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Leveraging the Systems Engineering Life Cycle Process for Reverse Engineering

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Introduction

- The aerospace defense industry is well-known for keeping systems in use for long periods of time

- Pictured: U-2 Dragon Lady, first 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.

Average Fleet Age

- Average fleet age has continued to increase over the last decade
- By 2019, the average age of aircraft in the USAF is more than 29 years old
- Many aircraft were designed before modern tools and manufacturing processes existed

Reference: Government Accountability Office (GAO) Report GAO-21-101SP
https://www.gao.gov/products/gao-21-101sp

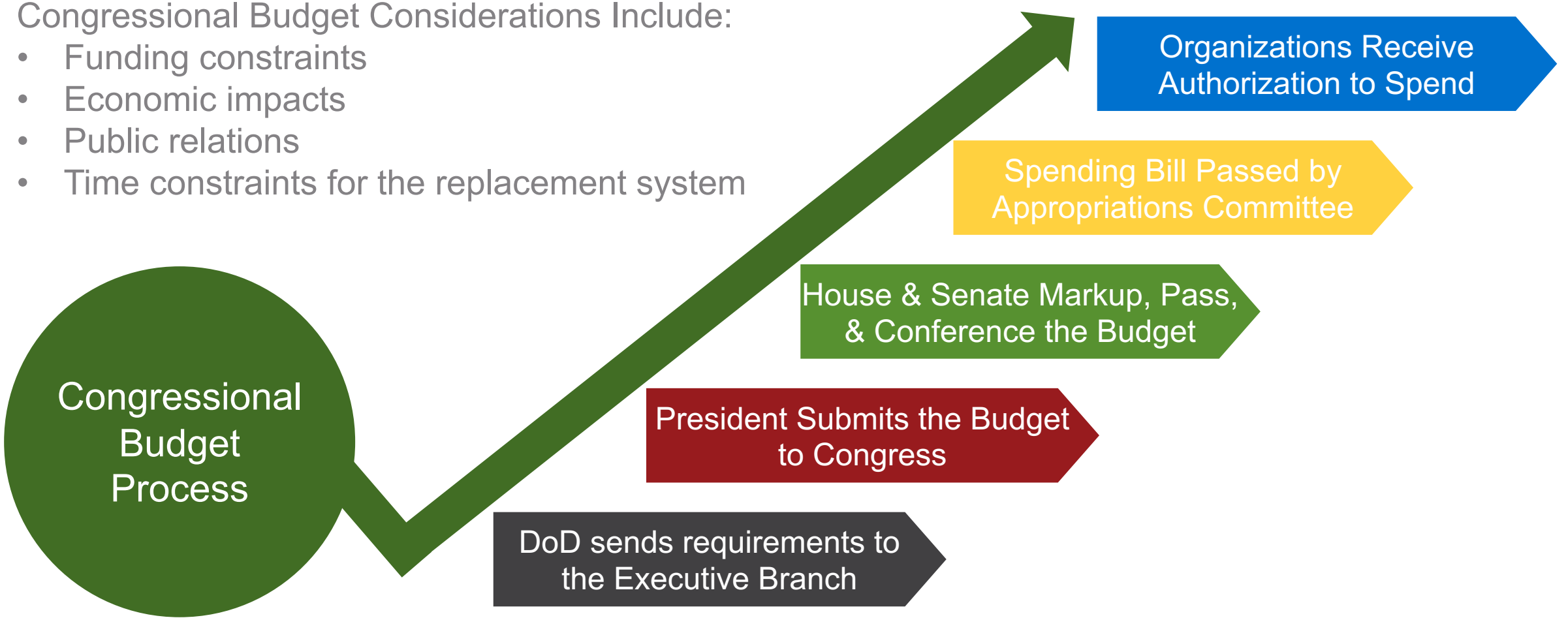
Barriers to System Replacement

- For the DoD, planned system retirement must be approved by Congress
  - Technical considerations not always primary
  - Political considerations for replacement schedules often take precedence

Congressional Budget Process

Congressional Budget Considerations Include:

- Funding constraints
- Economic impacts
- Public relations
- Time constraints for the replacement system

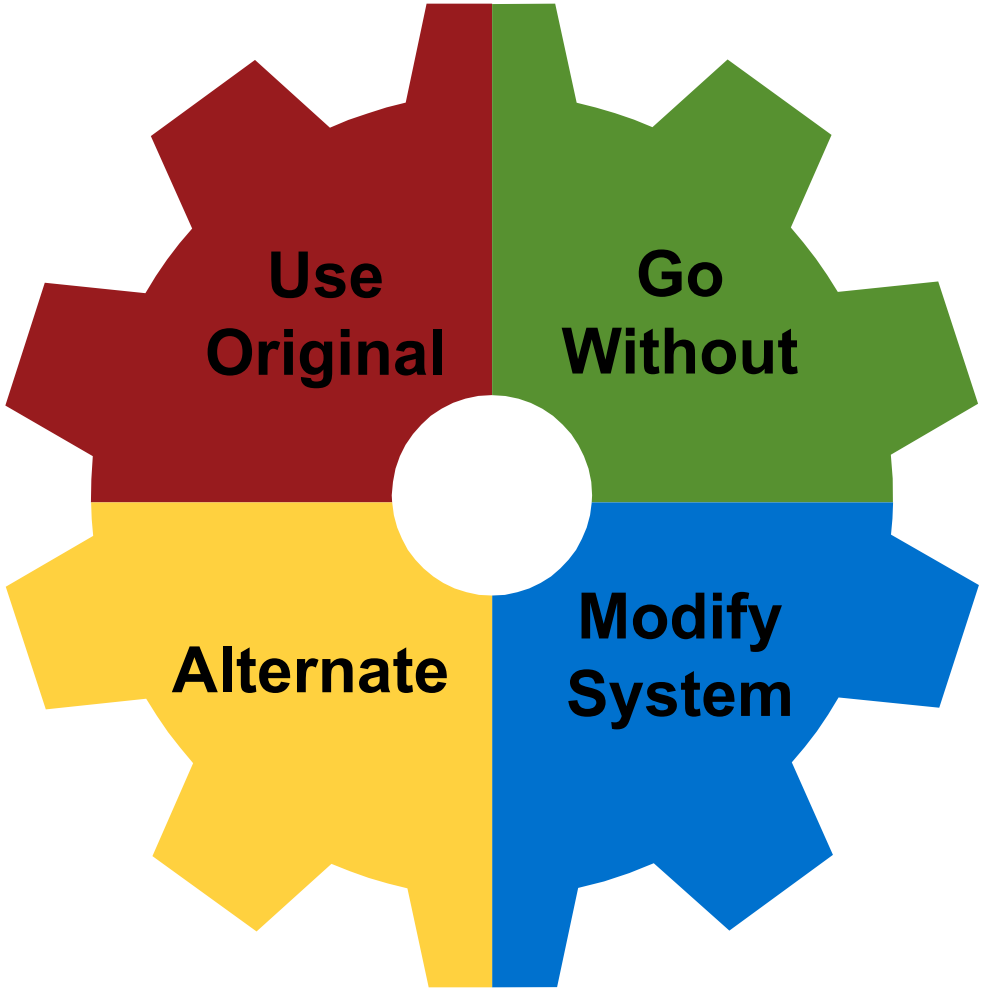


Industry Adjusts to Fill Demand

- Diminishing Manufacturing Sources and Material Shortages (DMSMS) programs
  - Resolves parts obsolescence issues
  - New defense guidebooks and regulations
  - Training for DoD DMSMS management
  - Parts and Materials Management Conference (PMMC) to exchange ideas related to DMSMS

