GLOBAL PRODUCT DATA INTEROPERABILITY SUMMIT 2019

Value Based Decision-Making: The Missing Element in MBE and MBSE

Dr. Daniel P. Schrage, Professor Emeritus and Dr. Dimitri Mavris, Boeing Advanced Systems Analysis Professor, School of AE, Georgia Tech

Biosketches of Dr. Daniel P. Schrage and Dr. Dimitri N. Mavris

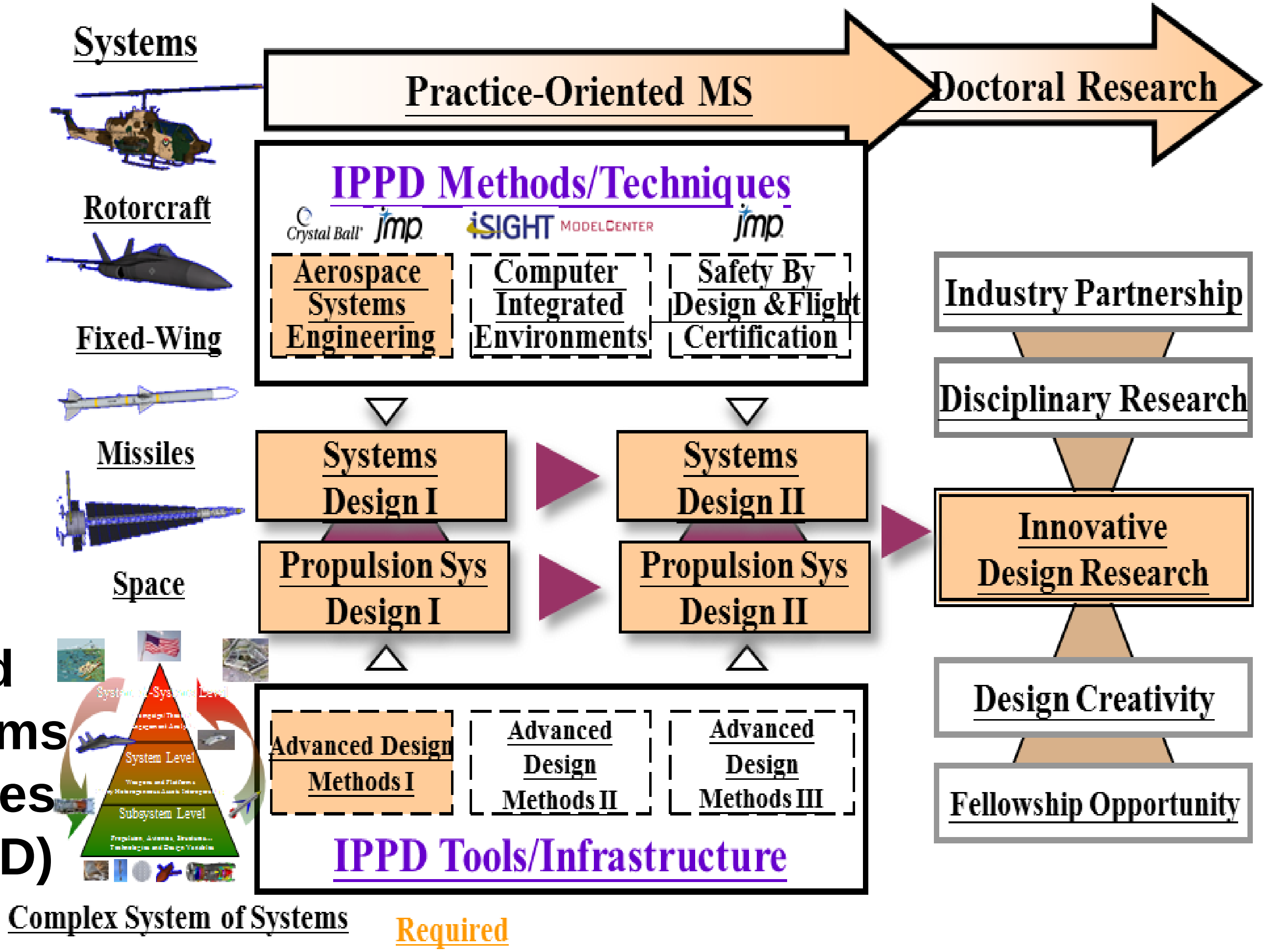
- **Dr. Daniel P. Schrage, Professor Emeritus, Georgia Tech**
  - **Professor and Director of the Georgia Tech Vertical Lift Research Center of Excellence (VLRCOE), 1984-2018; Director of the Georgia Tech Center for Aerospace Systems Engineering (CASE), 1994-2018**
  - **Engineer, Manager and Senior Executive with the US Army Aviation Research and Development Command (AVRADCOM), 1974-1984**
  - **Active Duty Army Aviator and Commander in South Vietnam, 1970-71, and Field Artillery Missile Battery Commander in Germany, 1968-69**
  - **Education: BS USMA, West Point; MSAE Georgia Tech; MBA Webster U.; D.Sc ME, Washington U.(Saint Louis, MO)**

Dr. Dimitri N. Mavris, Boeing Advanced Systems Analysis Professor;

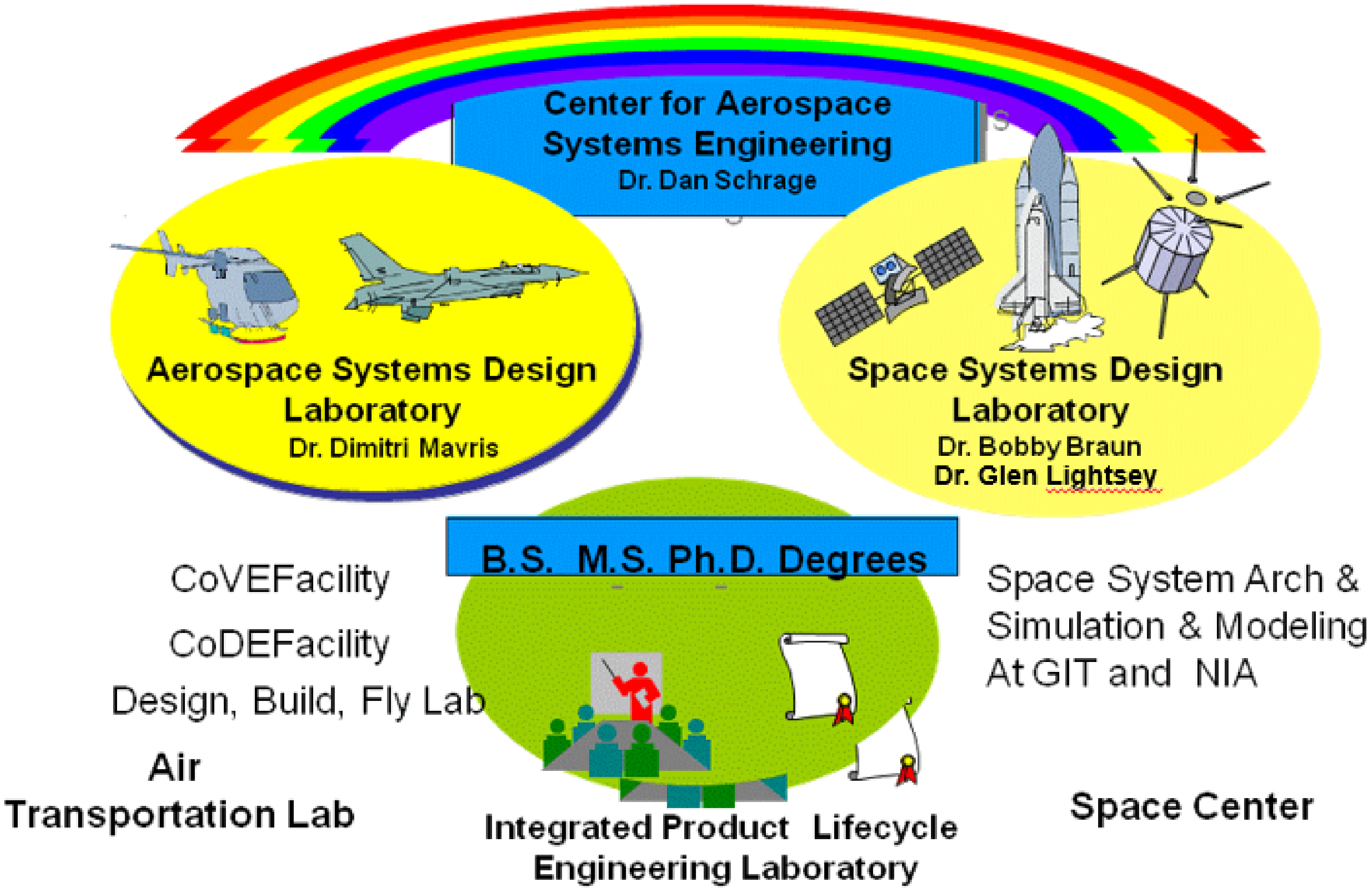
  - **Regents Professor, School of AE, Georgia Tech**
  - **Director, Aerospace Systems Design Laboratory (ASDL), School of AE, 1992-Present; G**
  - **Education: BSAE, MSAE, and PhD, School of AE, Georgia tech**

The Georgia Tech Graduate Program in Aerospace Systems Design

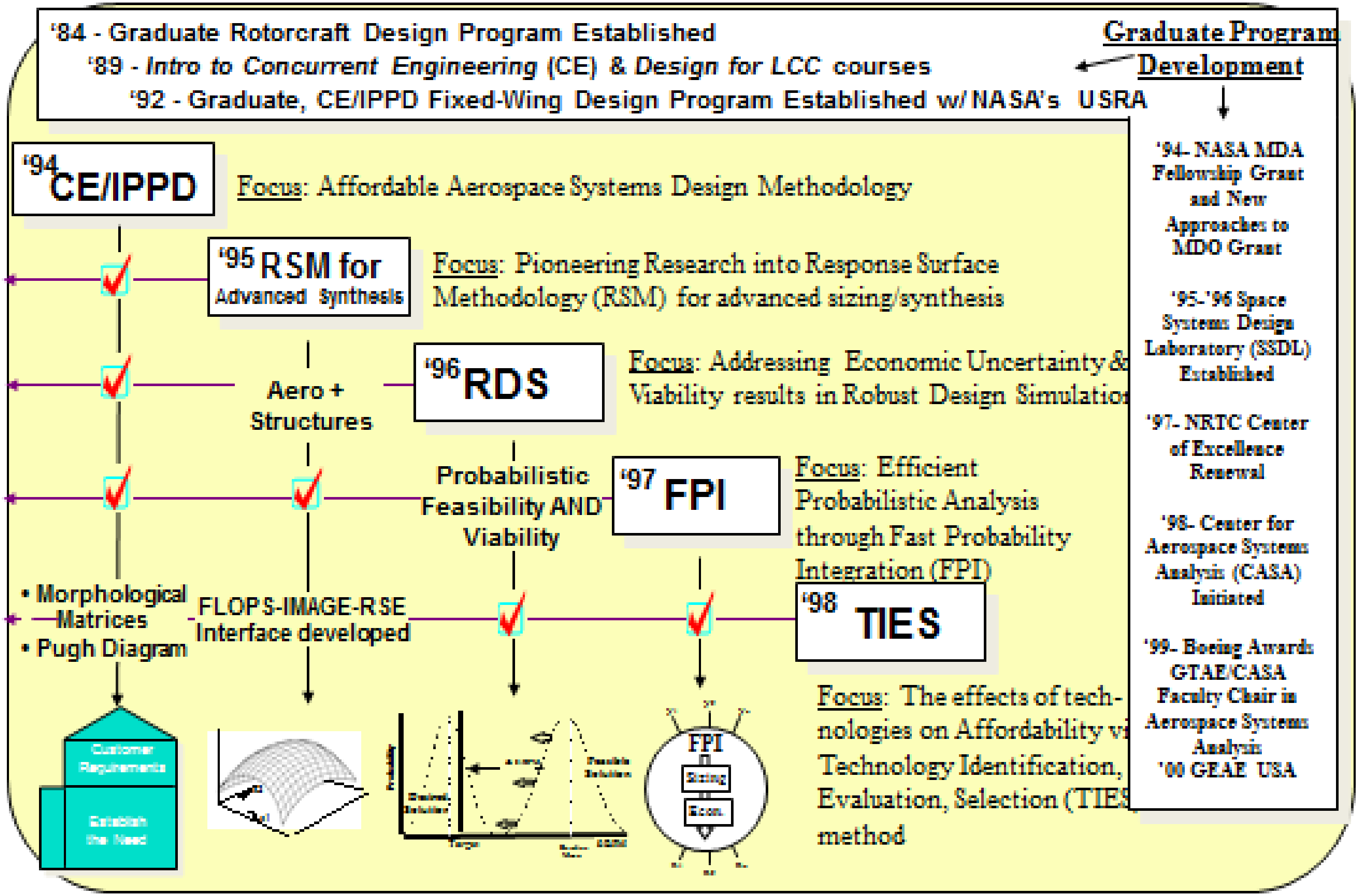
- The Georgia Tech Graduate Program in Aerospace Systems Design is the largest of its kind in the world with ~ 200 grad students, 35 research engineers & 10 faculty
- Two major laboratories, the Aerospace Systems Design Laboratory (ASDL) and The Space Systems Design Laboratory (SSDL), support substantial research and education programs with industry and government
- As illustrated in the Figure on the right; a Practice-Oriented MS Program with required Courses are identified; Most Aerospace Systems and System of Systems are addressed; Includes Integrated Product/Process Development (IPPD) Methods/Techniques/Tools/Infrastructure



The Aerospace Systems Design Laboratory (ASDL) and The Space Systems Design Laboratory (SSDL) are the Major Support Laboratories



Evolution of Georgia Tech Aerospace Systems Design IPPD Research during the 1990s

