SYSTEMS ENGINEERING RESEARCH CENTER (SERC)
ACQUISITION INNOVATION RESEARCH CENTER (AIRC)

A DECADE OF DIGITAL ENGINEERING RESEARCH, INSIGHTS PAST AND FUTURE FROM THE SYSTEMS ENGINEERING RESEARCH CENTER

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Sponsors: US Navy NAVAIR, US Army Armaments Center, US Space Force, OUSD (R&E)

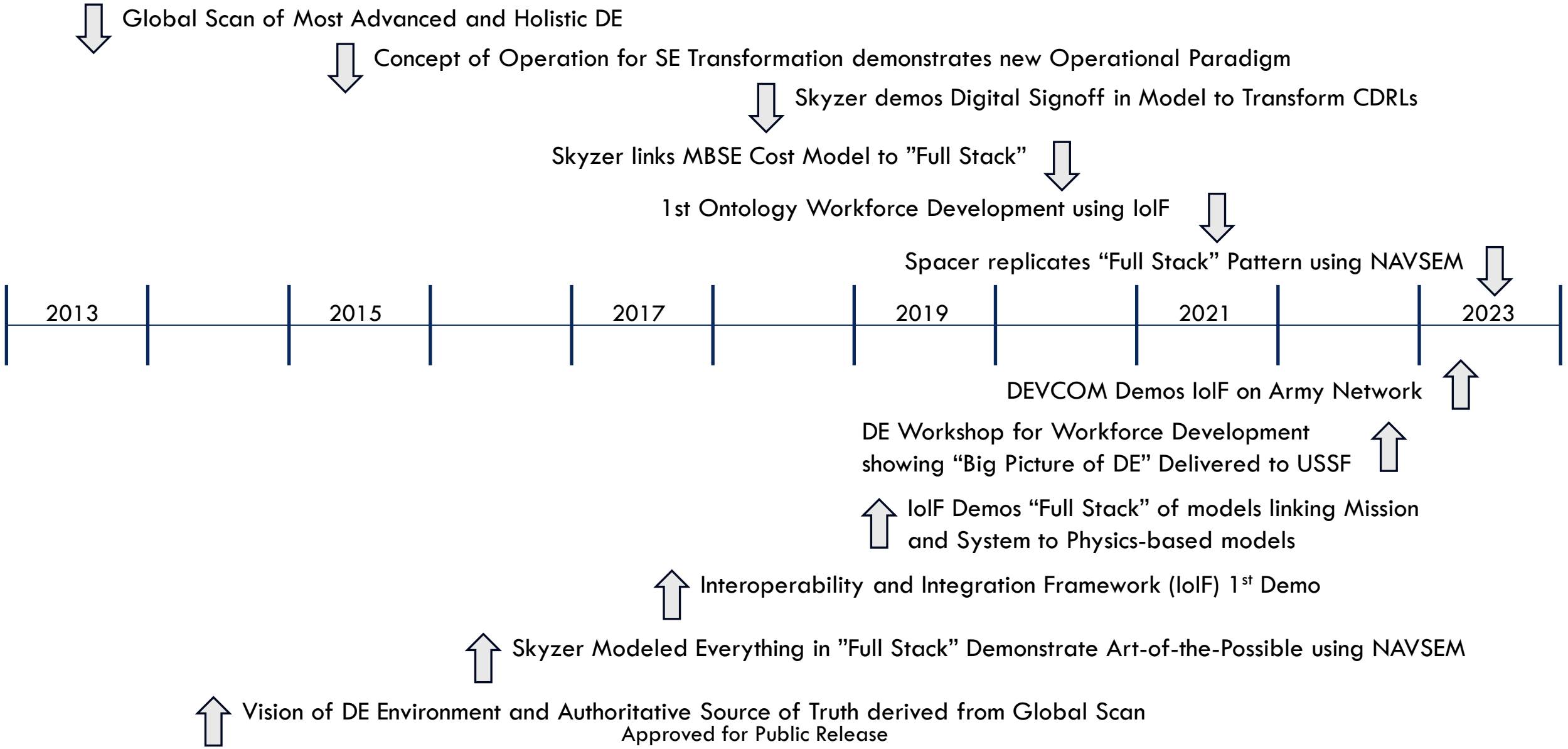
27th Annual Systems and Mission Engineering Conference

Approved for Public Release

SYSTEMS ENGINEERING RESEARCH CENTER

AIRC ACQUISITION INNOVATION RESEARCH CENTER

10 YEARS OF DE RESEARCH, INSIGHTS PAST AND FUTURE (NON-EXHAUSTIVE)



DEMONSTRATING NEW DE WORKFLOWS IN OPEN PROJECT SETTINGS

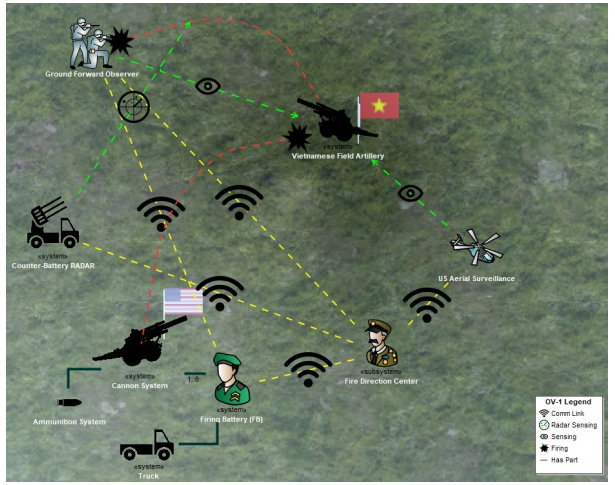
2016: Skyzer Modeled Everything in "Full Stack" Demonstrate Art-of-the-Possible using NAVSEM