Approaches to DMSMS Resolution

Use the Original
Buy or build the original component part or system



Go Without
Use the system without the part, or don't use the system

Alternate
Usually a Commercial-Off-The-Shelf (COTS) component; use it as-is or modify it to fit the system

Modify the System
Modify the system to go without the part or use an alternate part

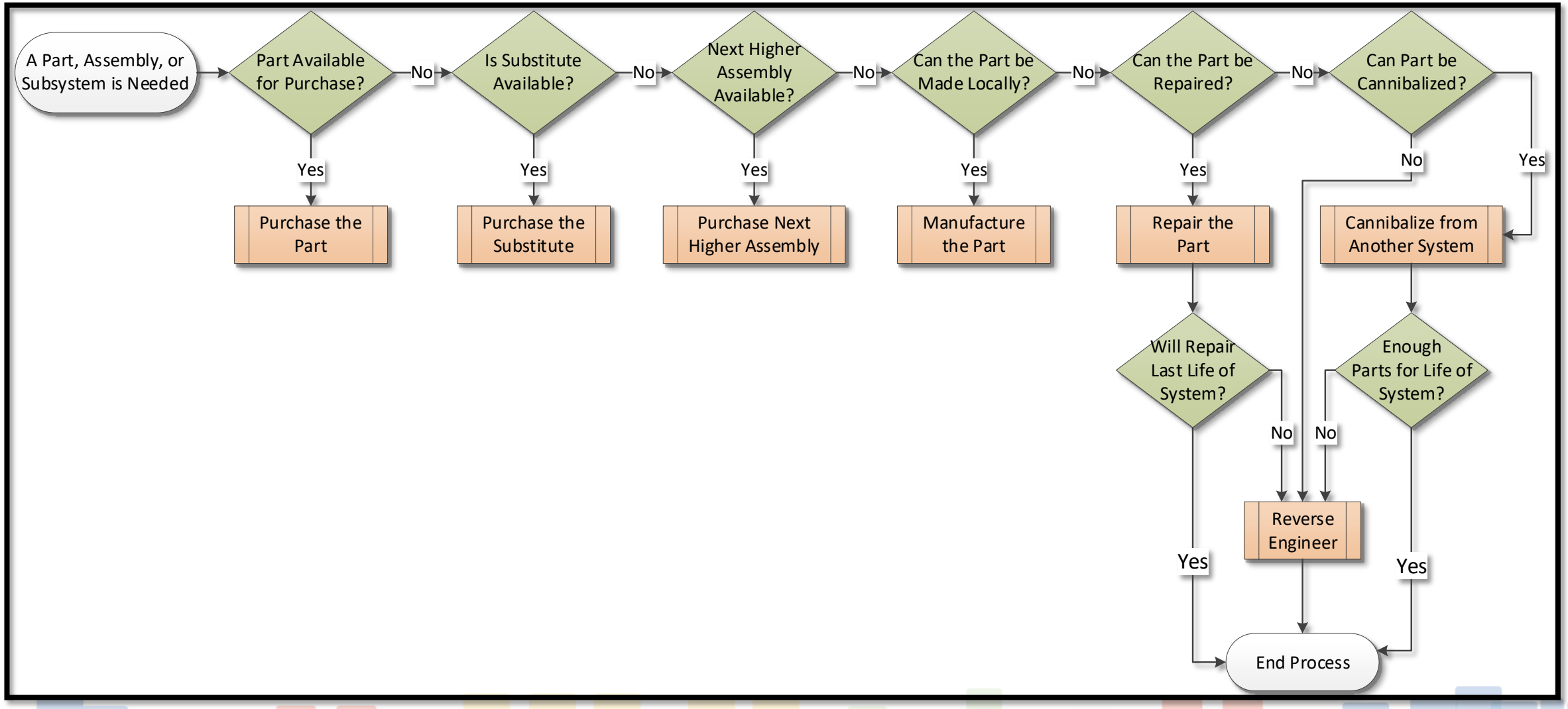
Reverse Engineering (RE)

- Plays large role in DMSMS industry
  - Few customers like the “Go Without” option
  - Utilized when original vendors no longer exist and/or no longer have the technical data
  - Use the Original Option
    - Design still works well, just need parts refresh
- Appealing in the DoD
  - Is not a modification from a funding perspective
  - System does not change from user perspective

RE Definition

- Definition (can vary based on industry)
  - Analyzing a system to develop data that defines the components in order to reproduce new or maintain existing parts or subsystems
- For this presentation, focusing on mechanical and structural components