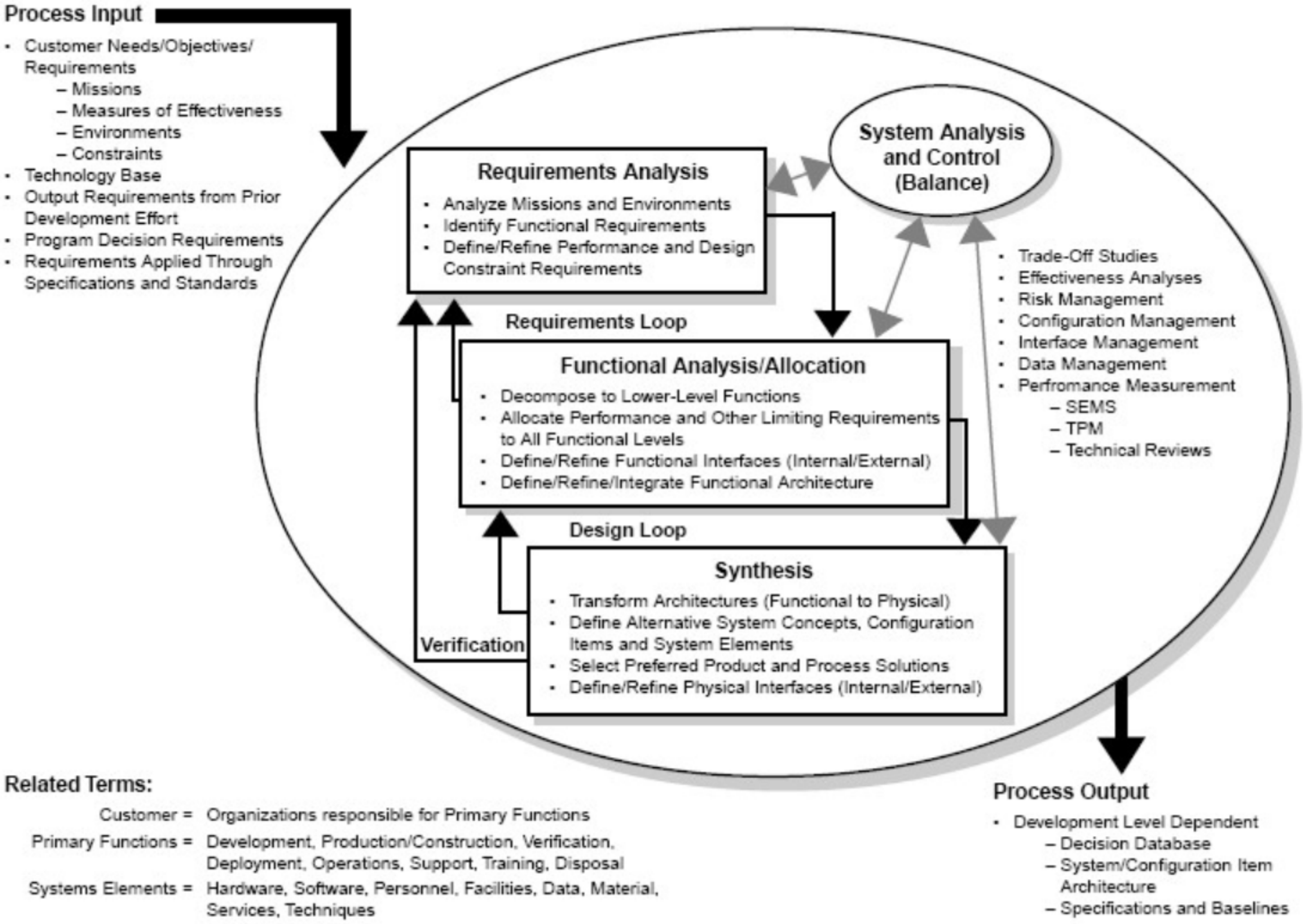


Presentation Outline

- **Review of Systems Engineering Fundamentals from the 1960s-70s**
- **Discuss Integration of Quality/Concurrent Engineering Recomposition Methods/Tools with Systems Engineering Decomposition Methods/Tools in a Top Design Decision Support Process for Systems Analysis through Integrated Product and Process Development (IPPD) in the 1980s-1990s**
- **Review Development of IPPD through Robust Design Simulation (RDS) in the 1990s-2000s to address the Risk and Uncertainty in Decision-Making**
- **Review the Establishment of the Integrated Product Life-cycle Engineering (IPLE) Laboratory for including Product Lifecycle Management (PLM) Methods/Tools in a Computer Integrated Environment through a Strategic Alliance with Dassault Systems and Professional Education with Boeing**
- **Positioning Georgia Tech, through ASDL and SSDL, to become a world leader in Global Product Data Interoperability through Digital Transformation**

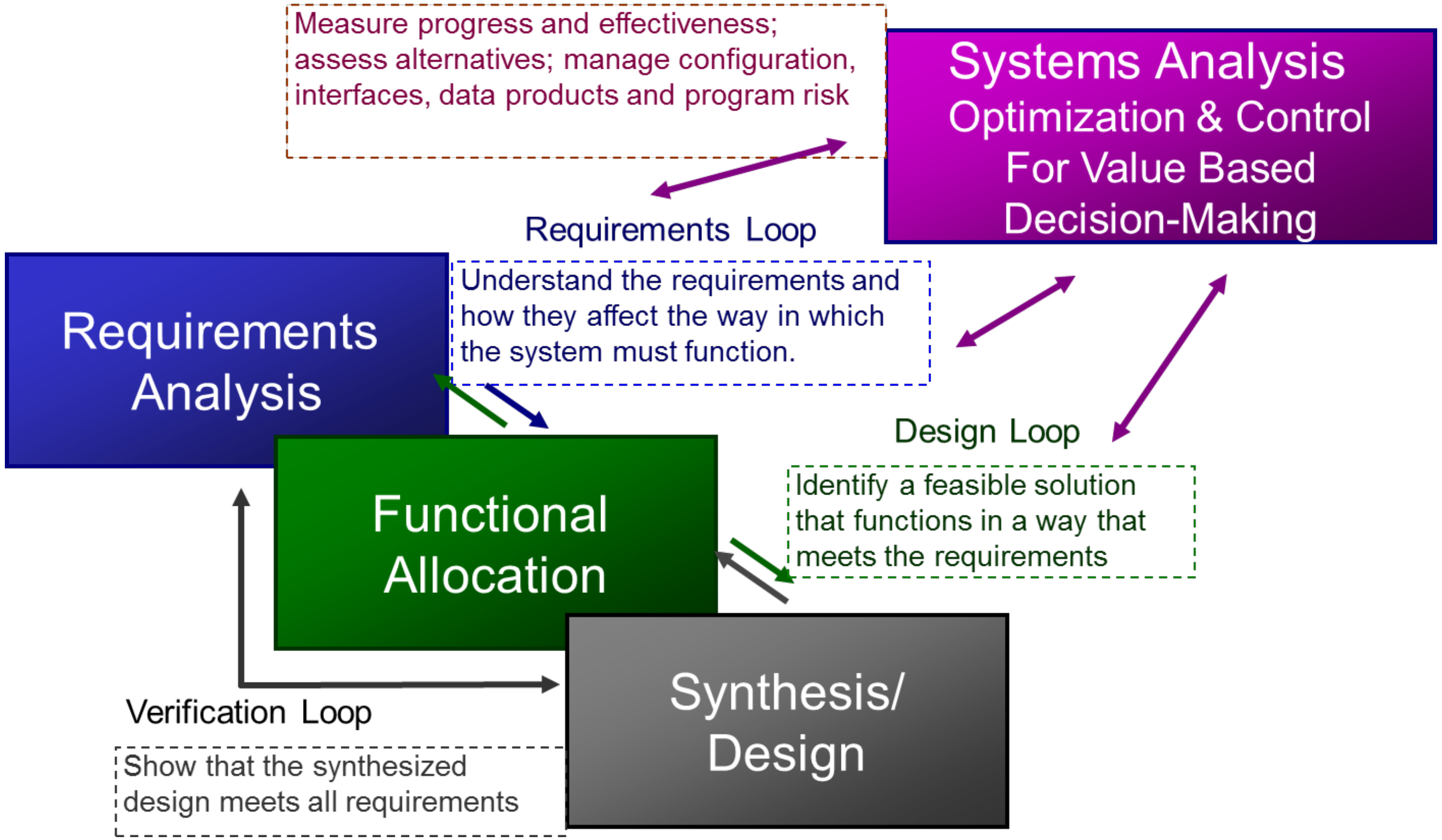
Systems Engineering Fundamentals from 1960s-70s

- **Systems Engineering activities are illustrated and focused in the Systems Engineering Process iterative flow between *Requirements Analysis, Functional Analysis and Synthesis***
- **However, System Analysis and Control is where Design Trades and Optimization are used for Value Based decision-making but are often not addressed**



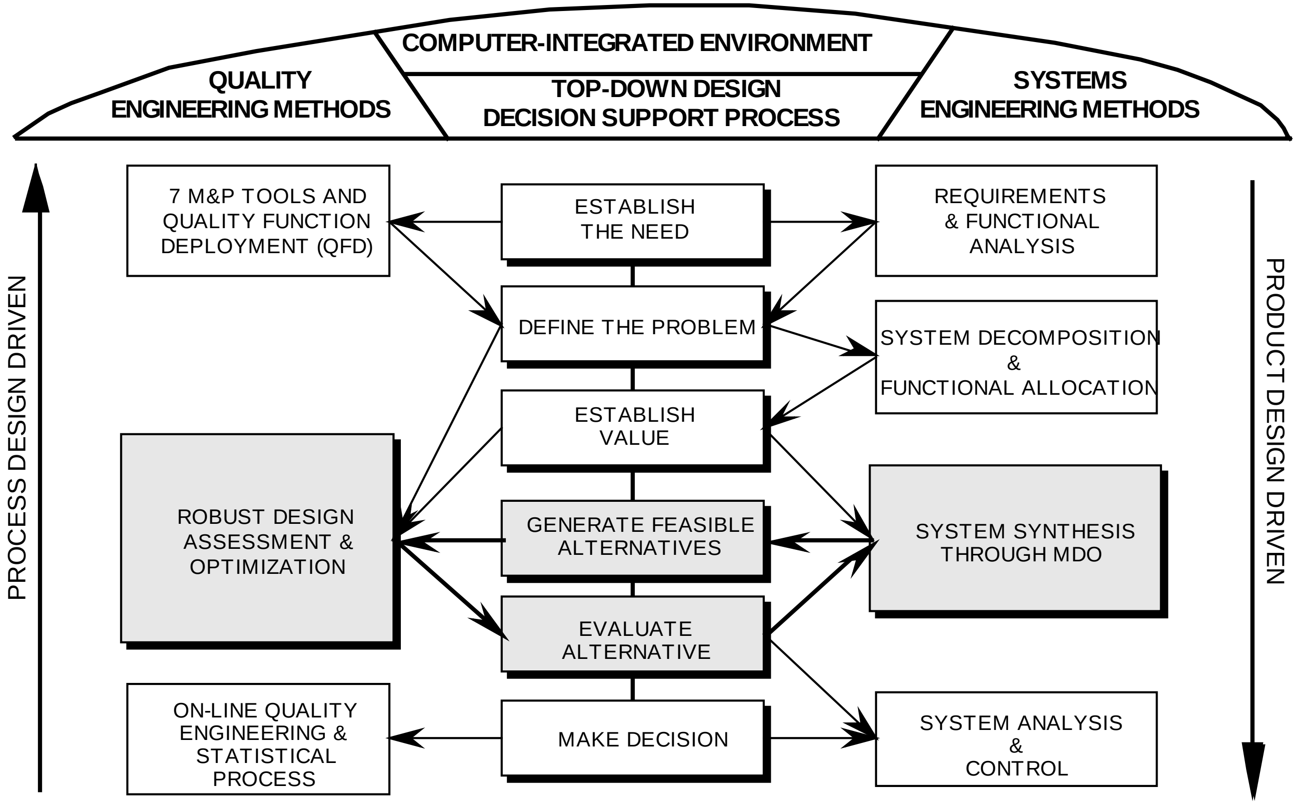
Systems Engineering Fundamentals from 1960s-70s

- **System Analysis through Optimization & Control should be based on Value-Based Decision-Making**
- **Multi-Attribute Decision Making (MADM) tools, as a Minimum can assist in Successful Trade Studies**



Top Down Design Decision Support Process Drives Value Based Decision Making

Quality Engineering:
- Provides the Bottom Up Re-composition Approach from On-Line Quality Statistical Process Control
- Is Process Design Driven
- Can provide Robust Design Assessment & Optimization, often Using experimental Based tools.
- Provides the necessary Translation of the Voice of The Customer into Key Product & Process Requirements Using Quality Function Deployment (QFD)



Traditional Systems Engineering:
- Provides the Top Down Decomposition Approach needed
- Is Product Design Driven
- Provides System Synthesis through Multi-disciplinary Design Optimization (MDO), often using gradient based tools
- Provides Product Input for System Analysis and Control

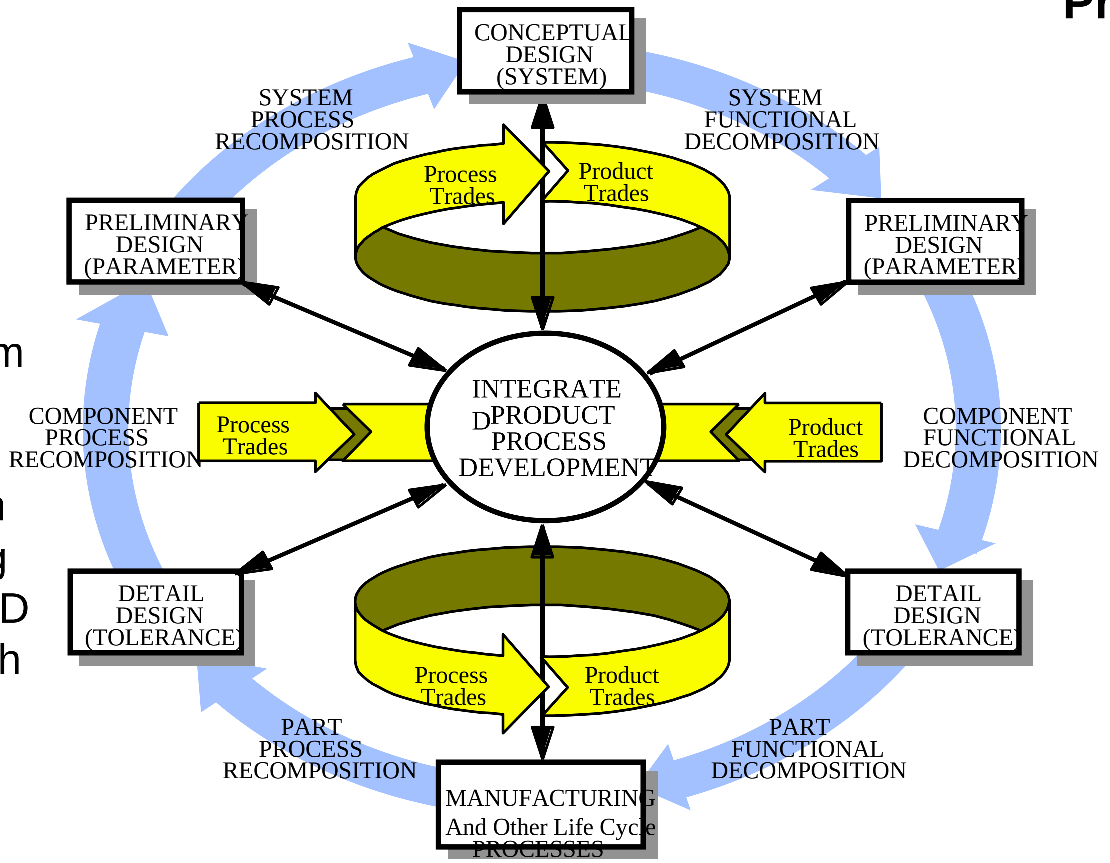
Computer Integrated Environment Provides the Data Exchange as Indicated by Arrows

The IPPD Methodology Provides the Centerpiece for Advanced Systems Analysis Trade Studies based on Value-Based Decision Making

The Figure Below Vertically Represents the Product/System Development Cycle

Process Re-composition Trades

- Should be included initially in Product/System Trades using QFD
- Biggest leverage can be made during Component Process Trades
- Reduction in Part/LRU Trades Should be possible if Product/System and Component Product & Process Trades
- .The Development Time line from Conceptual Design to Manufacturing Can be greatly reduced through IPPD
- .Other Life Cycle Processes, such as Operations and Support can also be greatly reduced by their inclusion In the IPPD Trade Study Process



Product Decomposition Trades

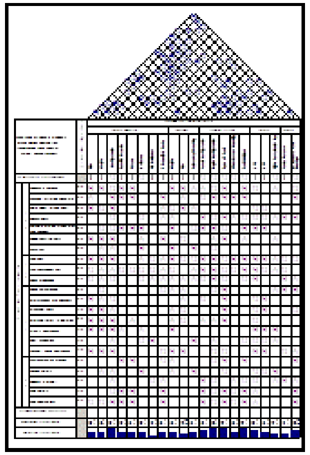
Product Decomposition Trades

- Product/System Trades usually Start during Conceptual Design;
- Component Trades are traditionally done During Preliminary design;
- Part/LRU Trades are usually done
- During Detail/Critical Design without IPPD Manufacturing Process trades often results in redesign Iteration back through the left side Recomposition Process, resulting in cost and schedule delays

