Transition to Digital Engineering

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Overview

- Introduction
- Evolution of Systems and Complexity
- Future Trends and Implications
- Systems Engineering at CSU
- Summary

Birth of Formal Term of "Systems Engineering"

- Formal "systems engineering" originated from Bell Telephone Laboratories in the 1940s as an approach for complex engineering analysis
- First formally applied to support the Manhattan Project and WWII nuclear weapons production program
- Implementation under a highly aggressive schedule and challenging conditions across 30 sites in the US, UK, and Canada, which employed 130,000^{+} people

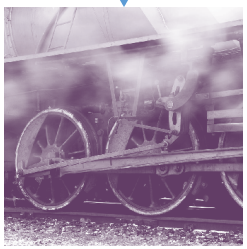
Historical Perspective of Systems Engineering

5000 BC

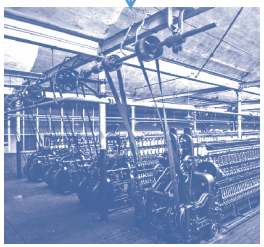
1200

1750

1850



1900



1980 AD

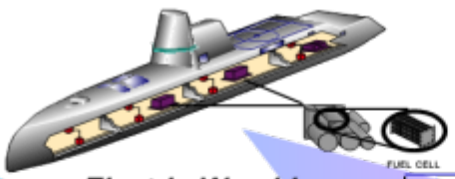
1980 AD

Energy & Power Technologies…
- Enabling a More Electric Force

POWER GENERATION
- Fuel Cells & Fuel Reforming
- Novel Power

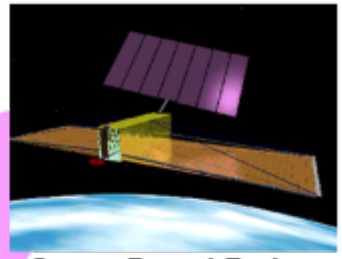
ENERGY STORAGE
- Batteries
- Capacitors

POWER CONTROL AND DISTRIBUTION
- Switching & Conditioning
- Power Transmission & Distribution
- Thermal Management

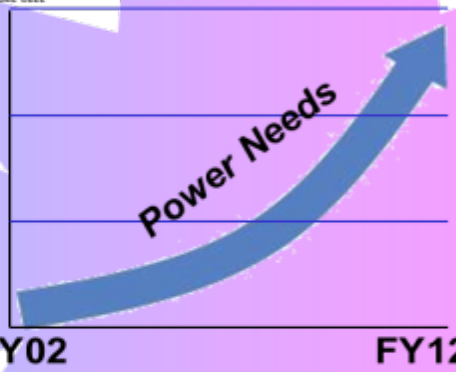


Electric Warship

More Electric Aircraft



Space Based Radar

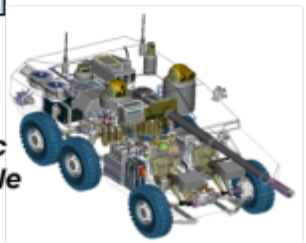


High Power Microwave

Warrior

New Operational Capabilities

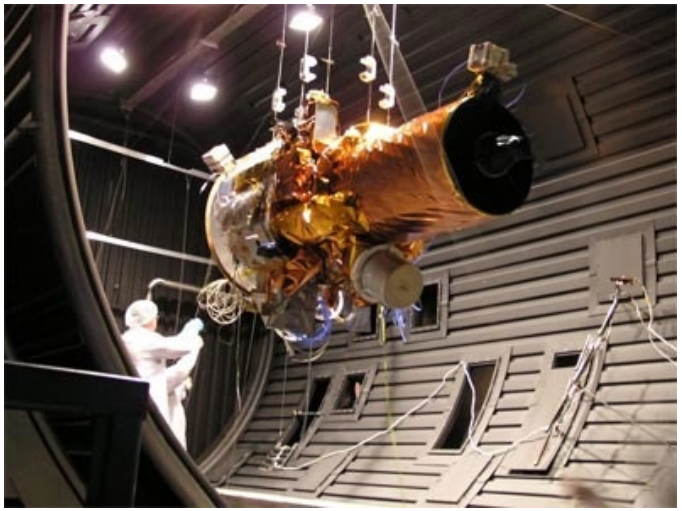
Electric/Hybrid Weapons

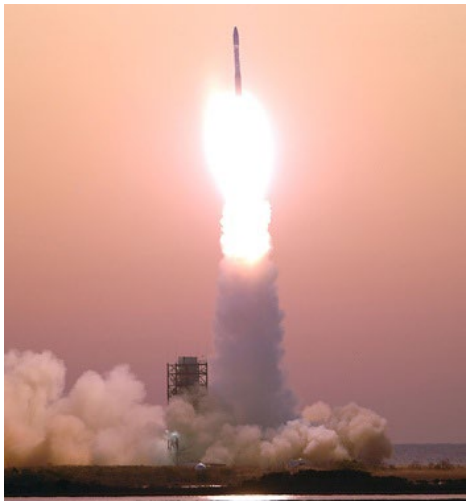


Hybrid/Electric Combat Vehicle

Space Test Program-1 Launch

Tactical Satellite Experiment-2 (TacSat-2)





Successful Launch, 16 Dec 06

Ground Terminal – China Lake

Capability:

- Field tasking/data downlink in same the pass
- One meter tactical imagery
- Specific emitter ID & geolocation
- Dynamic retasking
- Autonomous tasking/checkout/on-orbit maintenance, on-board data processing
- Total mission cost w/ launch ~$63M

Notes:

- First of TACSAT series on-orbit
- Utilized the Minotaur launch vehicle
- Launched from Wallops Island Facility
- Successfully commanded spacecraft from China Lake ground station