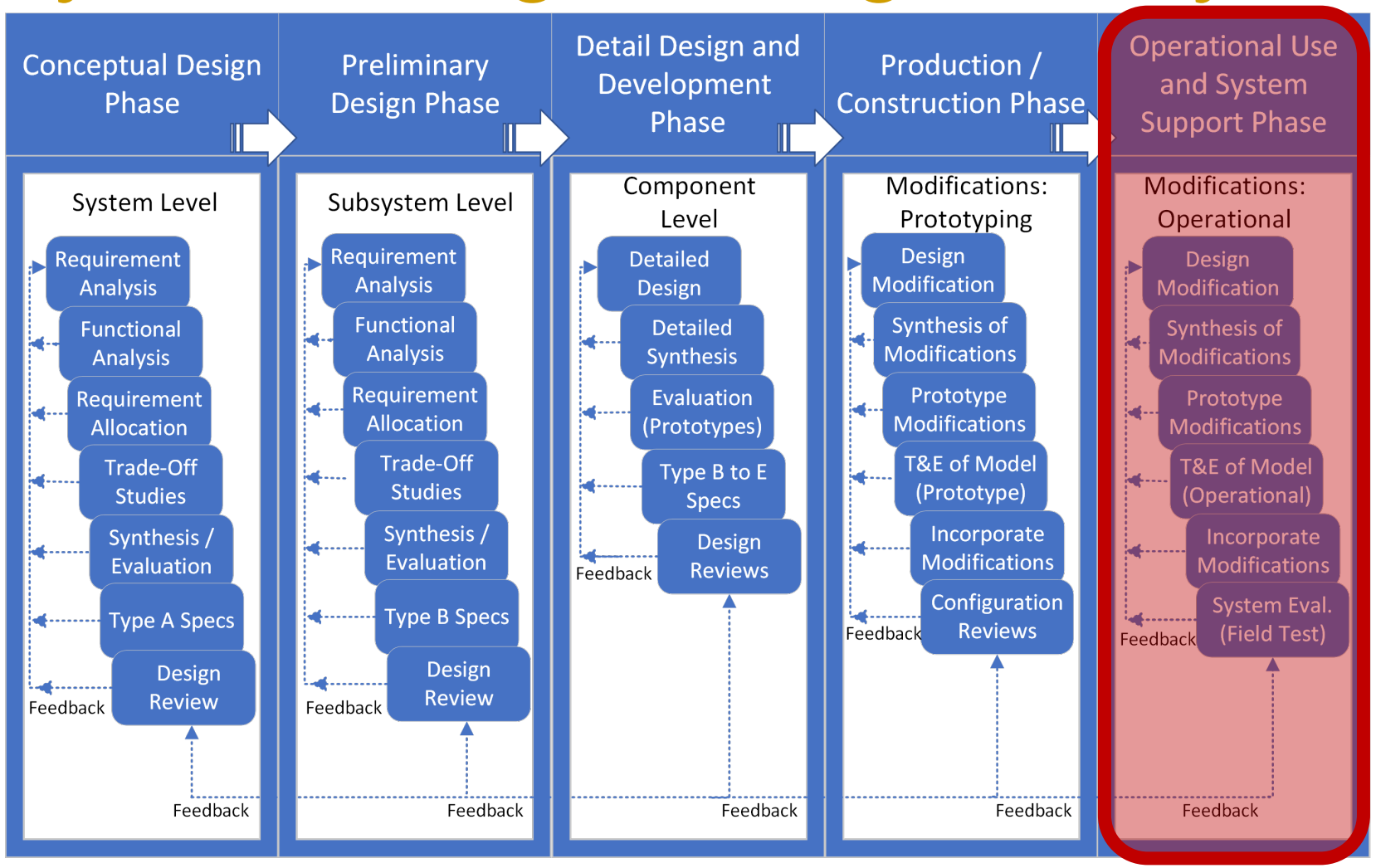
DMSMS Tactical Support Options



Reverse Engineering Impacts on LCM

- Several studies have shown the benefits of reverse engineering for logistics support
  - None link RE to life cycle management process
  - Most focus on the resulting physical product
  - Missing the root cause of why RE is necessary
- Don’t always incorporate RE into systems engineering life cycle model processes

Systems Engineering Life Cycle



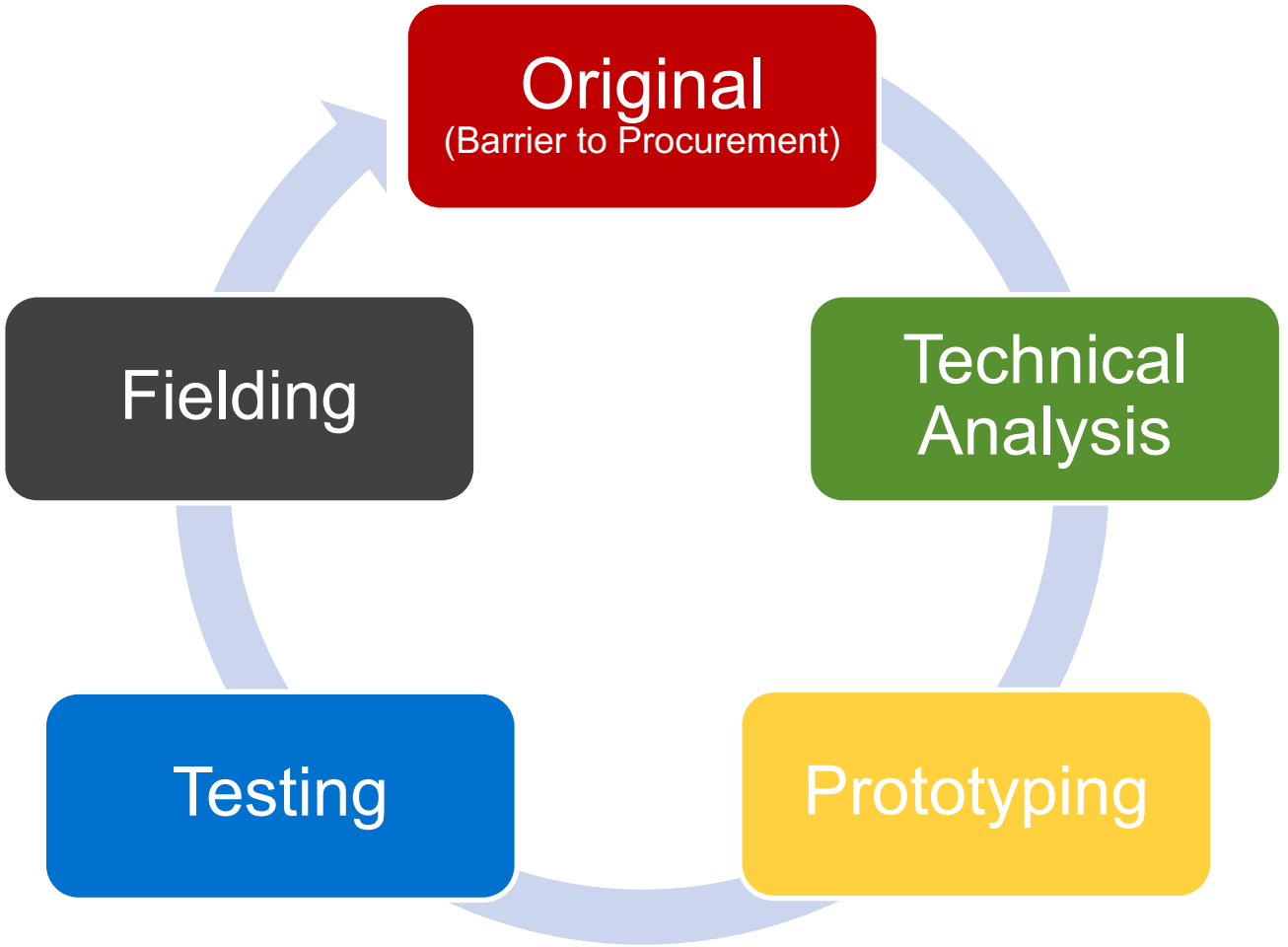
RE activities are a "red flag" that the system has failed to perform as designed

Blanchard, B. S., & Fabrycky, W. J. (2006). *Systems engineering and analysis*. Upper Saddle River, N.J: Pearson Prentice Hall.

Concept: RE Driven by Changes

- If current requirements are correct
  - The system operates and performs as intended
  - Requirements for support functions are adequate
  - RE would not be required
- Consider:
  - If there are issues with the system, current requirements are inadequate
  - If there aren't issues, why is RE required?

