AIAA Transformative System Engineering Task Force

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AIAA TSE TF, January 2024

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Transformative System Engineering Task Force Statement of Need/Charter

- Problem Statement:
  - How to Develop and Integrate a Joint Architecture
  - How to Accomplish in Time Needed Given the Peer Competition and Rapidly Evolving Market Conditions
  - Use Case: Developing/Fielding Autonomous System of Systems Capabilities
- Need Statement:
  - AIAA, as a valuable industry resource, must improve its ability to meet member needs related to transform system engineering to support DoD modernization and NASA programs.
  - Supporting disruptive entrants to commercial space and air marketplace.

Transformative System Engineering Task Force Statement of Need/Charter

- Stressing Autonomy System of System Tasks
  1. Research & Development (R&D) and System of Systems Architecture Integration: Advanced Concepts, Proprietary Models/Sims, Flexible Traceable Architectures
  2. Dynamic Mission Requirements Development/Sustainment: Timeline/Need Driven
  3. Digital Engineering and Budget Integration: Performance and Delivery Estimation
  4. Autonomy Mission Metrics in the System Engineering Process: Different Providers, Standards, Processes, and Users with Common Needs

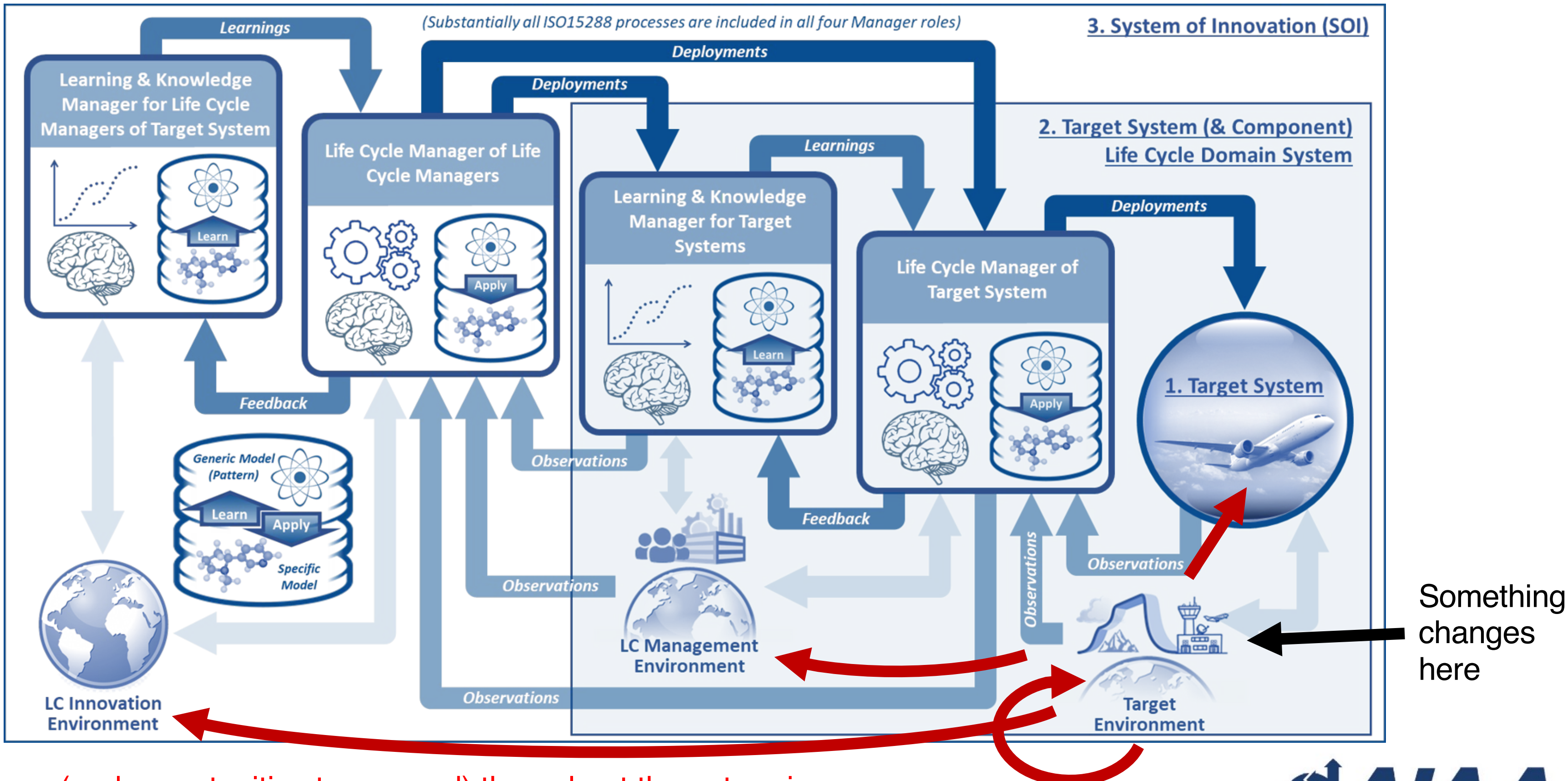
Task 1: Research & Development (R&D) and System of Systems Architecture Integration

Task 2: Dynamic Mission Requirements Development/Sustainment

Task 2: Problem

- Problem: Modern Aerospace Systems must adapt to unparalleled requirements volatility due to **advancing technologies**, **operating concepts**, **adversary capabilities**, **environmental change**, **geopolitics** and **regulation**
  - Requirements changes mid-course during development strains delivery schedules and overall mission assurance, stressing both fielded systems and engineering processes
  - Requirements changes after delivery may result in mission failure if adaptation not feasible
- Need: Tools, processes and development cultures that are sensitive to potential future mission needs and are both adaptive and capable of developing adaptive systems
- Solution: Some foundations exist (MBSE, rapid prototyping, resilience/adaptability concepts) but need better definition of the challenge to enable effective tailored approaches

