Systems Engineering Methods for Validation and Verification of Changes to Legacy Fielded Systems

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SYSTEMS ENGINEERING
COLORADO STATE UNIVERSITY

Introduction

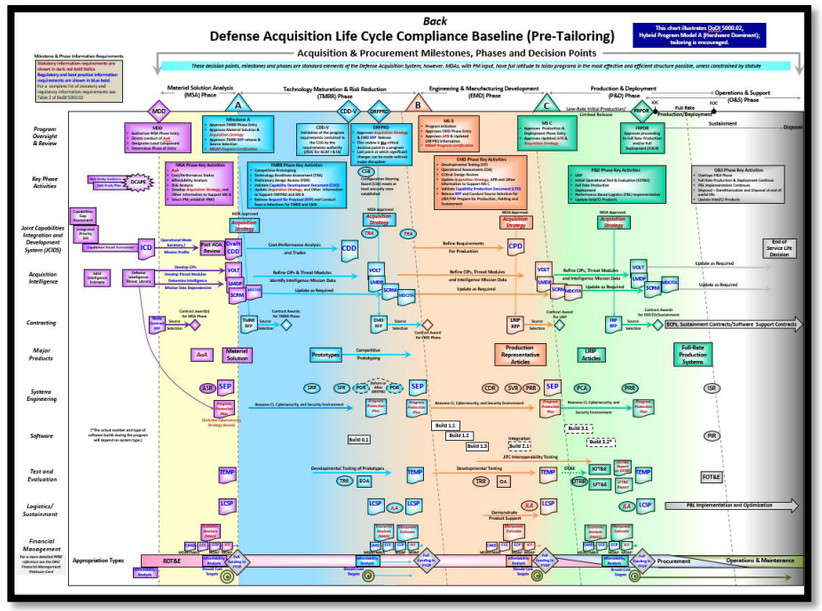
- Most USAF fleets did not meet Mission Capability Goals
  - Government Accountability Office Report GAO-21-101SP
- The DoD has unique challenges
  - Political influence on system decisions
  - Aging systems, increasingly difficult to sustain

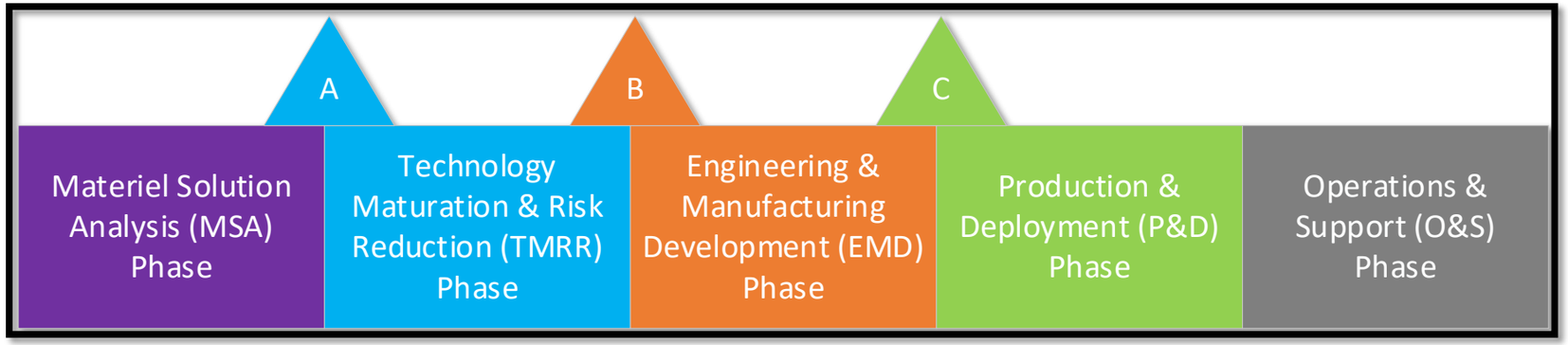
Pictured:- U-2 Dragon Lady
- Fielded in 1955
- Still in use today

Photo Reference: U.S. Air Force, U-2 Dragon Lady
https://www.af.mil/News/Photos/igphoto/2002864066/mediaid/5460041/
Disclaimer: DoD Instruction 5410.20 - The appearance of U.S. Department of Defense (DoD) visual information does not imply or constitute DoD endorsement.