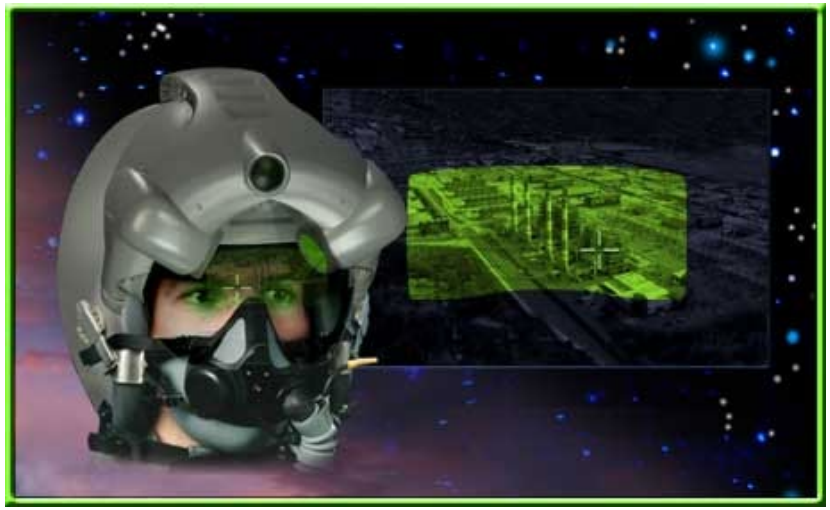
21st Century Trends and Implications
- Global Considerations

- Increasing:
  - Rate of Change of Technology on a Global Scale
  - Complexity in Aerospace and Terrestrial Systems
  - Technical Capacity of the Global Workforce
  - Private Sector R&D (Growing Faster than Public Sector)
  - Data Required to Validate Models
  - Integrated Tests at Scale Needed
- Cost Optimization / Affordability is Increasingly Important

21st Century Trends and Implications

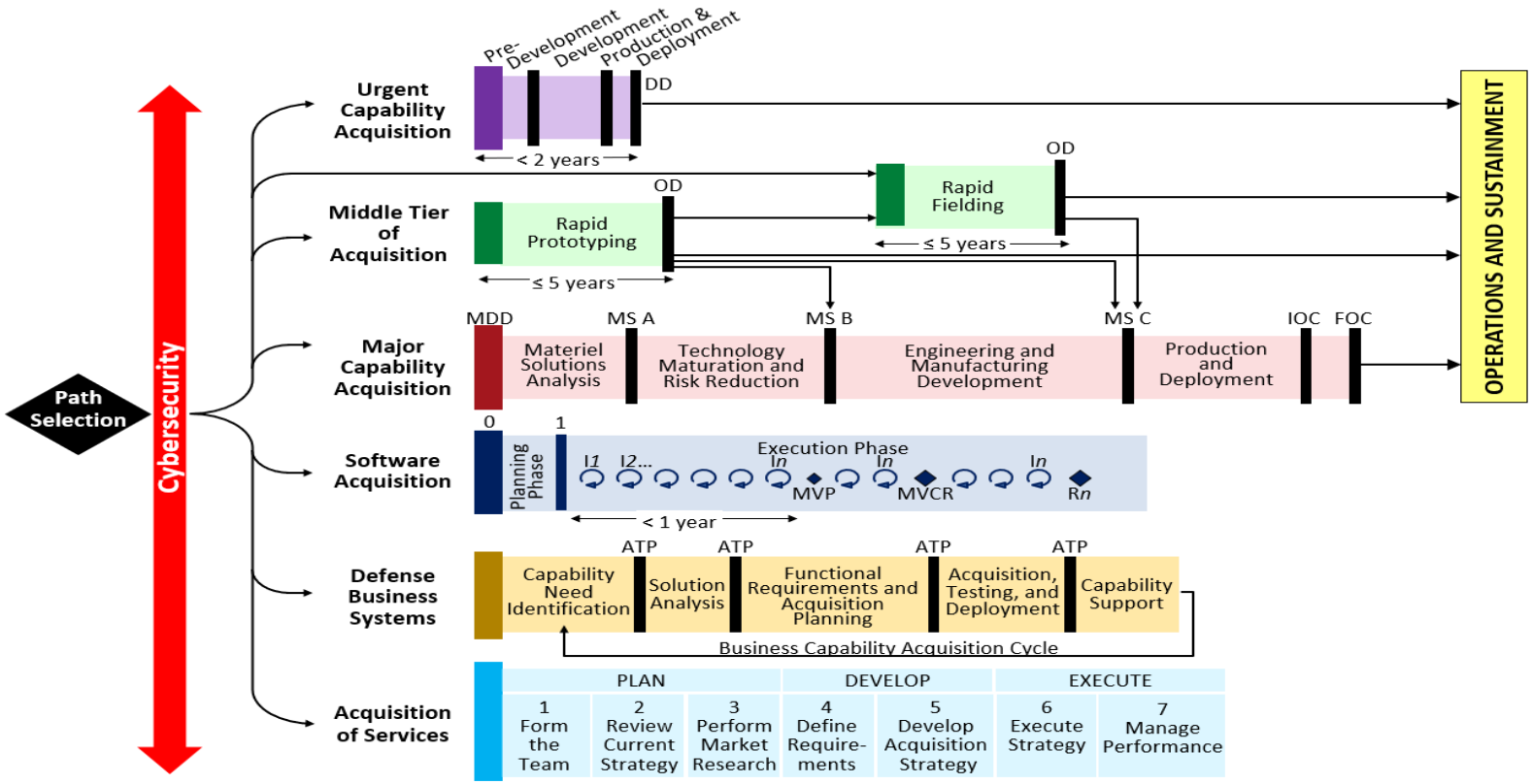
- Global Considerations, cont.

