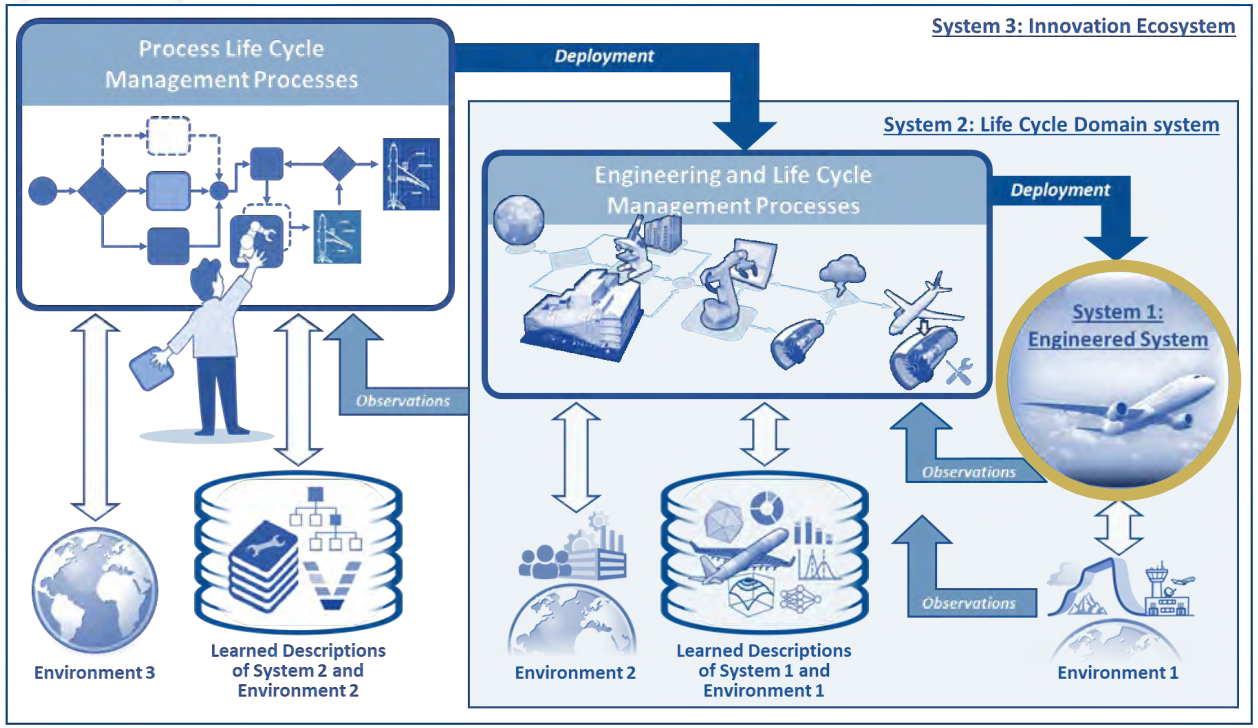
Digital Engineering For Transformative Aerospace

Olivia J. Pinon Fischer, Ph.D.

Assistant Professor
Daniel Guggenheim School of Aerospace Engineering
Georgia Institute of Technology

Industry Challenges & Research Context

The imperative for digital engineering



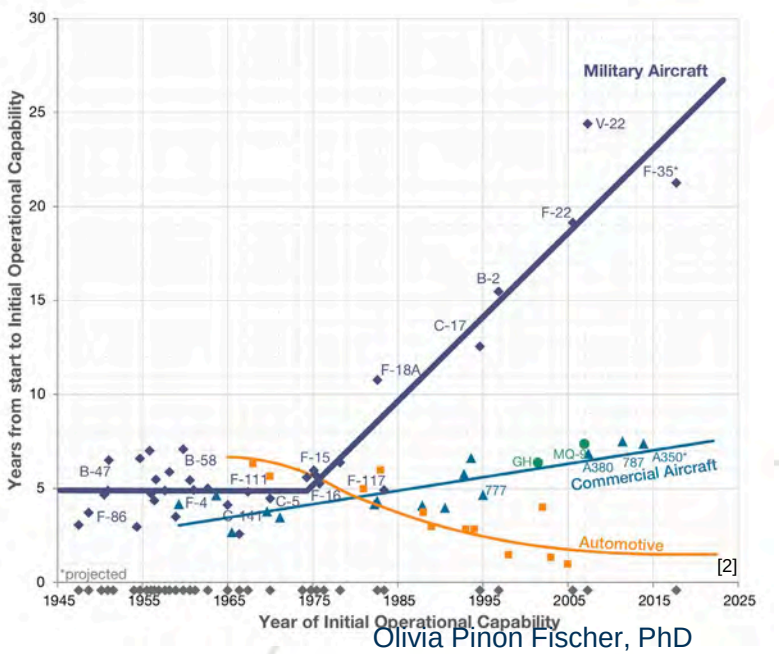
System 3: Lifecycle managers of System 2: Observation, Improvement, Deployment, etc.

System 2: Lifecycle managers of System1: Engineering, Production, Sustainment, etc.

System 1: The Engineered System


[4]


[3]

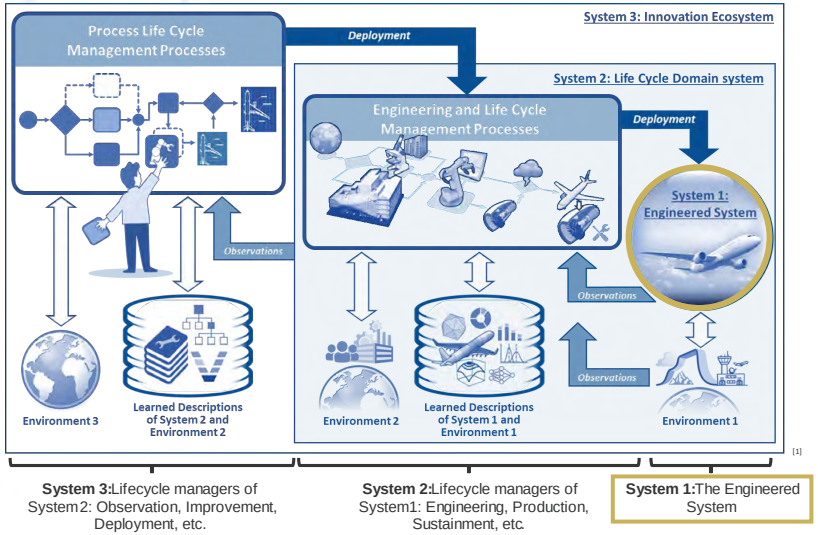


[2]

[1] Schindel, William D. "Realizing the Value Promise of Digital Engineering: Planning, Implementing, and Evolving the Ecosystem." *INSIGHT* 25, no. 1 (2022): 42-49.
[2] Dan Patt, Time-to-Market: A DARPA study on Capability Fielding (Washington, DC: DARPA, 2013 Internal Report).
[3] https://www.twz.com/air/construction-of-first-collaborative-combat-aircraft-drone-has-begun-at-general-atomics
[4] https://www2.deloitte.com/us/en/insights/industry/aerospace-defense/decarbonizing-aerospace.html

Industry Challenges & Research Context

The imperative for digital engineering

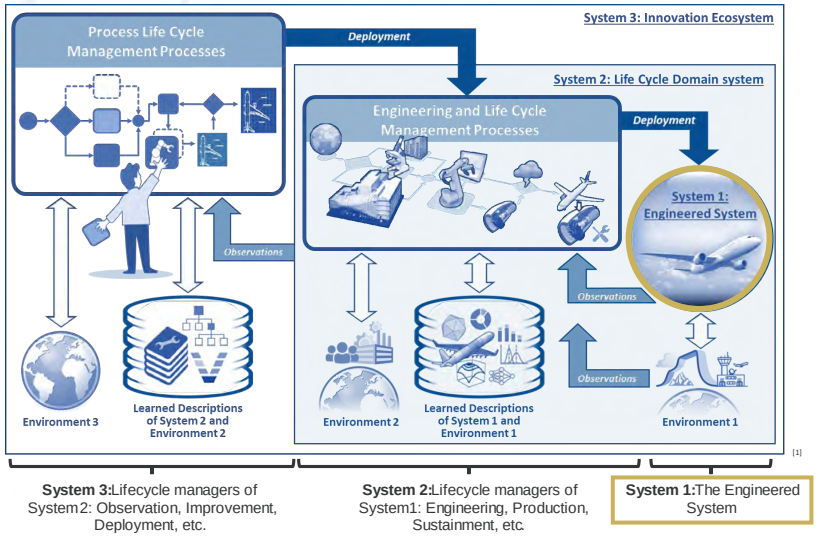


"…**engineers spend less than half their time on "legitimate design acts"** with the remainder devoted to resolving ambiguity, determining what must be known, and how to work with others (Bucciarelli 1988). The **cost of collaboration is even higher** when considering the total team effort incurred as person-time." [4]

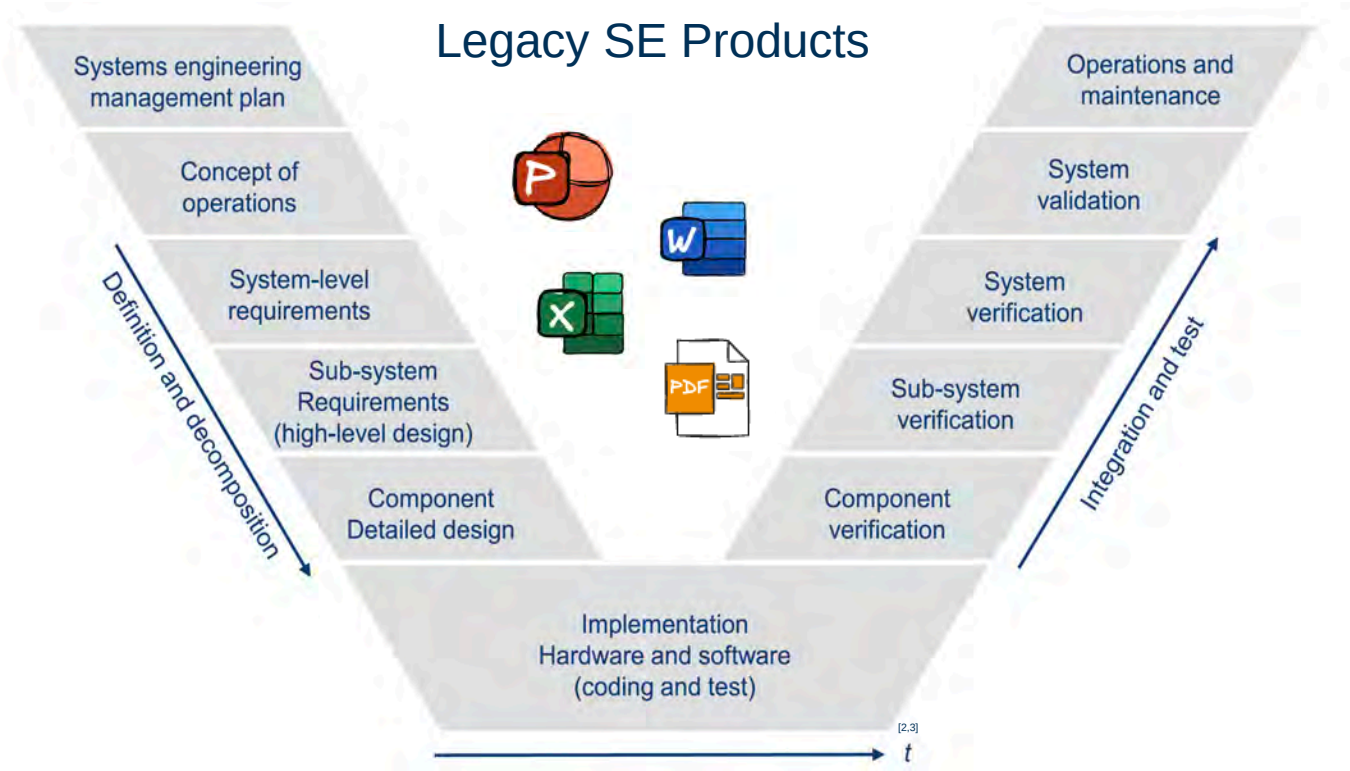
[1] Schindel, William D. "Realizing the Value Promise of Digital Engineering: Planning, Implementing, and Evolving the Ecosystem." *INSIGHT* 25, no. 1 (2022): 42-49.
[2] Voth, J. M., & Sturtevant, G. H. (2022). Digital engineering: expanding the advantage. *Journal of Marine Engineering & Technology*, *21*(6), 355-363.
[3] Aerospace Workshops, Digital Engineering Overview, July 2024
[4] Grogan, P. T., & de Weck, O. L. (2016). Collaboration and complexity: an experiment on the effect of multi-actor coupled design. Research in Engineering Design, 27(3), 221-235.