Traditional Reverse Engineering



Misconceptions for RE

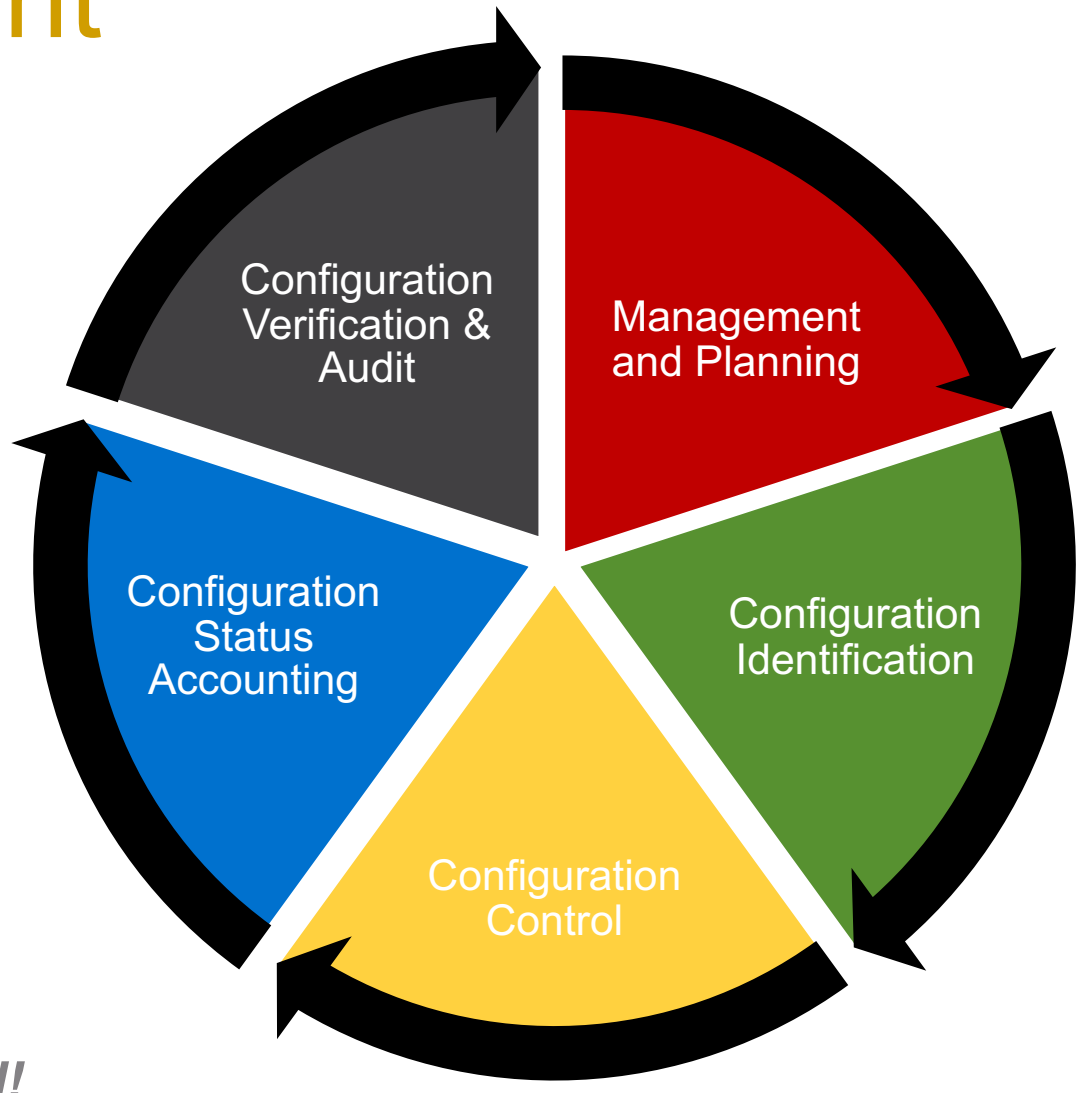
- RE should result in exactly the same:
  - Form, fit, and function
  - Processes and manufacturing techniques

- The reason RE is necessary:
  - ***Requirements for the System Have Changed***

Changes are Prevalent

Industries Anticipate Change, Demonstrated By:

- Development of Process Controls
- Configuration Management Career Fields
  - Training or Certifications
- Publication of Guides or Regulations
  - MIL-HDBK-61A
  - IEEE 828-2012
  - EIA649C



Industry Recognizes that Change is Expected!

Changes Not Limited to Physical

- Changes that impact the system may not be related solely to hardware or software
- Consider Operational Feasibility Elements
  - Maintainability, Supportability, Reliability, Testability, Usability, Producibility, Disposability, Sustainability, Affordability, etc.

Ex. Technical Data Changes

- Transparent film drawings for manufacturing
  - Older aircraft designed with Mylar drawings
  - Non-dimensional technical data on transparent film
  - Laid on top of parts to compare contour
- Change Issue: Modern manufacturers use CAD
  - Requirements for physical system have not changed
  - This issue has influenced RE efforts

Mylar Un-dimensioned Drawing

Pictured:

Kathy Power, Technical Data Specialist, pulls a Mylar un-dimensioned drawing to crate an airframe structure.

Photo Reference: Tinker AFB
https://www.tinker.af.mil/News/Photos/igphoto/2000364786/

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Systems Engineering Impact

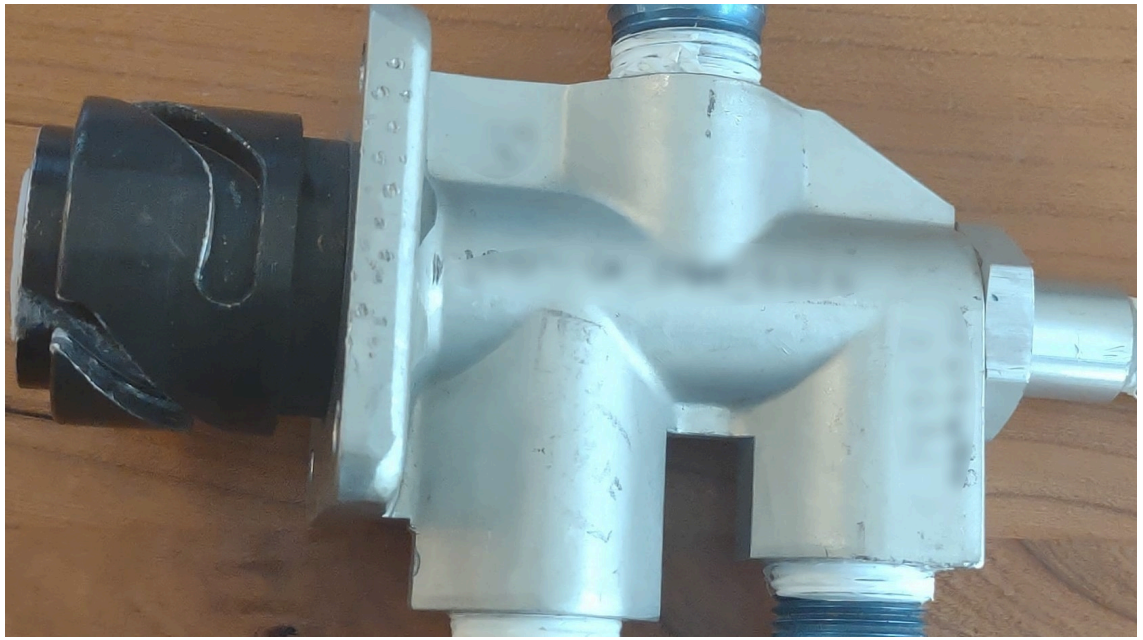
- Tech data requirements have changed
  - Stakeholder needs have changed (maintainers and manufacturers need digital data)
- Impacts the logistics ability to source vendors for parts
  - Performance impacts if parts aren't procured
  - Results in DMSMS issue (can't get parts)