- Systems Approaches
  - Application and Integrate Other Sectors (e.g., Energy Systems)
  - Digital Thread and Model-Based Systems Engineering
- Evolving Technologies
  - Additive Manufacturing
  - Information-intensive Systems
  - Increasing Autonomy
- Cyber Opportunities and Challenges
  - Internet of Things (IOT)
  - Assured Operations
  - Security



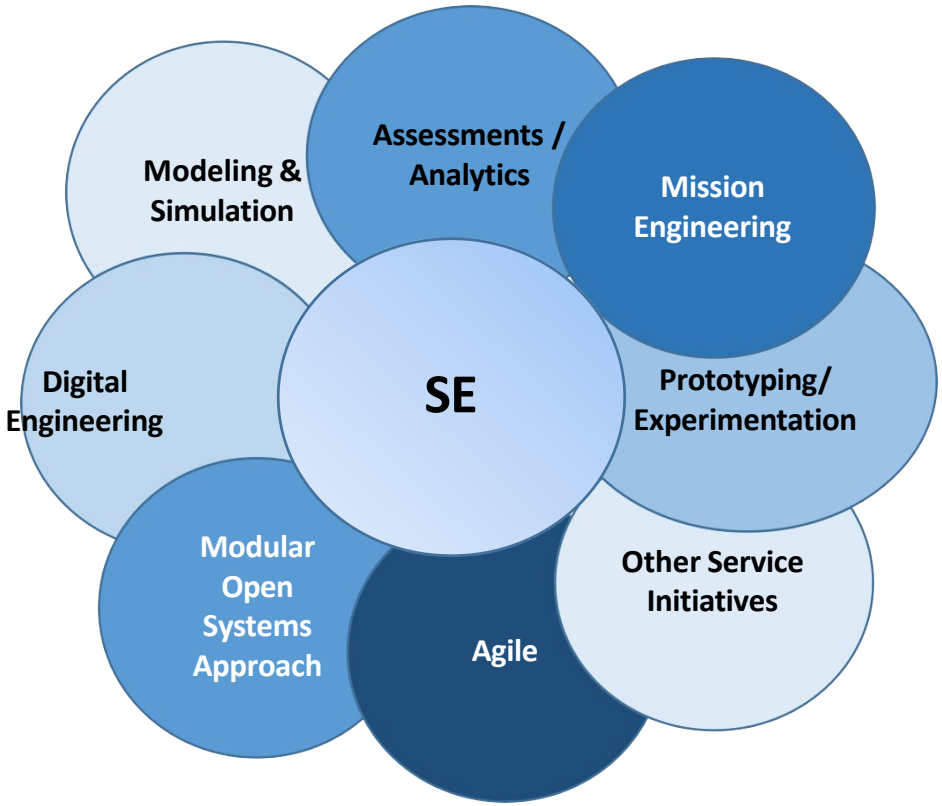
Newly Revised 5000 series Adaptive Acquisition Pathways

- Newly Revised 5000 series Adaptive Acquisition Pathways policies show a new way to increase flexibility and innovation



DoDI 5000.02, January 23, 2020

Integrating Modern Practices



Systems Engineering Modernization Initiative, Nadine Geire, Dir SE OUSD (SE), https://www.cto.mil

Transforming SE

- In National Defense Magazine Sept 2021, Holly Dunlap and Dave Chesebrough, in their Article "Transforming Our Systems Engineering Approach using Digital Technology" point out the problems with maintaining technological superiority by our cumbersome rules of the US acquisition system and efforts taking place to transform systems engineering
- NDIA Systems Engineering Division is leading the charge in 2 transformative areas
  - Digital engineering
  - Modular open systems approach (MOSA)

Definitions?

- *Digital Engineering* is:
  - An integrated digital approach that uses authoritative sources of systems data and models as a continuum across disciplines to support lifecycle activities from concept through disposal.
  - An integrated approach to building trusted sources of data and models that are used in a continuum across engineering disciplines. Digital Engineering is used throughout. The lifecycle of a program from conception through decommissioning.
- *Digital Engineering* aims to:
  - Modernize and achieve efficiency and consistency in engineering and leverages the use of computer models and data to integrate engineering tasks across disciplines, virtually, before going into production.

From public sources, professional organizations, DoD Industry OEMs

Digital Thread

- A communication framework that connects traditionally siloed elements in design, manufacturing and support, and provides an integrated view of an asset throughout its lifecycle
- Digital connections among authoritative, historical, & cross-discipline technical data throughout a product's life cycle
- Complete collection of data & information that ties the virtual representation and physical object that flows the entire product lifecycle
- A communication and data flow framework that allows an integrated view of a product across its entire lifecycle…an unbroken link from the original computer model to the final physical product…full traceability and connectivity from concept through design, manufacturing, and service

From public sources, professional organizations, DoD Industry OEMs

Digital Twin

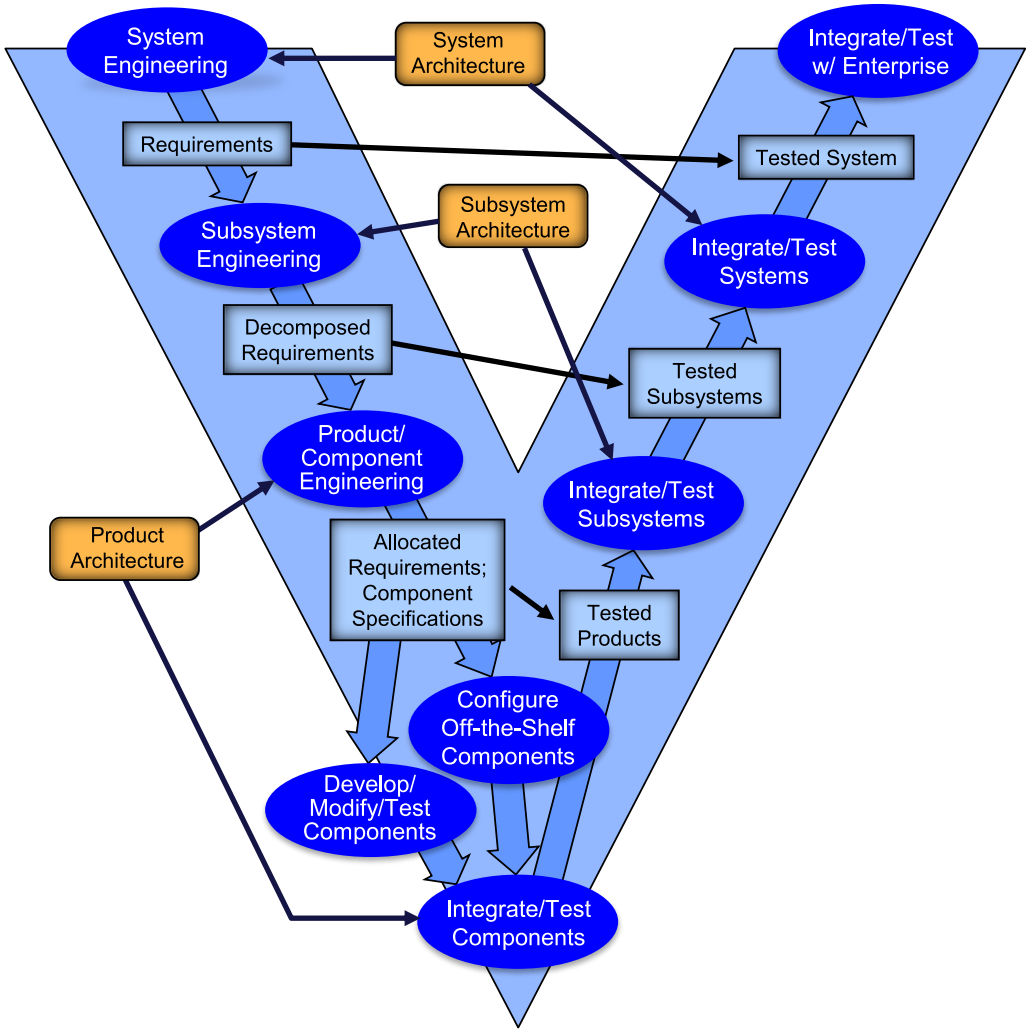
- A virtual representation that serves as the real-time digital counterpart of a physical object or process
- A virtual representation of a physical object or system to enable understanding. The digital twin stores all of the knowledge about an asset, from its inception through its manufacture and service life.
- A virtual representation of a physical object or process…used to test and validate products in a virtual environment before the products even exist in the real world…. Give engineers early warning of product failures to prevent unplanned downtime and improve product performance. …Once it exists, can be used to troubleshoot failure conditions, assess the impact of new mission environments, and evaluate product improvements