Change Can Be Introduced in Many Ways



Resulting changes (and opportunities to respond) throughout the enterprise

Task 2: Current Work

- Methodology:
  - Develop a strawman framework to lay out a “dynamics space” that allows for identification of key differentiating sources of mission dynamics
  - Identify systems challenges in key regions of the space
  - Map current and emerging practices to challenges they address
- Projected Outcomes:
  - Taxonomy for mission requirements dynamics
  - Best practices/approaches mapped into dynamics space
  - Areas where addition research, new tools, and new development activities are needed

Relevant Sources of Insight

- Complex adaptive systems
- Transdisciplinary engineering practices
- Agile software engineering
- Open/modular systems architecture
- Exploratory modeling

Initial Dynamics Taxonomy Considerations

Sources of Dynamics

- Complexity/emergence
- Volatility in environment
- Technical change
- Non Technical Change
- Resolution of Uncertainty

Resulting Needs

- Changes in time or speed
- Changes in degree or extent
- Changes in scale
- Change in function
- Change in ecosystem

Factors Impacting Response

- Availability of time or resources
- Availability of information
- Composition of and capabilities elsewhere in ecosystem
- Phase in life cycle
- Others

Task 2: Next Steps

- Next Steps: Conduct small engagements to validate and apply framework
  - What do teams do when a requirement changes? How do they know?
  - What is it about different parts of the dynamics space that stresses engineering processes and system capabilities?
  - What are candidate transformative SE capabilities and design principles that can address challenges?
  - How would candidate approaches/capabilities be expected to help in different regions of the dynamics space?
  - What gaps exist that require new tools/methods, or extension/maturation of existing approaches?
- Proposal for wider AIAA: Industry partnerships to assess approaches

Please join us to help AIAA address this important set of challenges

Task 3: Digital Engineering and Budget Integration/DOD Transformation

USD(R&E)

OUSD (R&E) Systems Engineering & Architecture (SE&A)

Transforming SE Brief for AIAA SciTech

Mr. Daniel Hettema
Director, Digital Engineering, Modeling & Simulation

Office of the Under Secretary of Defense for
Research and Engineering

Jan 11, 2024

Aligned to National Defense Strategy (NDS)

Gen Lloyd Austin
SECDEF

*"Our current system is too slow and too focused on acquiring systems not designed to address the most critical challenges we now face. This orientation leaves little incentive to **design open systems** that can rapidly incorporate cutting-edge technologies, creating long-term challenges with obsolescence, interoperability and cost effectiveness."*
2022 NDS, pg. 27

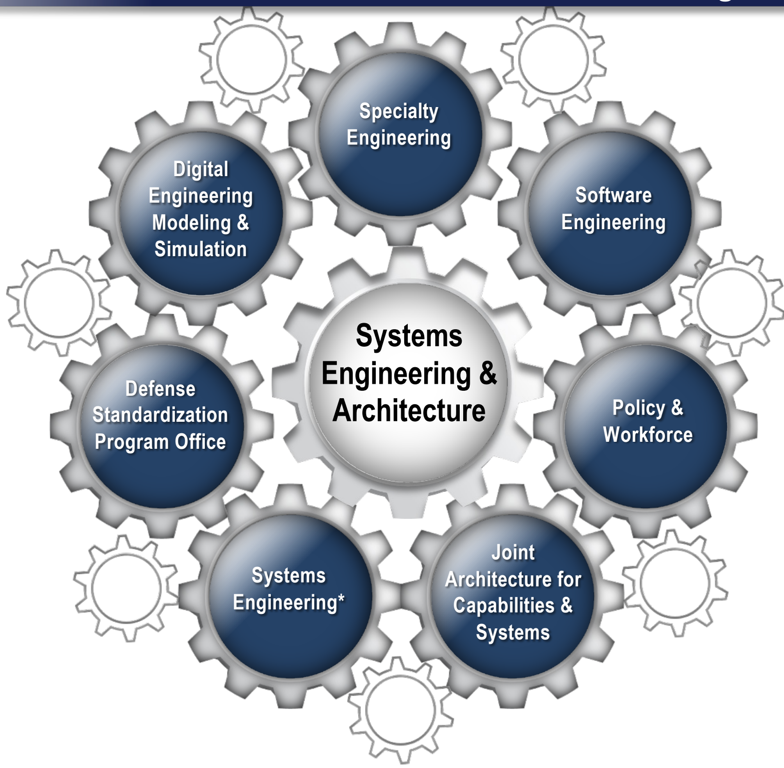
*"The nuclear enterprise will increase focus on research, development, test and evaluation efforts; government purpose data rights; and faster development of technologies and **system concepts through digital engineering** and **open architecture designs**…"*
2022 NDS, pg. 58

Prioritize speed of delivery, continuous adaptation, and frequent modular upgrades

https://www.defense.gov/Spotlights/National-Defense-Strategy/

Overview Systems Engineering & Architecture (SE&A)

SE&A promotes innovative engineering principles and techniques to advance DoD engineering practice