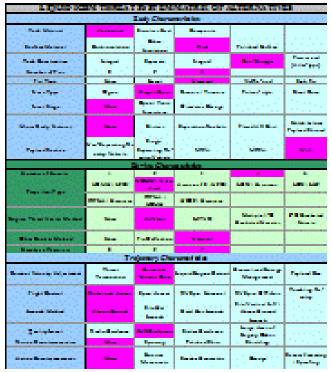
Global Product Data Interoperability is a Key for this Computer Integrated Environment

Use a Multi-Attribute Decision Making (MADM) for Down Selection

QFD tool translates customer desires into engineering factors **(Columns of TOPSIS)**

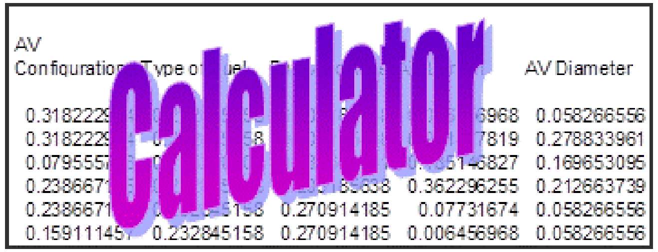


Matrix of Alternatives and literature search identify concepts for the **Rows of TOPSIS.**



Characteristics

Concepts

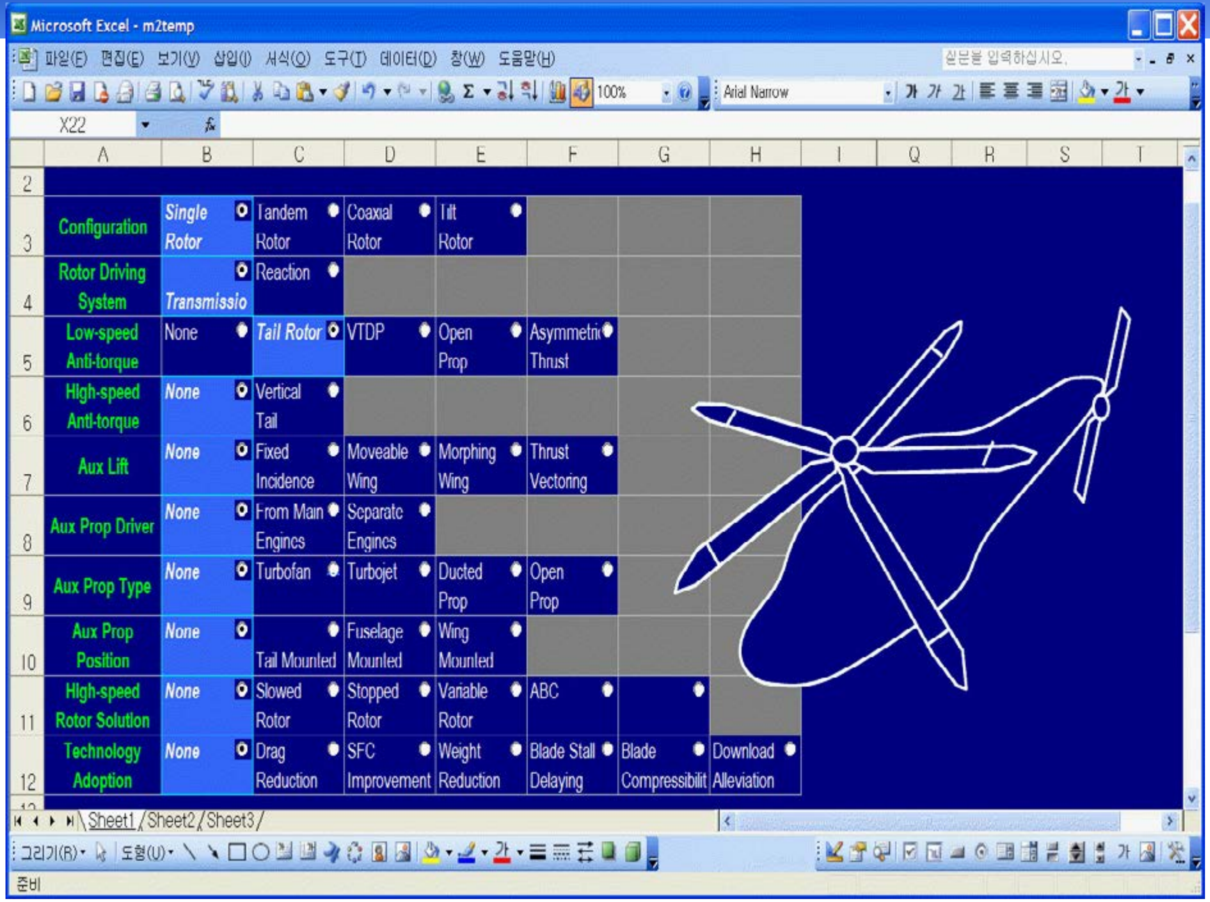


TOPSIS Mathematical Method

	THE RANKINGS	Grade
1	Titan II (off the shelf)	100.0%
2	Atlas II 1st stage	96.7%
3	Titan II w/ new 1st stage and mod Stage 2 engine	92.5%
4	Other existing missile w/ H2O2 engines	91.4%
5	Titan II, Missile w/ both mod engines	89.3%

Interactive Reconfigurable Matrix of Alternatives (IRMA) used for Scoping Intractable Problems

- The *Interactive Reconfigurable Matrix of Alternatives* helps scope an intractable problem space to a manageable one
- Qualitative method that often uses quantitative analyses for multi-attribute decision making
- Enumerates all possible combinations and their dependencies



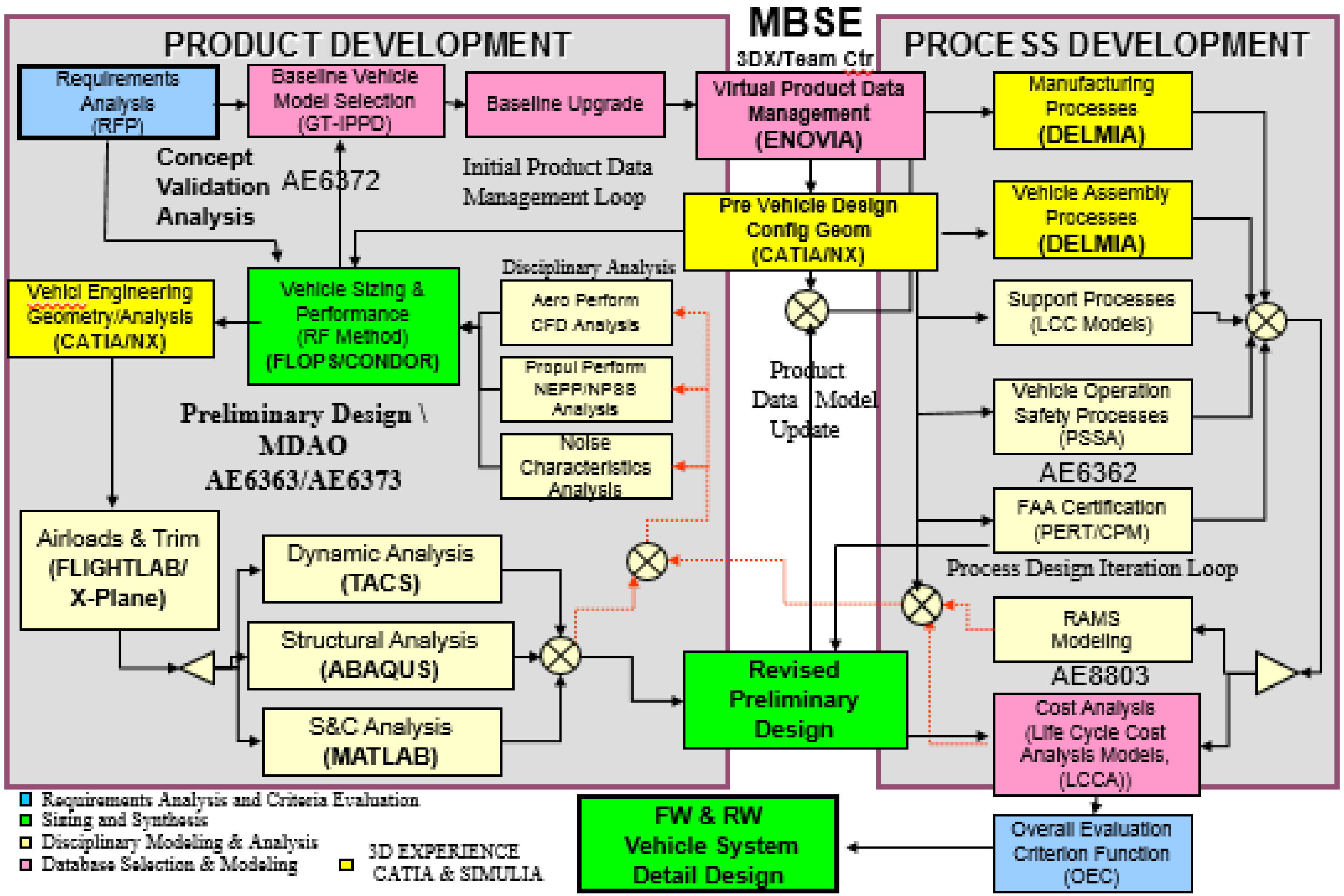
Configuration	Single Rotor	Tandem Rotor	Coaxial Rotor	Tilt Rotor			
Rotor Driving System	Transmissio	Reaction					
Low-speed Anti-torque	None	Tail Rotor	VTDP	Open Prop	Asymmetric Thrust		
High-speed Anti-torque	None	Vertical Tail					
Aux Lift	None	Fixed Incidence	Moveable Wing	Morphing Wing	Thrust Vectoring		
Aux Prop Driver	None	From Main Engines	Separate Engines				
Aux Prop Type	None	Turbofan	Turbojet	Ducted Prop	Open Prop		
Aux Prop Position	None	Tail Mounted	Fuselage Mounted	Wing Mounted			
High-speed Rotor Solution	None	Slowed Rotor	Stopped Rotor	Variable Rotor	ABC		
Technology Adoption	None	Drag Reduction	SFC Improvement	Weight Reduction	Blade Stall Delaying	Blade Compressibilit	Download Alleviation

IRMA Takes Morphological Matrix and Makes it Interactive

An Aircraft IPPD MDAO & MBSE Implementation with Value Based DM: 2000s

Product Development

- Begins with Requirements Analysis To Define the Problem Establish the Value
- Product Data sent to Virtual Product Data Mgt
- Selected Concept(s) Synthesized and Sent for Preliminary Design Iteration Through MDAO
- Physics Based Models are integrated into MDAO w/ Model Center Design Structure Matrix
- Preliminary Design Results sent for Revised Preliminary Design



Process Development

- Begins with Data from Virtual Product Data for Manufacturin Processes
- Receives Data from Pre-Vehicle Design Config Geom for Vehicle Assembly Processes; Support Processes; Vehicle Operations Safety Processes; and FAA Certification
- Updates Revised Preliminary Design which feeds LLC and the Overall Evaluation Criterion (OEC)

Terminology for a Model and Model Based Engineering

(Laura E. Hart Lockheed Martin, IS&GS, Presented at the Delaware Valley INCOSE Chapter Meetingm July 30, 2015)

Terminology

- Model:
  - A simplified version of a concept, phenomenon, relationship, structure or system
  - A graphical, mathematical or physical representation
  - An abstraction of reality by eliminating unnecessary components
  - The objectives of a model include;
    - to facilitate understanding
    - to aid in decision making, examine 'what if' scenarios
    - to explain, control, and predict events

> “Model-Based Engineering (MBE): An approach to engineering that *uses models as an integral part of the technical baseline* that includes the requirements, analysis, design, implementation, and verification of a capability, system, and/or product throughout the acquisition life cycle.”
>
> Final Report, Model-Based Engineering Subcommittee, NDIA, Feb. 2011

Terminology and Definition for Model Based Systems Engineering (Laura E. Hart ibid)

Terminology

- MBSE: Model Based Systems Engineering
  - Those aspects of MBE specifically associated with SE
  - includes behavioral analysis, system architecture, requirement traceability, performance analysis, simulation, test, etc.

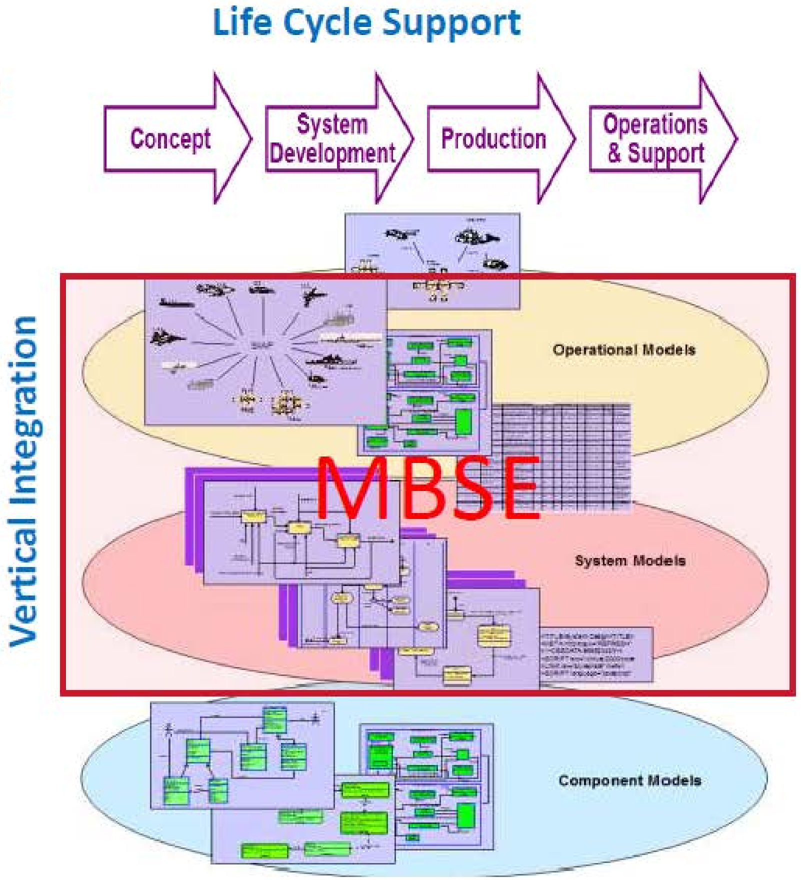
"Model-based systems engineering (MBSE) is the *formalized application of modeling* to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases."