From public sources, professional organizations, DoD Industry OEMs

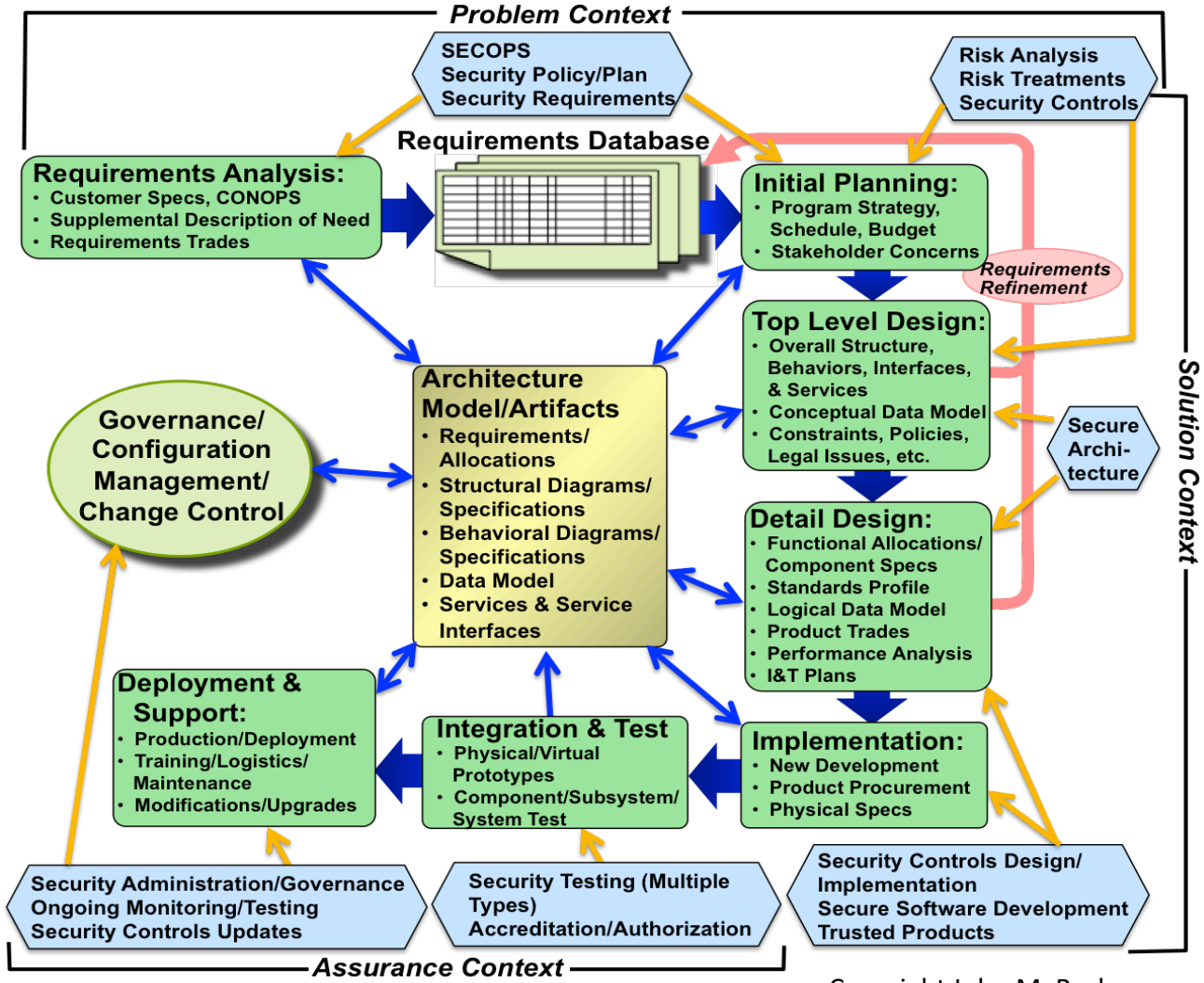
Stakeholders for DE

Systems Engineering Modernization Initiative, Nadine Geire, Dir SE OUSD (SE), https://www.cto.mil

Classic SE "Vee"