DoD Systems Engineering Life Cycle

- Challenges to systems engineering begin with the DoD Life Cycle Model, used for Major Acquisitions
  - Linear, does not illustrate how to manage change

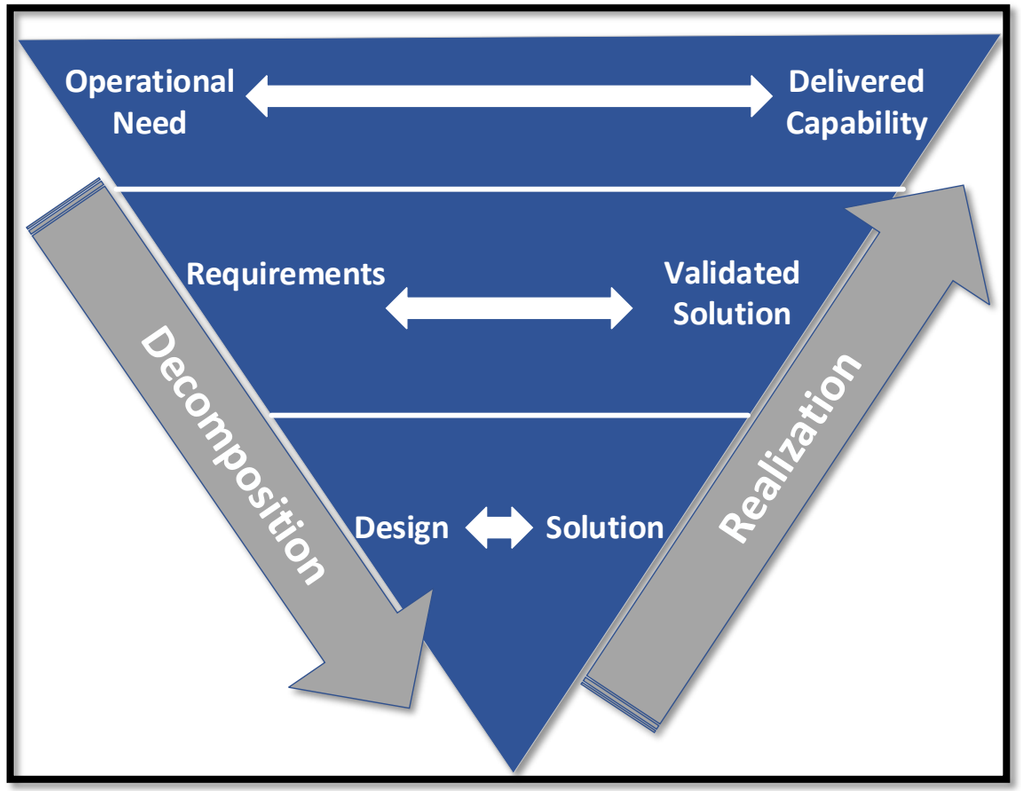




Reference: Defense Acquisition University, "Defense Acquisition Life Cycle Wall Chart," *Defense Acquisition University, Tools Catalog*, 2020. https://www.dau.mil/training/career-development/logistics/blog/Updated-DoD-Acquisition-Life-Cycle-Wall-Chart (accessed Jan. 17, 2023).