INCOSE SE Vision 2020 (INCOSE-TP-2004-004-02, Sep 2007)

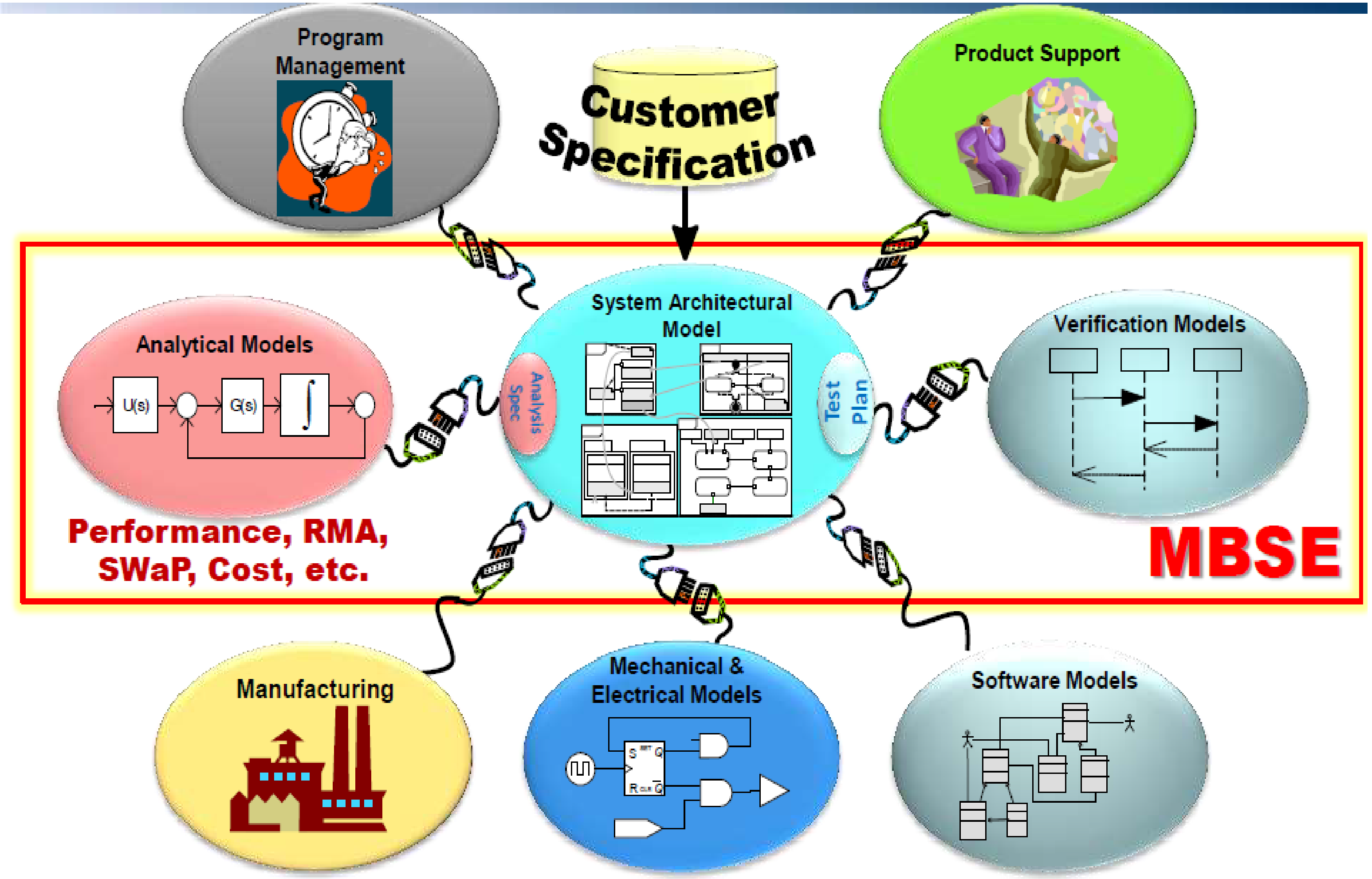
MBSE is Intended to Provide Life Cycle Support
(Laura E. Hart ibid)

MBSE Focus

- Formalizes the practice of systems development through the use of models
- Broad in scope
  - Includes multiple modeling domains across life cycle from SOS to component
- Results in quality/productivity improvements & lower risk
  - Rigor and precision
  - Communications among development team and customer
  - Management of complexity

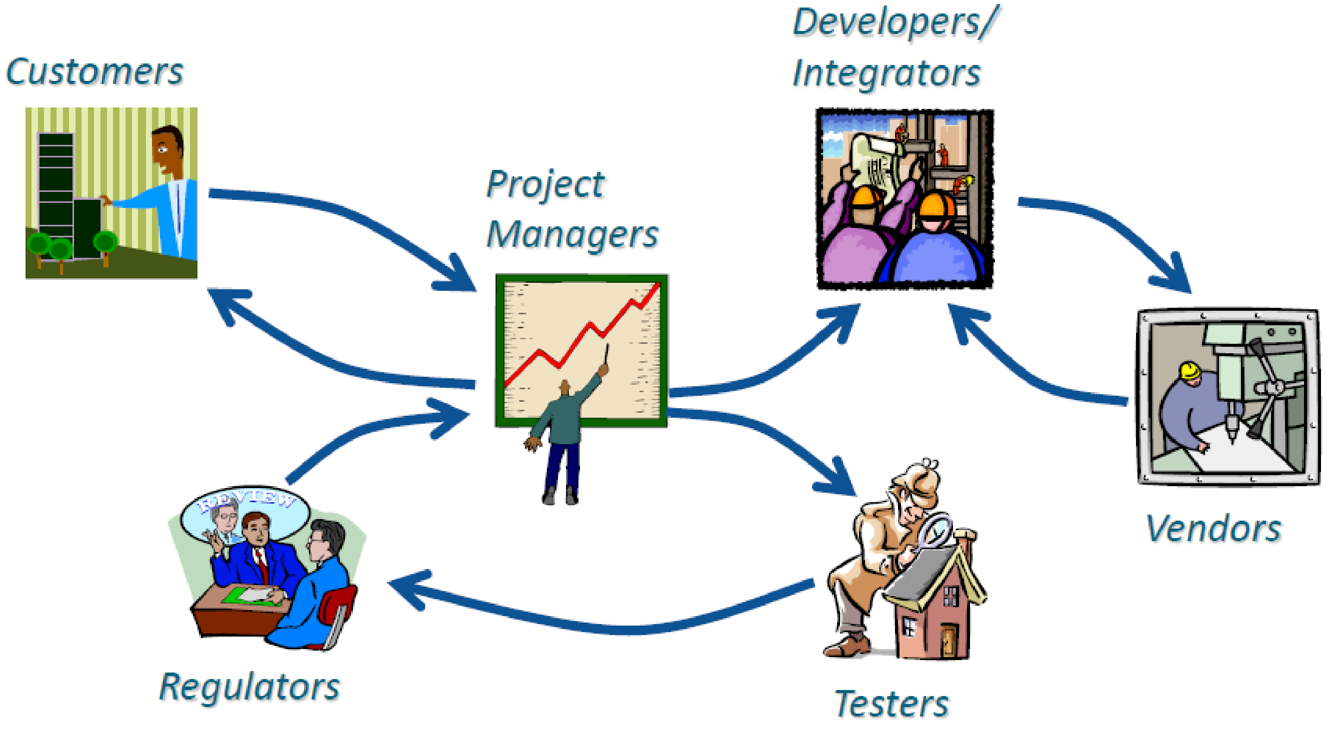


Concept of An Integrated MBE/MBSE Environment



Key Stakeholders Must be Identified for Participation in System Acquisition

Stakeholders Involved in System Acquisition

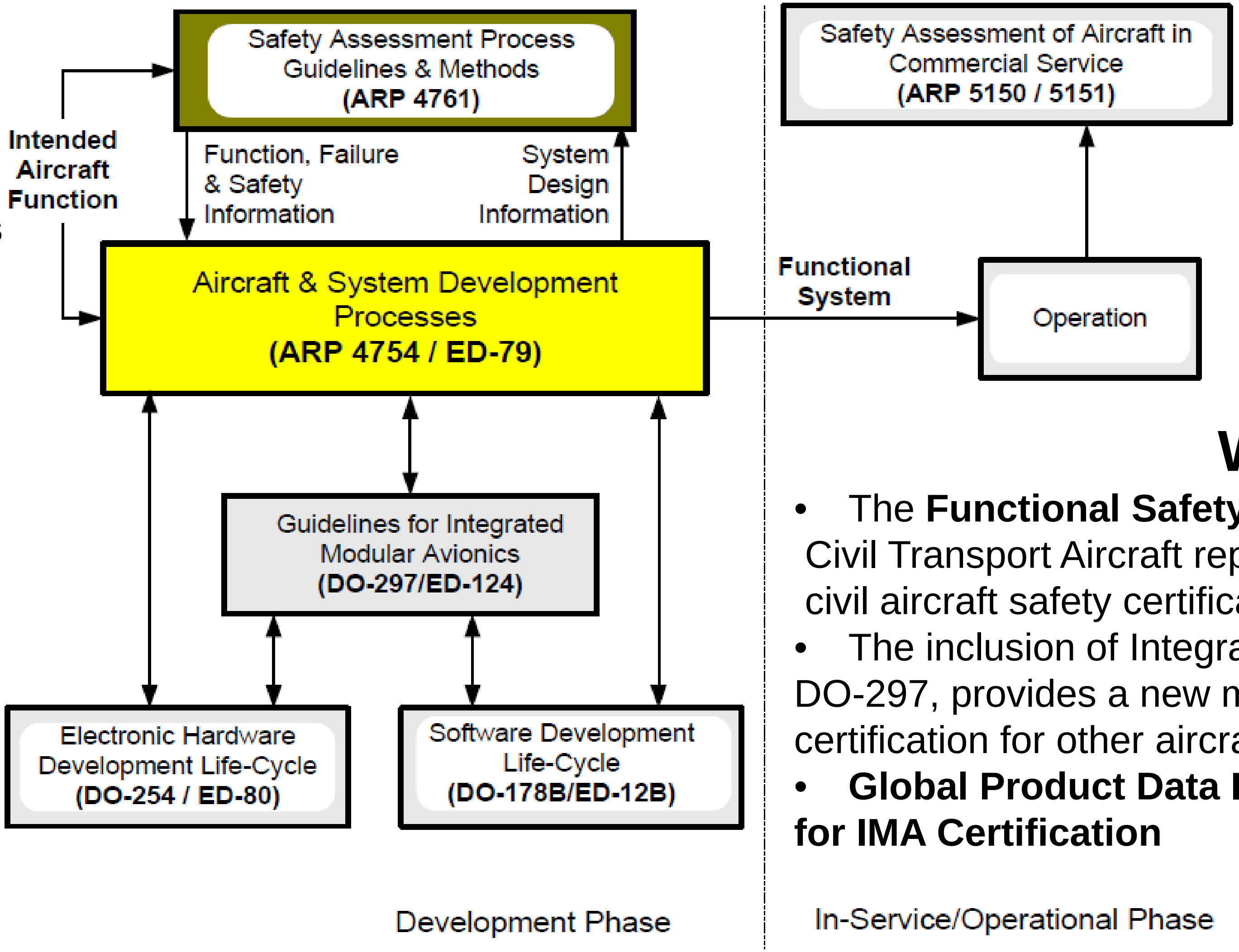


Modeling Needed to Improve Communications across all Stakeholders

Current Approach: Use Civil Aircraft and Systems Development Process with Integral Processes for Development Assurance Value Based Acquisition (DAVBA)

What

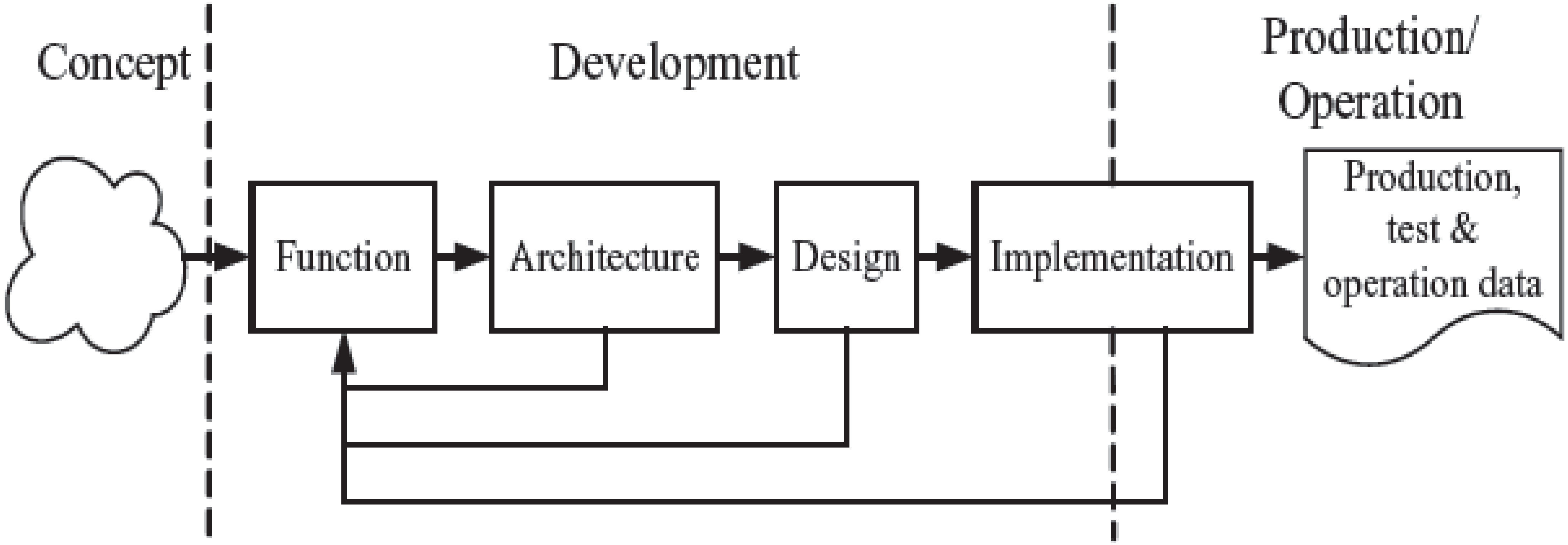
- Civil Aviation Development and Certification Standards are **based on worldwide consensus with Continuous on-going updates**
- As illustrated in the Figure Development and Safety Assessment are closely Coupled.
- Also, software and electronic hardware have recently been integrated with Integrated Modular Avionics
- **Global Product Data Interoperability is essential for Civil Aviation worldwide**



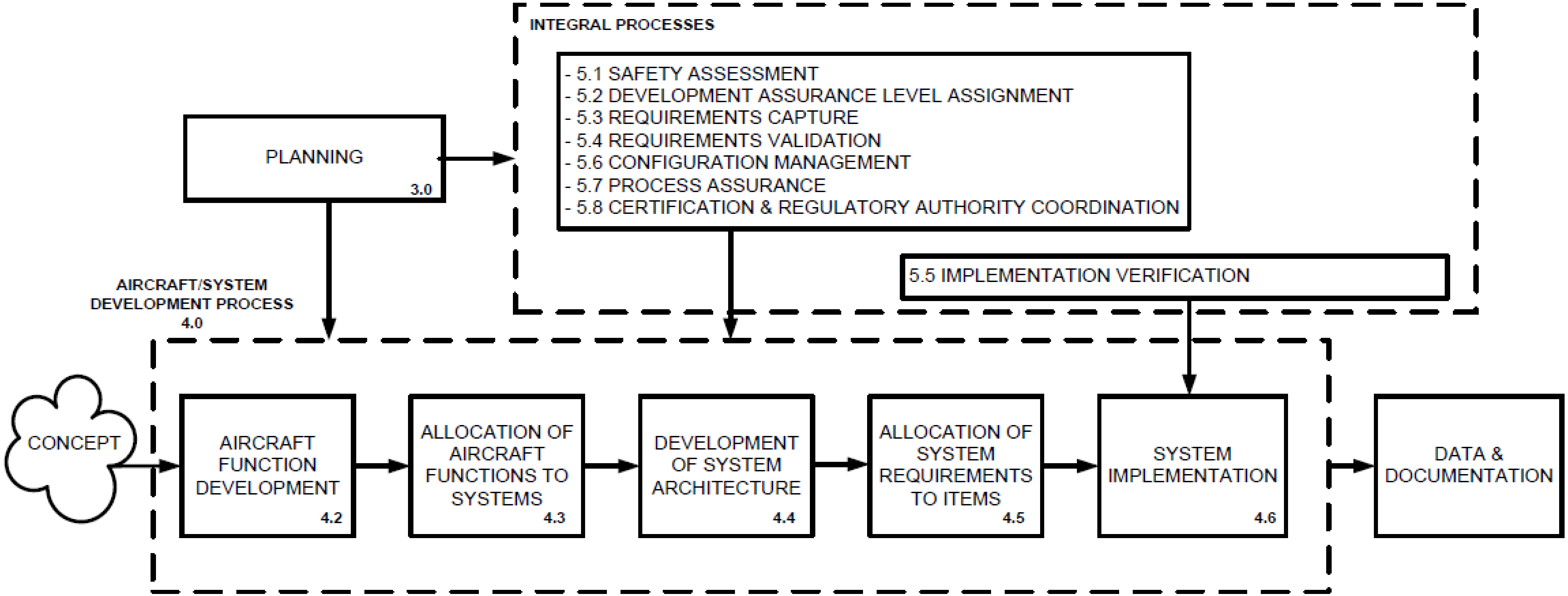
Why

- The **Functional Safety Management** approach for Civil Transport Aircraft represents the "Holy Grail" for civil aircraft safety certification of all aircraft types
- The inclusion of Integrated Modular Avionics (IMA), DO-297, provides a new model for integrated software certification for other aircraft, both civil, military and UAS
- **Global Product Data Interoperability is essential for IMA Certification**