CyberSecurity in All SE Phases



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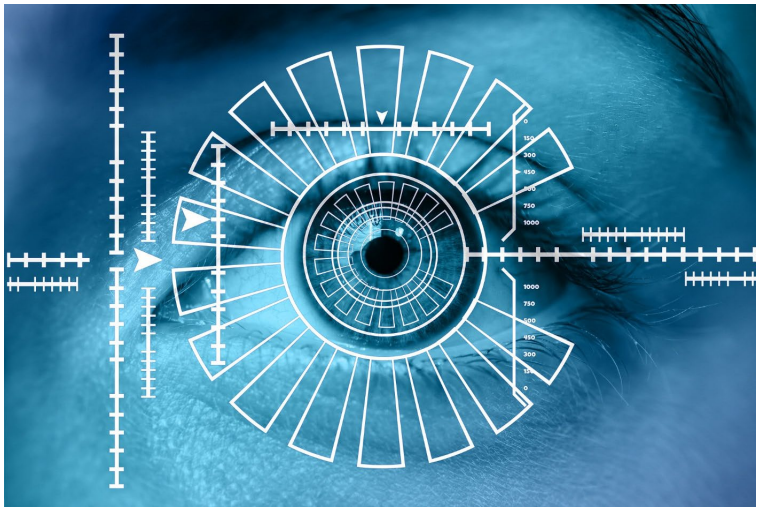
- Start with the basic flow of an MBSE process anchored in an architecture model
- Successive cybersecurity activities map to this flow
- Development of a secure solution can be organized into Problem, Solution, and Assurance Contexts

Intended Outcomes

- Built-in Flexibility
- Speed to the Battlefield
- Speed to all services
- Recapturing technical dominance
- Digitally documented system development even on legacy systems
- Secure documentation, communication, systems
- More competitive due to reuse, innovation



What Does This Mean? Big Changes

- The traditional "V" is still in use but repetitive in shorter time frames (Rolling wave, Agile) – increased flexibility
- Transition from document to digital project artifacts
- Automatic generation of reports from digital artifacts
- Central depository and "digital thread" throughout system development and retirement
- Changes in attitudes and culture within the established SE community
- Cyber Security required at all levels

Case Study – Boeing T-7A Red Hawk

T-7A Red Hawk livery rendering by Boeing

Boeing T-7A

- In September 2018, Boeing was received the USAF contract worth $9.2 billion to build 351 advanced trainer aircraft and 46 associated ground-based training simulators. This plane is replacing the U.S. Air Force's T-38
- T-7A Red Hawk, a supersonic 47 ft long plane, was purpose-built to include provisions for growth, improve supportability and innovate a maintenance-friendly design
- This build "broke the norm" by incorporating
  - Digital engineering processes
  - Agile software development
  - An open architecture mission system to enable more rapid, affordable future aircraft development
  - Modular design
  - Advanced fighter-like performance

Design for Maintainability and Flexibility

- Side opening cockpit canopy
  - Easy to change seats out
- High wings
  - Easy to inspect and access
- Drop Down Door panels
  - Easy access at the right height
- Maintenance Control panel and single point refueling
  - On same side, easy access to both
- Fast Engine Changes
  - Takes only 4 people a few hours
- Interchangeable parts
  - Simplified supply chain for rudder, stabilizers, and actuators

Digital Engineering Success

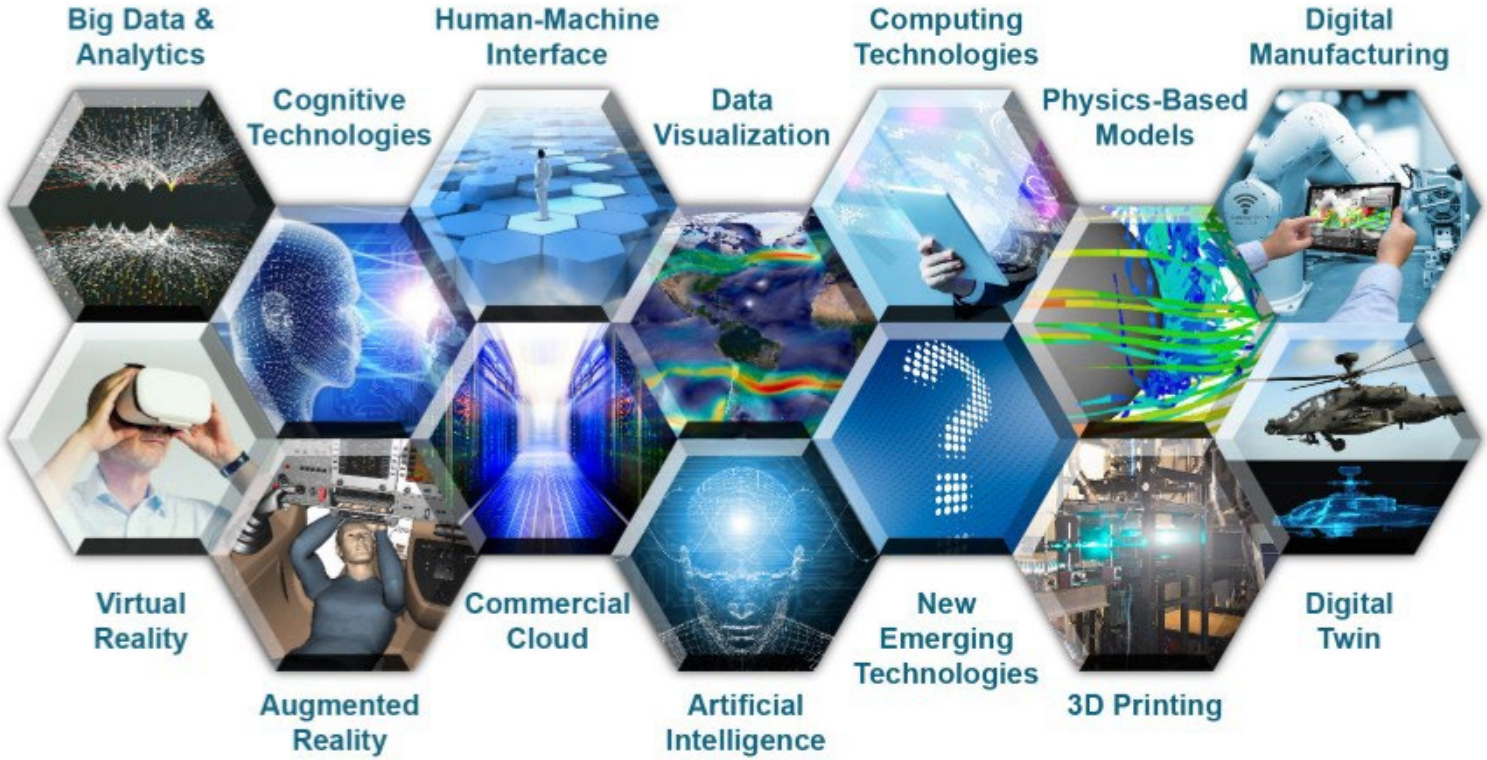
- Fully designed using 3D model-based definition and data management systems
- **Concept to first flight in 36 months!**
- Accelerated build times and increased quality and affordability
- All of the knowledge is reusable!
- According to Boeing, compared to traditional aircraft development programs, T-7A experienced:
  - ***A 75% increase improvement in first-time engineering quality***
  - ***An 80% reduction in assembly hours***
  - ***A 50% reduction in software development and verification time***