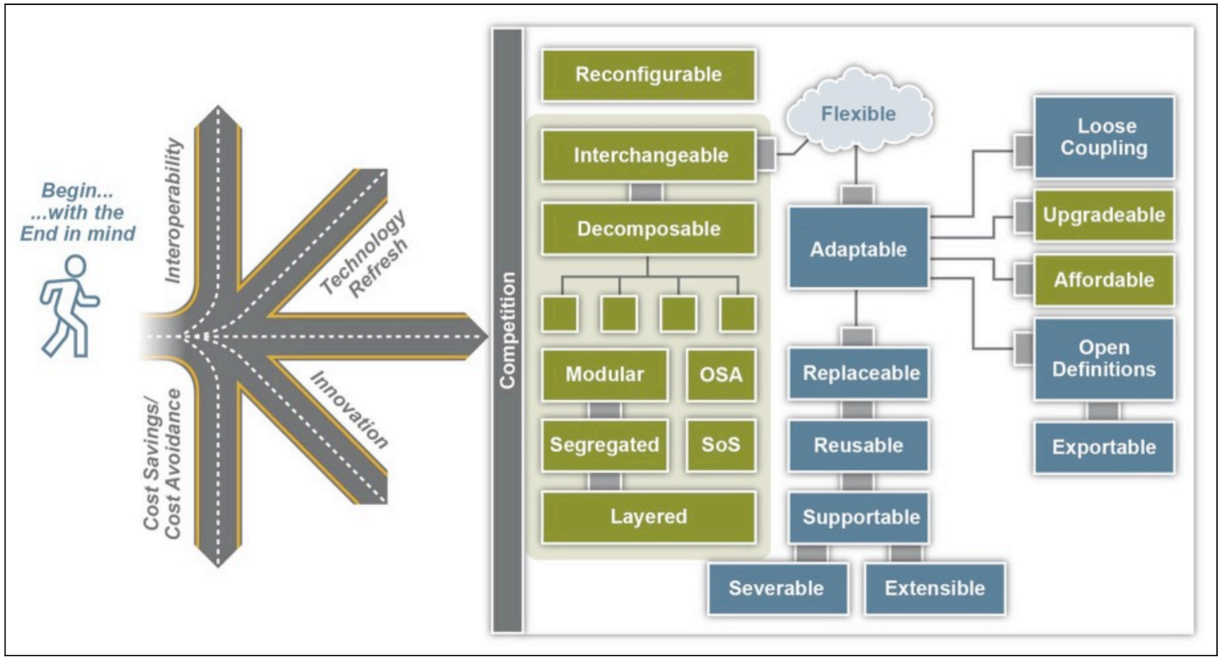
Lines of Effort

1. Advance the Engineering Practice
2. Connect and Strengthen the Technical Community
3. Develop the Workforce
4. Advance and Manage Standards
5. Provide Technical Expertise for Independent Engineering Assessments
6. Provide System of Systems (SoS) Architecture Guidance

*Includes Modular Open Systems Approach (MOSA)

Appling Modular Open Systems Architecture (MOSA) to Drive Innovation

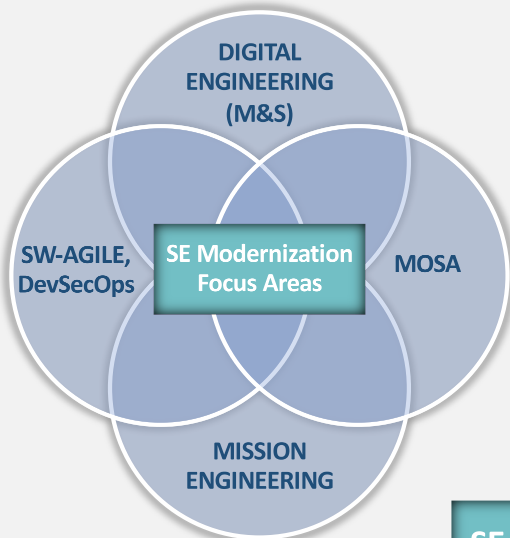
- **Standards** – Identify standards and specifications which facilitate modularity and openness
- **Architecture** – Rely on architectures accessed from authoritative sources of truth
- **Interfaces** – Acquire systems with modular system interfaces
- **Data Rights** – Use relevant technology forecasts to identify and appropriate technical data rights



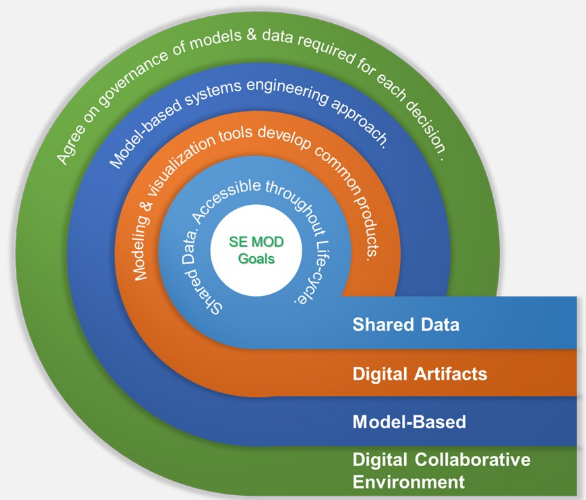
By using modular design techniques, open standards, and architectures that enable open systems, programs can achieve MOSA benefits