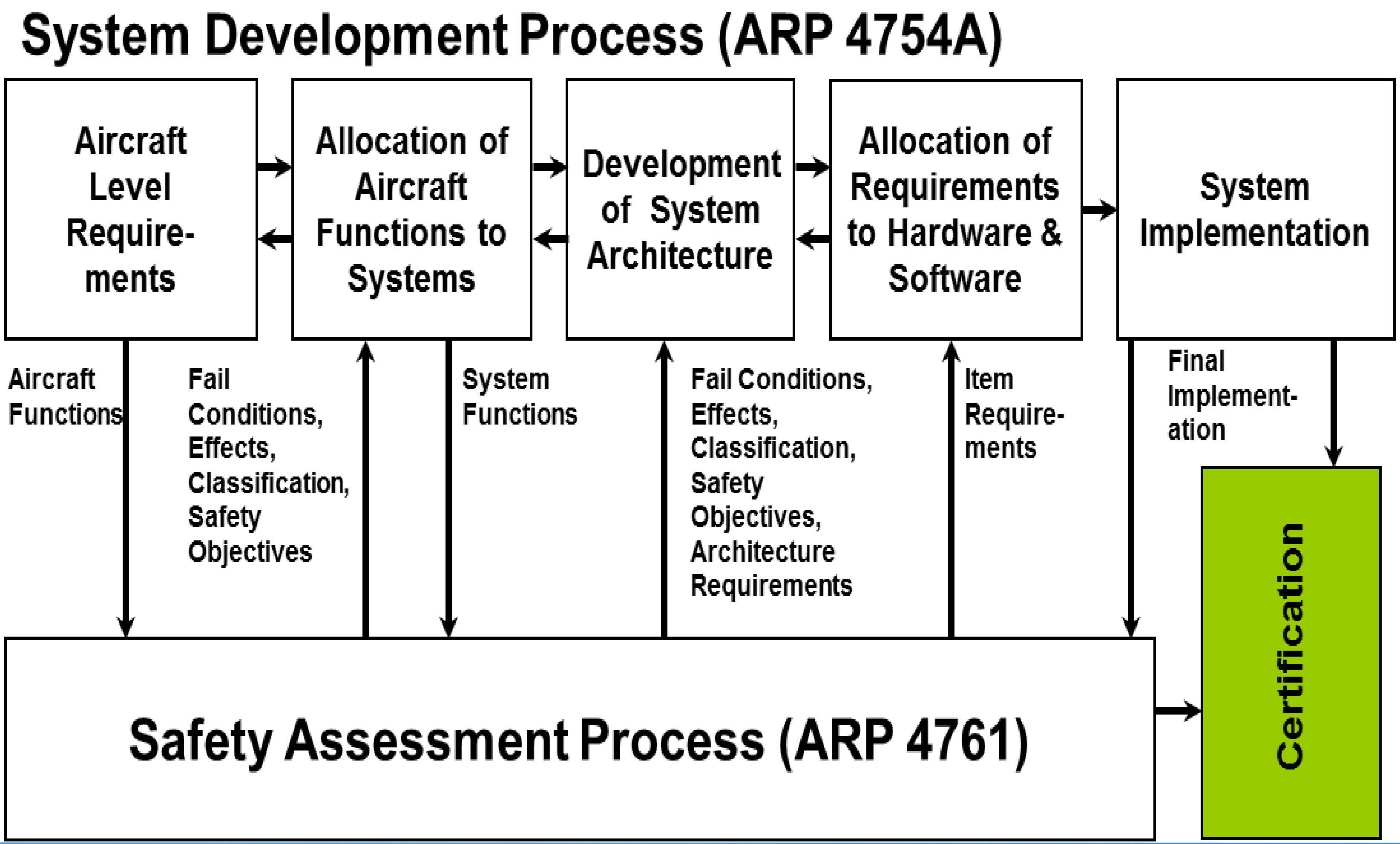
The Simplified ARP 4754A Civil Aircraft and Systems Development Process in the Figure Below



ARP 4754A Civil Aircraft and System Development Process Model including Integral Processes

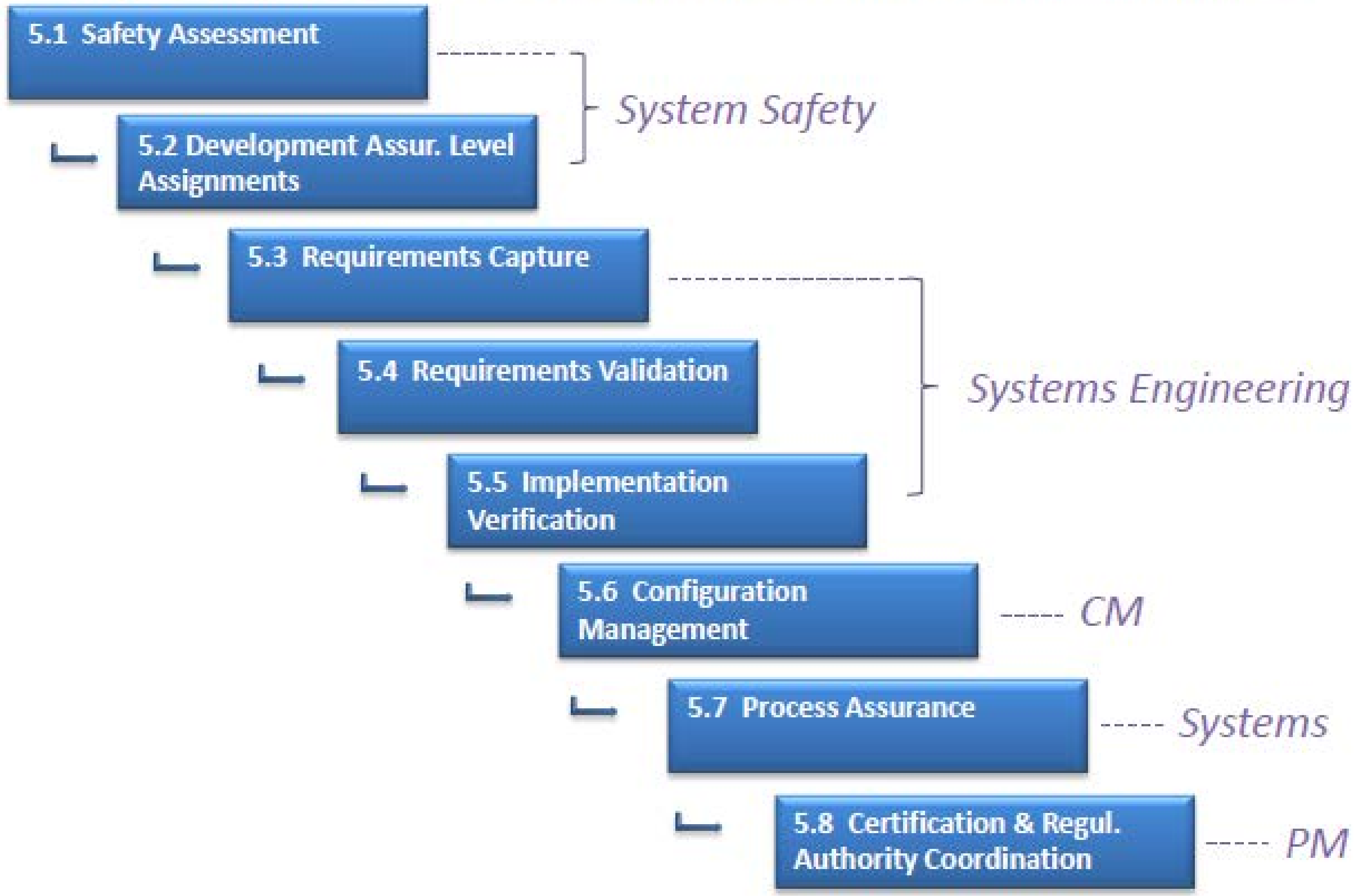


The Functional Safety Management (FSM) Integral Safety Assessment for Commercial Transport Aircraft (Part 25) is Illustrated Below

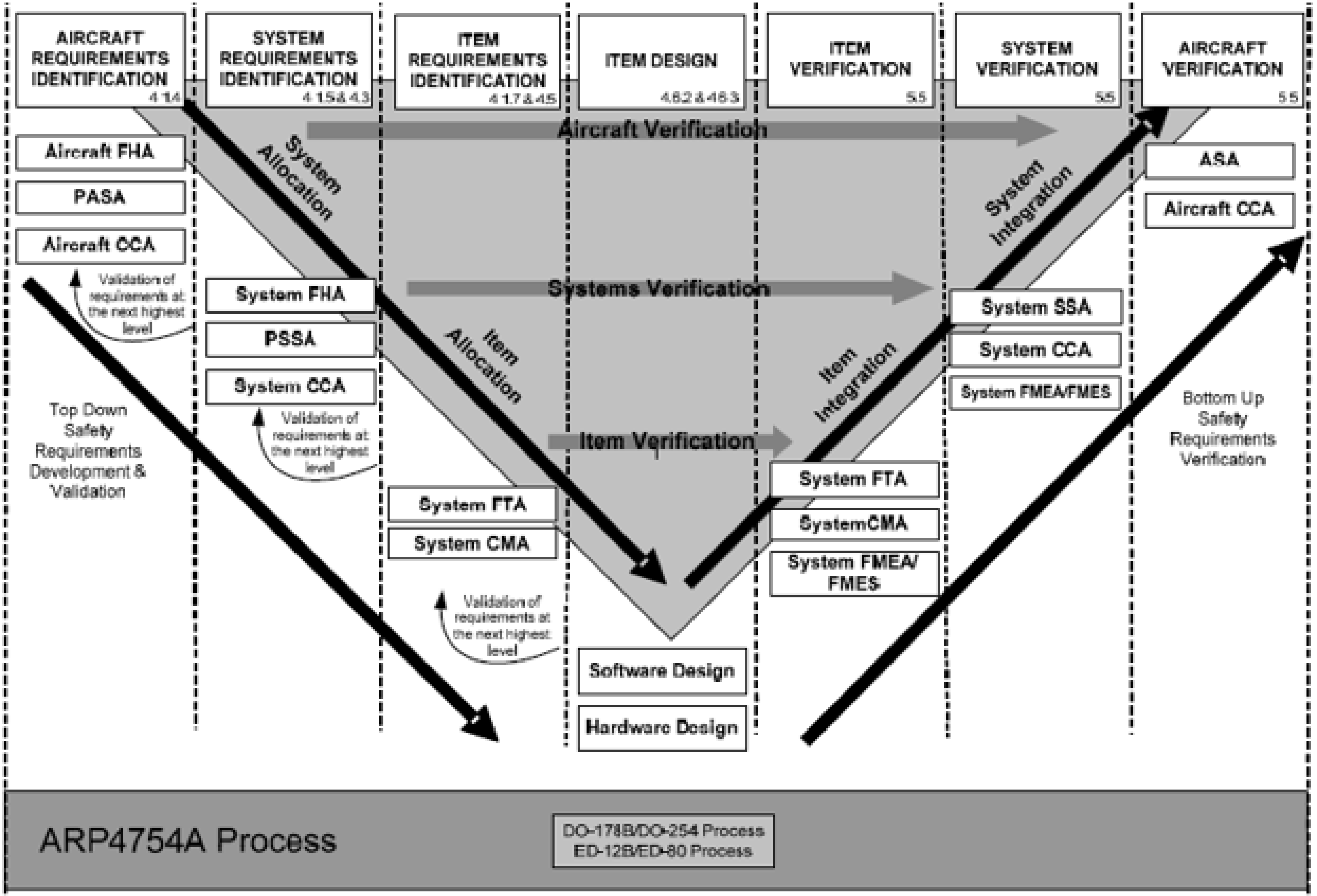


ARP 4754A Civil Aircraft & Systems Development Integral Processes

- Please refer to ARP4754A Section 5 for further descriptions and information.



ARP 4754A Civil Aircraft and Systems Development Vee Diagram



Proposed Development Assurance Value Based Acquisition (DAVBA) Technical Approach for Future Vertical Lift (FVL)

- **Take the *Georgia Tech Integrated Product and Process Development (IPPD) through Robust Design Simulation (RDS) approach* to provide a DAVBA Airworthiness Qualification and Specification Compliance Environment**
- **Build off of the Civil Aircraft Consensus Best Practices as identified in SAE ARP 4754A and apply them where applicable for the DAVBA Virtual Stochastic Prototyping (VSP) using the Dassault Systemes RFLP and PCC MBE methods**
- **Develop DAVBA Environment in two new ADSs with VSP of baseline FVL medium aircraft, e.g. UH-60M & notional advanced FVL medium aircraft concepts**
- **Provide the two new Draft ADSs as Deliverables for Consensus Building among the Vertical Lift community**

Example of Value Based Decision Decision Making Approach Using MBSE

2015 NRTC Year End Review

- **Project Title: Development Assurance Value-Based Acquisition (DAVBA) Approach for Airworthiness Qualification and Specification Compliance**

- **Project Number: NRTC-FY15-W-01**

- **Principal Investigator:**
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- **Team Members:**
University of Alabama at Huntsville
Clausewitz Technology
Dassault Systemes Government Solutions

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Why is a New Army Aircraft Aeronautical Design Standard (ADS) Based on a DAVBA MBSE Approach Required?