Industry Challenges & Research Context

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System knowledge resides in **discrete**, **static** and **stove-piped products** (drawings, pdfs, slides, etc.) [3]



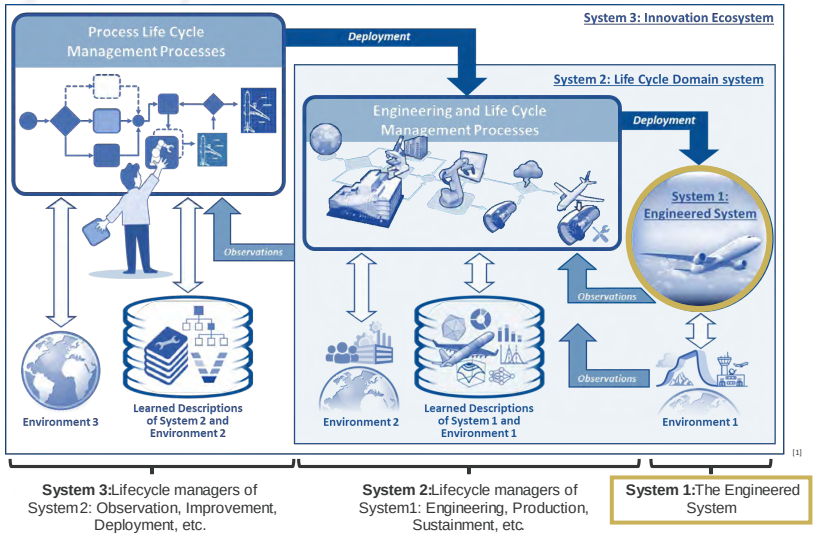
The Systems Engineering Vee

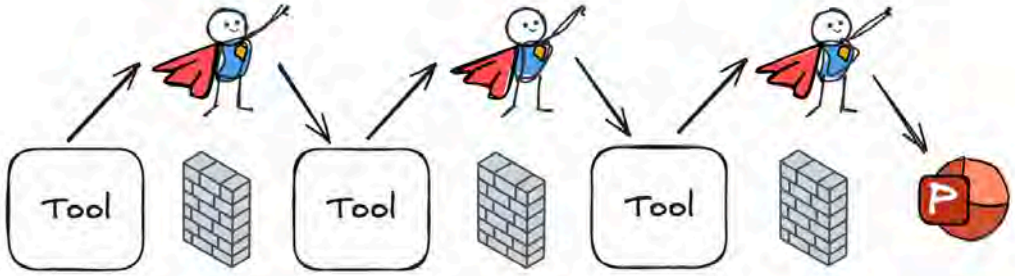
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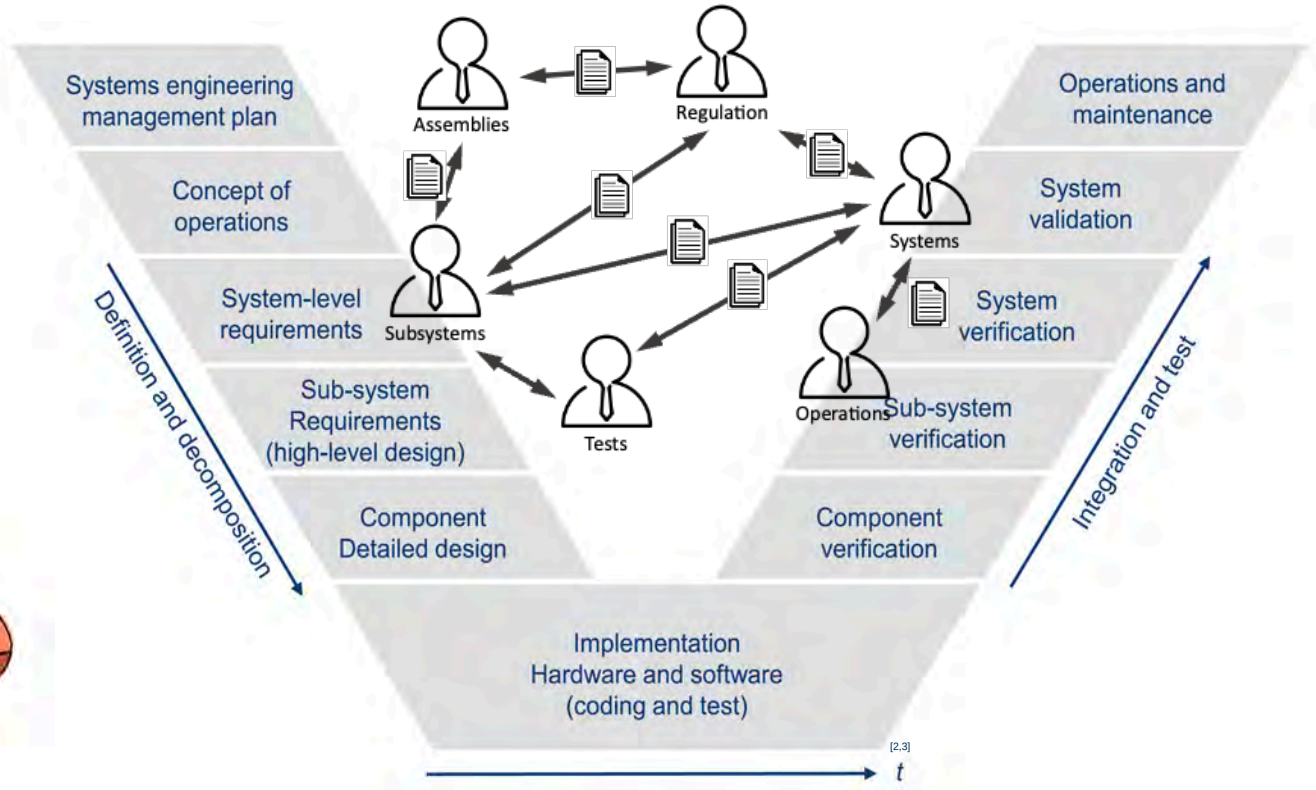
Industry Challenges & Research Context

The imperative for digital engineering





Document-Centric: communication of requirements, system data, processes and other artifacts done primarily through various forms of documents.



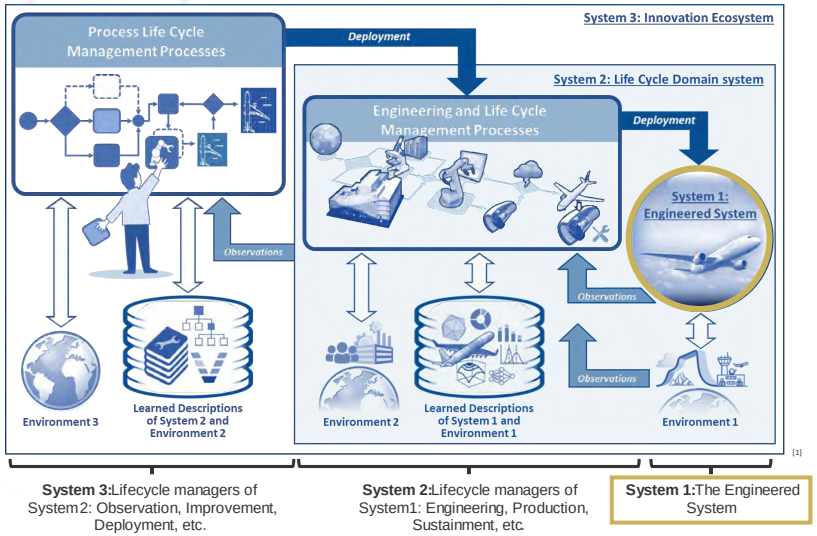
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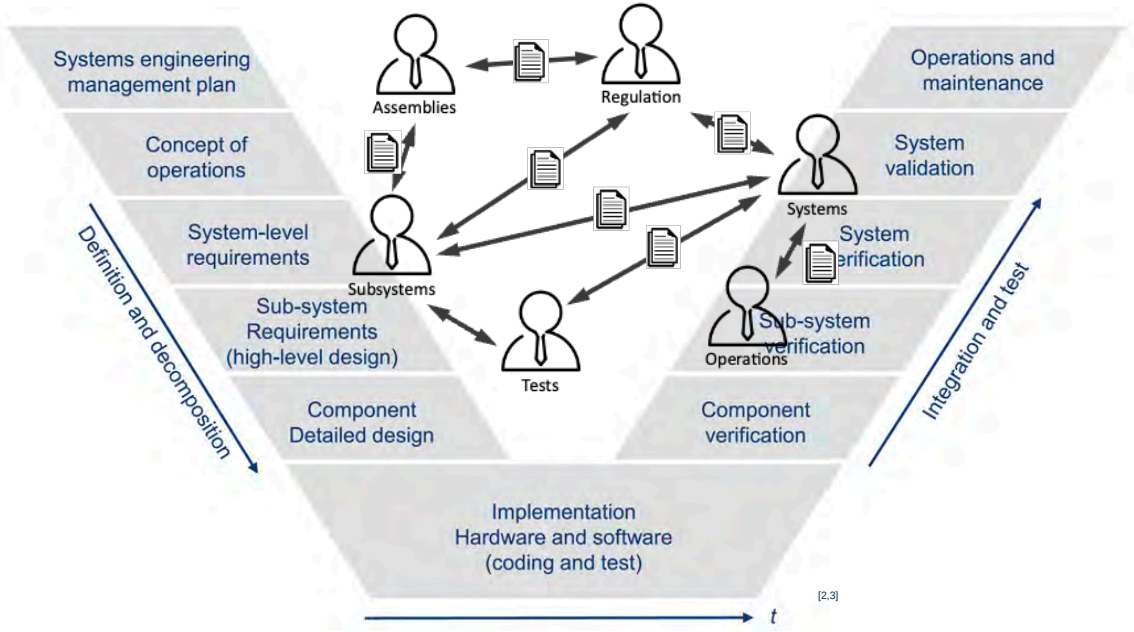
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[2] Voth, J. M., & Sturtevant, G. H. (2022). Digital engineering: expanding the advantage. *Journal of Marine Engineering & Technology*, *21*(6), 355-363.
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Industry Challenges & Research Context

The imperative for digital engineering





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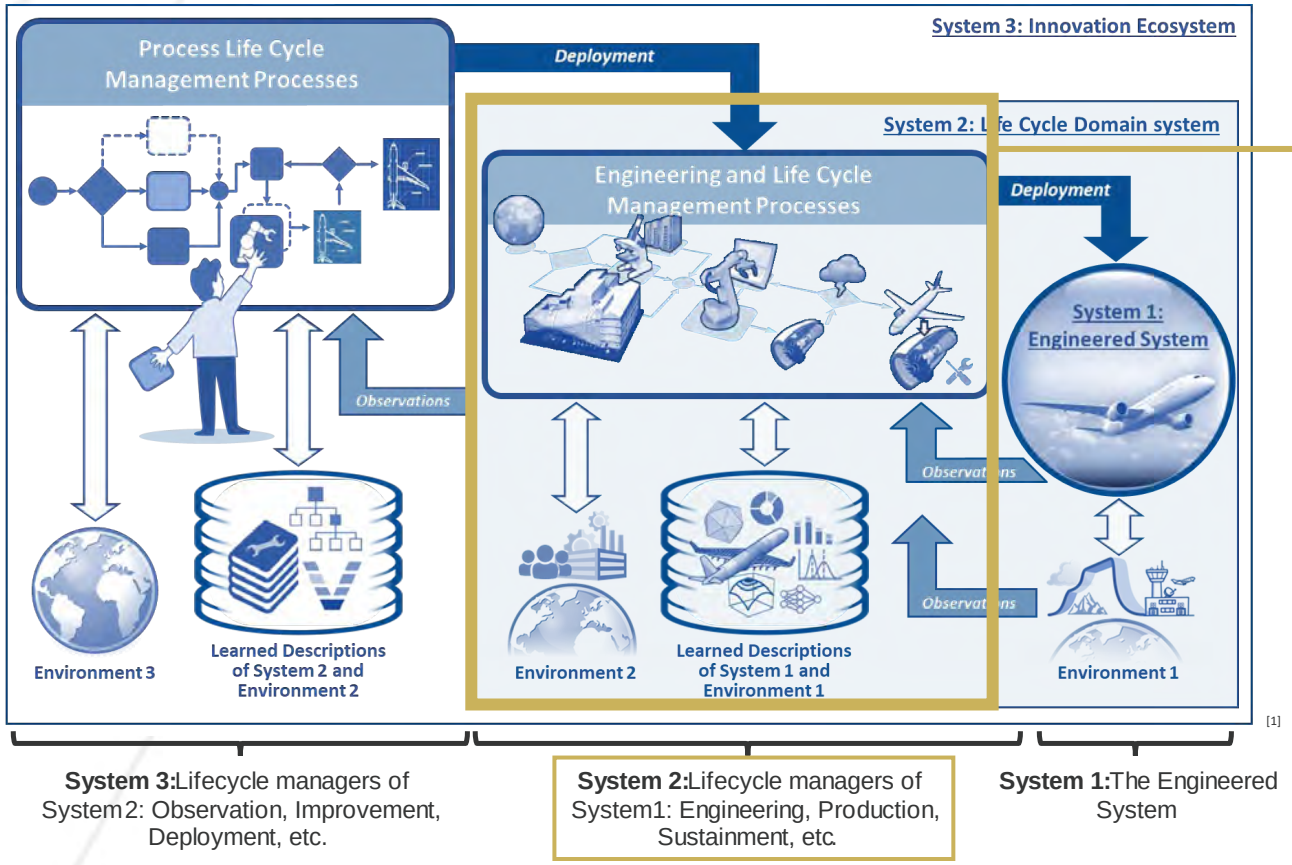
TRAC ILITY

[1] Schindel, William D. "Realizing the Value Promise of Digital Engineering: Planning, Implementing, and Evolving the Ecosystem." *INSIGHT* 25, no. 1 (2022): 42-49.
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Industry Challenges & Research Context