Ex. Manufacturing Method Changes

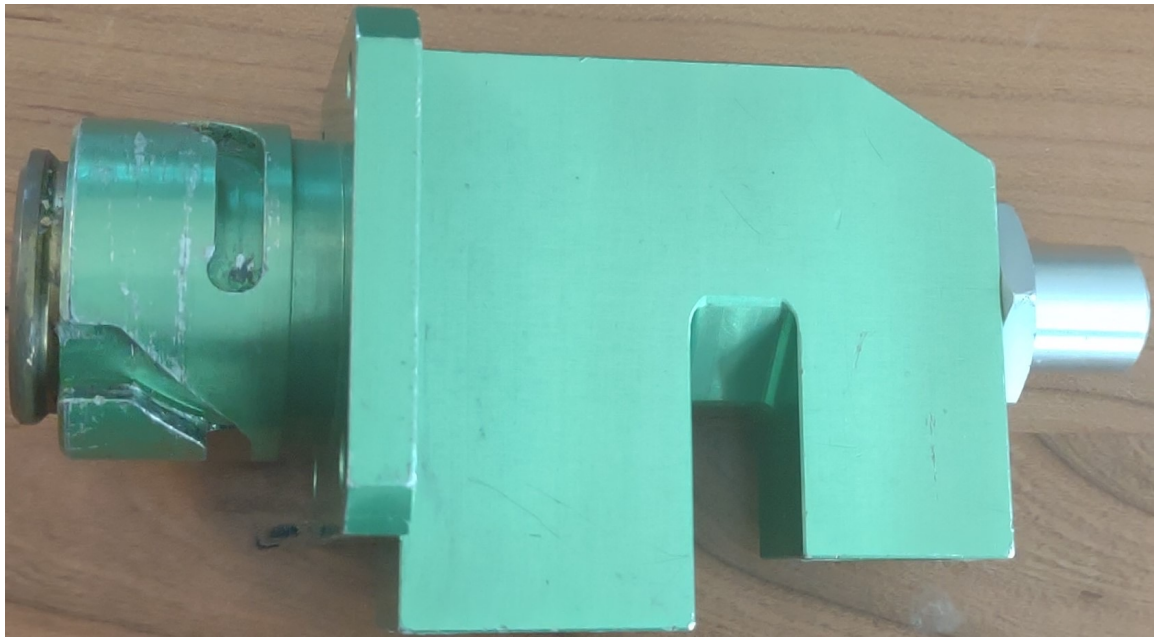
- In mi-20th century, cast parts were common for mass production
  - Easy way to get standardized sizes
  - Facilitated incorporation of production lines
  - Cost effective for the time period
- Change Issue: Mass quantities are not required, casting phased out as a method

Old vs. Modern Methods

Older Cast Valve



Modern Machined Valve



Ex. Manufacturing Method Changes

- New technology offers better approach for manufacturing products
  - Changing original designs may allow systems engineers to leverage benefits
  - Eliminate existing design flaws that customers originally accepted with system fielding

3D Printed and Legacy Duct

- Bottom pictured duct, originally sheet metal
  - Rubber elbow is unique, mass produced
  - Sheet metal ducts occasionally need replacement if damaged
- Top pictured duct, 3D printed replacement
  - Rubber elbow removed
  - Can be printed on demand
- Opportunity to improve
  - Design adjusted to accommodate requirements changes
  - Parts can be printed on demand

Systems Engineering Impact

- Large quantities not required in O&S Phase
  - Fleet no longer in production
    - Parts replaced on condition
  - Smaller fleet sizes from retirements
    - Lower quantities of replenishment parts required
- New technology offers opportunity to improve
  - Rapid manufacturing techniques are more cost effective
    - CNC programmable milling machines
    - 3D printing or additive manufacturing

Ex. Repair Technique Changes

- Changes to repair requirements
  - Modern methods and techniques for repair
  - Changes to repair tasks as aircraft age
    - More (or more invasive) inspections or tasks
- Change Issues: Modern repair techniques may have unknown impacts

Modern Repair Methods

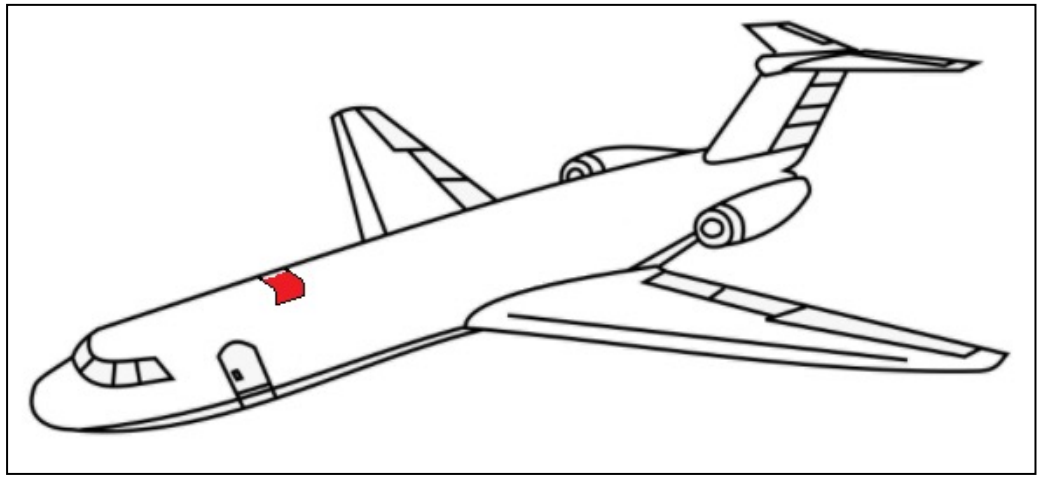
Aircraft Skin Panels

- Older aircraft designed with bonded aluminum honeycomb skin panels
- Repair methods have changed over time
  - Includes fiberglass overlays
  - Fiberglass is non-conductive
    - Can’t be used as a grounding surface