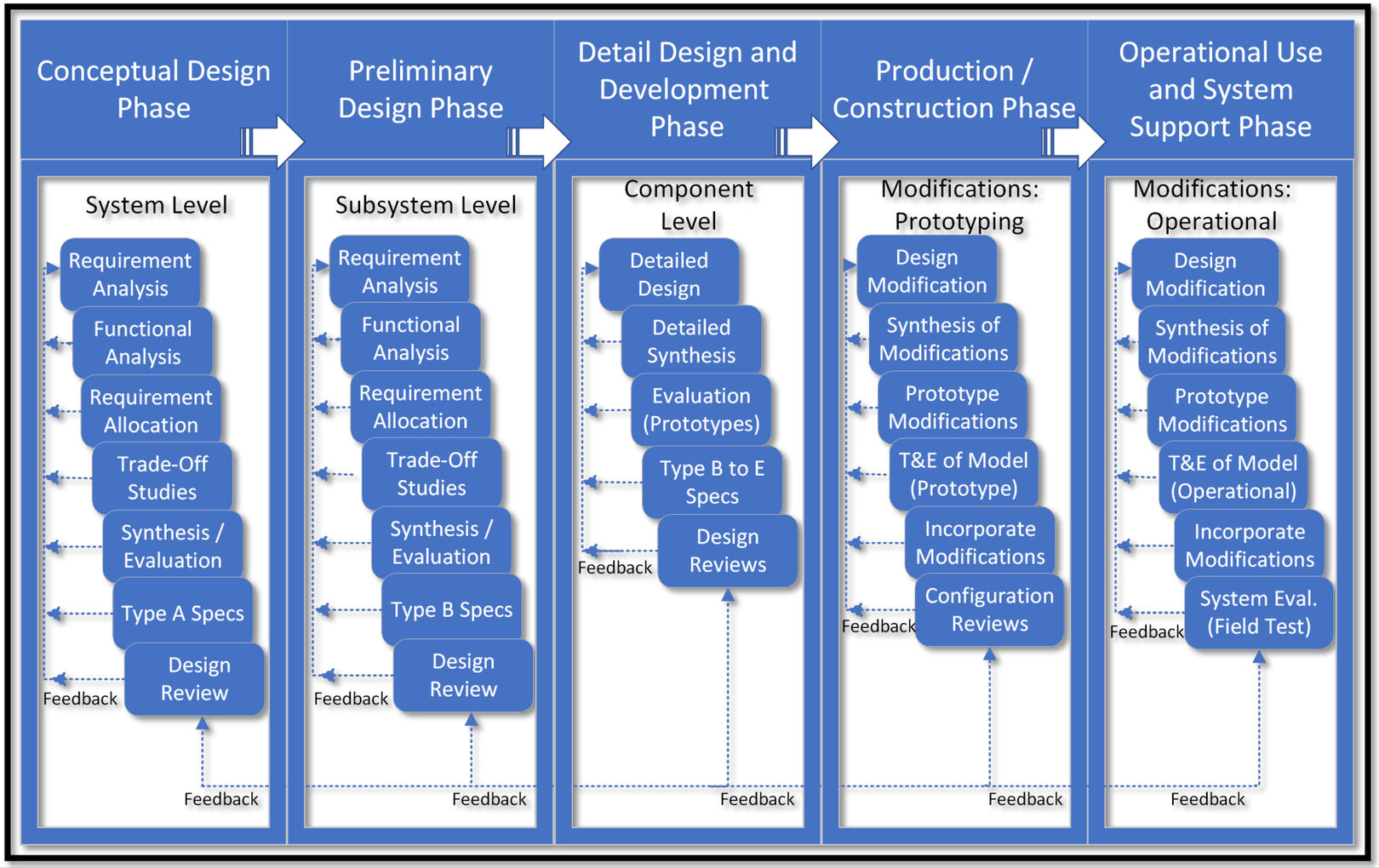
DoD Systems Engineering Process

- The DoD Vee model connects development phases and delivered capability, but lacks specifics
- Not as refined as the industry version of the Life Cycle Management model
  - Still better than the DoD life cycle model



Recreated from Department of Defense Systems Engineering Diagram, Defense Acquisition University (2022)

Commercial Life Cycle Model

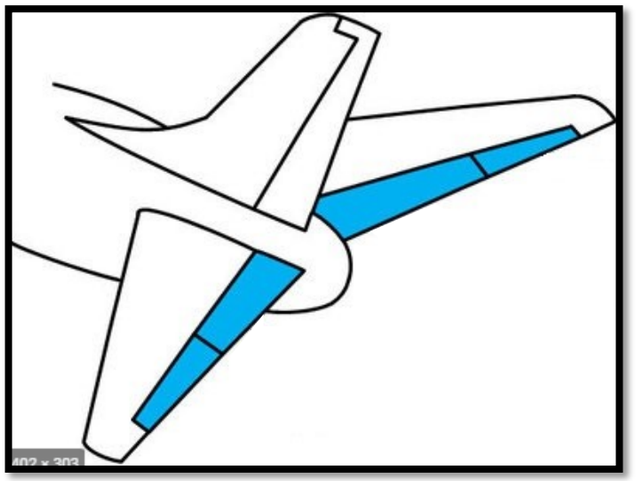


- Accommodations for change are built into the model
- Accepts that change is inevitable, and managing change should be an inherent part of the process

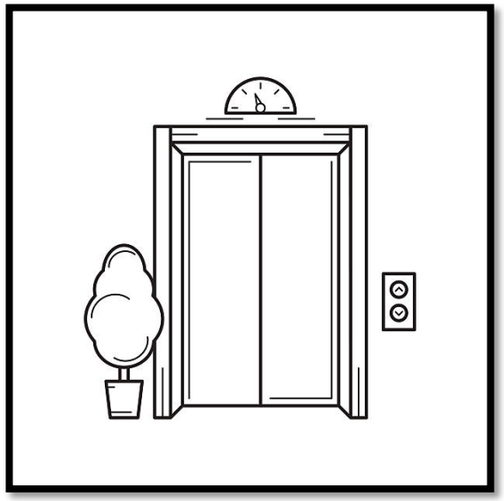
Reference: B. S. Blanchard and W. J. Fabrycky, *Systems Engineering and Analysis*, Fifth. Boston: Prentice Hall, 2011.