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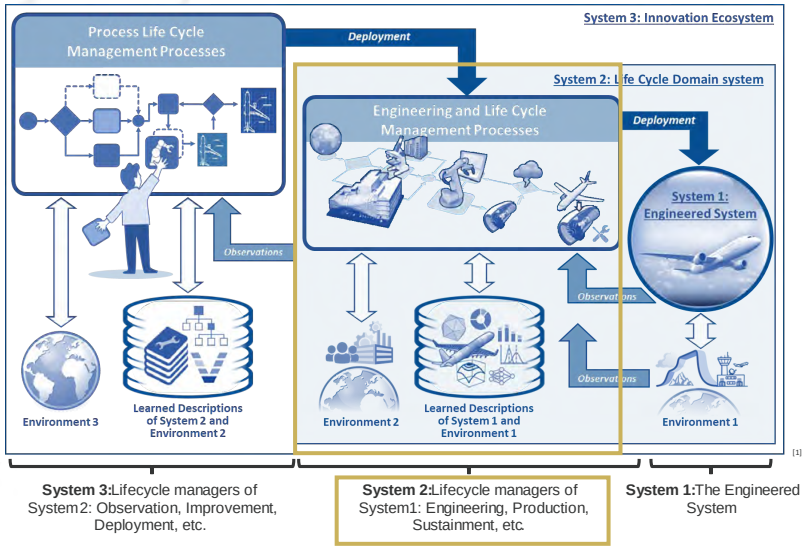


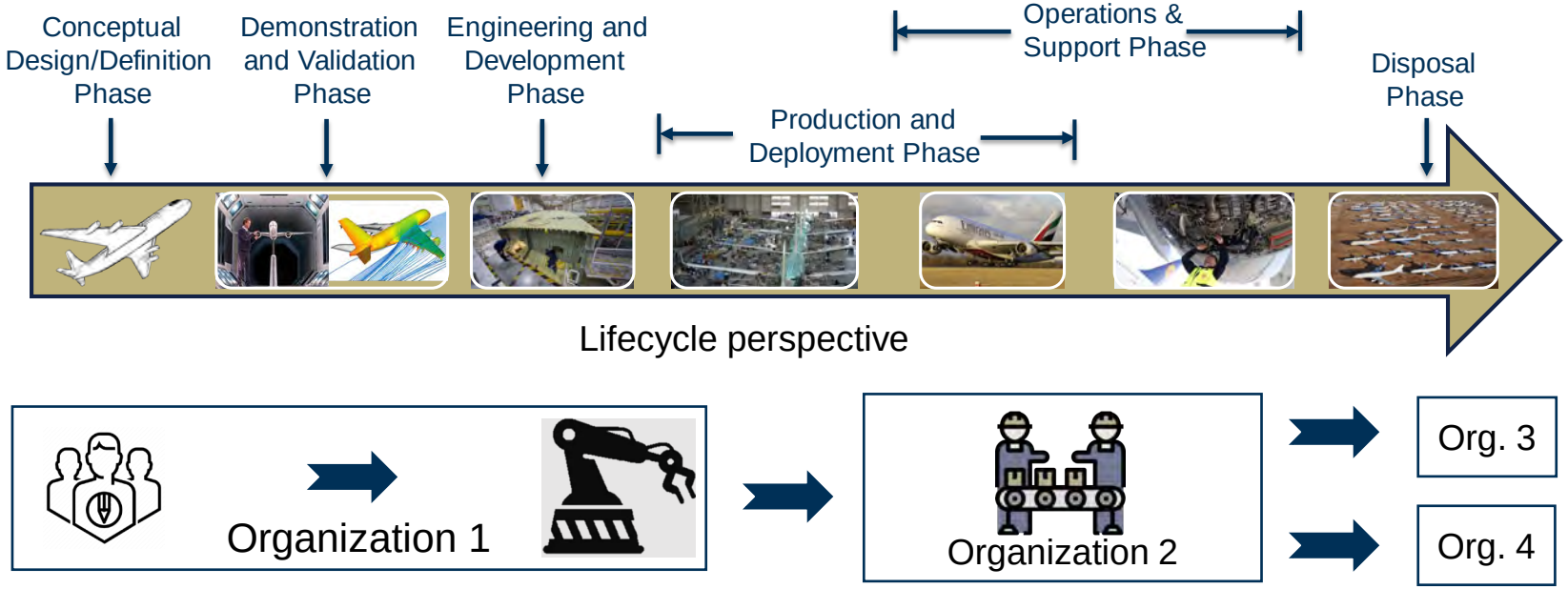
The distributed network of **organizations**, **processes**, **data**, **models**, and **governance structures** that collectively define how systems are developed, validated, produced, deployed, and improved [1].

[1] Schindel, William D. "Realizing the Value Promise of Digital Engineering: Planning, Implementing, and Evolving the Ecosystem." *INSIGHT* 25, no. 1 (2022): 42-49.
[2] Grogan, P. T., & de Weck, O. L. (2016). Collaboration and complexity: an experiment on the effect of multi-actor coupled design. Research in Engineering Design, 27(3), 221-235.

Industry Challenges & Research Context

The imperative for digital engineering





Exchange/Hand-off of data and models occurs at every phase

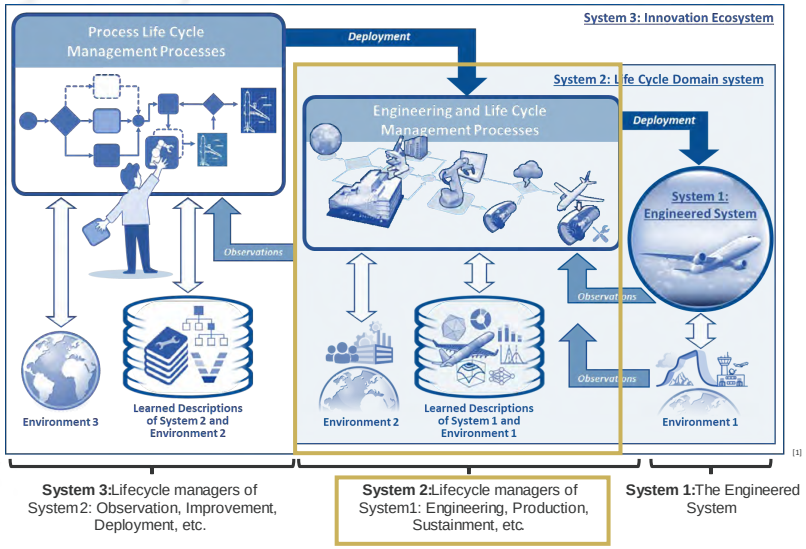
- Within organizations and across different organizations

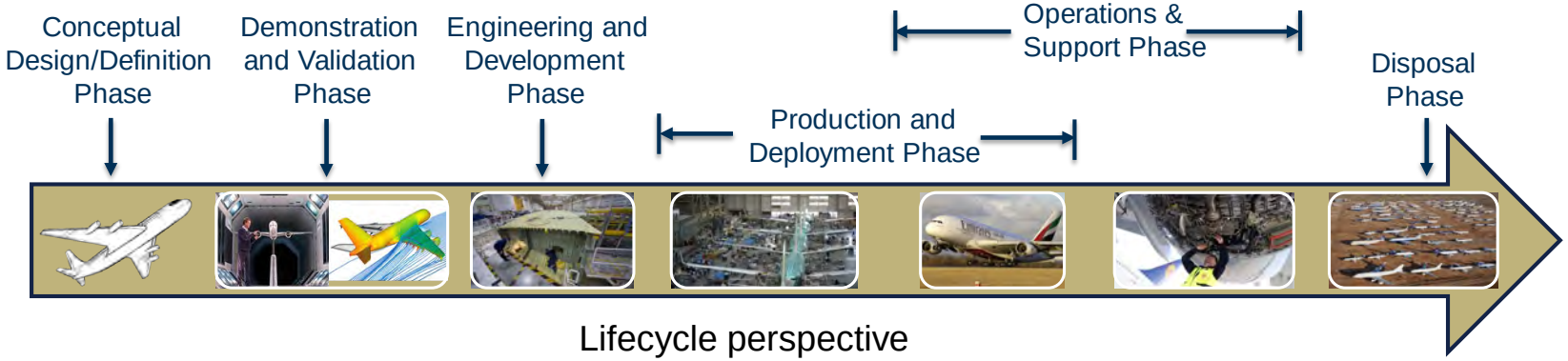
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Industry Challenges & Research Context

The imperative for digital engineering





Lack of digital continuity leads to

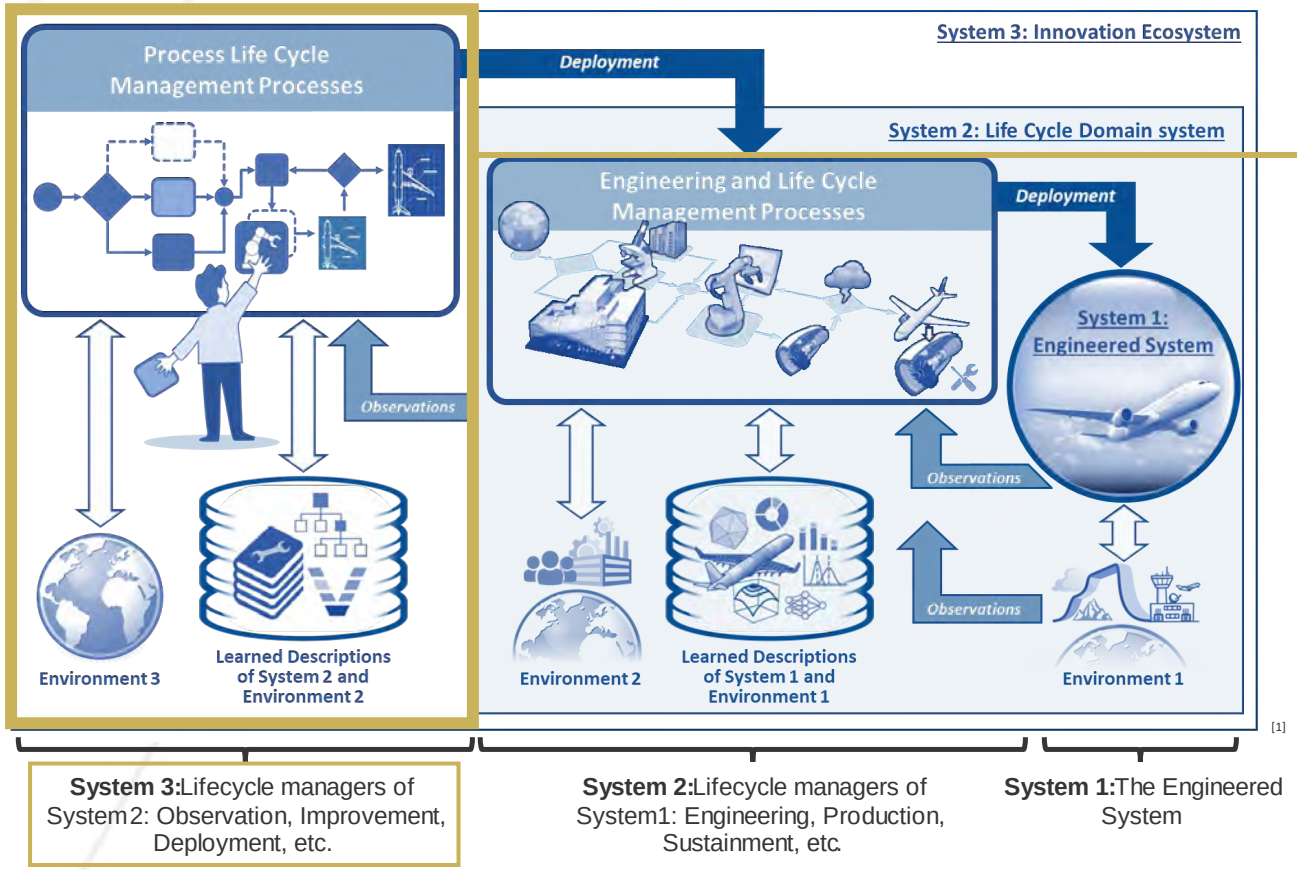
- Lack of visibility [2]
  - Demand visibility for supply chain
  - Supply capability/capacity visibility for customers
- Slow response to sudden demand changes [2]
- Issues arise when information is inconsistent between OEM and suppliers → Impact on part quality, lead times → Rework, etc.

[1] Schindel, William D. "Realizing the Value Promise of Digital Engineering: Planning, Implementing, and Evolving the Ecosystem." *INSIGHT* 25, no. 1 (2022): 42-49.
[2] AIAA Digital Engineering Integration Committee, *Digital Thread for Supply Chain*, January 2025

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Industry Challenges & Research Context

The imperative for digital engineering



System 3: Lifecycle managers of System 2: Observation, Improvement, Deployment, etc.

System 2: Lifecycle managers of System1: Engineering, Production, Sustainment, etc.

System 1: The Engineered System

The **Innovation Ecosystem:** definition and advancement of engineering, production, support, scientific methods [1]

29% of hardware engineering cost is spent on data wrangling [2]

[1] Schindel, William D. "Realizing the Value Promise of Digital Engineering: Planning, Implementing, and Evolving the Ecosystem." *INSIGHT* 25, no. 1 (2022): 42-49
[2] Istari Digital, SciTech 2026, Orlando, FL.