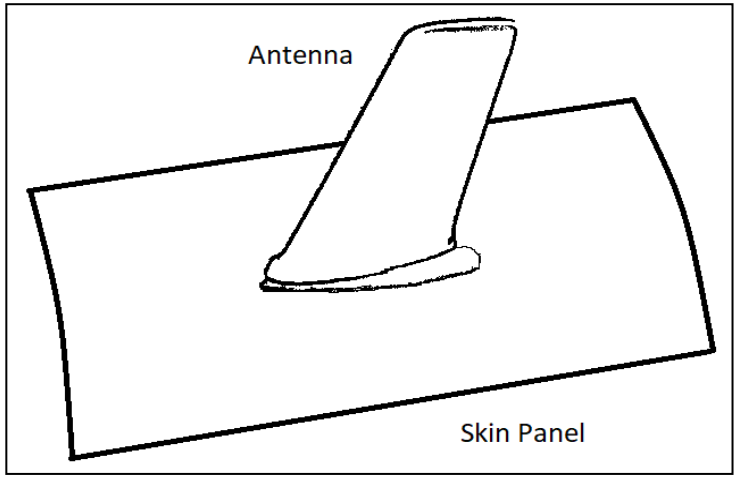
Honeycomb Test Coupon

Example – Antenna Skin Panel

Skin Panel Supporting Radar Antenna



Antenna Installed on Skin Panel



- Original aluminum honeycomb panel served as a grounding surface for aircraft antenna

Systems Engineering Impact

- Selected repair method was excellent for maintaining structural performance
  - Repair was selected without consideration for the system as a whole
  - Design of repair resulted in unacceptable performance at the system level

Summary of Examples

- Changes Can Impact System Longevity
  - Mylar, Technical Data Changes
    - Changes to economic considerations impacted manufacturing methods and techniques
  - Valve/Duct, Manufacturing Changes
    - Changes to part quantity requirements provided opportunity to utilize new manufacturing methods
  - Skin Panels, Repair Technique Changes
    - Changes to repair strategies caused issues with performance when legacy requirements not documented

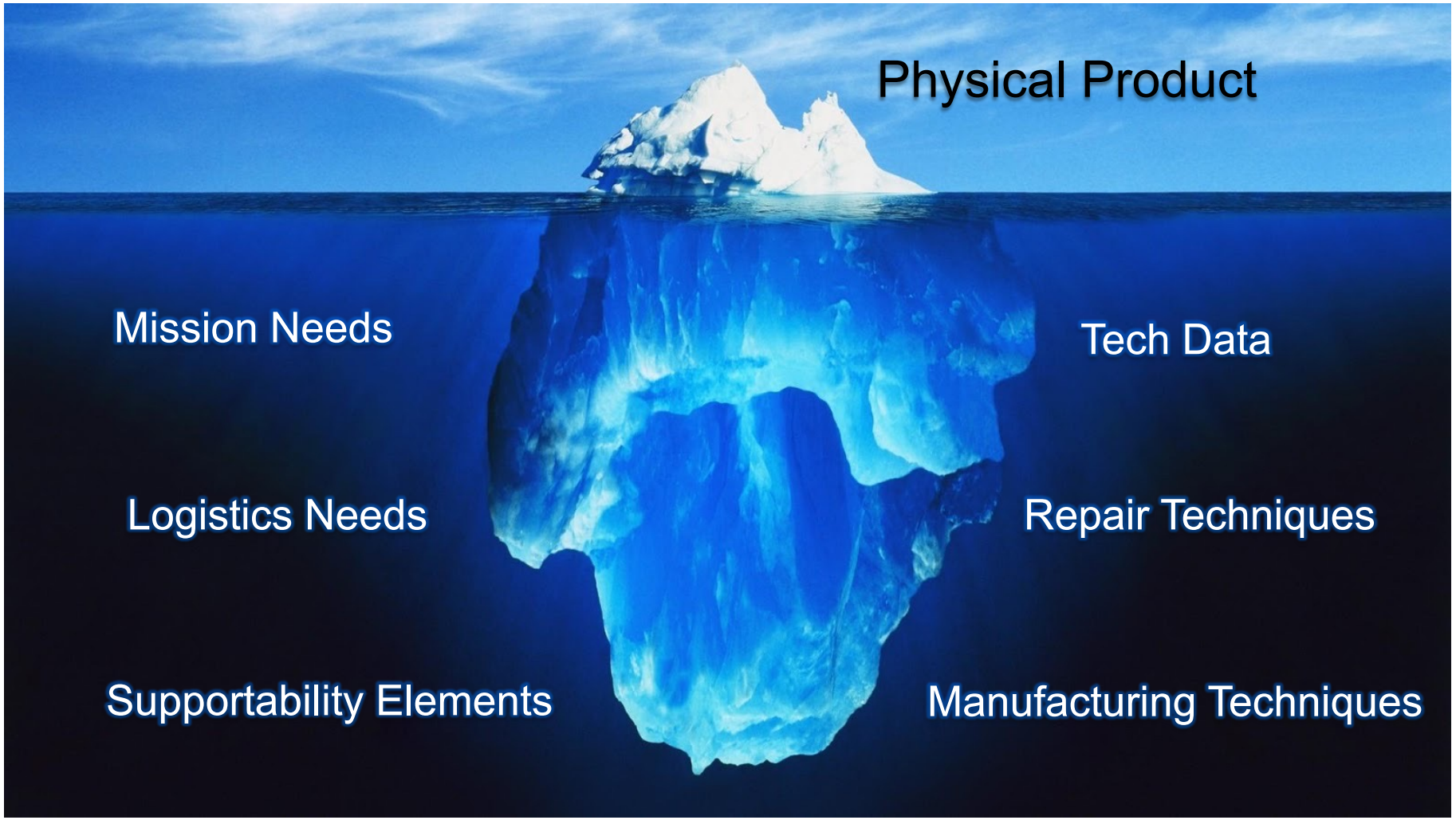
Impact to Operations

Product	Old Technology	New Technology	Requirements Impact	Result
Valve Casting	Casting	Machining	Technical Data	Success
3D Printed Duct	Sheet Metal Duct	3D Printed Duct	Manufacturing Data	Success
Antenna Mount	Ferrous Alloy	Non-Ferrous Material Sub.	Repair Data	Failure

RE Should Not Start with End-Product

- Don’t fall into the trap of
  - Re-identifying original requirements
  - Re-accomplishing the production phase only
  - How will this change the end result?
- The original product requirements failed before system end-of-life
  - Performance of the system is impacted