Success for the T-7A

- It even restarts engine in mid-flight
  - https://www.youtube.com/watch?v=eNSs9yXSorw
- US Navy is now considering the T-7A to replace another trainer – the T- 45 Goshawk
  - https://www.youtube.com/watch?v=N84KveYcAGM

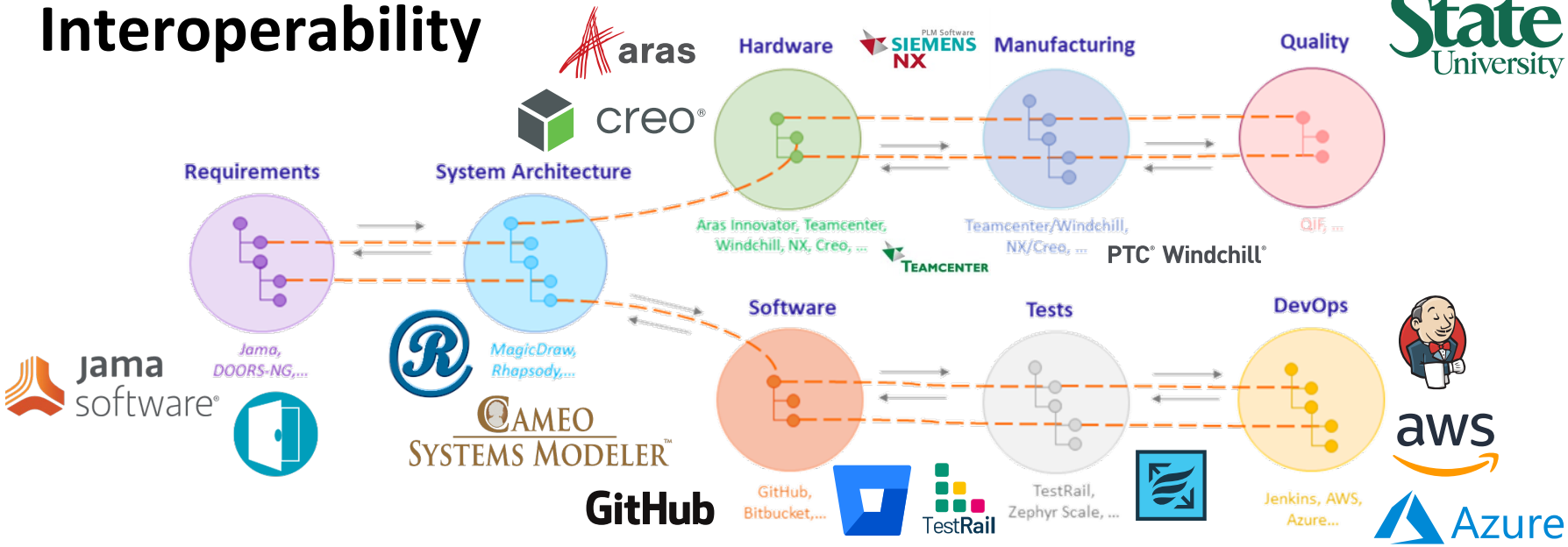
What do you need to do digital engineering?

Enabling Technologies



DoD DES 2018, page 12

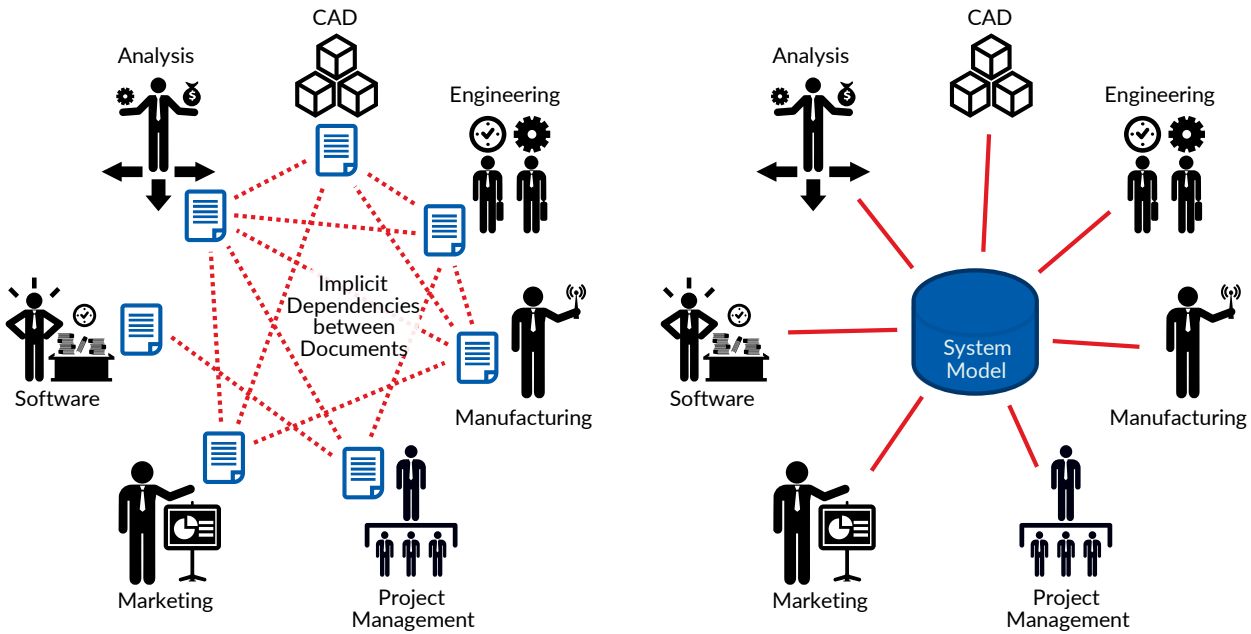
Enabling the Digital Thread with Tools and Interoperability