Context Matters

- INCOSE defines a system as:
  - an integrated set of elements, subsystems, or assemblies that accomplish a defined objective. These elements include products (hardware, software, firmware), processes, people, information, techniques, facilities, services, and other support elements
  - “System” is often mis-identified as a physical product only
- To mitigate the confusion, instead define
  - System – physical product
  - Operational Feasibility Elements: the software, processes, people, information, techniques, facilities, services, etc. that help the physical product accomplish the objective
  - ***Enterprise System***: physical product combined with the operational feasibility elements such as supportability, maintainability, training, etc. that make operation of the system possible



Elevator



Facilities

Supply

Training

Enterprise System

Transportation

Maintenance

Support Equipment

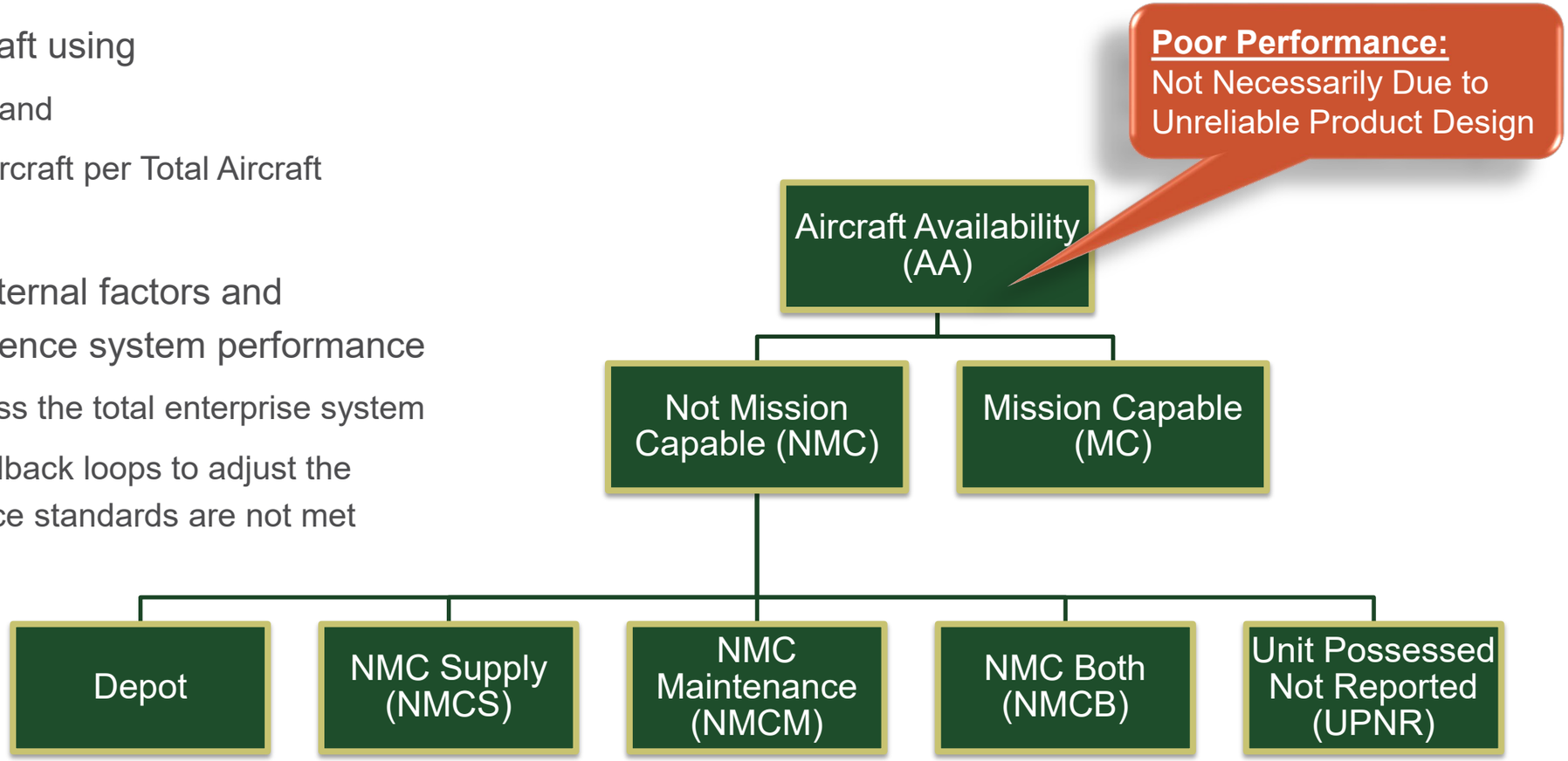
Analyze Operational Feasibility Elements