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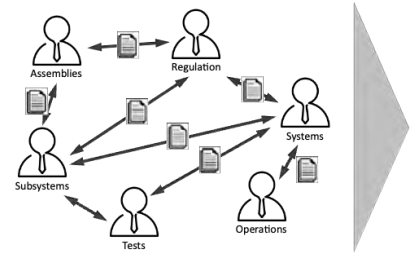
Digital Engineering



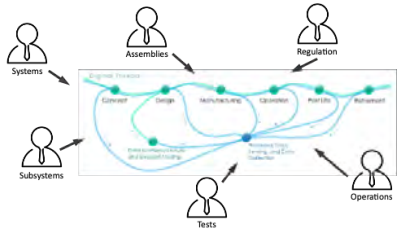
"An integrated digital approach that uses **authoritative sources of system** data and models as a **continuum** across disciplines to support lifecycle activities from concept through disposal." [1]

The formalization and institutionalization of **modeling as a primary, lifecycle-spanning engineering approach**

→ better traceability, consistency,
→ improved cross-stakeholder collaboration

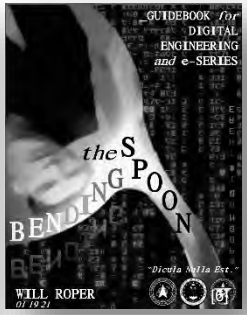


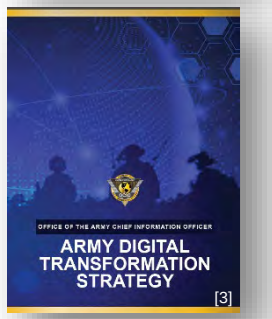
Document-Centric: communication of requirements, system data, processes and other artifacts done primarily through various forms of documents.



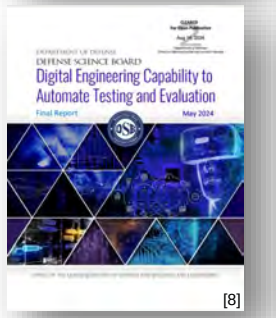
Model-Centric: Communication of requirements, system data, processes and other artifacts is done primarily through models.













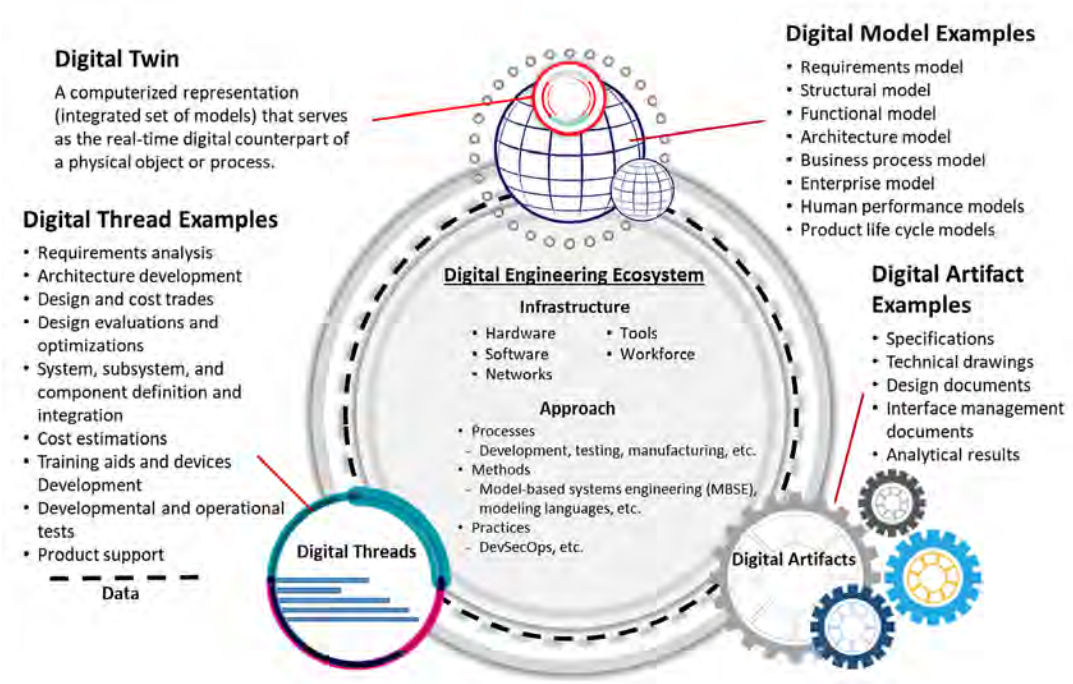
"Digital" in DE is not about digital tools - we've been using digital tools for decades. What's different is the **pervasive integration of information**, **knowledge**, **wisdom**, and **workflows** enabled by digital infrastructure and digital environments" [10]

[1] U.S. Department of Defense (DoD) Digital Engineering (DE) Strategy, https://man.fas.org/eprint/digeng-2018.pdf
[2] Noguchi, R. A., Wheaton, M. J., & Martin, J. N. (2020, July). Digital Engineering Strategy to Enable Enterprise Systems Engineering. In INCOSE International Symposium (Vol. 30, No. 1, pp. 1727-1741).
[3] Office of the Army Chief Information Officer, 2021, Army Digital Transformation Strategy
[4] www.af.mil/Portals/1/documents/2020SAF/There_Is_No_Spoon_Digital_Acquisition_7_Oct_2020_digital_version.pdf
[5] https://media.defense.gov/2021/May/06/2002635623/-1/-1/1/USSF%20VISION%20FOR%20A%20DIGITAL%20SERVICE%202021%20(2).PDF
[6] https://software.af.mil/wp-content/uploads/2021/01/Bending-the-Spoon.pdf
[7] Zimmerman, P., Gilbert, T., & Salvatore, F. (2019). Digital engineering transformation across the Department of Defense. *The Journal of Defense Modeling and Simulation*, *16*(4), 325-338.
[8] https://dsb.cto.mil/wp-content/uploads/2024/08/DSB_DE_Final-Report_050124_Stamped.pdf
[9] https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/500097p.PDF?ver=bePIqKXaLUTK_Iu5iTNREw%3D%3D
[10] Ryan Noguchi, Aerospace Corporation

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Digital Engineering

An Interdisciplinary Field



Digital Engineering Framework [1]

[1] https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/500097p.PDF?ver=bePIqKXaLUTK_Iu5iTNREw%3D%3D

5-Year Vision

- Improved interoperability via standards like SysML v2 for better integration across disciplines.
- Digital threads spanning concept-to-sustainment will move from pilot demonstrations to contractual requirements in major acquisition programs.
- Pervasive development of Digital Twins → more evaluation and testing before production
- Large language models and multi-agent systems will be embedded in engineering toolchains within 3-5 years, but **evidence and trust will remain an issue**.
- As systems-of-systems and joint all-domain operations become the norm, the engineering advantage will increasingly belong not to the organization with the best platform model, but to the one with the best-connected ecosystem. **Open, interoperable digital ecosystems** will **become a competitive differentiator.**

Research Themes

Research Themes



End-to-End Digital Continuity

Requirements, models, and lifecycle data often remain disconnected across tools and organizations. Digital continuity links these artifacts to support digital certification and assess how design decisions affect mission outcomes.



Evidence-Driven AI Evaluation

AI could play a growing role in model-centric aerospace engineering. Domain-specific evaluation and benchmarking are needed to assess its capabilities and limitations before engineers rely on its outputs.



Open, Collaborative DE Ecosystems

Closed, proprietary toolchains limit reuse, transparency, and end-to-end analysis across organizations. Open digital engineering ecosystems support the collaboration needed for multi-partner space missions and defense programs.

Research Themes



End-to-End Digital Continuity

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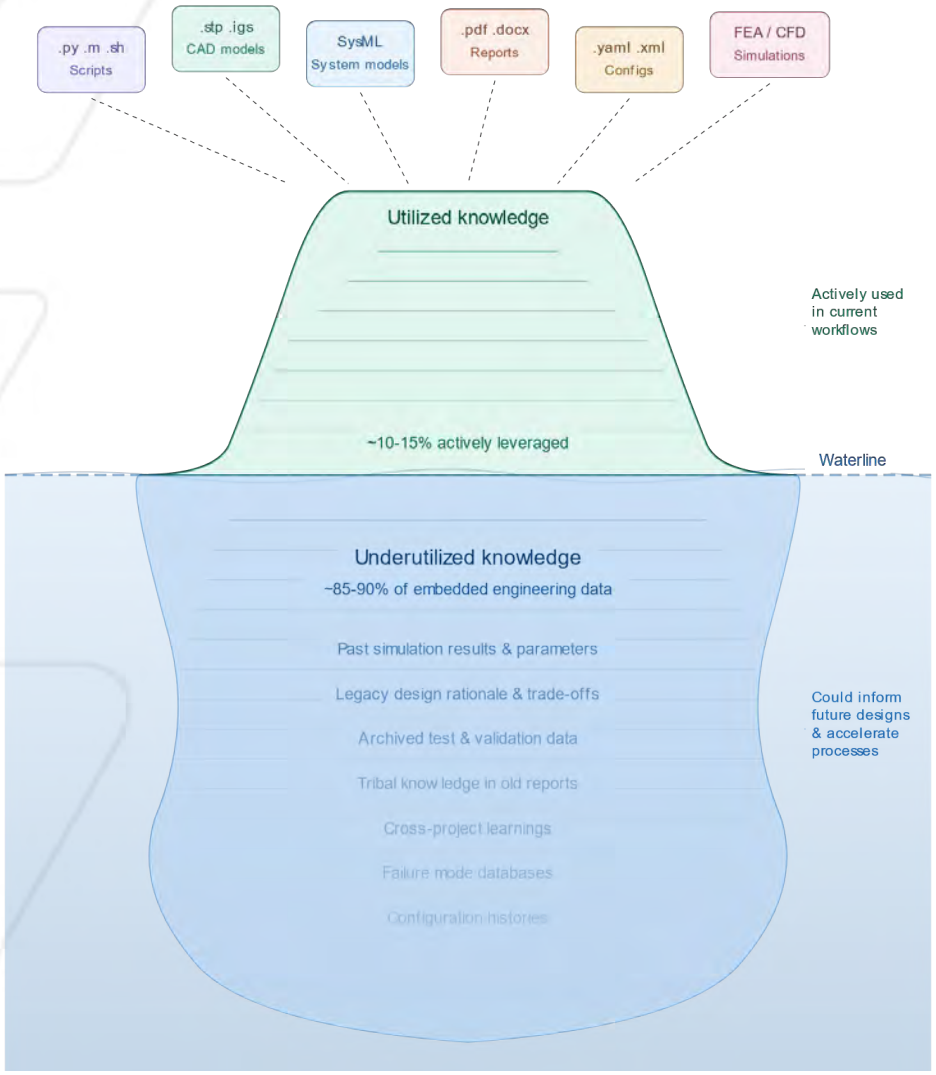


Open, Collaborative DE Ecosystems

Closed, proprietary toolchains limit reuse, transparency, and end-to-end analysis across organizations. Open digital engineering ecosystems support the collaboration needed for multi-partner space missions and defense programs.

Industry Challenges & Research Context

The imperative for digital engineering



- Organizations generate hundreds of heterogeneous artifacts Scripts, CAD, SysML, PDFs, reports, configs, etc.
- **Vast amounts of data/engineering knowledge** embedded within **artifacts** (simulations, codes, reports, etc.)
- Existing repositories contain valuable information that could **inform future designs** and **accelerate processes**, yet much of this data remains **underutilized**

Challenges to overcome

- **Volume** and **diversity** of data and artifacts generated has **grown faster than the organization's ability to curate, connect, and reuse them.**

→ Most of the data is hidden within artifacts [3] → Searching for richly contextualized information is **time-consuming**, **error prone** and **onerous** [1,4]