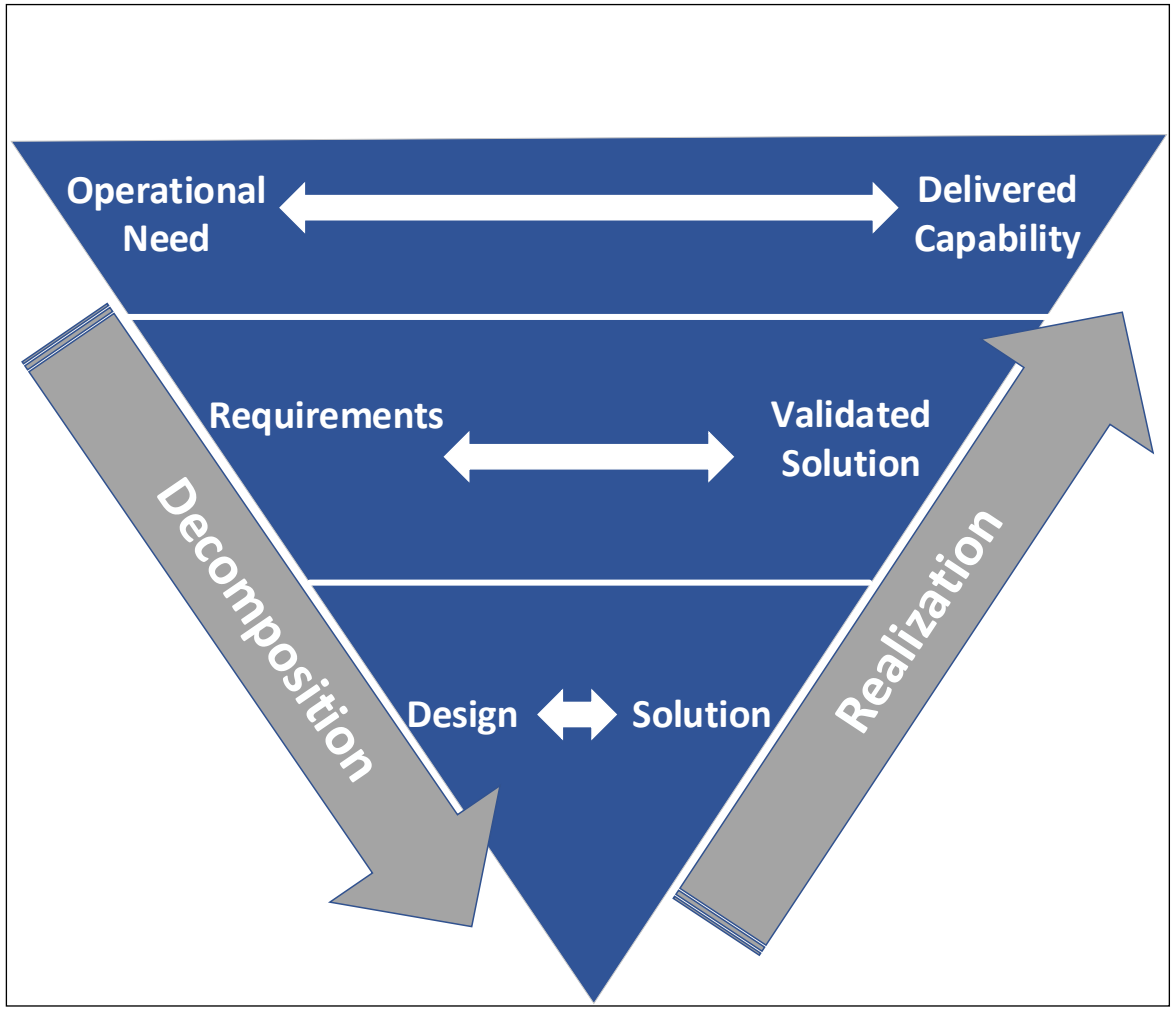
Requirements are More Than Physical



RE is Still a Great Tool!

- Implement by following the Systems Engineering Life Cycle Model
  - Identify all ***current*** requirements
    - Don’t assume original requirements are still valid
- Consider changes to supportability factors
  - More than just the physical product
  - How items are repaired, manufactured, etc.

RE Technical Analysis Starts Here



Not Here
Because Current Capability Does Not Meet the Need

Systems Engineering Process

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

Re-Accomplish SE Life Cycle Phases

- But this time, use real-world data
  - Original system likely designed with estimated data or data from models
    - What led to system performance failure?
    - What was missing in the original requirements?
    - Can estimated data used in original analyses be replaced with real-world performance data?

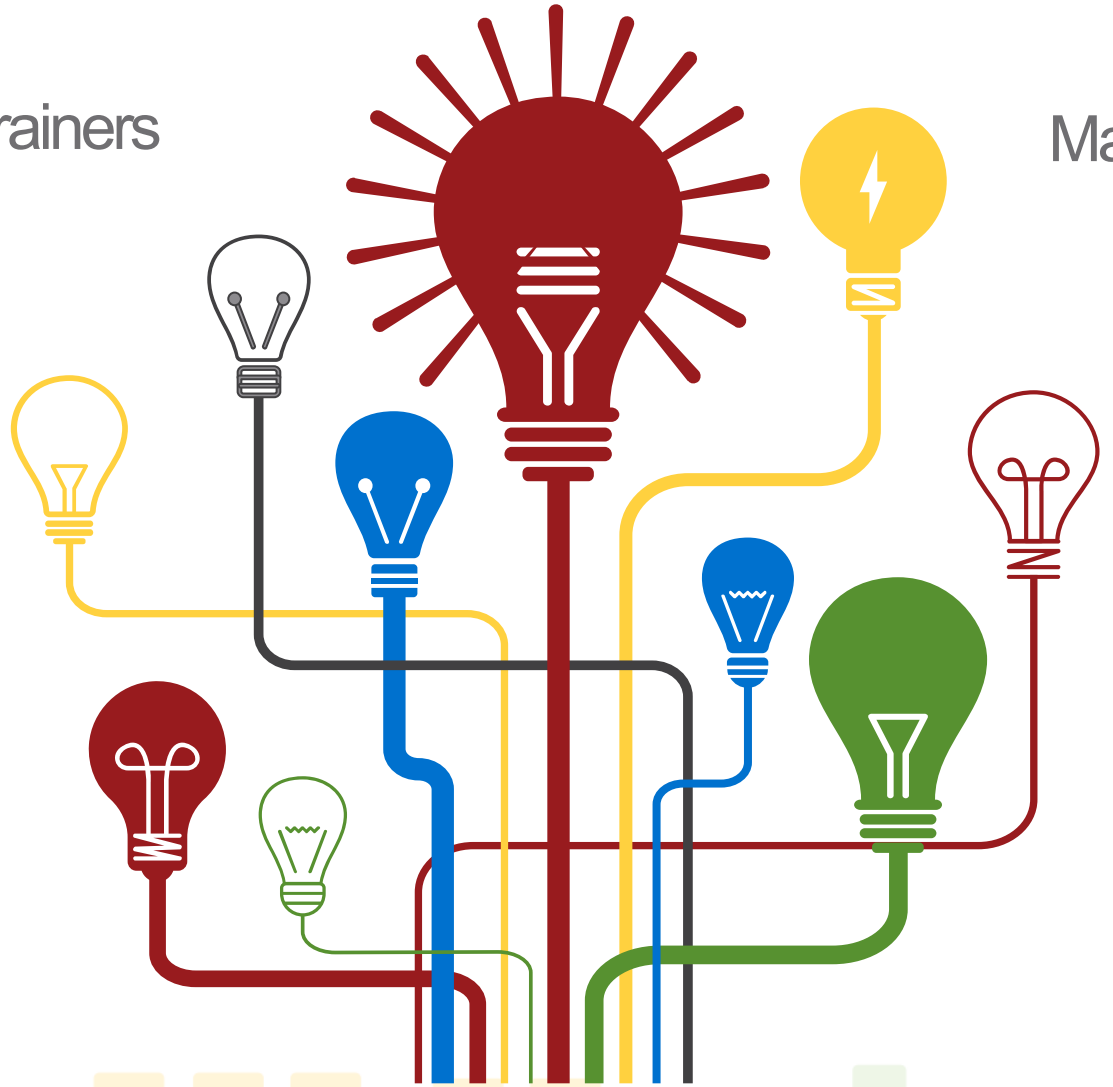
Re-Identify Problem or Need

- Validate the need for the System
  - After decades of use, requirements change, get added, or get removed
  - The need for ***the system itself*** may change
- Types of Feedback Data to consider:
  - MTBF, MTTR, service hours, cost to repair, downtime, repair data, reliability data, etc