- Changes to operational feasibility elements impacts enterprise system performance
- Systems engineers should identify performance metrics for all aspects of the enterprise system
  - **Usability Data**: sortie quantity, length, frequency, utilization rates
  - **Programmatic Data**: operational costs, schedule performance
  - **Reliability Data**: Mean-Time-Between Failure (MTBF) rates, sensor data
  - **Maintainability Data**: maintenance hours, assistance requests, recur rates
  - **Supportability Data**: supply logs, orders/requisitions, backorders
    - Disconnect with DOD funding for these considerations (i.e. can't upgrade VORTAC on aircraft budget allocation)
  - **Other**: Facilities, training, manufacturing techniques, facility availability, corporate organizational structure, logistics, etc.

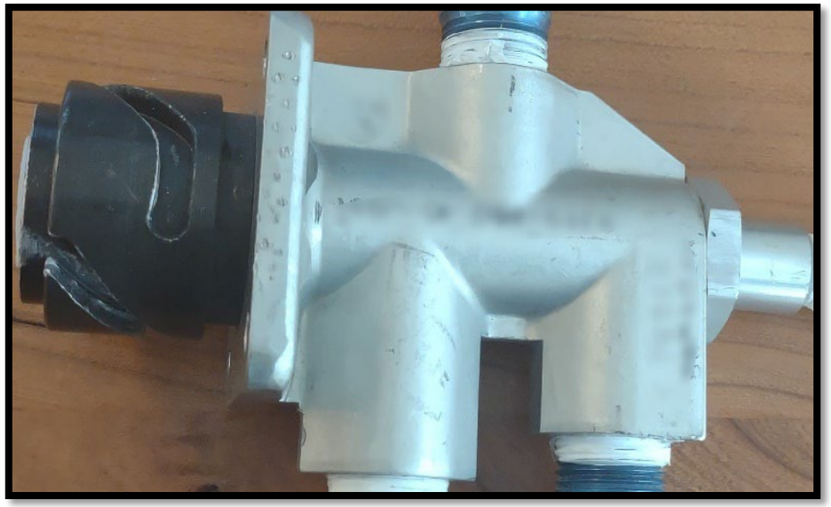
Can't Land Aircraft without Ground Radios

Typical Performance Indicators

- The Air Force monitors aircraft using
  - Aircraft Availability (AA), and
  - Mission Capable (MC) aircraft per Total Aircraft Inventory (TAI)
- Provides little insight into external factors and considerations that can influence system performance
  - Metrics should encompass the total enterprise system
  - With monitoring and feedback loops to adjust the system when performance standards are not met