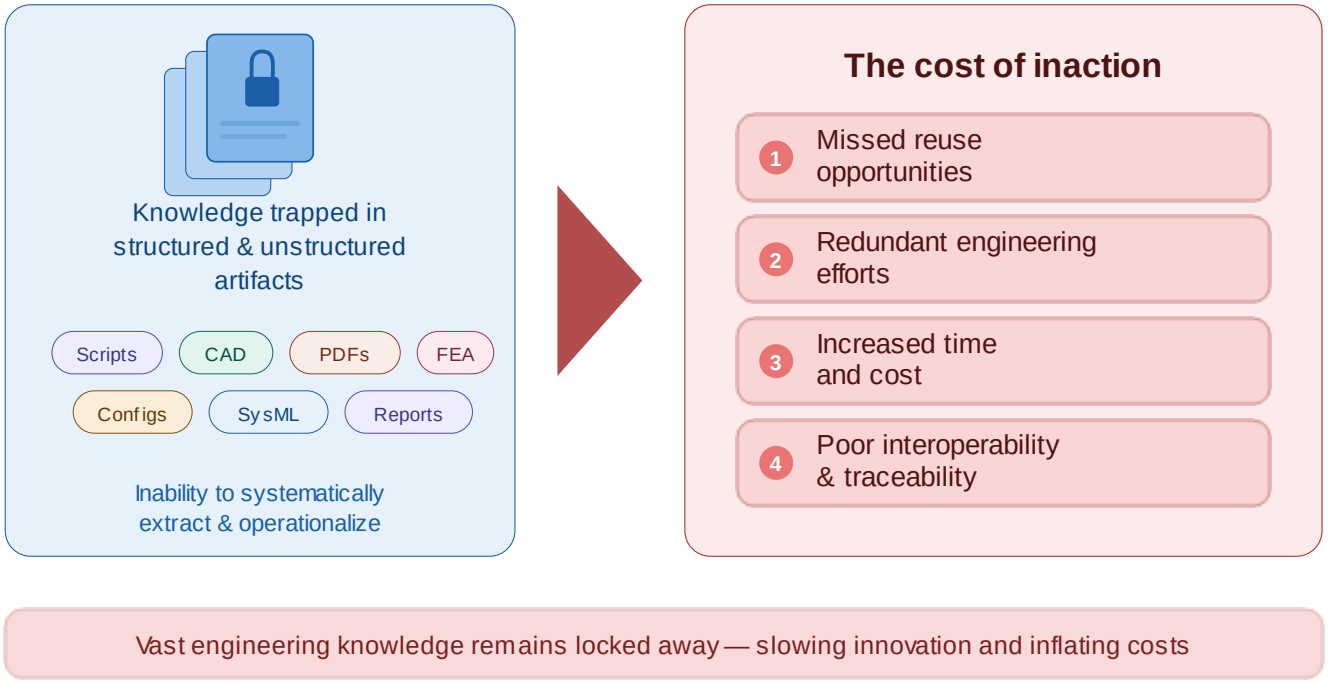
- Manual tagging fails: **Labor-intensive**, **inconsistent across annotators**, **dependent on domain expertise**, and **fundamentally unscalable**

End-to-End Digital Continuity

AI for Knowledge Discovery

Common Challenges

- **Metadata Standardization Gap -** Lack of standardized metadata complicates data organization and retrieval across digital curation platforms.
- **Manual Curation Burden -** Curation processes are manual and time-consuming, slowing down efficient data management and sharing.
- **Ineffective Search Mechanisms -** Current search tools fail to capture deeper semantic relationships, limiting effective information discovery.
- **Privacy and Compliance Needs -** Sensitive research data requires local-first solutions to ensure privacy and regulatory compliance.

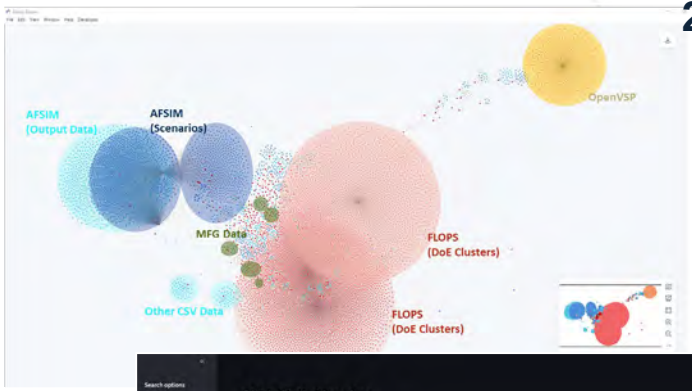


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End-to-End Digital Continuity

AI for Knowledge Discovery

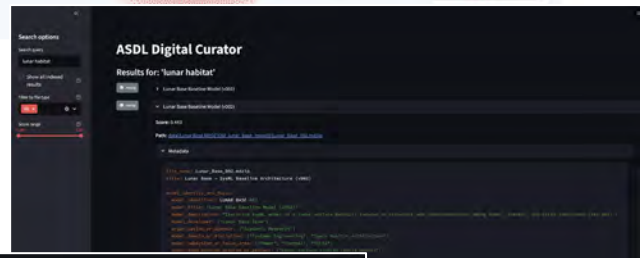
Converting unstructured artifacts into actionable knowledge



DEVINCI: Digital Engineering Value In Capturing Information for Reuse [1]

Sponsor: Air Force Research Laboratory (AFRL)

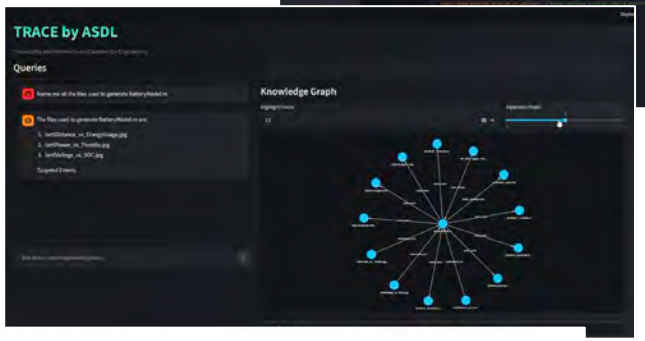
Demonstrated the benefits of knowledge, data, and tool reusability to accelerate product development and acquisition



Benchmarking Ontology-Guide Multimodal LLM Pipelines for Engineering Simulation Knowledge Curation [5]

Sponsor: SLB

Developed an automated framework that integrates textual and visual information through optical character recognition (OCR) and vision-language models (VLMs), embeds multimodal content into a vector database, and applies retrieval-augmented generation (RAG) guided by an engineering metadata ontology to produce structured metadata.



Traceability & Retrieval via AI Curation for Engineering

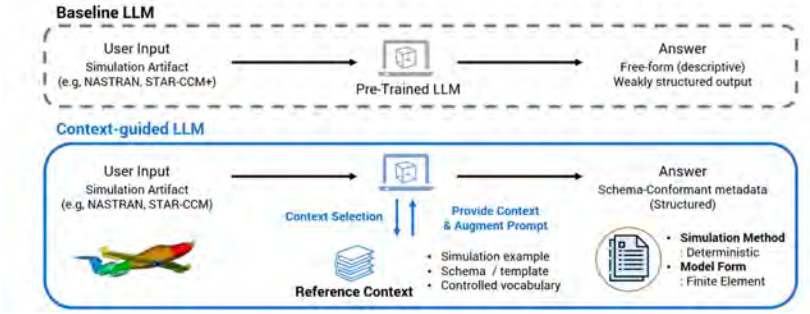
Sponsor: Gulfstream Aerospace

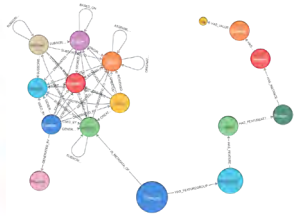
Developed a structured, automated approaches to retrieving and linking compliance-relevant data within engineering workflows

Schema-Guided Extraction and Reference-Free Clustering Evaluation of Simulation Metadata

Sponsor: Siemens Technology

Developed a prompt-engineered large language model pipeline for automating the extraction of structured metadata from simulation artifacts.





[1] J.D. Kambhampaty, G.S. Schlichting, C. Coletti, J.P. Evans, A.V. Reddy, O.J. Pinon Fischer, D.N. Mavris and R.E. Graves, *Graph-Based Digital File Curation for Engineering Reuse: Methodology and Case Study*, AIAA SciTech 2024 Forum, Orlando, FL, January 8-12, 2024, AIAA 2024-1133, https://doi.org/10.2514/6.2024%E2%80%911133
[2] Shalva Begiashvili, Digital Curation for Lunar Base Engineering Artifacts, Georgia Institute of Technology, December 2025
[3] J.D. Kambhampaty, J.L. Ortiz Solano, H. Strauss, A. Palaniappan, S. Bisso, O.J. Pinon Fischer, D.N. Mavris, J. Matlik, A. Karl and J. Dahlstrom, *Knowledge Graphs as Models of Integrated Digital Environments*, AIAA SciTech 2024 Forum, Orlando, FL, January 8-12, 2024, AIAA 2024-1132, https://arc.aiaa.org/doi/abs/10.2514/6.2024-1132
[4] TRACE, ASDL/Gulfstream Grand Challenge Team, 2026
[5] M. Davis, O. Garib, A.J. Kennedy, O.J. Pinon Fischer and D.N. Mavris, *Benchmarking Ontology-Guided Multimodal LLM Pipelines for Engineering Simulation Knowledge Curation*, 2026
[6] AIMC, ASDL/Siemens Grand Challenge Team, 2026

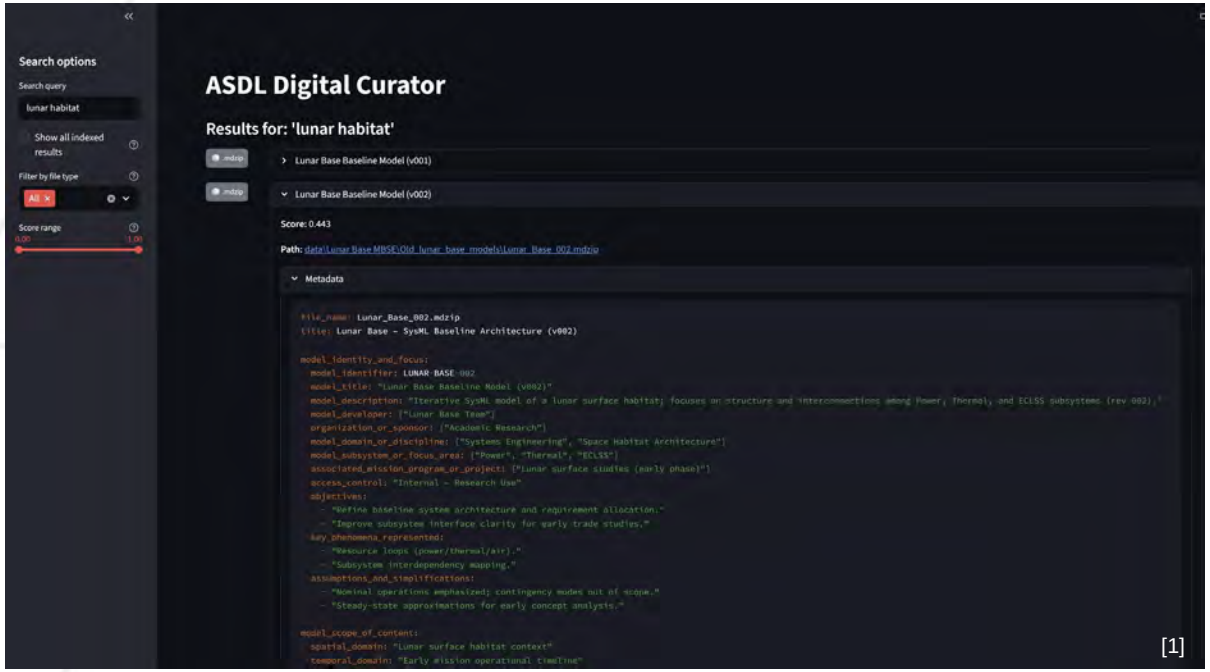
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Realizing The Digital Enterprise

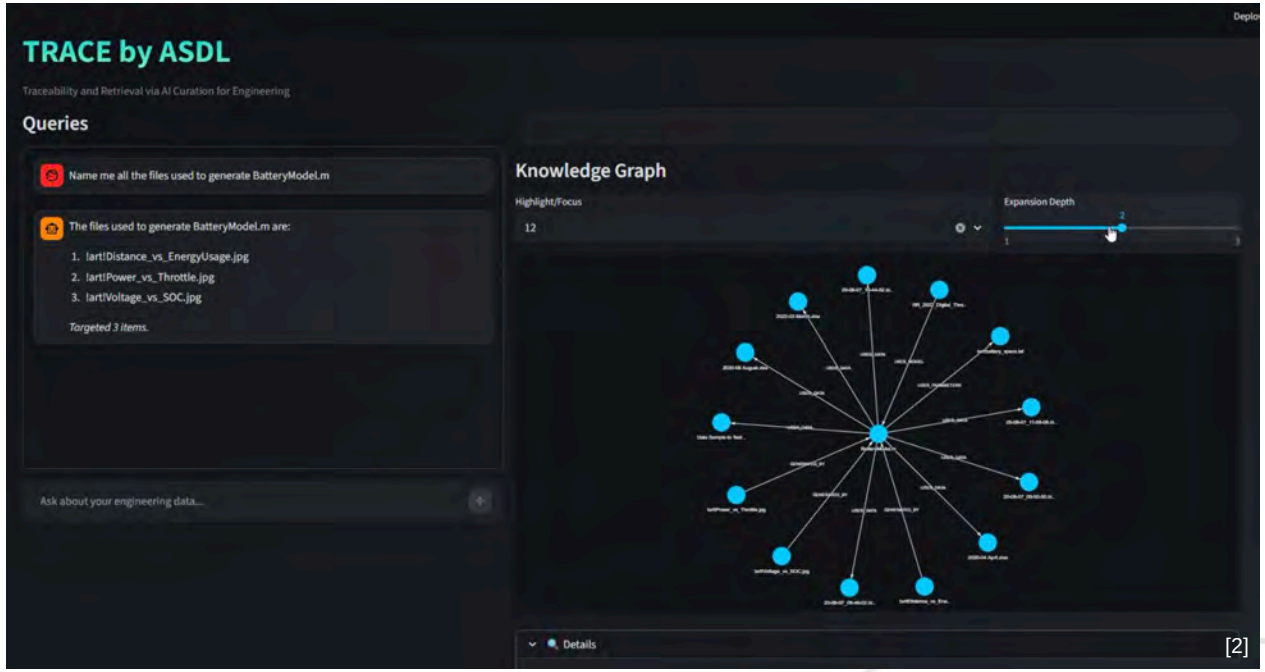
To be of value, enterprise data needs to be