Modernizing our SE

SE Modernization Focus Areas



SE Modernization Goals



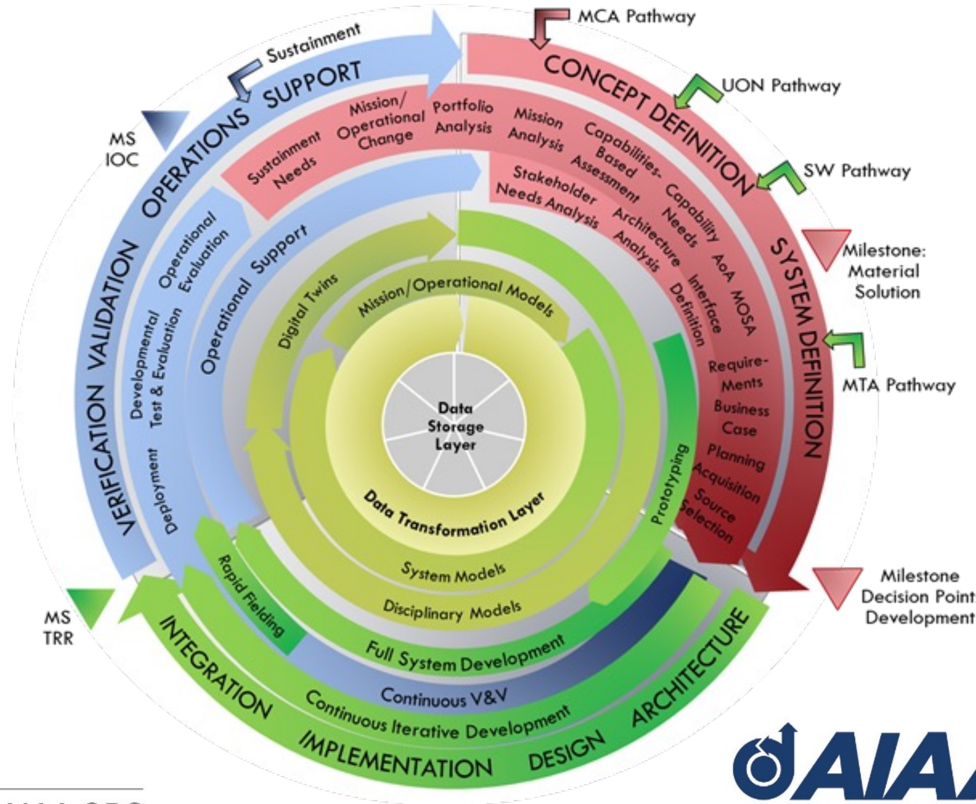
SE Modernization Problem Statement

Challenge: DoD lacks an **<u>integrated approach</u>** to implementing a digital transformation, including digital practices, processes, and artifacts, within the systems engineering focus areas, which in turn delays the ability of programs to develop the processes, skills, and training required to deliver a robust, disciplined approach to weapon system acquisition.

New Model for SE in a Fully Digital & Iterative World

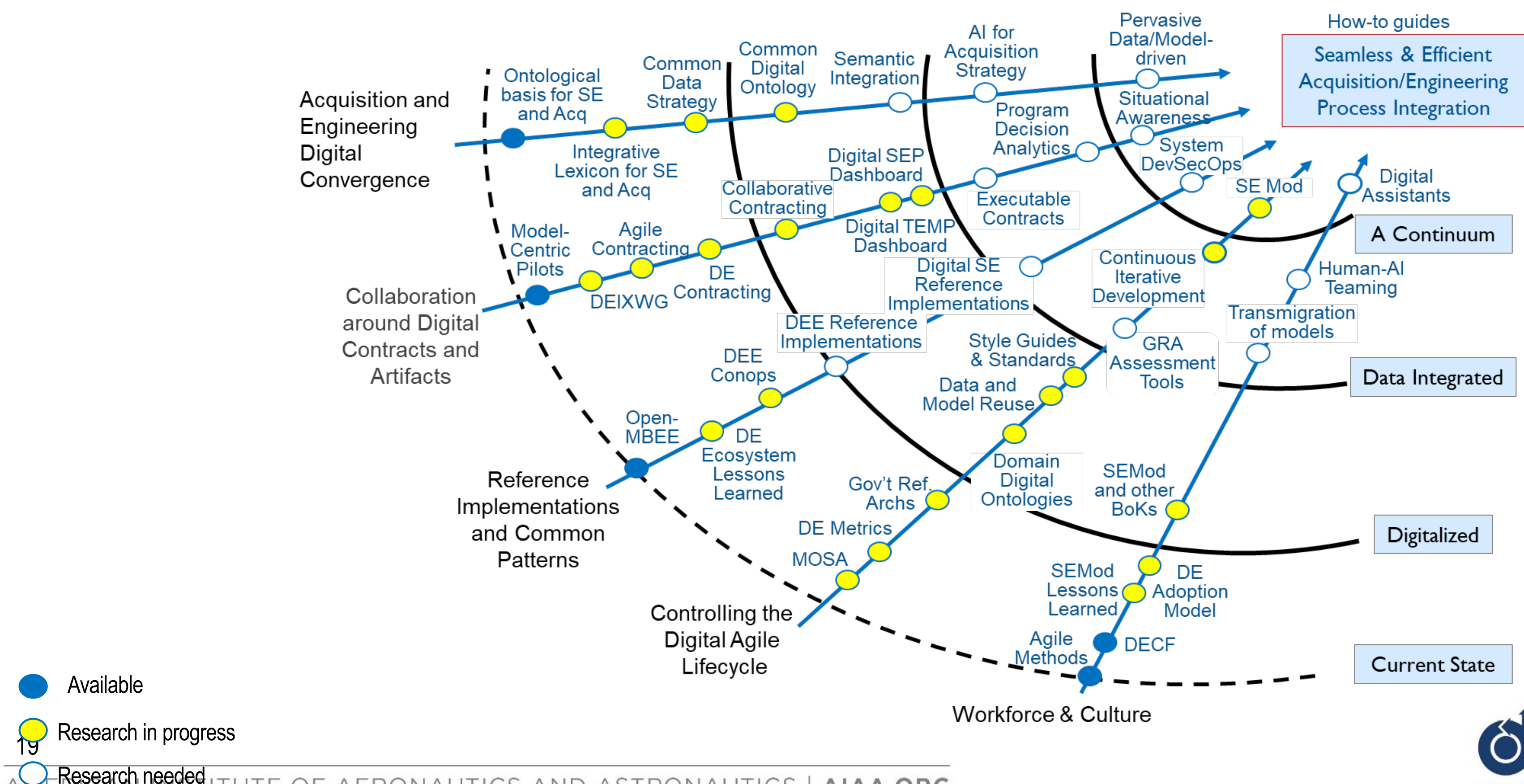
- Cyclic nature of modern SE
- Still milestone-based
- SE core principles in every Acq pathway
- Flexible system life cycle entry points:
  Learn-Build-Measure (MCA)
  Build-Measure-Learn (Mid-Tier, SW, UON)
  Measure-Learn-Build (Sustainment)
- Continuous Iterative Development processes (around the circle)
- Continuous Data Management and Transformation processes (at the core)