- Military Safety and Airworthiness Qualification standards provide a traditional Qualification Assurance approach, e.g. at the end of development, rather than a Development Assurance Level (DAL) at the beginning of Aircraft Development
- Cyber Physical Vehicle Systems (CPVS) require Co-Design of Cyber and Physical Systems which requires aircraft guidance for implementing a next generation Integrated Modular Avionics (IMA) standard which includes Reconfiguration and Multi-core processors Certification
- No equivalent to ARP 4754A exists in the military standards; last update of military airworthiness qualification was ADS-51-HDBK in 1996
- Contiguous Example required for explicit description on how to apply the DAL Approach from Aircraft Functional Development Assurance Level(FDAL) to Software/Hardware Item Development Assurance Level (IDAL)

Transfer of Civil Aircraft Best Practice Guidelines to Military Aircraft

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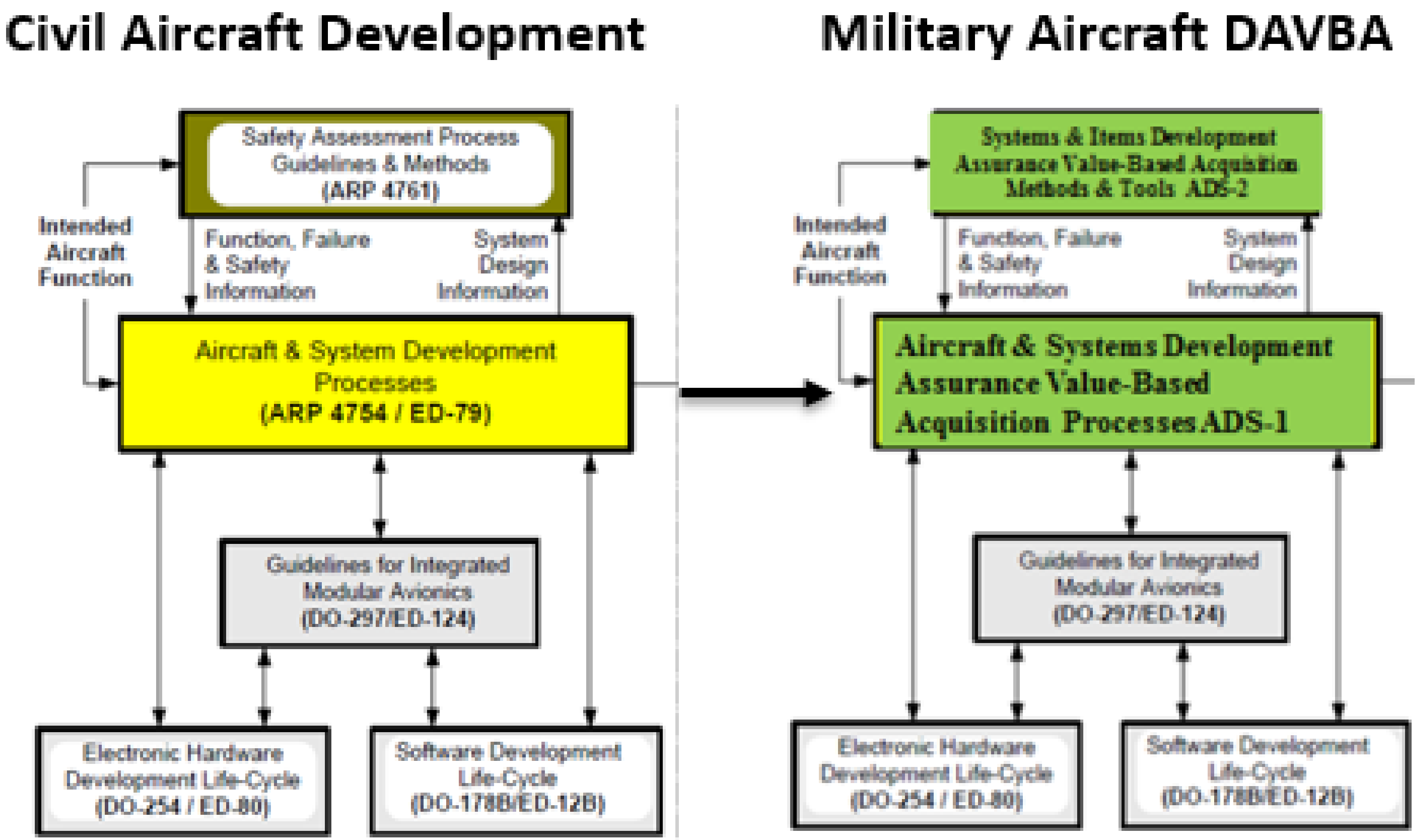
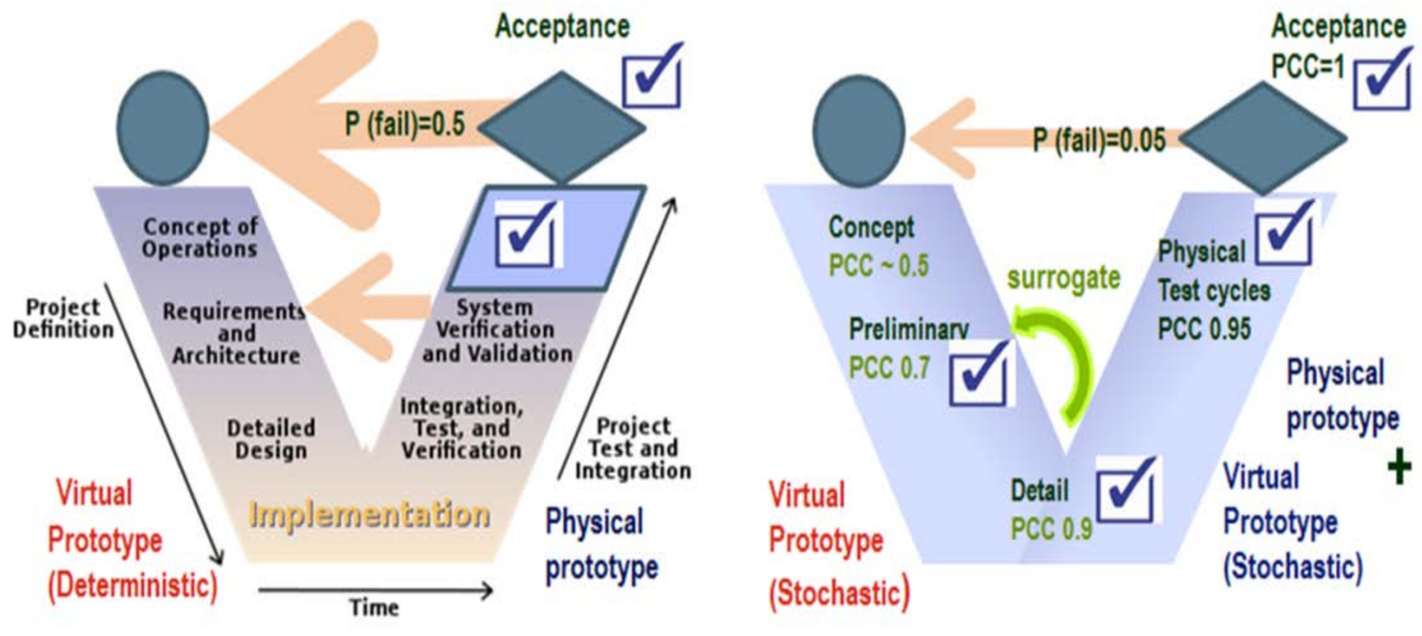


ARP 4754A Development Assurance Approach

Development Assurance level (DAL) for functions, item of equipment, item of software.

- The DAL is the means for prescribing the measures to be taken in order to avoid errors during the development of onboard functions systems and items.
- The DAL definition and the allocation process is described in SAE ARP 4754A document
- DAL is determined using the Safety/Reliability Assessment Process.
- The quality procedures to apply for the development of a function or an item depend on the DAL associated to this item. These quality procedures for the onboard systems are given in:
  - ✓ ARP 4754A/ED 19A for functions, systems, equipment development,
  - ✓ DO 178 B / ED 78B for software design,
  - ✓ DO 254 / ED 80 for electronic hardware design,
  - ✓ Aircraft manufacturer/equipment suppliers internal documentation for development and design.

Transfer from Deterministic Virtual Prototyping to Stochastic Virtual Prototyping



Proposed Notional Vee Diagram Layout for FVL DAVBA Approach

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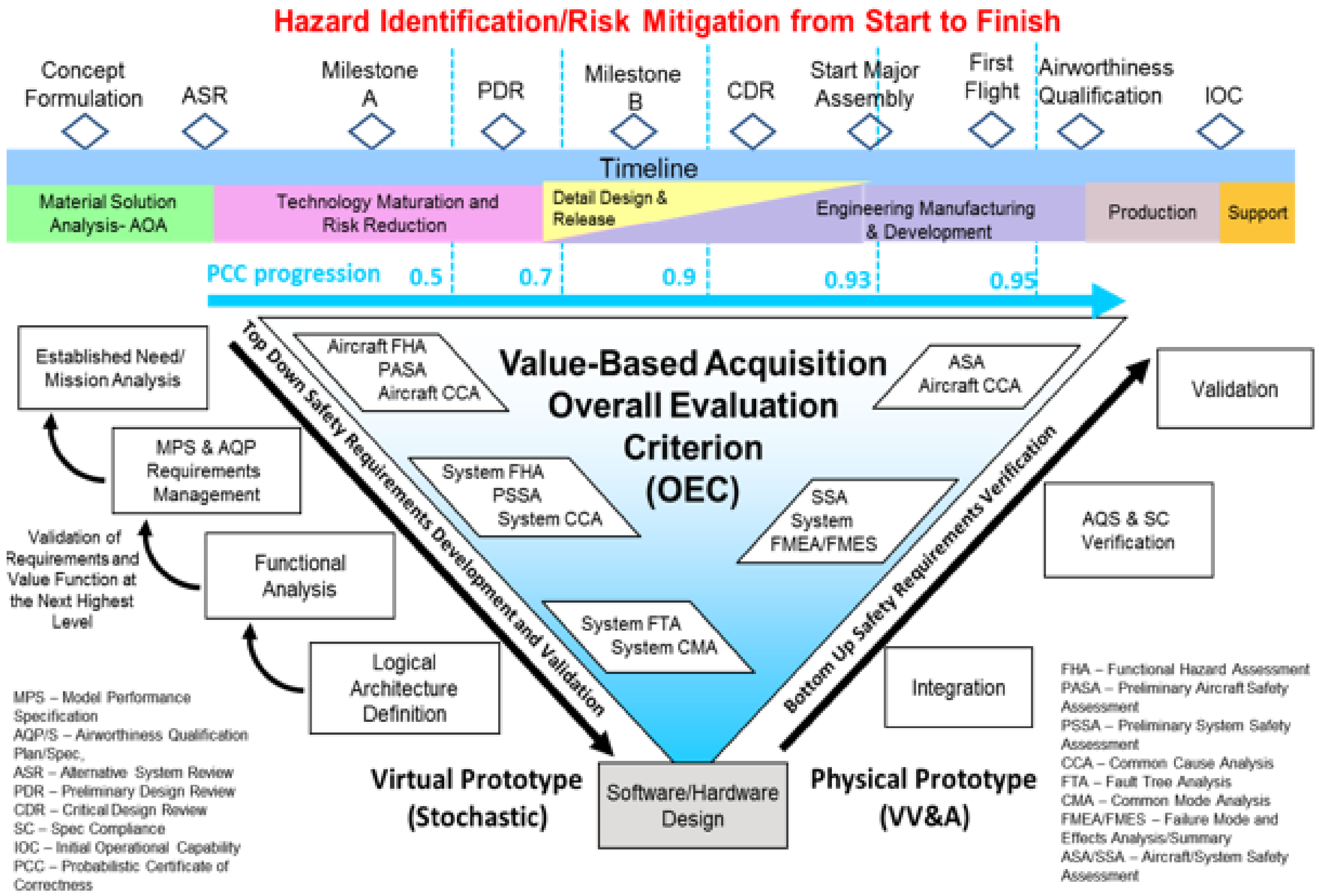


Value Based Acquisition (VBA) Approach

$$DAVBAMetric = SystemEffectiveness / LCC$$

$$\frac{\alpha(A_{Matl}) + \beta(C_{Perf}) + \delta(D_{SysRel+Surv})}{\phi(\mathrm{RDTE} + \mathrm{PC} + \mathrm{O\&S} + \mathrm{DC})}$$

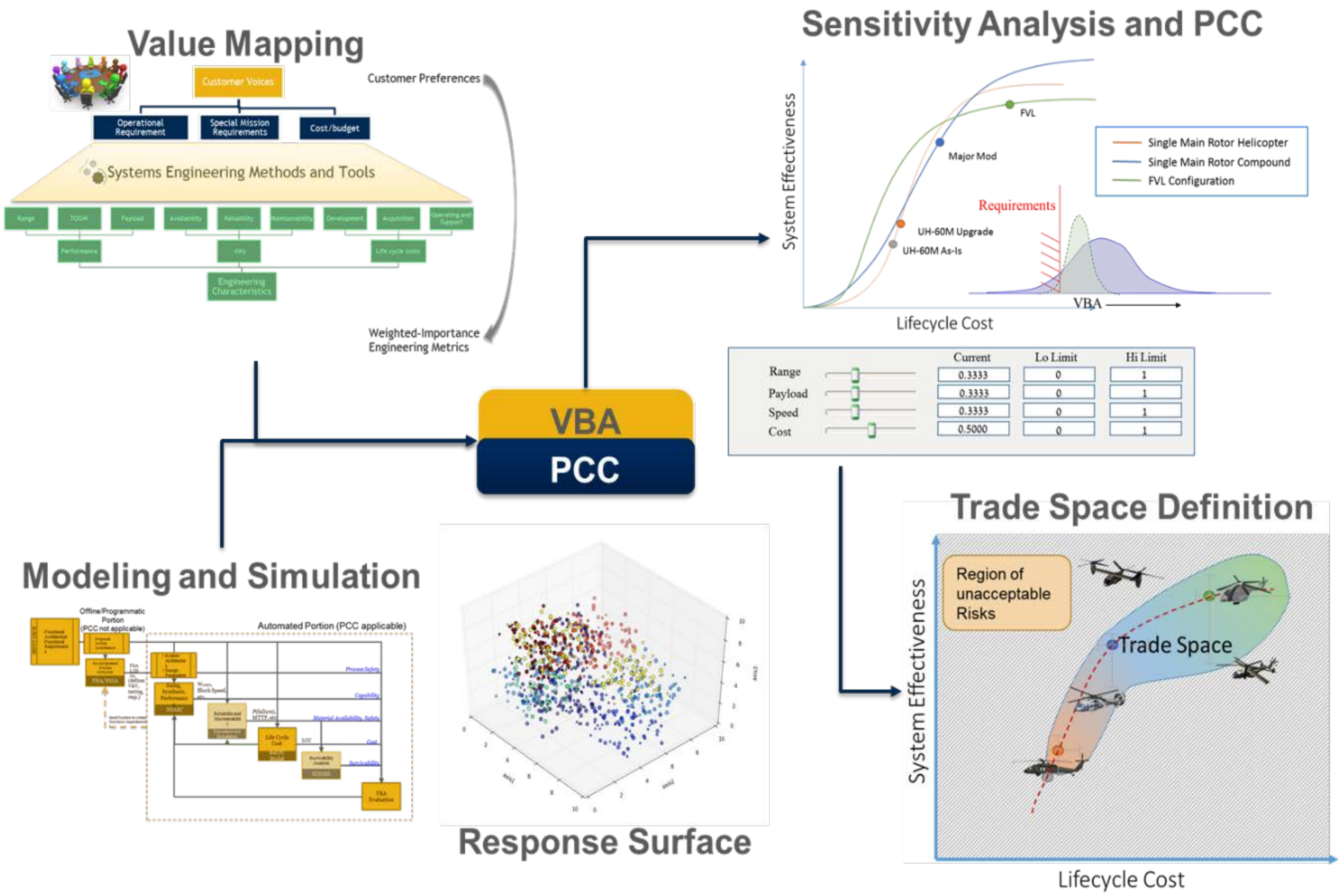
$$A_{Oper} = \frac{MTBF}{MTBF + MTTR + ALDT} \qquad C_{Perf} = MCI * = \frac{Payload_{HOGE} * (BlockSpeed)}{W_{Empty} + W_{Fuel}}$$

$D_{Safety + Surv}$ = Functional Development Assurance Level (FDAL) + Survivability $(1 - P_D * P_H * P_K)$