ORGANIZED

- Can be searched to recall old projects and designs
- Can archive knowledge beyond any single engineer



[1]

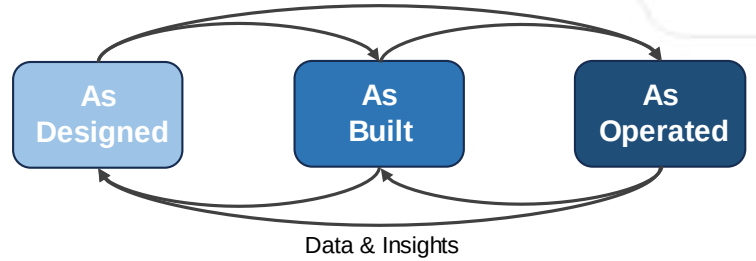


[2]

[1] Shalva Begiashvili, Digital Curation for Lunar Base Engineering Artifacts, Georgia Institute of Technology, December 2025
[2] TRACE, ASDL/Gulfstream Grand Challenge Team, 2026

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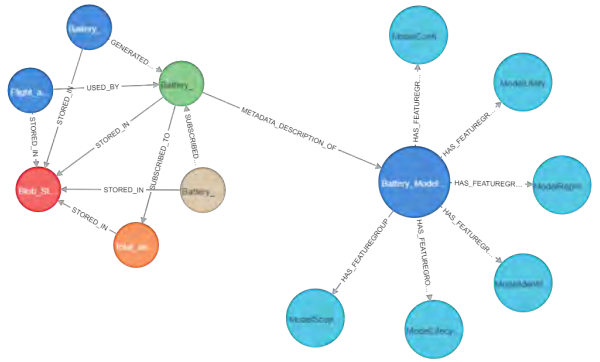
Realizing The Digital Enterprise



To be of value, enterprise data needs to be

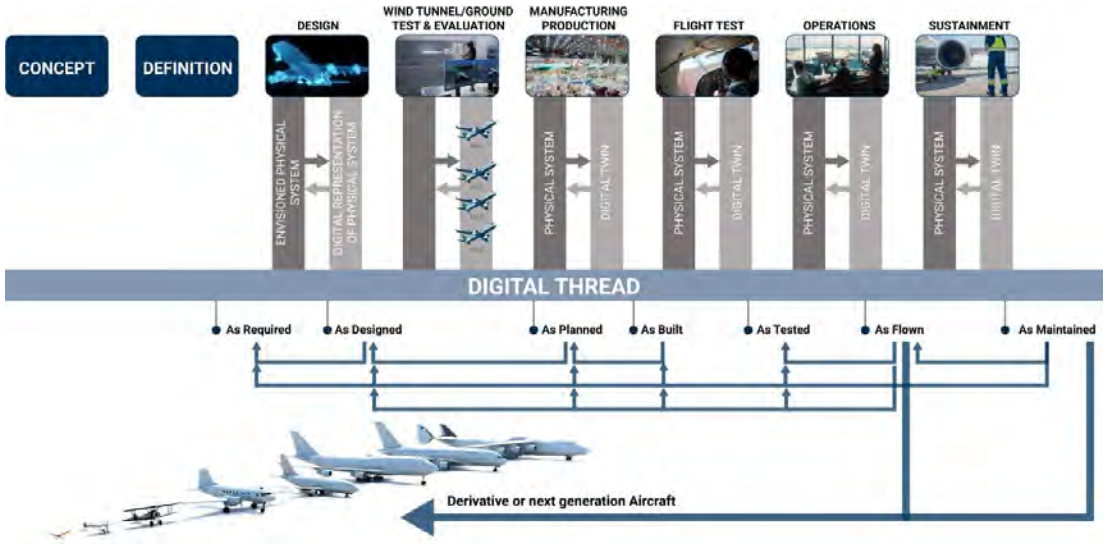
ORGANIZED

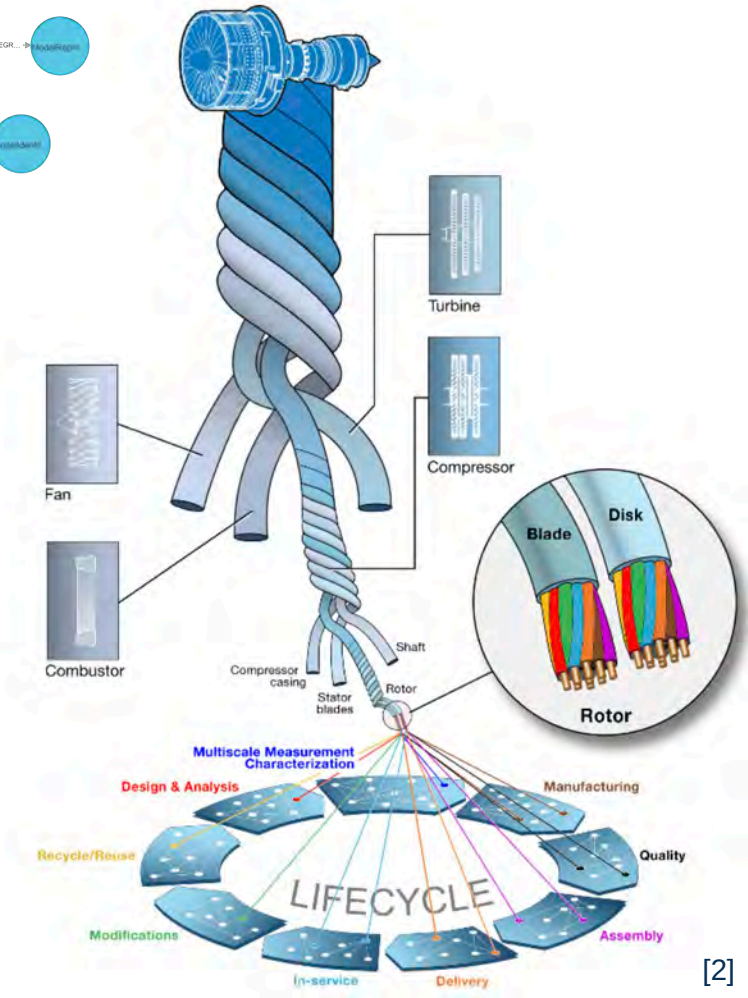
- Can be searched to recall old projects and designs
- Can archive knowledge beyond any single engineer



CONNECTED

- Can be traced to designs and platforms across lifecycle
- Can track dependencies and construct reusable modules





[2] AIAA Digital Engineering Integration Committee, *Digital Thread: Definition, Value and Reference Model* , American Institute of Aeronautics and Astronautics (AIAA).

[2]

Realizing The Digital Enterprise

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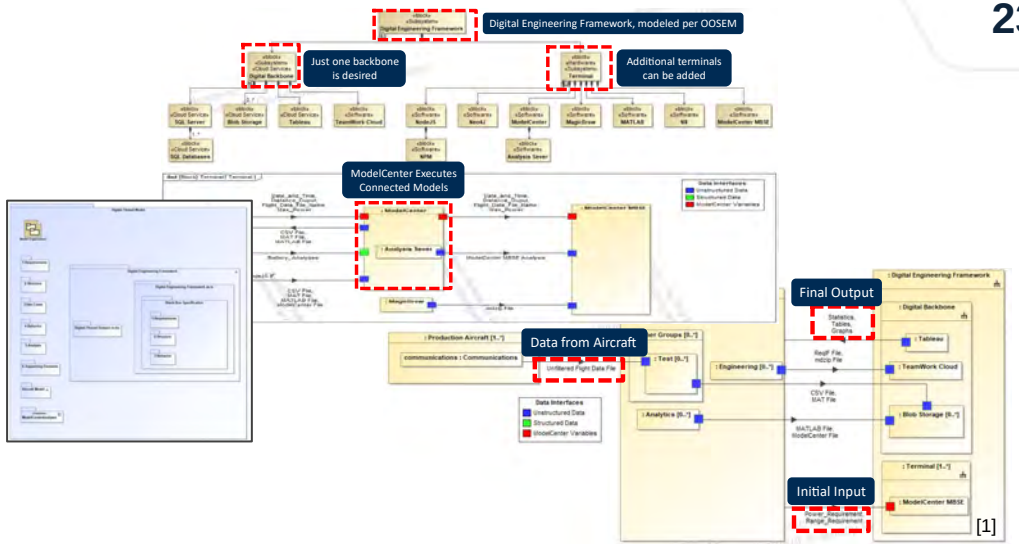
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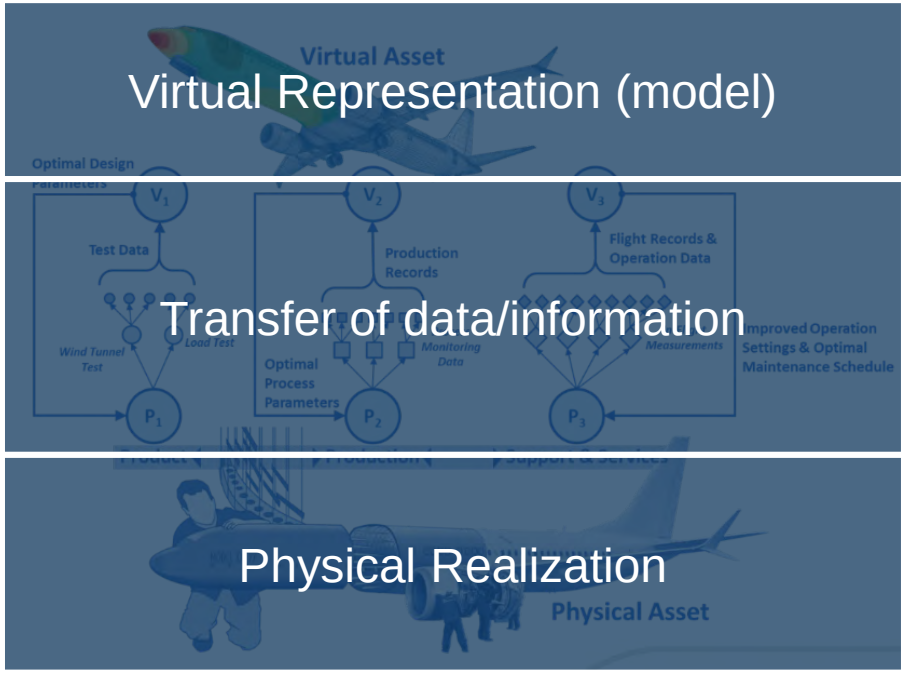
- Can be traced to designs and platforms across lifecycle
- Can track dependencies and construct reusable modules

MODELED

- model: a mutable, abstract representation of a system
- Can architect data connectivity
- Can reduce time-to-deliverable
- Can support inference and learning of data environment
- Can align analysis of a data environment with enterprise objectives



[1]



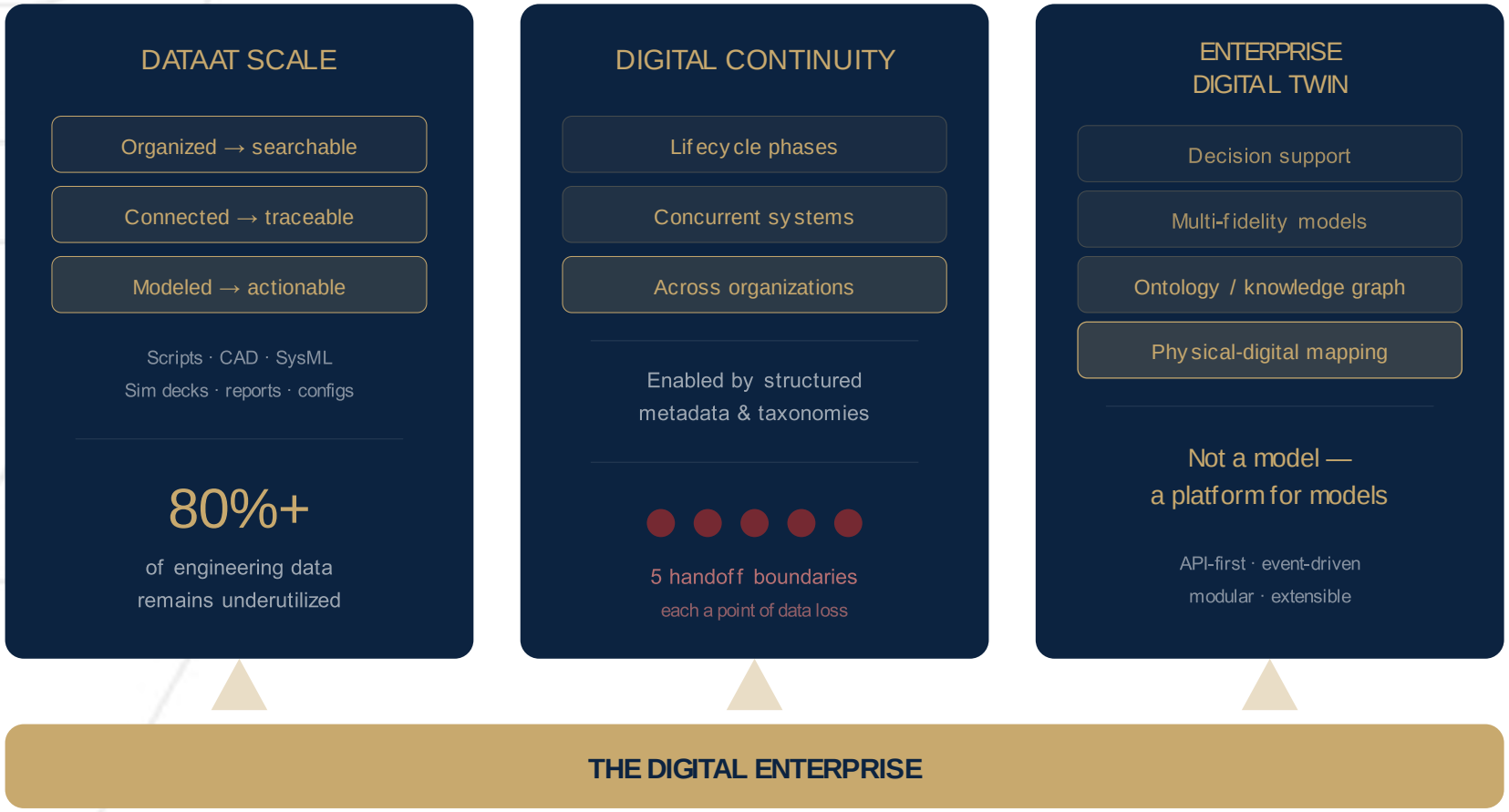
Example representation of the digital twin concept [2]