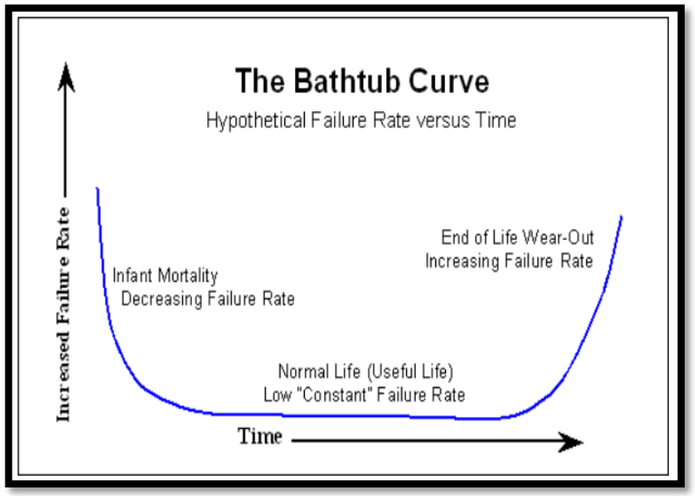


Case Study: Changes in Manufacturing



Legacy Valve: Cast aluminum

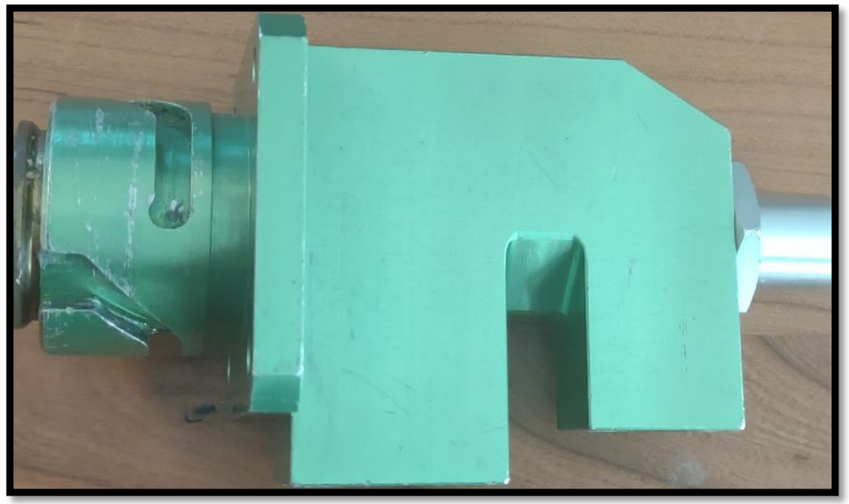
Originally intended to last the life of the system, but system use extended past original intent due to service life extension.



Parts failed at natural end of life, NOT a product design or reliability issue

Vendor resisted manufacture with legacy casting requirements, due to cost

D. J. Wilkins, “The Bathtub Curve and Product Failure Behavior (Part 2 of 2),” *Reliability Hotwire*, 2002. https://www.maths.tcd.ie/~donmoore/project/project/Write up/22 mar 2006/hottopics22.htm (accessed Oct. 13, 2022).



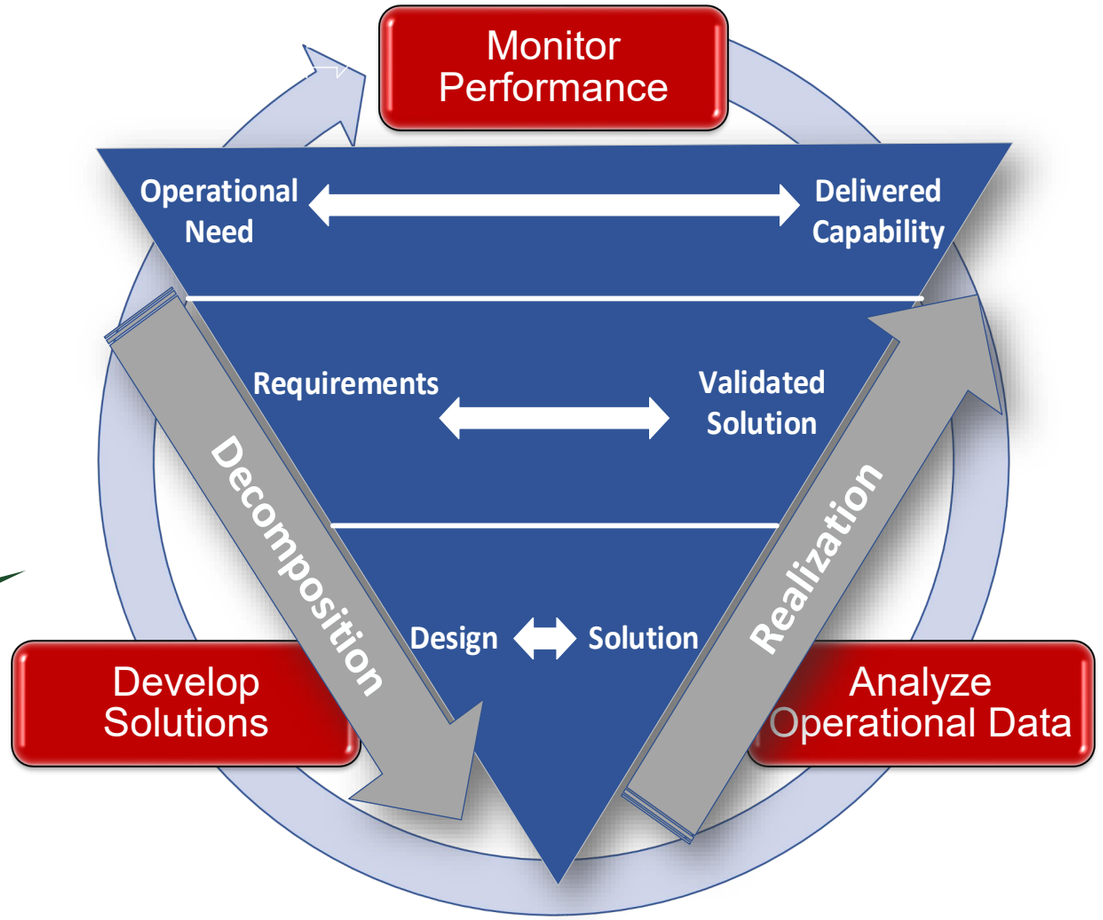
New technology authorized to allowed CNC machining, more cost effective than casting for small quantity parts