Learn	Needs analysis & Planning
Build	Implementation
Measure	Test, Evaluation, Support
	Data & Models



AIAA SHAPING THE FUTURE OF AEROSPACE

Draft Digital SE Modernization Roadmap

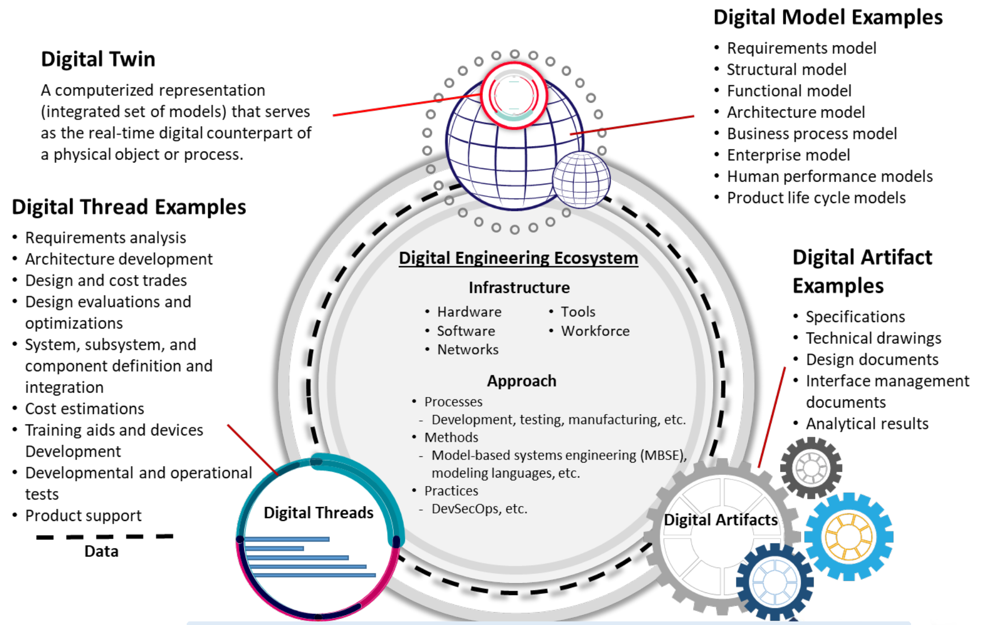


DoD INSTRUCTION 5000.97, "DIGITAL ENGINEERING"

Purpose: The Department of Defense is transforming its engineering practices to incorporate digital technology and innovations into an integrated, digital, model-based approach. This instruction establishes policy, assigns responsibilities, and provides procedures for implementing and using digital engineering in the development and sustainment of systems.

This policy directs:

- Programs started after the date of the policy will incorporate digital engineering during development unless the program's decision authority provides an exception.
- Programs started before the date of the policy should incorporate digital engineering, to the maximum extent possible, when it is practical, beneficial, and affordable.
- Digital engineering should be addressed in the Acquisition Strategy and in the Systems Engineering Plan.
- Digital engineering methodologies, technologies, and practices support a comprehensive engineering program for defense systems.



Data management should a ... ble, and secure.

Digital engineering transforms DoD systems engineering practice.

Modernizing our Systems Modeling Language

SysML v2 Transition Guide

- SysML V2 is a significant change from SysML V1
- Getting in front of this change presents an opportunity to do better
- Using the Skyzer Model to test implementation
- Accelerate adoption and improve practice consistency when v2 releases

DEC 2022
Project Kickoff

JAN 2023
Workshop 1 INCOSE IW

MAR 2023
OMG TIM

MAY 2023
FAQ Draft

JUN 2023
SysML V2 Transition Guide Outline

AUG 2023
Publish FAQ

OCT 2023
Initial Draft SysML V2 Transition Guide

DEC 2023
Final Draft SysML V2 Transition Guide

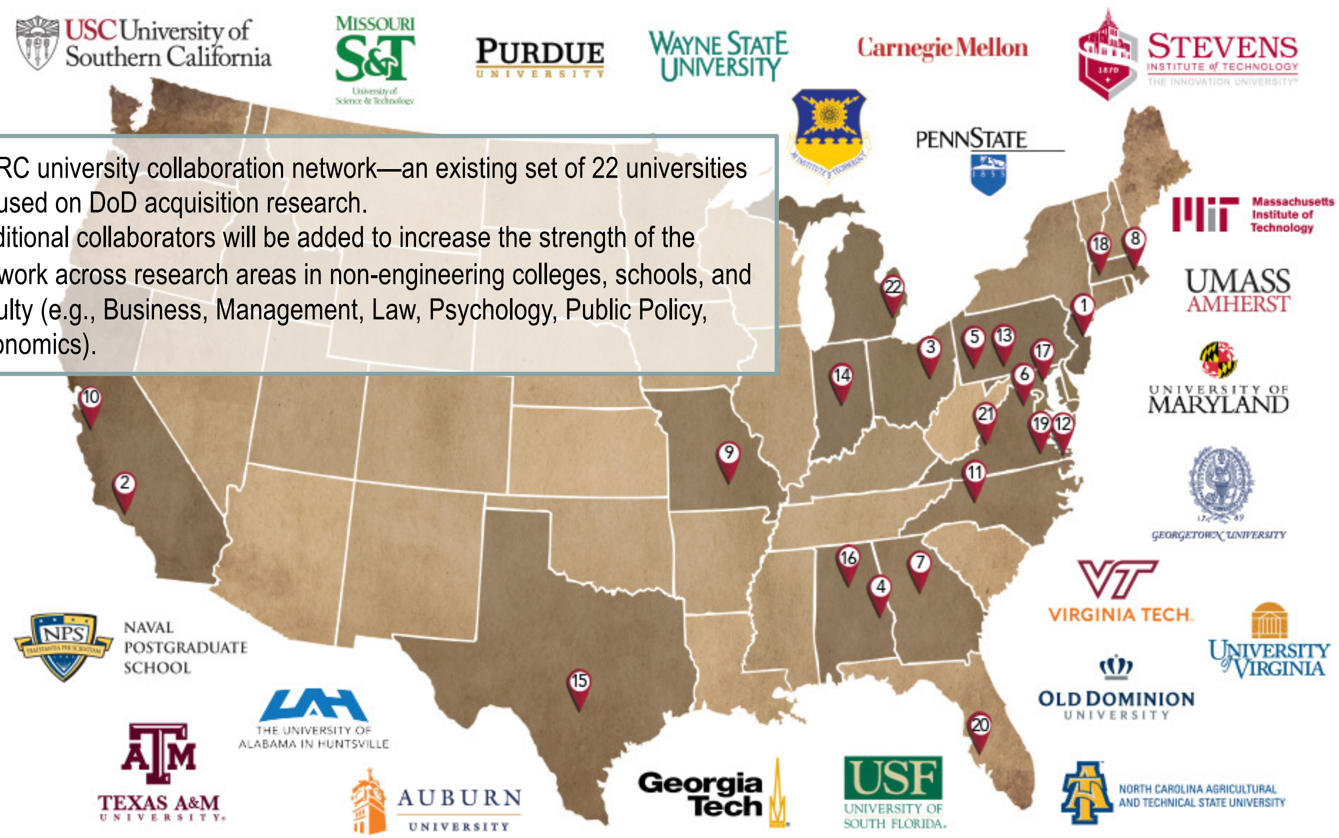
MAR 2024
Published SysML V2 Transition Guide