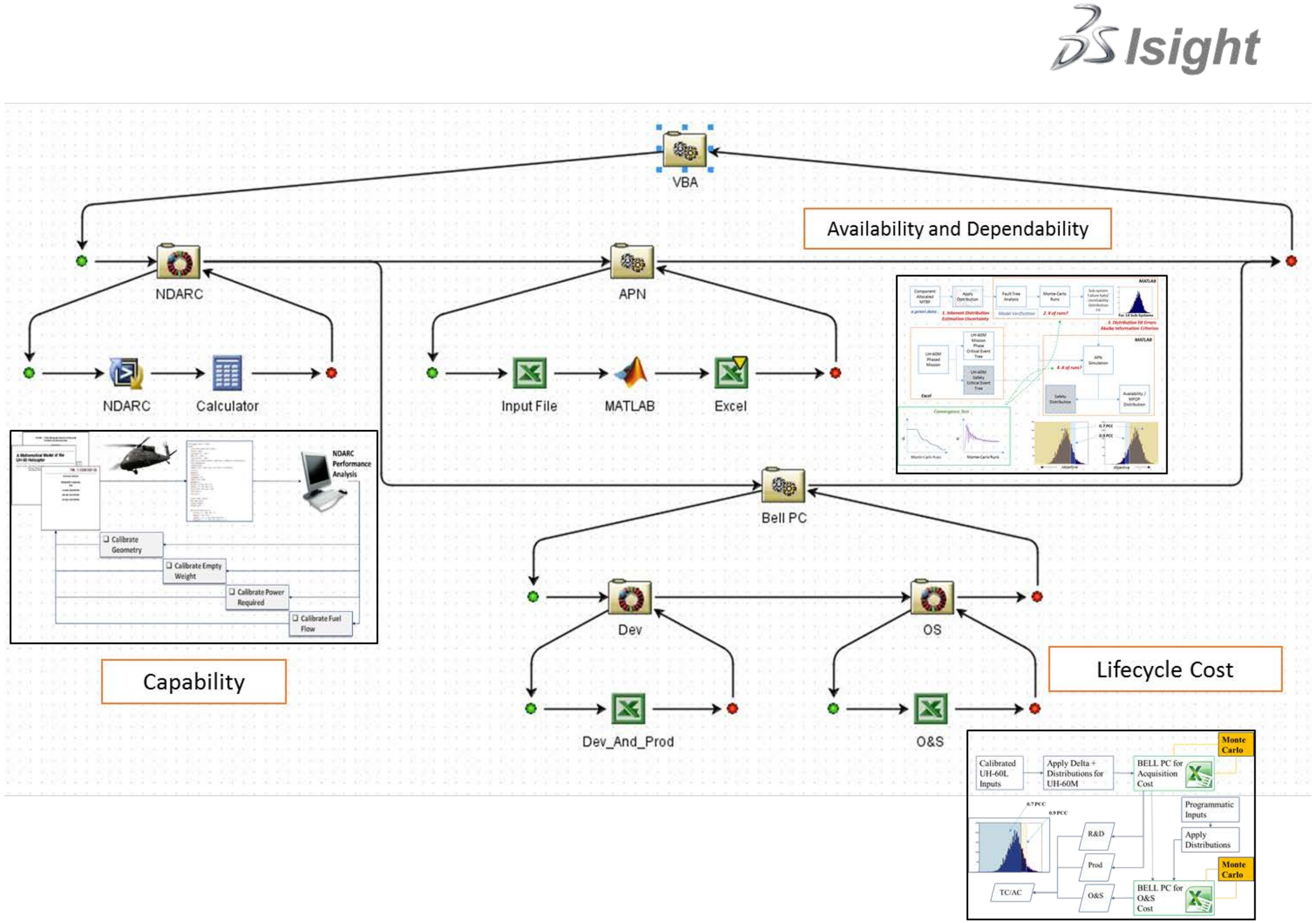
$$\varphi LCC = \varphi_1\ \mathrm{RDTE} + \varphi_2\ \mathrm{PC} + \varphi_3\ \mathrm{O\&S} + \varphi_4\ \mathrm{DC}$$

- α , β , δ , are system effectiveness weighting variables determined by user-developer consensus
- $\Phi_{1,\,2,\,3,\,4}$ are life cycle cost weighting variables determined by user-developer consensus
- The quantitative VBD/A model when defined, analyzed and optimized through Virtual Stochastic Prototyping (VSP) can become the basis for contracting

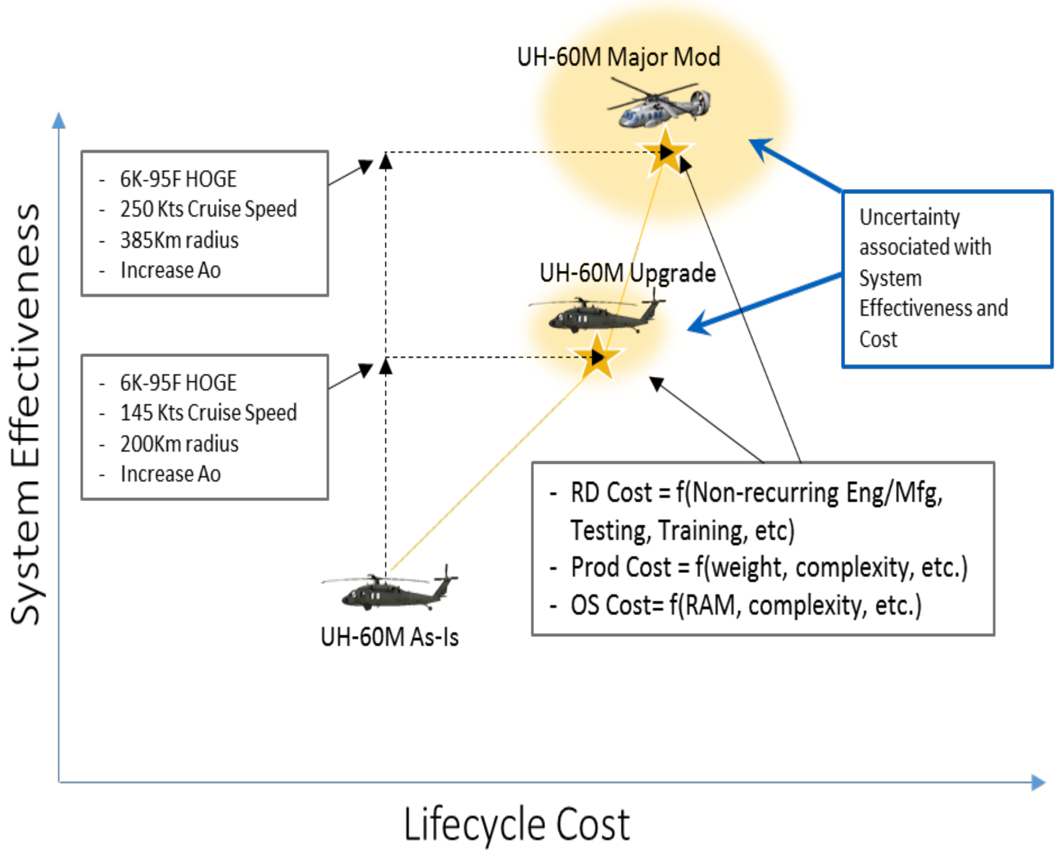
Model-Based Systems Engineering (MBSE) Approach for DAVBA

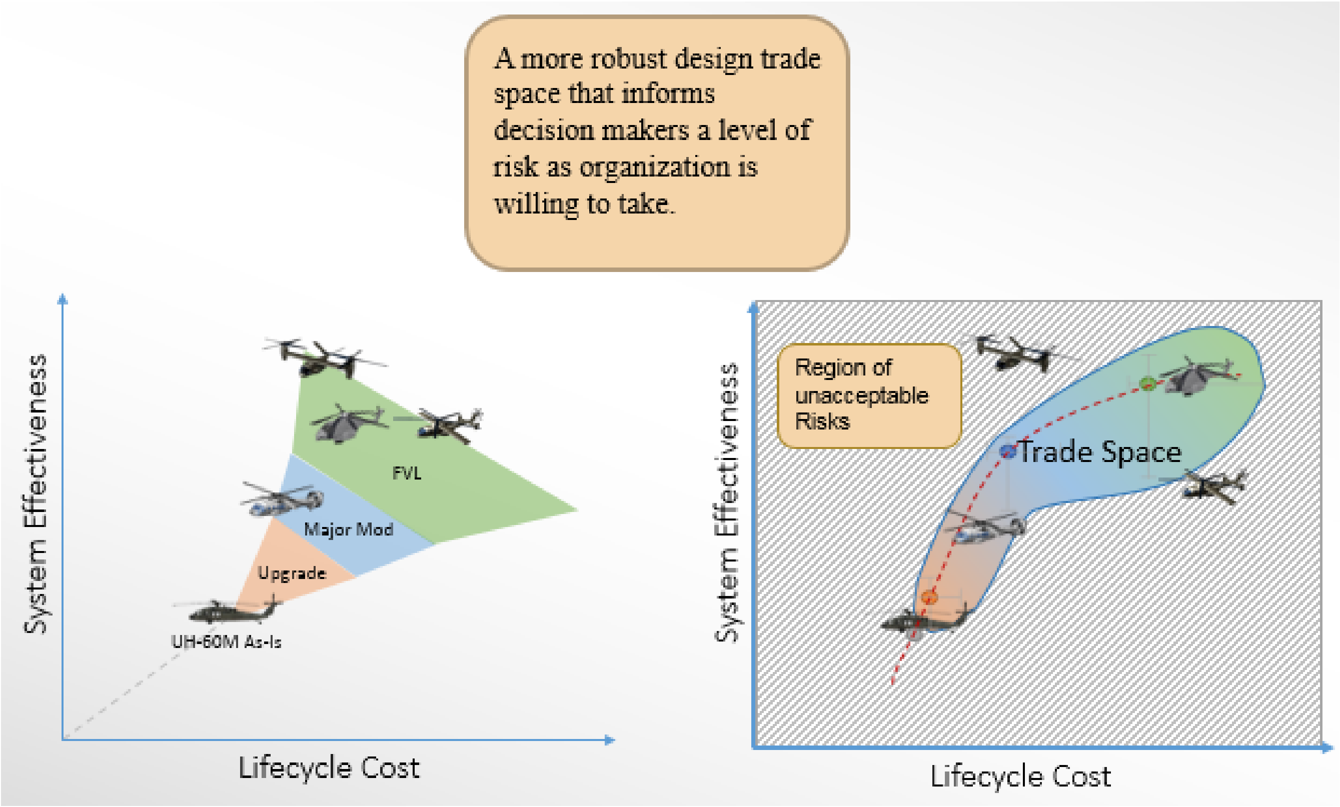


Model Based Systems Engineering (MBSE) Implementation in DS Isight



DAVBA Proof of Concepts Results for UH-60M Upgrades and Proposed FVL Approach





Value Driven Cost Capability Analysis Now Required for DoD Major Weapon System Decision-Making

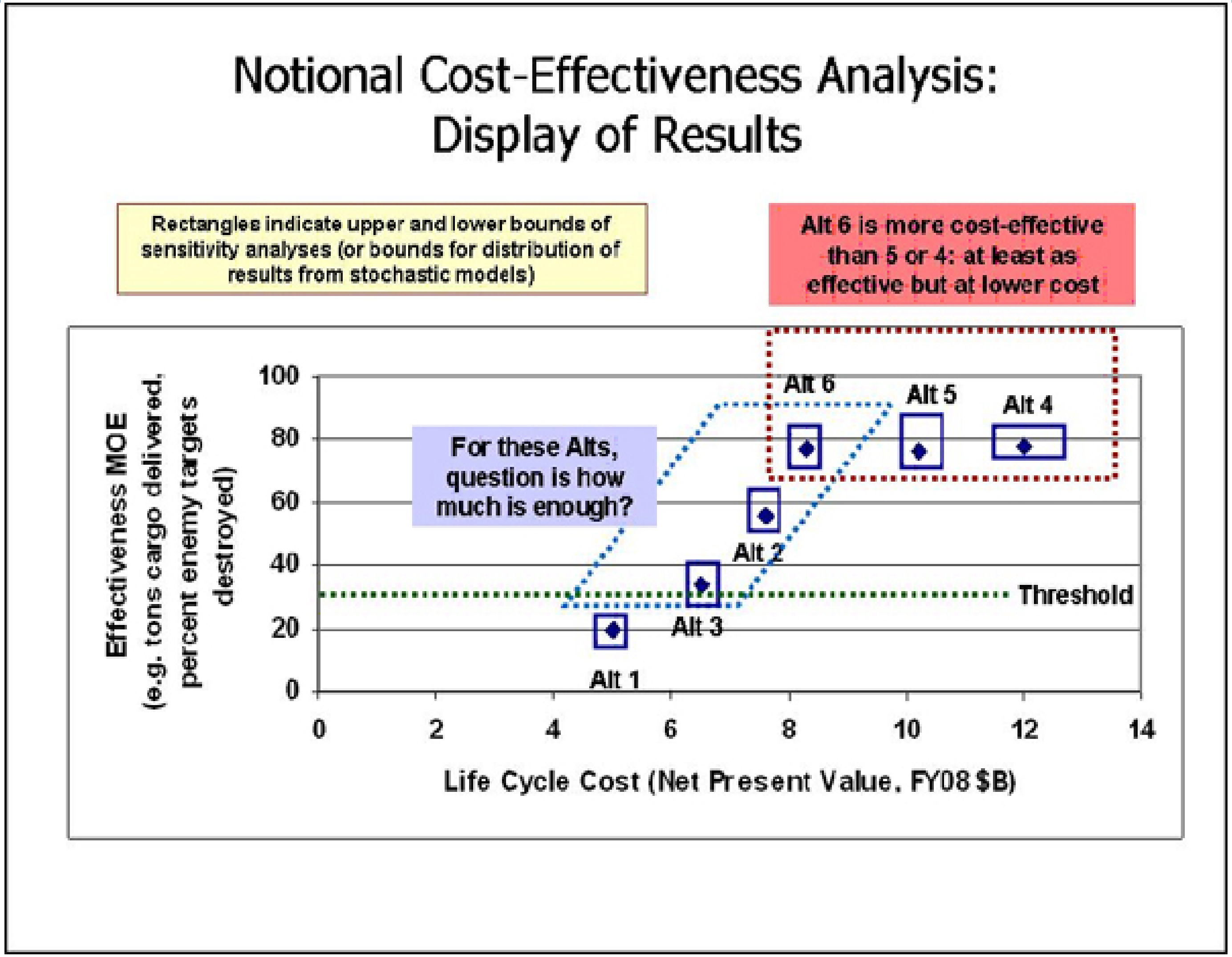
- **Cost and Schedule over runs and lack of achievement in performance objectives for large complex defense systems has led to the need for required Cost Capability Analysis (CCA)**
- **U.S. Air Force Material Command (AFMC) has introduced CCA, applied it to Pilot Projects, and now require it at all critical milestones. AFMC additional CCA initiatives:**
  - **Air Force Life Cycle Management Center (AFLCMC) has established a Standard Process for CCA**
  - **Air Force Institute of Technology (AFIT) has established a CCA Certificate Program in the Graduate School of Engineering and Management**
- **The U.S. Army Aviation Development Directorate awarded a one year VLC NRTC S&T contract to Georgia Tech, entitled: *A Development Assurance Value Based Acquisition (DAVBA) Approach for Airworthiness Qualification and Specification Compliance.* It included two key elements:**
  - **Development of a Draft Aeronautical Design Standard (ADS) entitled: *Military Aircraft & Systems Development Assurance and Value Based Acquisition*, which calls for a CCA approach**
  - **Development of a CCA example for the Draft ADS applying the DAVBA approach to the UH-60M as a FVL Baseline**

What is Cost Capability Analysis

(Defensed Acquisition Guide – Systems Engineering, 2016)

- **A Cost Capability Analysis (CCA) is an *analytical tool used by Program Management to examine cost and military utility*. It allows for better understanding and decision making of the effects of requirements on cost and capability. The *purpose of a CCA is to support delivery of cost-effective solutions* through deliberate trade-off analysis between operational capability and affordability.**
- **A CCA uses Multi-Objective Decision Analysis (MODA) that results in a trade space between cost and warfighting capabilities. The MODA utilizes an attribute hierarchy to assign a value score to each alternative. Alternatives then are compared based on the requirement attribute score and cost to determine which are most efficient (i.e., provide greatest performance for the cost, or lowest cost for given performance). Once these efficient alternatives are identified, *it's up to the <u>Program Manager</u>, working with the stakeholders, to decide the proper trade-off between cost and performance on the efficient alternatives*.**