- **Tools**
  - **There are many different tools that answer specific aspects of the digital engineering needs**
  - **Tools often require training and the right mindset for effective use in a digital engineering environment**
- **Interoperability**
  - **Many large tool vendors are building interoperability between other tools (enabling digital threads between different kinds of data and tools)**
  - **There are also formats/standards (SysML, ReqIF, Modelica, FMI, XML schemas, CSV, Open Services for Lifecycle Collaboration (OSLC), etc.) that facilitate more general interoperability between and inside of the different layers**

Modified from https://intercax.com/2021/07/20/new-video-introduction-to-syndeia-the-digital-thread-platform-for-model-based-engineering/

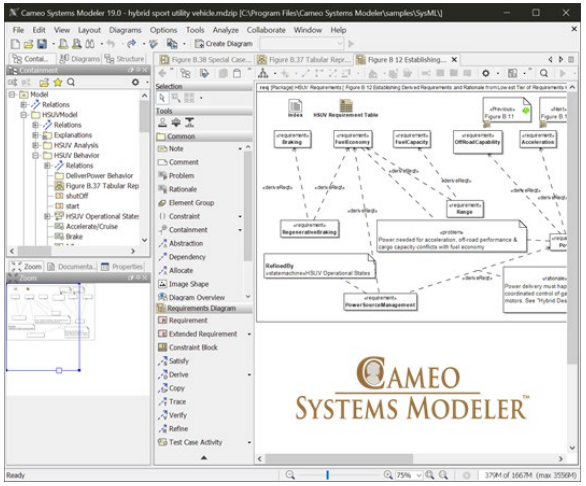
Model-based Systems Engineering (MBSE)



(a) Traditional document-centric SE approach

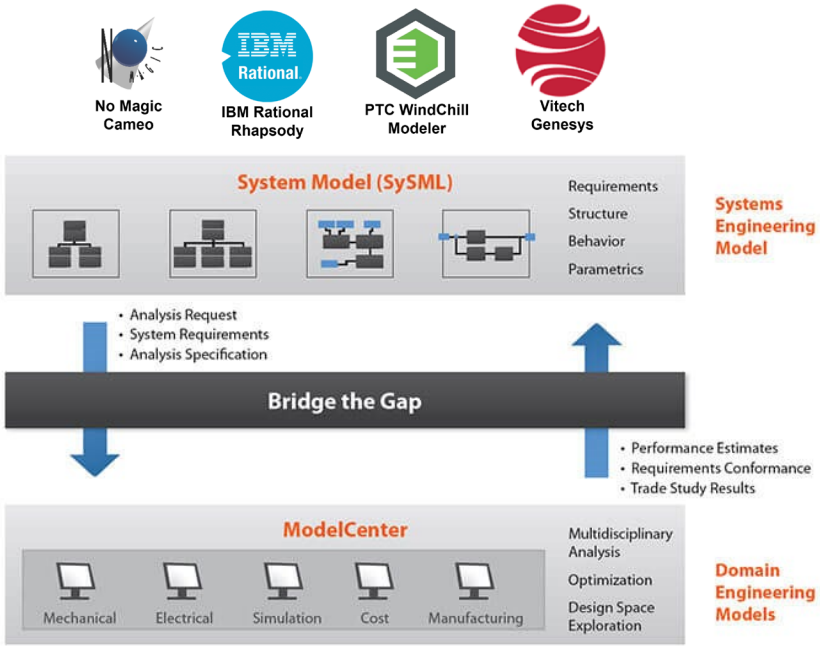
(b) Model-based SE approach

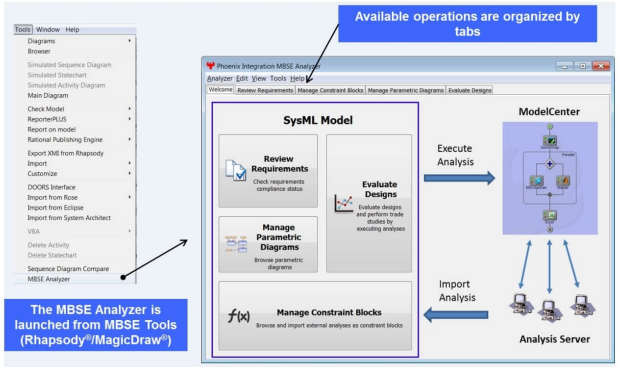
Tools like Cameo Systems Modeler support MBSE



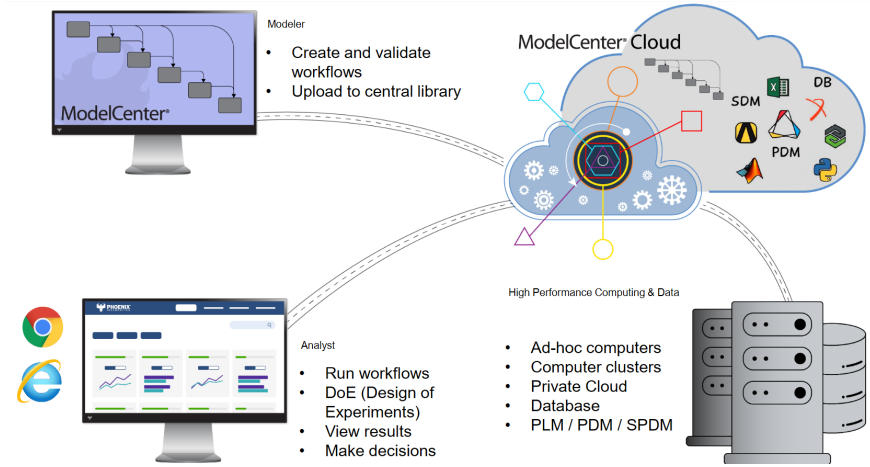
- **MBSE puts models at the center of system design and management**
- **Single source of truth – single point of access and modification for data/system understanding**
- **Discipline-specific views of the system can be created**