Re-Analyze Operational Requirements

- Review stakeholder requirements
  - Operational users (aircrew)
  - Maintainers
  - Logisticians and other Support Functions
- Feedback Data: Use your Experts
  - People who interface with the system have valuable feedback not typically available in technical reports
  - Target those who interact with the system or any of its supportability processes

Feedback from Operations



Re-Identify Maintenance & Support Concepts

- Logistics requirements should be a focus of requirements analysis
  - Support the system until decommissioning
- DMSMS issues are symptoms of undocumented requirements changes
  - Inadequate logistics planning/requirements
  - Need to determine what changed since system fielding that led to DMSMS issues

Identify Logistics Requirements Changes

- Identify changes to the way we
  - Procure parts
  - Repair parts
  - Manufacture parts
- Document the changes
  - Feedback into systems engineering processes

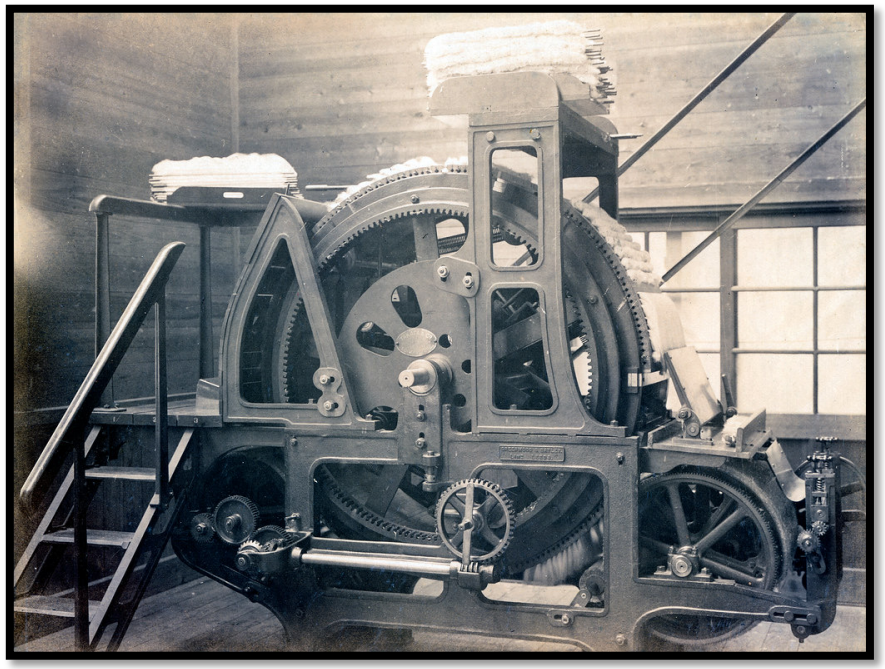
Evaluate New Technology

- Investigate modern processes and technology
  - Incorporate into the requirements development phase
- Many DMSMS issues are identified when logistics can no longer provide support
  - Too late to accomplish traditional RE
  - New technology may negate the need for RE

Consider New Technology Options

This

Not This



Consider New Technology Options

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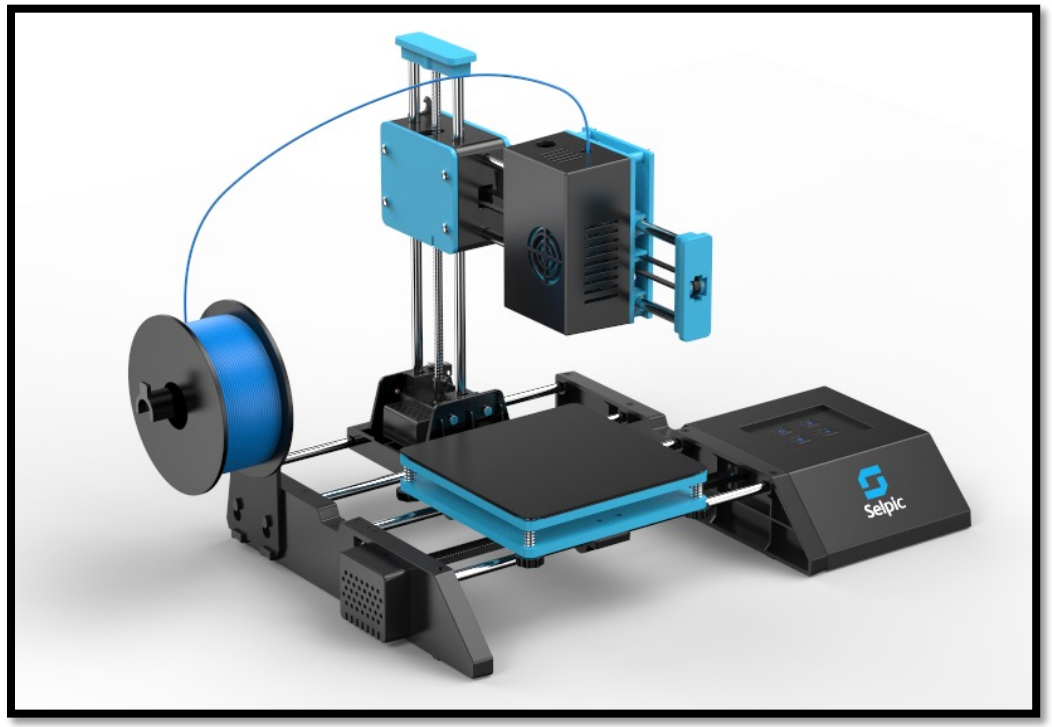

Not (Always) This

Conclusion

- When Systems Engineers face DMSMS issues:
  - Re-accomplish the Systems Engineering analysis process
    - Don’t skip the early phases (Mission Needs, Requirements Analysis, etc.)
  - Include feedback and data from real-world system operation
  - Adequately plan for changing requirements
  - Monitor system performance throughout the life cycle
    - Use feedback data to improve the system throughout its life cycle
- ***Don’t Start with the Solution!***
  - The original solution has already failed once!

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