[1] Oroz, Juan, Zayn A. Roohi, Sabastian Abelezele, Gabriel Fronk, Ruby Al Fawares, Olivia J. Pinon-Fischer, Aroua Gharbi et al. "Implementing the Digital Thread-A Proof-of-Concept." In *AIAA SciTech 2023 Forum*, p. 1405. 2023.
[2] AIAA Digital Engineering Integration Committee, *Digital Twin: Definition and Value - An AIAA and AIA Position Paper*. 2020, American Institute of Aeronautics and Astronautics (AIAA)

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Building the Digital Enterprise

From Data Foundations to Agentic Workflows



An organizational operating model in which data, models, and decisions flow continuously across the full product and production lifecycle: **across disciplines, across organizational boundaries, and across the supply chain.**

Strategic Applications in A&D

- Virtual certification and qualification
- Cross-program knowledge reuse
- Predictive sustainment [3]
- Accelerated acquisition
- Supply chain continuity
- New Product Development [1]
- Product Manufacturing [2]
- Etc.

[1] Mueller, S.R., Pinon Fischer, O.J., Bagdatli, B., Cimtalay, S., Mavris, D.N., Faveto, A., Mazzoldi, A., Croue, N., "Towards a Methodology for the Definition and Evaluation of Enterprises through Modeling and Simulation: Application to Product Development," AIAA SciTech 2025 Forum, Orlando, FL, January 6 10, 2025, AIAA-2025-1660, https://arc.aiaa.org/doi/10.2514/6.2025-1660
[2] Lepez Da Silva Duarte, N., Pinon Fischer, O.J., Bagdatli, B., Mavris, D.N, "Towards a Methodology for the Definition and Evaluation of Enterprises through Modeling and Simulation: Application to Product Manufacturing," AIAA SciTech 2026 Forum, Orlando, FL, January 2026, AIAA 2026-1354, https://doi.org/10.2514/6.2026-1354
[3] S.A Cantrell, C.H. Margolis, M.R. Krauss, O.J. Pinon Fischer and D.N. Mavris, Digital Twins for Sustainment-Oriented Wargaming, AIAA SciTech 2025 Forum, Orlando, FL, January 6-10, 2024, AIAA-2025-0706, https://doi.org/10.2514/6.2025-0706

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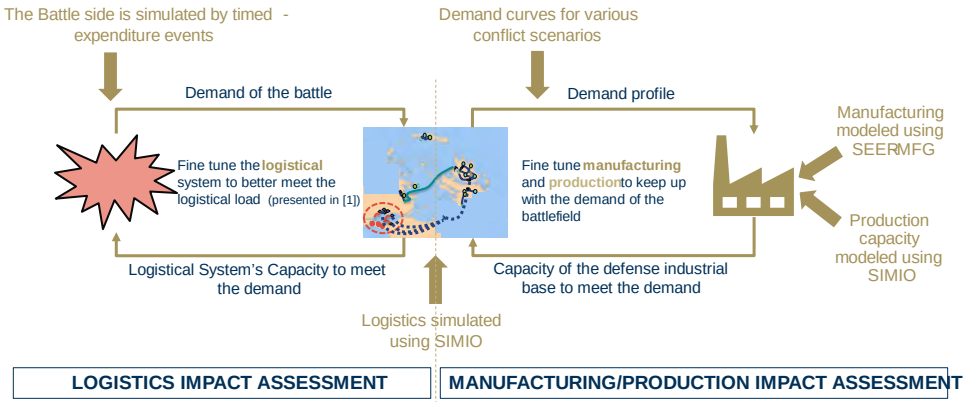
End-to-End Digital Continuity
Linking Missions to Supply Chains

Launcher Affordability, Manufacturability and Production Trade Study Support

Research Goal: Help NGMS **assess production and supply chain capacity**, **support design for manufacturability**, and advance adoption of a digital approach to rigorously and quantitatively perform these assessments. To be demonstrated through the **development of a digital modeling environment for launcher manufacturability and production and capacity modeling for a new undersea launcher system**.

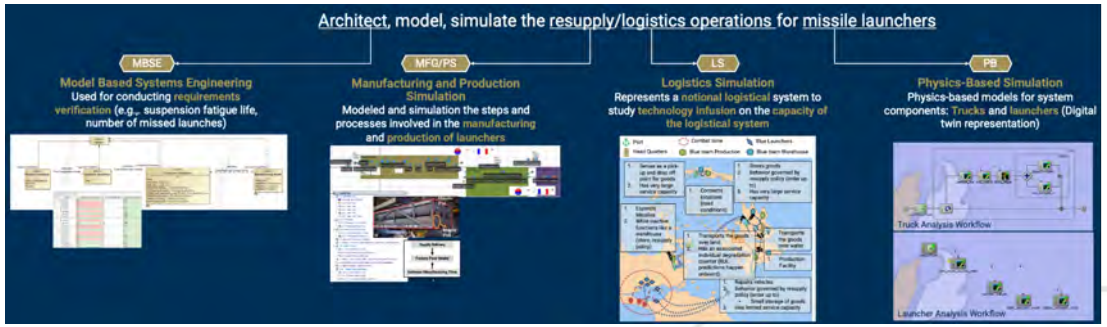
Year 4: Manufacturing & Production Modeling for Throughput Estimation and Demand Fulfillment

Research Goal: Investigate the impact that manufacturing and production capacity for a missile launcher have on the **ability to meet demand as signaled by a variety of conflict intensities and tempos**.



Year 3: Modeling and Simulation Environment for the Quantitative Assessment of Operational and Technological Improvements in Military Logistics

Research Goal: Better **quantify** the **impact that predictive digital twins have on logistic systems**. Gain a greater understanding of the impact that scenarios of interest will have on the supply of high-value systems, which in turn could **help inform an Industry-led Surge Buy-Plan**.



Years 1 & 2: Digital Twin Predictive Systems Modeling

Research Goal: Demonstrate the use of Model-Based Systems Engineering and physics-based modeling to support the **formulation and implementation of a multi-physics system-level digital twin**.

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End-to-End Digital Continuity
Linking Missions to Supply Chains



SCALED²CAT: Supply Chain And Logistics-Enabled Digital Design Configuration Analysis Tool

How can the U.S. vehicle design processes, industrial base, and supply chain be best leveraged to **respond to dynamic adversarial technologies and tactics**?

Research Objective: Developed capability to examine interactions between vehicle designs, logistics options, and supply chain selections to **trade mission effectiveness** and **deployment time**



DREAM: Digital Realization of Engineering and Analysis with MBSE

Research Objective: Developed a parametric framework to analyze the relationships between mission, logistics system, and vehicle parameters utilizing industry standard MBSE patterns and mission planning objectives

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Research Themes



End-to-End Digital Continuity

Requirements, models, and lifecycle data often remain disconnected across tools and organizations. Digital continuity links these artifacts to support digital certification and assess how design decisions affect mission outcomes.



Evidence-Driven AI Evaluation

AI could play a growing role in model-centric aerospace engineering. Domain-specific evaluation and benchmarking are needed to assess its capabilities and limitations before engineers rely on its outputs.



Open, Collaborative DE Ecosystems

Closed, proprietary toolchains limit reuse, transparency, and end-to-end analysis across organizations. Open digital engineering ecosystems support the collaboration needed for multi-partner space missions and defense programs.

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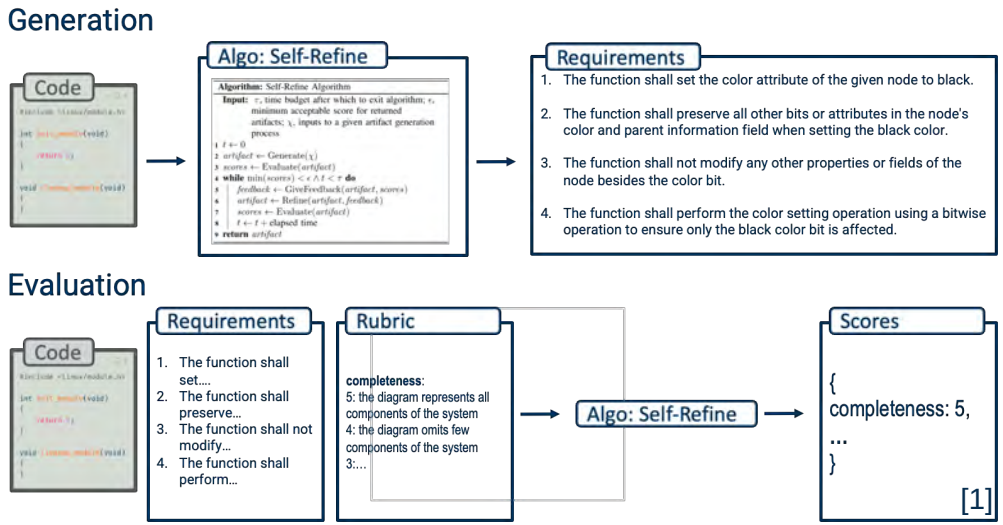
Evidence-Driven Evaluation & Benchmarking of AI for Model-Centric Aerospace Engineering

Reverse engineering provisional DO-178C certification artifacts with large language models

Focus: Generating provisional DO-178C certification artifacts with large language models

Research Objective: build experimental infrastructure to assess the feasibility of using LLMs in a reverse engineering context

- Provisional: **will be subject to human review**
- Generating DO-178C certification artifacts
  - Specifically in the context of reverse engineering
  - Per DO-178C “Reverse engineering may be used to regenerate software lifecycle data that is inadequate or missing…”
- With large language models (Specifically prompting, inference time techniques)



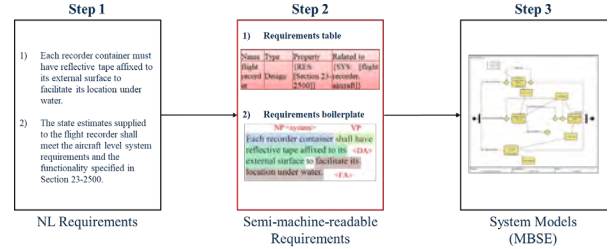
Challenges

- **There are many possible LLM system configurations:** We use the self-refine method, but there are a wide variety of prompting techniques; Other ideas include prompt optimization, optimizing over combinations of prompts and tools, evolutionary approaches, etc.
- **Artifact quality necessarily retain subjectivity:** Artifact goodness can have a lot to do with who is using the artifact and for what problem
- **How do we know the outputs (of an AI for RE suite of tools) can be trusted?** AIRE shifts an engineer from “author” in the traditional sense to “editor” or even “reviewer”, Modifying a user’s workflow with an AI for RE suite of tools changes the work they have to do, Measuring the quality of an AI for RE-like system may require an expanded evaluation scope, to consider the overall impact of the tool on certification decisions, not just artifact quality

[1] J. D. Kambhampaty , N. H. Wong , E. M. Theriot , M. M. Davis, O. J. Pinon Fischer, D. N. Mavris, and M. Souaya, *Reverse engineering provisional DO-178C certification artifacts with large language models*, Digital Avionics Systems Conference (DASC), September 2026, Orlando , FL

AI for Systems Engineering

Identify, develop, and implement tools and techniques to enable/support the automated translation of natural language (NL) aerospace requirements into semi-machine-readable requirements.







aeroBERT-Classifier
LM capable of classifying requirements into three types: Design, Functional, and Performance

aeroBERT-NER
LM capable of identifying five types of NEs: SYS, ORG, VAL, RES, DATETIME

Text Chunking
LM capable of identifying text chunks (NP, VP, etc.) in a requirement sentence

Converting requirements into a standardized form for use in model-based environment

Standardized Requirements

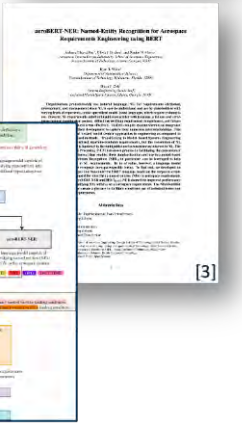
Requirements Table
Capture requirements and system properties in a tabular environment

Boilerplate identification
Identification of textual patterns in NL requirements to develop templates





Improving LLM performance in Aerospace NER task with Entity-adaptive data augmentation and fine-tuning strategies





Standardization of requirements for their use in a model-based environment:

- -Extraction of information from free-form NL requirements
- -Agile methodology **for creation of boilerplate templates**

[1] Tikayat Ray, A., Cole, B. F., Pinon Fischer, O. J., Bhat, A. P., White, R. T., & Mavris, D. N. (2023). Agile methodology for the standardization of engineering requirements using large language models. *Systems*, *11*(7), 352.
[2] Tikayat Ray, A., Cole, B. F., Pinon Fischer, O. J., White, R. T., & Mavris, D. N. (2023). aerobert-classifier: Classification of aerospace requirements using bert. *Aerospace*, *10*(3), 279.
[3] Tikayat Ray, A., Pinon-Fischer, O. J., Mavris, D. N., White, R. T., & Cole, B. F. (2023). aeroBERT-NER: Named-entity recognition for aerospace requirements engineering using BERT. In *AIAA SciTech 2023 Forum* (p. 2583).
[4] Tikayat Ray, A., Pinon Fischer, O. J., White, R. T., Cole, B. F., & Mavris, D. N. (2024). Development of a language model for named-entity-recognition in aerospace requirements. *Journal of Aerospace Information Systems*, *21*(6), 489-499.
[5] Cho, K., Pinon-Fischer, O. J., & Mavris, D. (2025). Improving LLM performance in aerospace NER task: Entity-adaptive data augmentation and fine-tuning strategies. In *AIAA AVIATION FORUM AND ASCEND, AIAA-2025*-3246

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Research Themes



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AI could play a growing role in model-centric aerospace engineering. Domain-specific evaluation and benchmarking are needed to assess its capabilities and limitations before engineers rely on its outputs.



