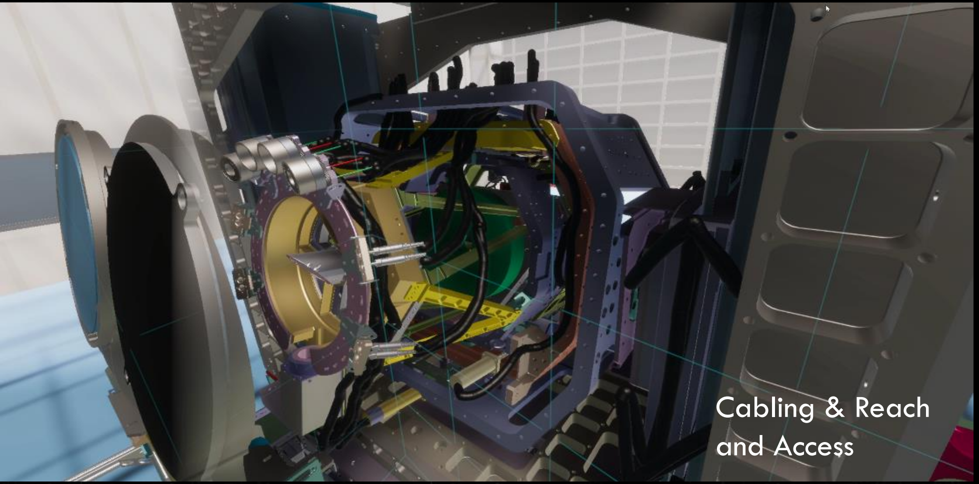
POC: Ryan Mcclelland

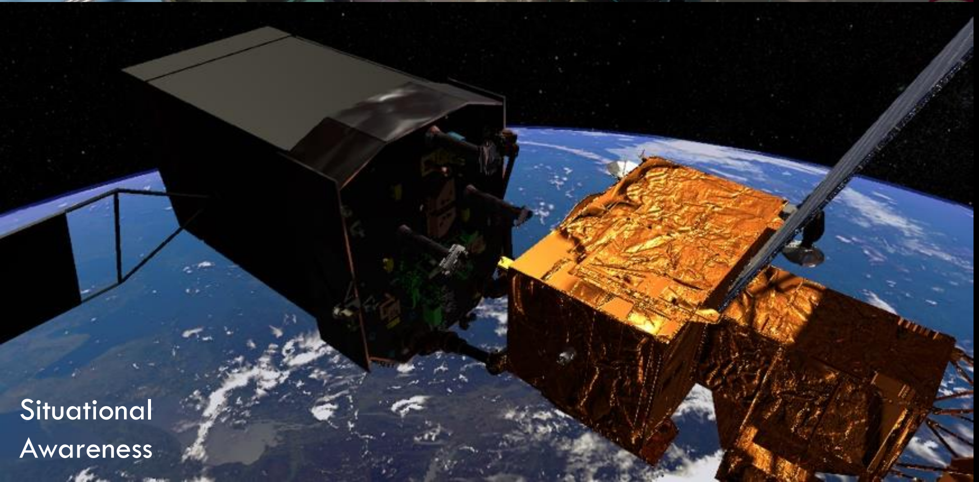
- AI enables 10x faster/cheaper spaceflight structure development
- Evolved Structures process
  - Design requirements are digitally encoded
  - Generative Design AI evolves optimal structures
    - Iterative design, analysis, fabrication simulation
  - Digital Manufacturing robots fabricate from CAD
- Typical metallic structures – now automated
  - Requirements → parts for fab in 1-2 days(!)
  - Parts ~3x stiffer/lighter/stronger vs human
  - Demonstrated by test
- The Future
  - Make all structure development 10x faster/cheaper
  - Trusses, flexures, lightweight optics, etc.