An Operational Feasibility Element, changes to manufacturing technology and manufacturer preferences, impacted performance which resulted in a physical product change

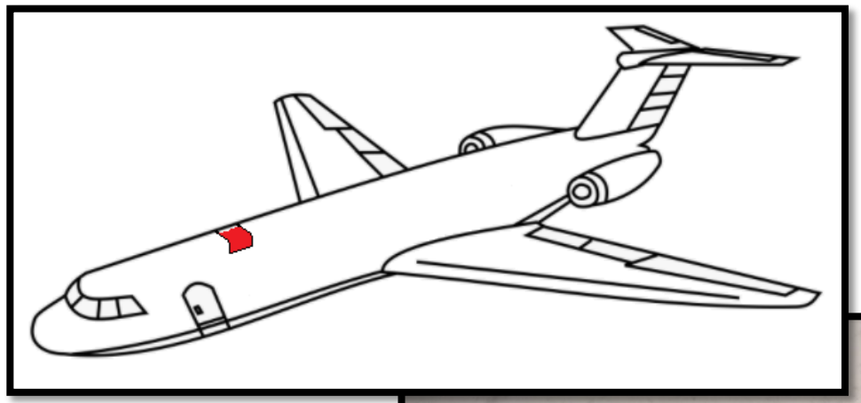
Proposed Method - Continuous Validation

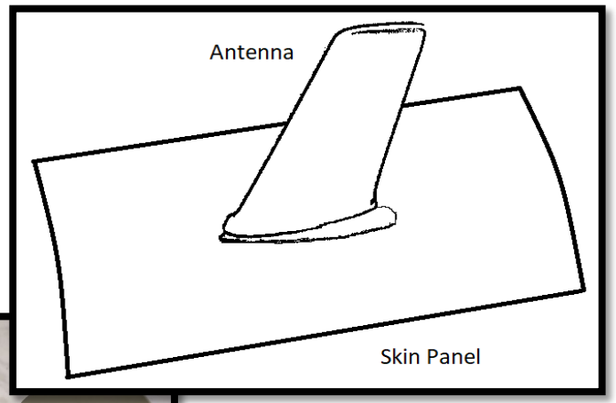
- With the proposed method, validation activities for the enterprise system never end
  - Continuous monitoring of all aspects that impact the system can avoid negative trends in performance as a system ages
  - Can accommodate failures of the enterprise system due to operational feasibility elements

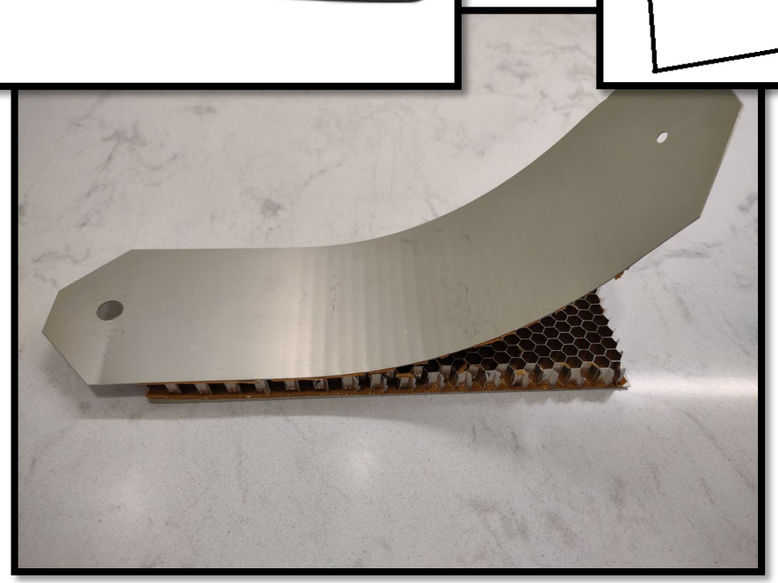
All stakeholders should continuously validate the enterprise system