Example of Tool Interoperability – Phoenix Integration ModelCenter MBSE





Translation support between digital models



Use case-driven and cloud connectivity between engineering activities

https://gpdisonline.com/wp-content/uploads/2020/10/Phoenix-Integration-Davenport-ModelCenterMBSE-MBSE-Open.pdf

Digital Engineering Expected Benefits

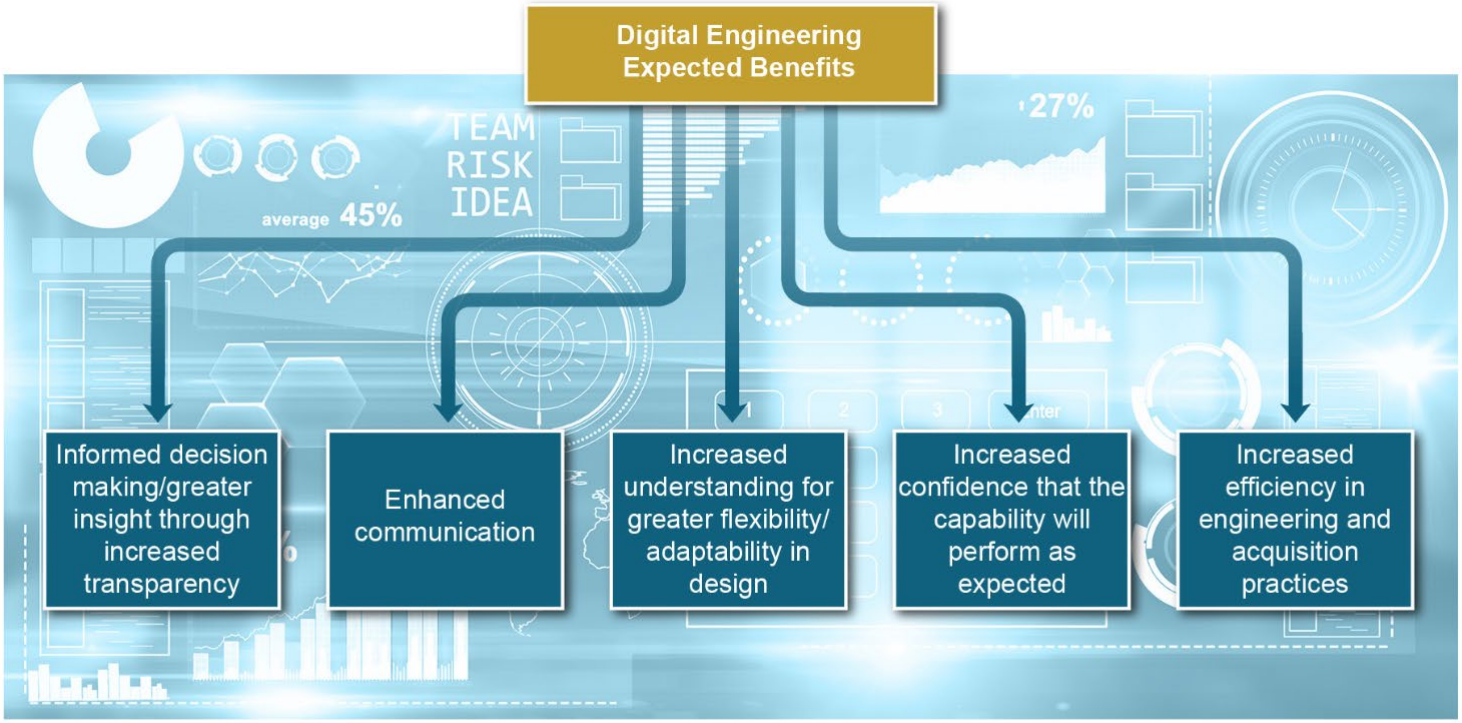


Figure 2: Digital Engineering Expected Benefits

https://man.fas.org/eprint/digeng-2018.pdf

Some Additional Key Points

- **Fundamental engineering principles prevail – going digital doesn't mean that the fundamental principles of engineering are out of date, they are just enhanced by technology**
- **Unlocking data is key – data capture and manipulation is essential and requires a digitally savvy engineer**
- **Digital evolution – processes are continuously evolving**
- **Collaborative practice is reborn – collaborative real-time processes of co-design and review are emerging**
- **Improved optioneering – enabling new, more efficient ways to generate multiple design options and evaluate them**

https://www.aurecongroup.com/expertise/digital-engineering-and-advisory/defining-digital-engineering

Tips

- **Keep up with the digital evolution – digital engineers must keep up with the digital trends and make it a habit to explore and learn about them**
- **Learn how to code and use the tools – fluency is required to realize the benefits**
- **Soft skills still matter – not everyone may always understand the technical aspects, so digital engineers must bridge that gap through effective communication and collaboration**
- **Diverse backgrounds and skills are important – the aim should be to get different kinds of expertise, specialization, and backgrounds into a team to develop effective enterprise-level digital engineering approaches**

https://www.aurecongroup.com/expertise/digital-engineering-and-advisory/defining-digital-engineering

CSU Systems Engineering Transformation Efforts

- Model-based Systems Engineering (MBSE)
- Digital Twinning (Batchelor, Herber, Simske, Vans)
- Digital Engineering (Batchelor, Herber)
- Augmented Reality/Virtual Reality (AR/VR) Environments and Classes (Vans)
- Secret Collateral Security Working area

Questions?