Designer	Expert Humans (2X)	AI
Design		
Design time	2 days	1 hour
Design iterations	4	31
Mass (kg)	0.27	0.2
1st Mode (Hz)	65	147
Max Stress (MPa)	103	14.8
Manufacturing	CNC - Difficult to machine (no quotes)	Automated CNC $1000 3 days

Ref. Autodesk Fusion 360 tool







Extended Reality (XR)

- XR provides several advantages
  - Quicker and more intuitive understanding of complex, spatially related, problems and situations (e.g., hardware integration & test reach and access, fit checks)
  - Reduced time and money with remote collaboration
- XR can be a valuable tool throughout the mission lifecycle (for engineering AND science tasks)
  - Integration with NASA pipelines, such as FEMAP, NASTRAN, Creo, Goddard Earth Observing System (GEOS), Earth Science Point Cloud, and Mission Operation Centers (e.g., GMSEC)
  - Data driven MRET (Mixed Reality Exploration Toolkit) projects can provide crucial situational awareness and foster analysis in Networking, Flight Dynamics, Distributed Systems Missions, Fault Detection & Mitigation, Communication Systems, Sample Return, Robotics, and In-space Servicing and Assembly
- Aligns with NASA Future of Work plan and facilitates hybrid work

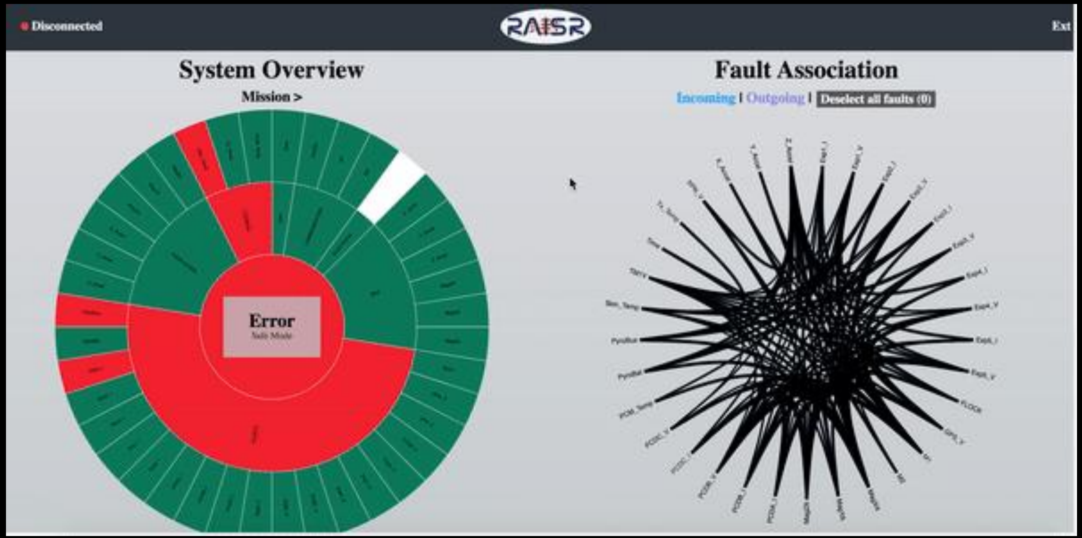
POC: Tom Grubb

Ref. NASA MRET (Mixed Reality Exploration Toolkit)

Autonomous Fault Mitigation Architecture

- Traditional spaceflight requires human-in-the-loop ground control intervention in anomalous fault scenarios
  - This paradigm is limiting due to time delays, data downlink bandwidth, and proximity restrictions.
- Project RAISR (Research in Artificial Intelligence for Spacecraft Resilience) addresses these limitations with an intelligent systems architecture, which uses AI for autonomous system-level fault diagnosis
  - Outperformed state-of-the-art AI approaches by ≥ 55%
  - Currently being used in a notional mission design for Distributed Systems Missions (DSM)
- Goddard of the future will see a new wave of scientific discovery through intelligent systems architectures, as they will enable
  - Fully autonomous spaceflight, eliminating the tethering need for human intervention
  - Next-gen spaceflight paradigms like DSM

Grecius, Tony, "Mars 2020 Perseverance Healthy and on Its Way." NASA Blogs. July 30, 2020.



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