Case Study: Repair Techniques







Aluminum Honeycomb Panel Test Coupon

- Aircraft structural panels have not changed, nor are they failing more frequently
- Legacy repair methods not compatible with modern shop capabilities or training
- New repair method not compatible with aircraft system requirements
- Changes in modern repair processes caused increased maintenance hours when systems began failing

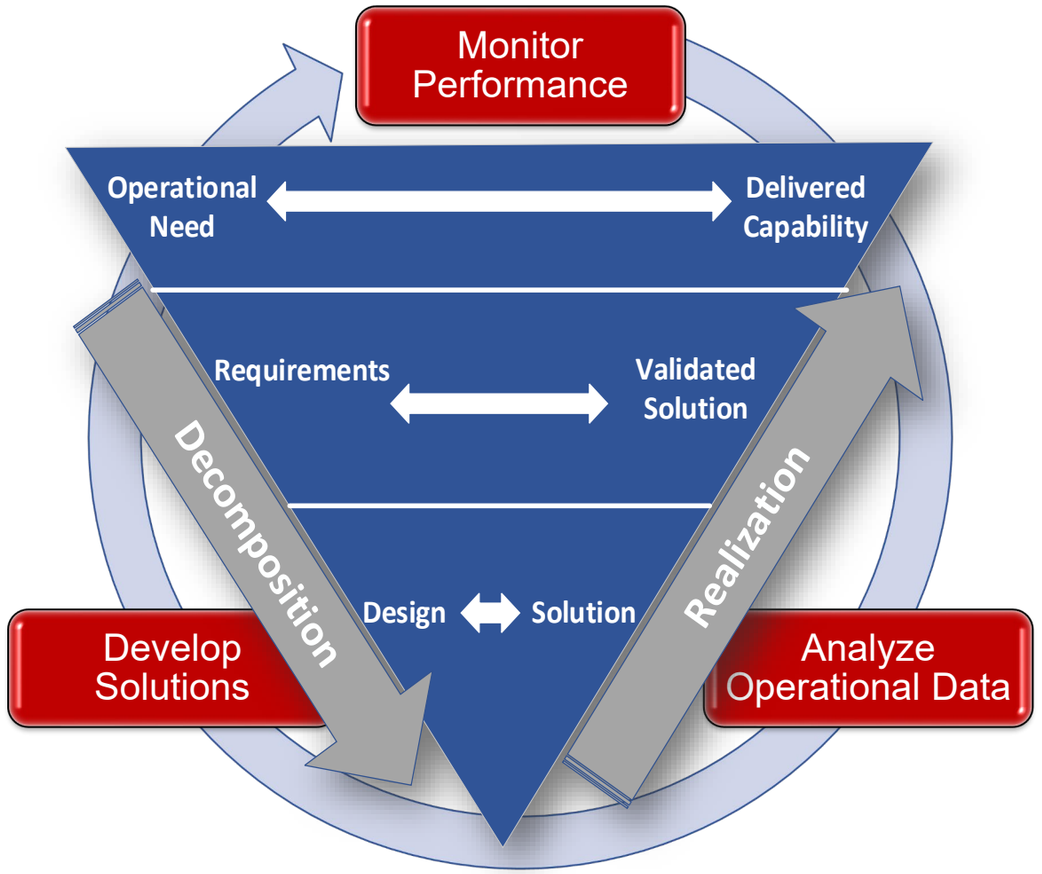
Case Study: Maintainability Improvements

- Original design included sheet metal ducts with unique, contoured rubber boots that took **too much time** to repair or replace.
- Aircraft system still in service after original design life ended, boots required replacement, but only occasionally
- Maintenance data showed trends of **high downtime** hours to accommodate part replacement due to duct configuration
- Engineers leveraged emerging technology to remove the custom boot completely, facilitate quicker replacement, and additive manufacturing technology.
  - 2-D to 3-D technologies (the enterprise lags technology)

3D Printed Duct and Sheet Metal Duct

Summary

- Changes to operational feasibility elements impact performance
  - The physical system has not caused the change in requirement
  - Solutions should address the root cause performance driver
- Stakeholders should continuously monitor system performance, but at the Enterprise System level
  - Include measures for all Operational Feasibility Elements
  - Analyze operational data to determine the root cause impacts
  - Document the requirements changes to develop solutions at the Enterprise System level
    - With the appropriate stakeholders and process owners, which may not be technical personnel
- Three Case Studies to demonstrate the challenges
  - Valve replacement, antenna panel, 3-D printed duct



Thank you

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