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Closed, proprietary toolchains limit reuse, transparency, and end-to-end analysis across organizations. Open digital engineering ecosystems support the collaboration needed for multi-partner space missions and defense programs.

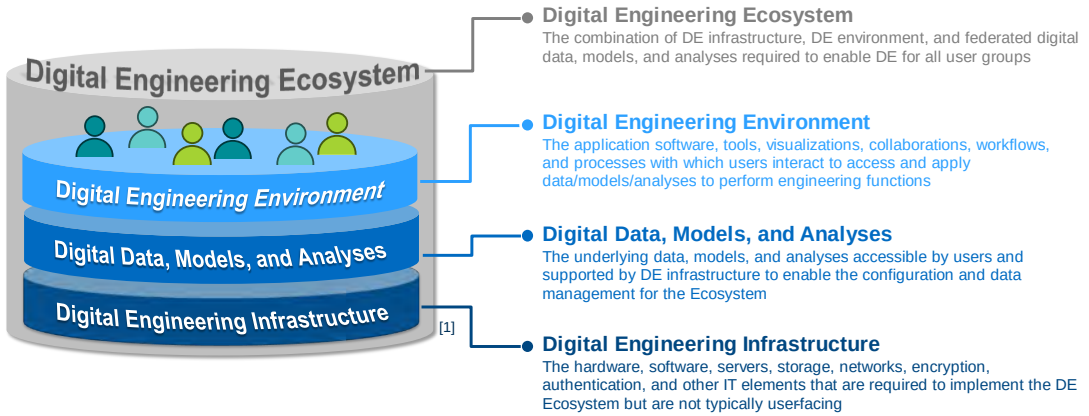
Collaborative Open Digital Ecosystems

CONTEXT

Digital engineering capabilities have grown rapidly, yet most environments remain closed, proprietary, and locked into proprietary toolchains. This isolation limits reuse, transparency, and end-to-end analysis across organizational boundaries — whether for Moon/Mars missions requiring multi-vendor coordination, or defense systems needing coherent "kill chain to supply chain" assessments across primes and government entities.

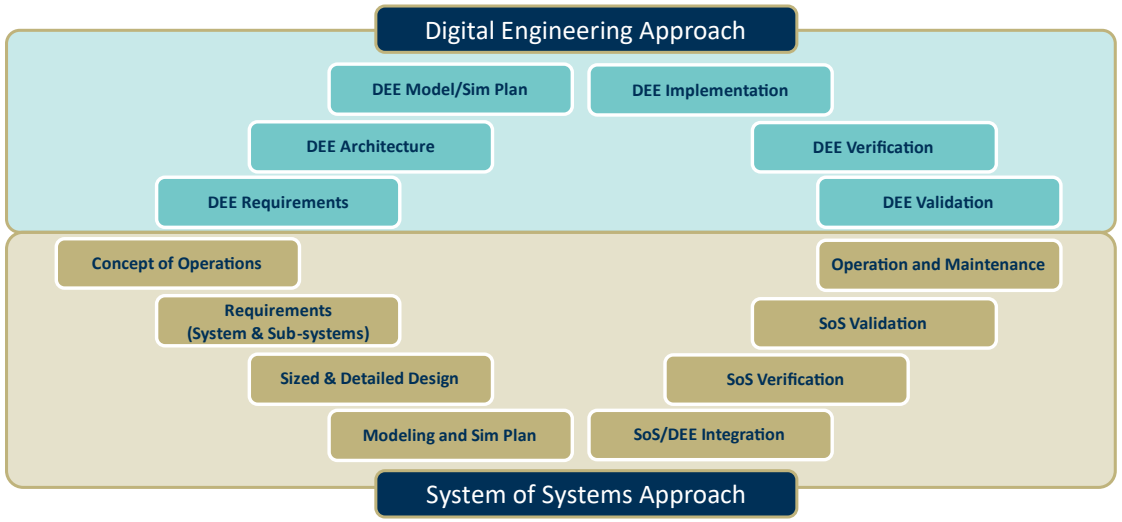
FOCUS

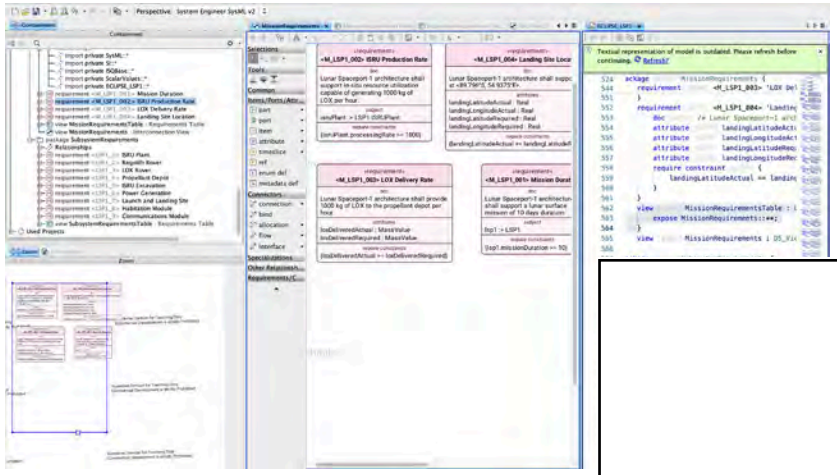
- Architect and prototype open, trusted, and scalable digital engineering ecosystems for multi-stakeholder collaboration
- Develop architectures and reference implementations for model/data/service interoperability across the lifecycle
- Research on open interfaces & ontologies, provenance & trust mechanisms, and scalable compute/data infrastructures for aviation, defense and space applications

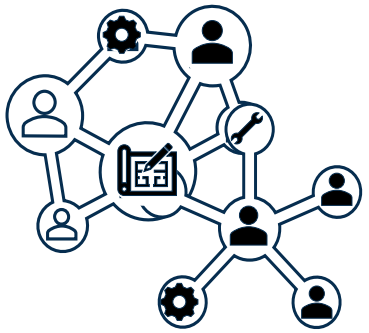


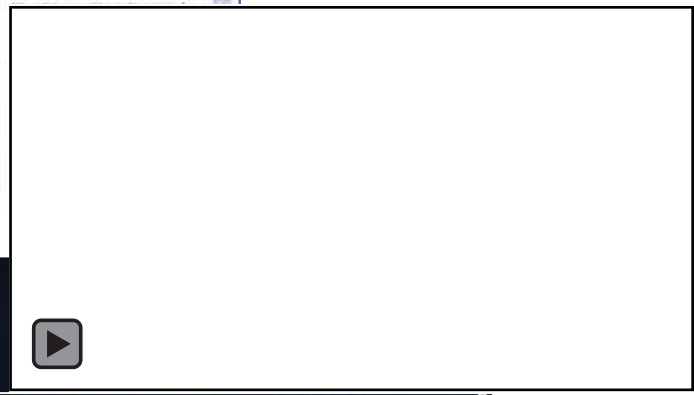
[1] Dennis Paul, John Reed, Christie Iacomini and Olivia Pinon Fischer, *Cislunar & Lunar Ecosystem and Economics Workshop – Aligning Multiple "Technical Baselines" into an Ecosystem using Digital Engineering Environments*, AIAA ASCEND, 23 July 2025

Architecting Digital Engineering Ecosystems

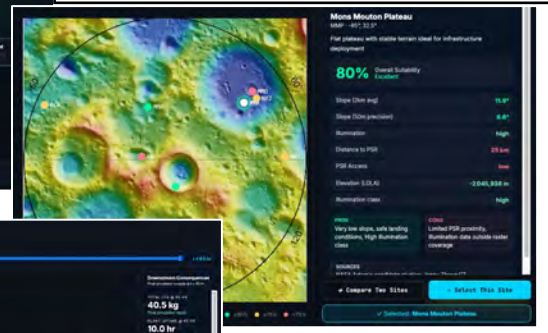


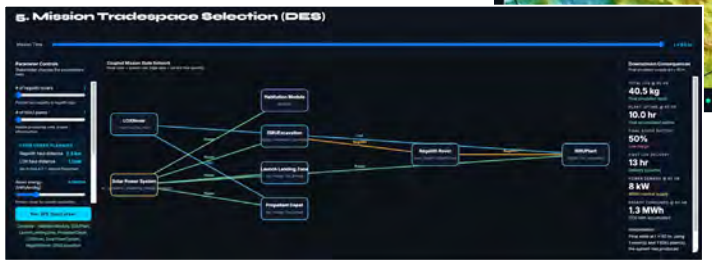












Research Objective

Enable a collaborative environment for mission planning and scenario testing for in-situ resource utilization on the Moon

End Product

A methodology and digital engineering ecosystem to enable collaboration and accelerate progress towards common goals in lunar surface operations

Concluding Remarks

Forces Driving the Transition

TECHNICAL

Documents cannot coordinate the systems we now build.

Software-defined functions, multi-physics couplings, and deep supplier interdependencies exceed what document decomposition can keep consistent.

ECONOMIC

Late discovery is expensive.

Requirements and interface errors are cheapest to fix before design, build, integration, and test. NASA / INCOSE cost-escalation data show large multipliers when requirements errors survive into integration, test, or operations.

REGULATORY

Customers and authorities increasingly expect model-based evidence.

DoD now requires digital engineering for new programs unless excepted. FAA and EASA recognize model-based development and verification guidance for airborne software through DO-331 / ED-218, but model-based evidence still has to satisfy the applicable certification objectives.

ORGANIZATIONAL

The ecosystem is becoming ready.

SysML v2, digital-thread tooling, and supplier-facing model-based exchange are maturing. Major primes are building supplier MBE capabilities, but adoption still depends on program contracts, tool maturity, data rights, and workforce skill.

The shift becomes hard to defer when system coupling, late-defect cost, customer expectations, and supplier data exchange all exceed what manual document synchronization can support.

Adoption Challenges

1 Cost, tools, and infrastructure

Tools, data environments, security, training, and governance all require up-front investment. The benefits may be real, but they are often hard to see in early cost and schedule data.

2 Culture and document habits

Programs still run through reviews, approvals, contracts, and sign-offs. MBSE works when it improves that flow, not when it creates a parallel one.

3 Legacy and contractual interfaces

Digital engineering has to connect with existing program, certification, accreditation, and supplier processes. A model that cannot feed the real workflow will not last.

4 Benefits are hard to quantify early

Many DE / MBSE benefits are expected or perceived, while consistent cost, schedule, and performance metrics are still immature.

Sources:
- RAND, *The Impact of Digital Engineering on Defense Acquisition and the Supply Chain: Insights from an Industry Survey*, 2024, https://www.rand.org/content/dam/rand/pubs/research_reports/RRA2300/RRA2333-2/RAND_RRA2333-2.pdf
- RAND, *A Framework for Assessing the Costs and Benefits of Digital Engineering: A Systems Approach*, 2024, https://apps.dtic.mil/sti/trecms/pdf/AD1223750.pdf
- RAND, *On the Use of Digital Engineering Artifacts for Integrating Processes in Acquisition Programs*, 2024, https://www.rand.org/content/dam/rand/pubs/research_reports/RRA2100/RRA2182-1/RAND_RRA2182-1.pdf
- SERC / INCOSE / NDIA MBSE Maturity Survey (2020): https://sercuarc.org/news/results-of-the-serc-incose-ndia-mbse-maturity-survey-are-in/
- Henderson, Kaitlin, Thomas McDermott, and Alejandro Salado. "MBSE adoption experiences in organizations: Lessons learned." *Systems Engineering* 27, no. 1 (2024): 214-239.

Thank you

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