DEFENSE ACQUISITION GUIDEBOOK Example
Chapter 3 -- Affordability and Life-Cycle Resource Estimates
3.3.3.7. Analysis of Alternatives (AoA) Study Plan—Cost-Effectiveness Comparisons



Air Force Materiel Command

LEADING EDGE TECHNOLOGY • WORLD CLASS SUSTAINMENT • WAR-WINNING SYSTEMS

Cost Capability Policy Update DRAFT

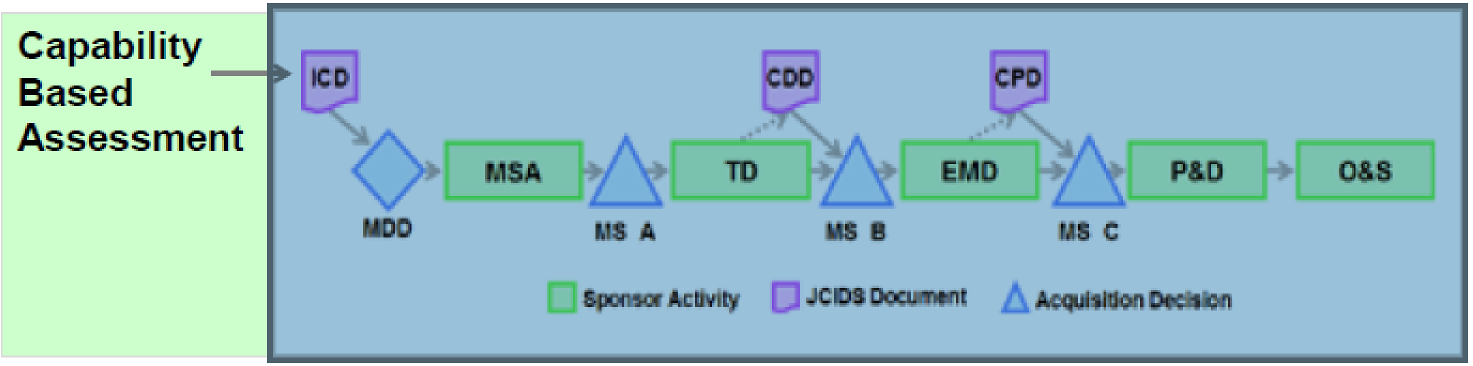
Mr. Harry Conley
HQ AFMC/A5C
25 March 14

One Team Delivering Capabilities to Fly, Fight & Win....Today & Tomorrow

When to Perform Cost Capability Analysis?

When to Perform It?

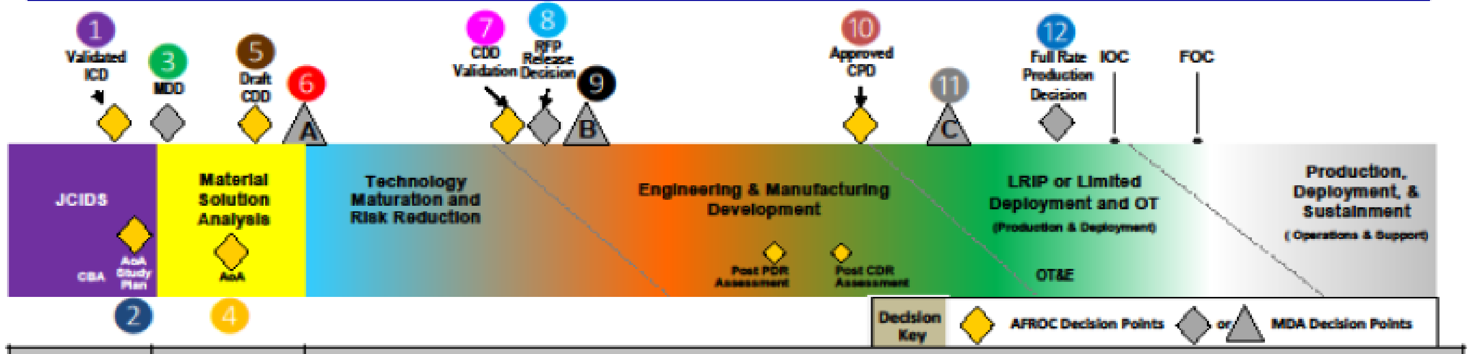
- Start early!
  - Works best when used at the earliest point before the ICD is developed to understand what the realm of the possible is; then throughout Life Cycle



- Reported at AFROC for AoA final report, Capability Development Document (CDD) and Capability Production Document (CPD)

When to Perform Cost Capability Analysis?

Cost Capability Analysis Decision Framework



Decision Points	AF Decision Maker*	Key Question
1 ◇	AFROC	What are the affordable and viable military concepts to mitigating the identified capability gap? Does the AoA Study Plan adequately describe the methodology for estimating the life cycle costs and operational effectiveness of the potential concepts identified in the study guidance to close the gap identified in the ICD?
2 ◇	AFROC	
3 ◇	MDA	
4 ◇	AFROC	Does the preferred solution provide the maximum military utility for cost within affordability constraints. Do the KPPs and KSAs reflect life-cycle trades between cost, schedule and performance resulting in the maximized military utility within the affordability constraints? For each KPP and KSA, what are the cost and operational impacts and resulting military utility to accepting a lower threshold value? Does the acquisition strategy reflect maximizing military utility?
5 ◇	AFROC	
6 △	MDA	
7 ◇	AFROC	Can you validate the preferred solution provides the maximum military utility for cost within affordability constraints. Do the KPPs and KSAs reflect life-cycle trades between cost, schedule and performance resulting in the maximized military utility within the affordability constraints? For each KPP and KSA, what are the cost and operational impacts and resulting military utility to accepting a lower threshold value? Does the acquisition strategy reflect maximizing military utility?
8 ◇	MDA	
9 △	MDA	
10 ◇	AFROC	Have changes to the program baseline been assessed to ensure the maximum military utility for cost within affordability constraints? If so, what trades were made to arrive at those values and what are the cost, schedule, technical, and operational implications?
11 △	MDA	
12 ◇	MDA	

* Final decision maker, other reviews may occur prior to final decision, i.e. AFRRG RSR for AF)

Lessons Learned Cost/Capability Pilot Program

Cost/Capability Pilot Programs - What We're Learning

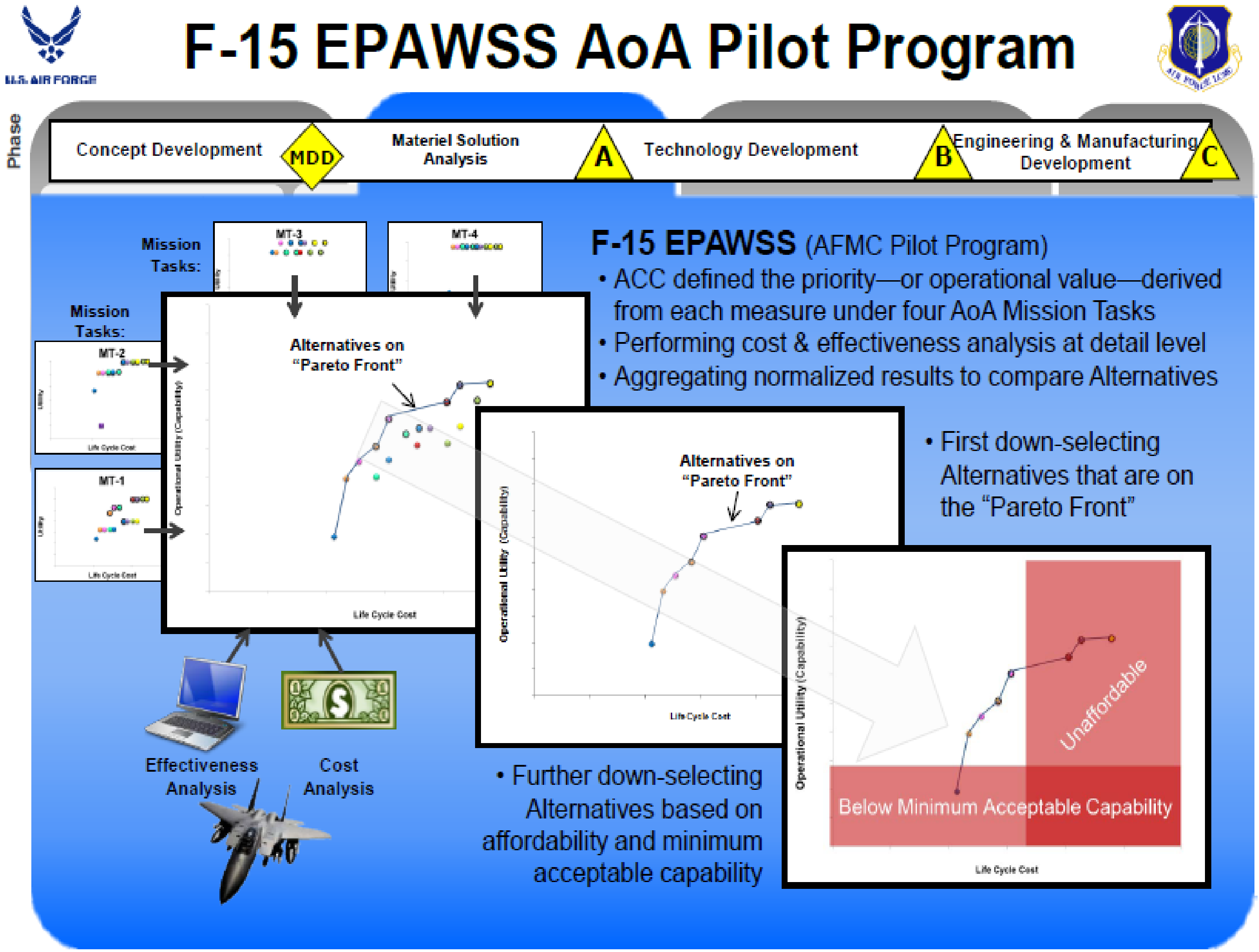
- **Trial programs for developing the analysis and capturing lessons learned:**

  Advanced Pilot Training (T-X)
  Presidential Aircraft Recapitalization (PAR)
  Ground-Based Strategic Deterrence (GBSD)
  Global Aircrew Strategic Network Terminal (Global ASNT)
  Three-Dimensional Expeditionary Long Range Radar (3DELRR)
  F-15 Eagle Passive/Active Warning and Survivability System (EPAWSS)

  - **No formal cost/capability process existed**
  - **Difficult to define military value/worth of a proposed capability**
    - **Must define military value before trades can be evaluated**
  - **Multi-disciplined team approach needed**
    - **Requirement owner/warfighter, PM, EN, cost analyst, ops research**
    - **Requires tight coupling of engineering and cost functions within the program office**
  - **Depicting results of analysis more difficult than expected**
  - **Industry analysis provided valuable insights to decisions**
  - **Cost capability methodology should be started in Development Planning (DP) and Analysis of Alternatives (AoA) timeframe and used throughout lifecycle**

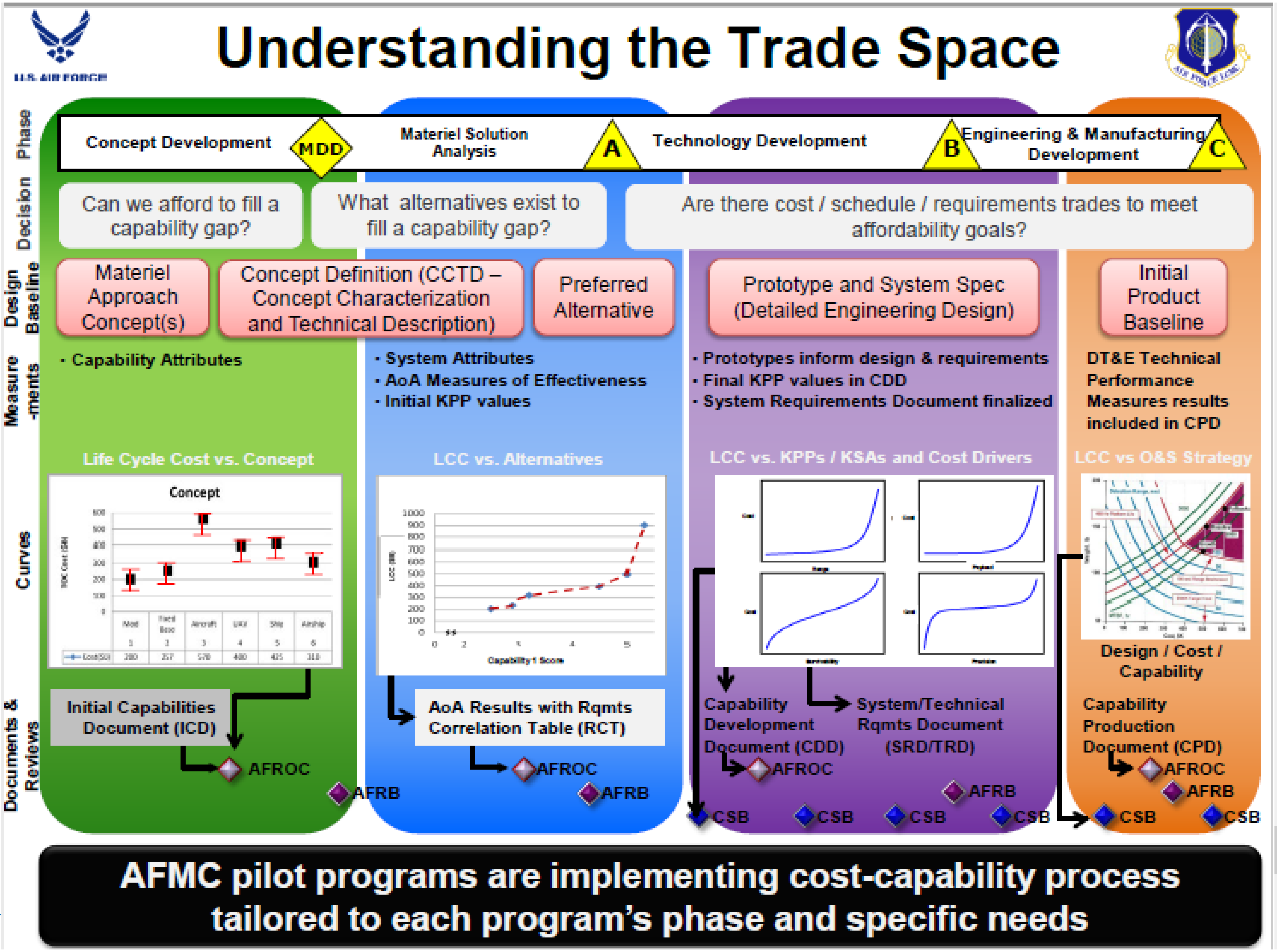
Results of a USAF Pilot Project on Application of CCA

Global Product Data Interoperability Summit | **2019**



EPAWSS = Eagle Passive/Active Warning Survivability System

AFMC Pilot Programs for progressive CCA Development and Evaluation



Identifying the Next Steps for Integrating GPDI into MBE and MBSE

- **Build off recent inclusions of GPDI in MBSE, such as Boeing is doing with its movement from the traditional Vee Diagram to a Diamond Diagram to capture the Digital Twin**
- **Recruit Industry-Government-Academia Stakeholders for creating a GPDI/MBE/MBSE Research and Education Consortium based on enhancing *Civil Aircraft and Systems Development Guidelines for Development Assurance and Value-Based Decision-Making* for other applications**
- **The Georgia Tech Graduate Program in Aerospace Engineering has the expertise, experience and resources to lead such a Consortium Effort**
- **Would be glad to work with Industry-Government and Academia pursuing this Partnership**