15,000+
models in DoD
Based on sampling counts of government owned ecosystems

25%
DoD engineers use models
Based on reported data and user assumptions of those ecosystems

Systems Engineering Research Center (SERC)

University Network



- SERC university collaboration network—an existing set of 22 universities focused on DoD acquisition research.
- Additional collaborators will be added to increase the strength of the network across research areas in non-engineering colleges, schools, and faculty (e.g., Business, Management, Law, Psychology, Public Policy, Economics).

- Only University Affiliated Research Center (UARC) for Systems Engineering funded at the DoD level – USD(R&E)
- Stevens Institute leads the network of universities
- Addresses all government acquisition and systems engineering, education, research, and practice

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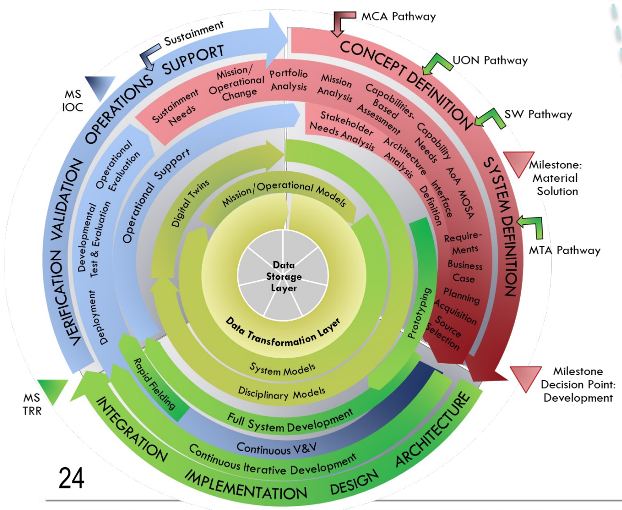
https://ac.cto.mil/engineering

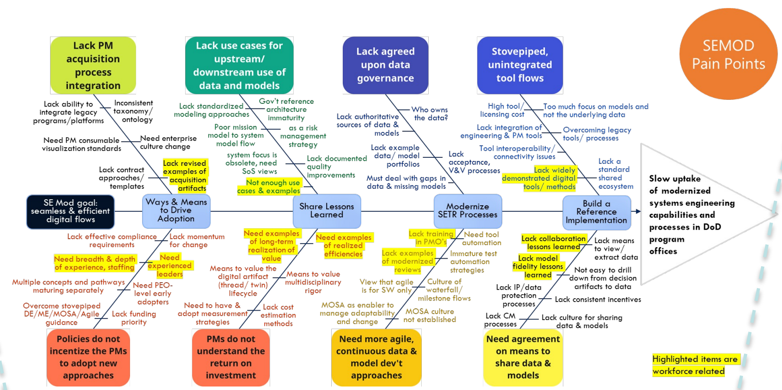
What?

How?

Why?

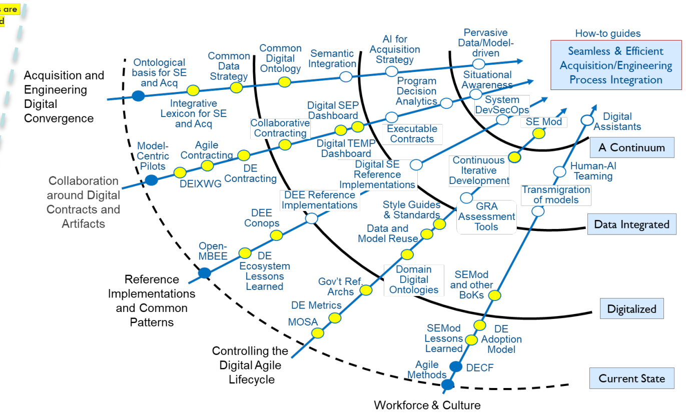
We envisioned a new mental model for systems engineering in a fully digital, iterative world





We captured a set of interrelated issues/ pain points/ challenges to implementation of this mental model

We drafted a roadmap of developmental needs and recommendations to improve the uptake of modernized systems engineering



June 2023

SHAPING THE FUTURE OF AEROSPACE

Task 4: Autonomy Mission Metrics in the System Engineering Process

Task 4: Problem

- Problem:
  - It is a strongly-held belief that autonomous systems will be much more capable, effective and trustworthy if autonomy is architected into our systems, rather than "bolted on". Unfortunately, rigorous architecting of autonomy capabilities is rare in our business, and there are no associated systems engineering methodologies that are widely adopted.
- Need:
  - In order to architect systems for greater autonomy*, systems engineers need to have a good understanding of the system use cases that are drivers for such capability.
- Solution:
  - Autonomous system use cases must be analyzed to extract the specific *mission needs, requirements and constraints* that will shape the architecture, and motivate the infusion of capabilities/technologies that meet these specifications.
  - Analysis and assessment of a proposed architecture requires a set of *metrics (measures of effectiveness)* that are specific to the use case.

** Very broad scope of autonomy, ranging from onboard automation to fully autonomous operations*

Task 4: Current Work

- **Methodology:**
  - Core team developed a template and an initial small set of example use cases for space and aviation.
  - Space Autonomy Use Case Workshop at ASCEND 2023, focused on developing:
    - a set of reference missions enabled by the availability of greater autonomy,
    - the constraints and requirements for these missions (as drivers for system autonomy capabilities), and
    - the metrics used to assess mission success.
  - The reference mission set represents different segments of the space community (e.g., robotic exploration, human exploration, defense, and commercial space), enabling discussion of similarities and differences across segments.
- **Outcomes (to date):**
  - Use case summaries for 16 reference space missions and 2 aviation scenarios
    - See 5 example use cases, on the following slides

Space Use Case Example #1: Long-Range Roving on Planetary Surfaces

- **Key Stakeholder(s)**: NASA Science Mission Directorate (Planetary Science), Planetary science community
- **Category**: Robotic Exploration
- **Title**: Endurance Long-range Lunar Mission from Planetary Science and Astrobiology Decadal Survey
- **Short Description**: A long-range, time-limited science/exploration mission to address the highest priority lunar science, revolutionizing our understanding of the Moon and the history of the early solar system recorded in the most ancient lunar impact basin. The mission would collect ~100 kg of samples in a ~1000 km traverse across diverse terrains in the South Pole Aiken basin, and deliver the samples for return to Earth by astronauts.
- **Main Assumptions**: Utilize Commercial Lunar Payload Services for delivery to the lunar surface
- **Driving Needs/Requirements**: Both daytime and nighttime driving; high-speed (autonomous) driving; minimal downtime due to mission anomalies.
- **Related Metrics**: average traverse speed; number and duration of anomaly resolutions (availability); number of anomalies requiring ground-in-the-loop resolution (resilience)
- **References**: https://www.nasa.gov/sites/default/files/atoms/files/kearns_nesc_unique_artemis_science_workshop_2022-06-07_v2.pdf, https://nap.nationalacademies.org/catalog/26522/origins-worlds-and-life-a-decadal-strategy-for-planetary-science

Space Use Case Example #2: Distributed Space Telescope

- **Key Stakeholder(s)**: NASA Science Mission Directorate (Astrophysics), Astrophysics science community, DoD, planetary defense
- **Category**: Robotic Exploration, Defense
- **Title**: Distributed Space Telescope (Lagrange point)
- **Short Description**: A future space telescope for high-resolution observations, composed by synthesizing an aperture from distributed elements.
- **Main Assumptions**: Serious digital signal processing, high-precision coordination and metrology (varies by observing wavelength), hundreds of meters physical span
- **Driving Needs/Requirements**: Wavelength, precision pointing, precision formation maintenance, communications latency/synchronization, edge computing implications for signal processing, opportunistic science
- **Related Metrics**: size of aperture, achievable resolution, position accuracy, number of vehicles, computational loads, availability of instrument, responsiveness to an observed signal of interest
- **References**:

Space Use Case Example #3: Earth Observing Sensor Webs

- **Key Stakeholder(s)**: NASA Science Mission Directorate (Earth Science), Industry (commercial remote sensing), Intelligence Community, DoD
- **Categories**: Commercial, Defense, Robotic Exploration
- **Title**: Earth Observing Sensor Webs
- **Short Description**: A dynamic and self-coordinating network of context-aware heterogeneous sensors in space, air, or on the ground, with autonomous data processing, and decision-making abilities would revolutionize our ability to respond to events of interest of both scientific and societal interest (e.g., natural disasters, or short-lived scientific processes).
- **Main Assumptions**: Constant and low-latency comms through Iridium or similar
- **Driving Needs/Requirements**: High throughput data processing, responsiveness, scalability, flexibility, inter-operability, affordability, evolvability.
- **Related Metrics**: Response time, #events of interest detected per unit time, operational costs
- **References**: Viros Martin, A., Cheng, K., Fang, A., Zheng, Z., Kress-Gazit, H., Mehta, A., ... & Sun, Y. (2021). Decentralized context-based on-board planning for earth observation missions. In *AIAA Scitech 2021 Forum* (p. 1469).

Space Use Case Example #4: Cislunar Space Domain Awareness

- **Key Stakeholder(s)**: NASA Exploration Systems and Space Operations Mission Directorates, Space Force, Industry, Intelligence Community
- **Category**: Human Exploration, Defense
- **Title**: Cislunar Space Domain Awareness
- **Short Description**: Sensing and awareness of activity on lunar surface, and in lunar orbit, including L1 and L2 Lagrange points
- **Main Assumptions**: Reasonable transportation costs; low SWAP; high processing capability; data products transmitted, not raw data; commercial and noncommercial capabilities; classified and unclassified data; power available
- **Driving Needs/Requirements**: deciding what to process, what to transmit; infrastructure: PNT, comm, power, logistics; mobility on orbit and on surface; fast on-board processing for sensors and autonomy; fault tolerance; radiation tolerance
- **Related Metrics**: # of objects/targets tracked, # of custody hand-offs, accuracy and precision of tracking, revisit times, identification time
- **References**:

Space Use Case Example #5: Smart Habitat for Space Travel/Leisure

- **Key Stakeholder(s)**: NASA Human Spaceflight Programs, commercial exploration
- **Category**: Human Exploration, Commercial
- **Title**: Smart habitats for space travel & leisure applications
- **Short Description**: Orbiting hotel for space tourists (eventually, on lunar/planetary surface)
- **Main Assumptions**: Mission duration, resupply frequency, crew size, and other key parameters will be as given by current plans (e.g., design reference missions).
- **Driving Needs/Requirements**: Maintenance, safety, fault detection & diagnosis, cleanliness, UX, natural language interface
- **Related Metrics**: function availability; comfort metrics; user-friendliness; risk transparency to tourists/astronauts; fault tolerance, availability of backup systems; time to return to Earth; responsiveness of onboard system to anomalies; cost per trip; turnover time – cost to refurbish between visitors; amount of advanced warning from prognostics
- **References**:

- Falco, Gregory. "Autonomy's Hierarchy of Needs: Smart City Ecosystems for Autonomous Space Habitats." *2021 55th Annual Conference on Information Sciences and Systems (CISS)*. IEEE, 2021.
- Rollock, Annika E., and David M. Klaus. "Defining and characterizing self-awareness and self-sufficiency for deep space habitats." *Acta Astronautica* 198 (2022): 366-375.

Aviation Use Case Example: Flight Deck Digital Assistance

- **Key Stakeholder(s)**: OEMs, Avionics Manufacturers, Commercial Operators, Defense Operators, General Aviation, Regulators
- **Short Description**: The use of a variety of decision aids both integrated and non-integrated (e.g., Electronic Flight Bags) that assist flight crews with performance of their tasks which will reduce cognitive workload, catch errors, and improve decision-making (e.g., speed of decisions, expansion of options considered) resulting in increased safety and efficiency of flight operations. Could include memory aids/reminders, anticipatory information retrieval, monitors/alerts, calculators, warnings, etc. leveraging intuitive interfaces including voice recognition.
- **Main Assumptions**: Appropriate information can be stored, and voice recognition capabilities can meet performance requirements.
- **Driving Needs/Requirements**: Voice recognition, real-time connectivity to necessary information, integration with aircraft telemetry and systems information, processing power
- **Related Metrics**: Cognitive workload reduction, Improvements in the quality of decisions (how much safer are the decisions), Error reductions
- **References**:

Kevin Burns, Craig Bonaceto, Steven Estes, John Helleberg; *Evaluating the Operational Safety of a Digital Copilot;* Cognitive Assistance in Government and Public Sector Applications AAAI Technical Report FS-17-02; https://cdn.aaai.org/ocs/15983/15983-69873-1-PB.pdf

Steinfeld, A., Quinones, P., Zimmerman, J., Bennett, S., and Siewiorek, D.2007. Survey Measures for Evaluation of Cognitive Assistants. Proceedings of the NIST Performance Metrics for Intelligent Systems Workshop, 189-193. Washington, DC.

Space use cases of autonomy (examples)

1. Long-range roving on planetary surfaces {civil}
2. Ocean World (e.g., Europa/Enceladus) surface/subsurface exploration {civil}
3. Planetary rotorcraft at places like Mars or Titan {civil}
4. Distributed space telescope {civil, defense}
5. Autonomous management of increasingly congested space {civil, defense, commercial}
6. Autonomous in-space servicing, assembly and manufacturing (ISAM) of satellites {civil, defense, commercial}
7. Earth observing sensor webs, e.g., for rapid autonomous response to natural disasters like floods/wildfires {civil, defense, commercial}
8. Smart habitats (Cislunar space stations and surface habitats) {civil, commercial}
9. AI assistant robot to support astronauts inside crewed spacecraft {civil, commercial}
10. Autonomous robots for surface operations (e.g., ISRU, assembly of structures) {civil, commercial}
11. Autonomous operations of communications and navigation infrastructure in cis-lunar/deep space {civil, commercial}
12. Management of long-duration human cruise, e.g., for Mars transit {civil}
13. Intelligence Community reconnaissance satellites {defense}
14. In-space Surveillance (satellite-to-satellite) [similarities with autonomous ISAM case above] {civil, defense, commercial}

Aviation use cases of autonomy (examples)

1. Unmanned cargo transportation {civil, defense, commercial}
2. Small drone over-the-horizon scouting {defense}
3. High-Altitude Long Endurance (HALE) aka HAPS {civil, defense, commercial}
4. Drone delivery services {commercial}
5. Reduce crew civil passenger air transport {civil, commercial}
6. Simplified Vehicle Operations / Unified Flight Controls {civil, defense, commercial}
7. Automatic aircraft safety systems (e.g., Auto-GCAS, Garmin Autonomi-Autoland) {civil, defense, commercial}
8. In-time Aviation Safety Management Systems {commercial}
9. Digital Flight Operations (automated operator-responsible separation capabilities) {civil, defense, commercial}
10. Flight Deck Digital Assistance (e.g., Digital Co-pilots) {civil, defense, commercial}
11. Multi-vehicle operations {civil, defense, commercial}
12. Loyal Wingman {defense}
13. Automated flight management for unmanned aircraft contingencies (e.g., lost c2 link) {civil, defense, commercial}
14. Beyond Visual Line of Sight Operations by Unmanned Aircraft {civil, defense, commercial}

Task 4: Next Steps

- Next Steps Within Task Force:
  - Further analysis of use case inputs from Space Autonomy Use Case Workshop at ASCEND 2023; extraction of specific mission needs, requirements and constraints, and metrics (measures of effectiveness); mapping to autonomy capability/technology needs
  - Synthesis of key patterns from the collected data
  - Conduct similar Workshop focused on Aviation use cases (possibly at Aviation 2024), and ensuing analysis/synthesis
  - Publication of report with findings
- Proposals for wider AIAA:
  - Target future Forum content on collection of mission data to assess per these metrics, and on the identified autonomy capability/technology needs