2017: DEVCOM Demos IoIF on Army Network

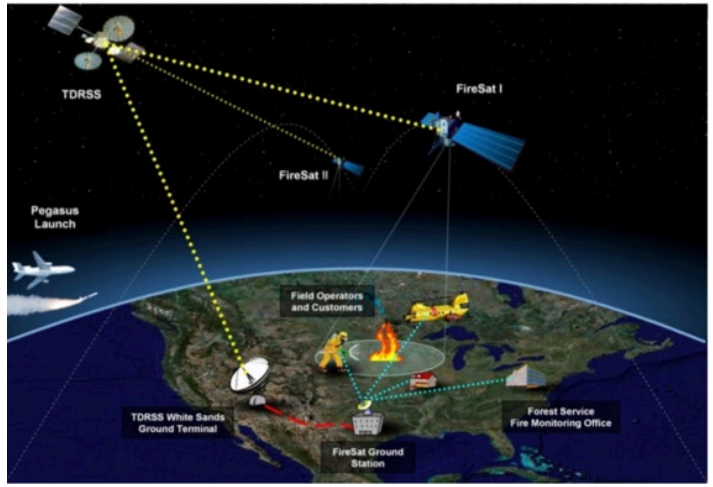
2023: Spacer replicates "Full Stack" Pattern using NAVSEM

Skyzer Search & Rescue

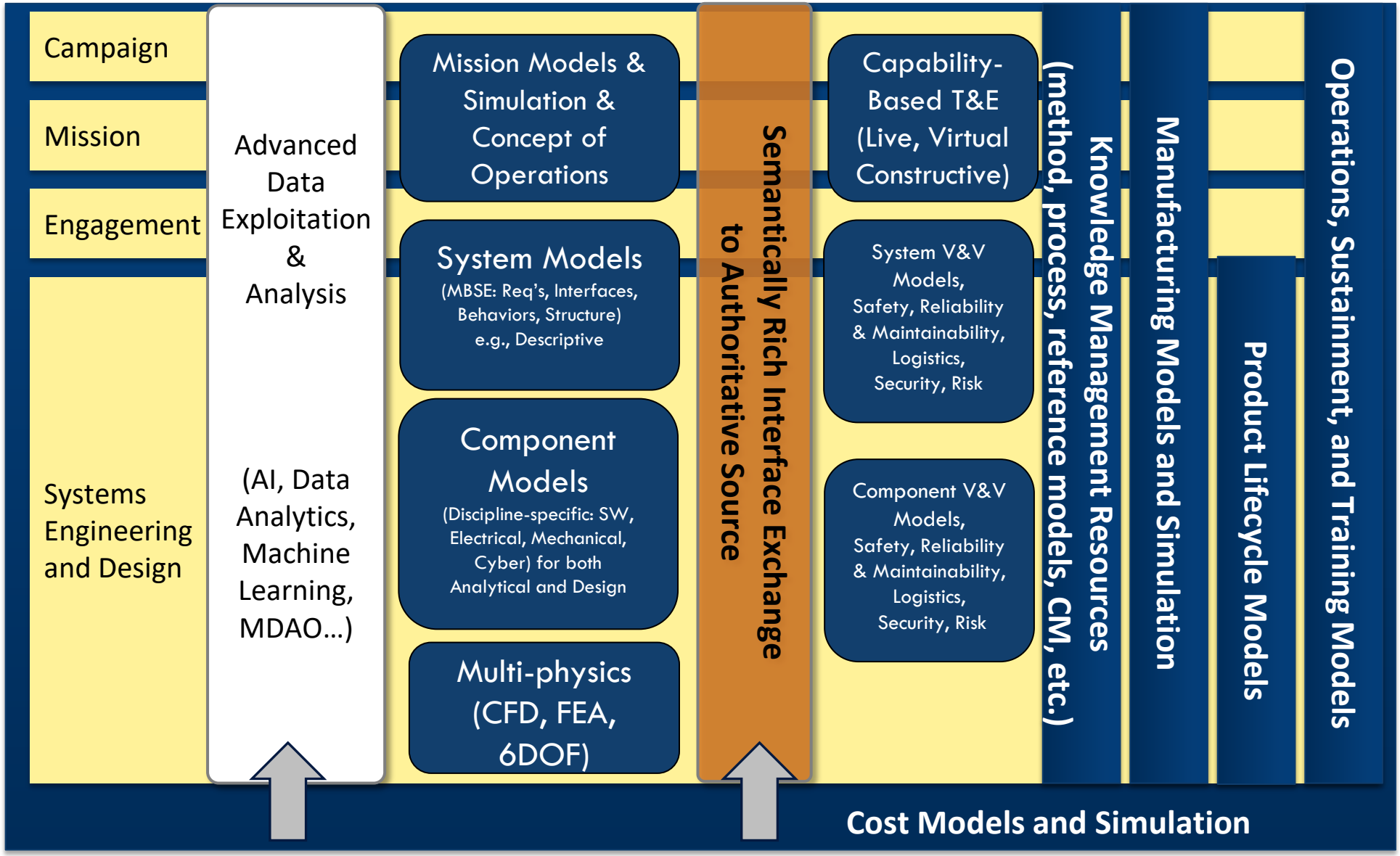
Armaments Missions



Spacer: FireSat



REFERENCE ARCHITECTURE FOR DIGITAL ENGINEERING ENVIRONMENT IN SUPPORT OF DE

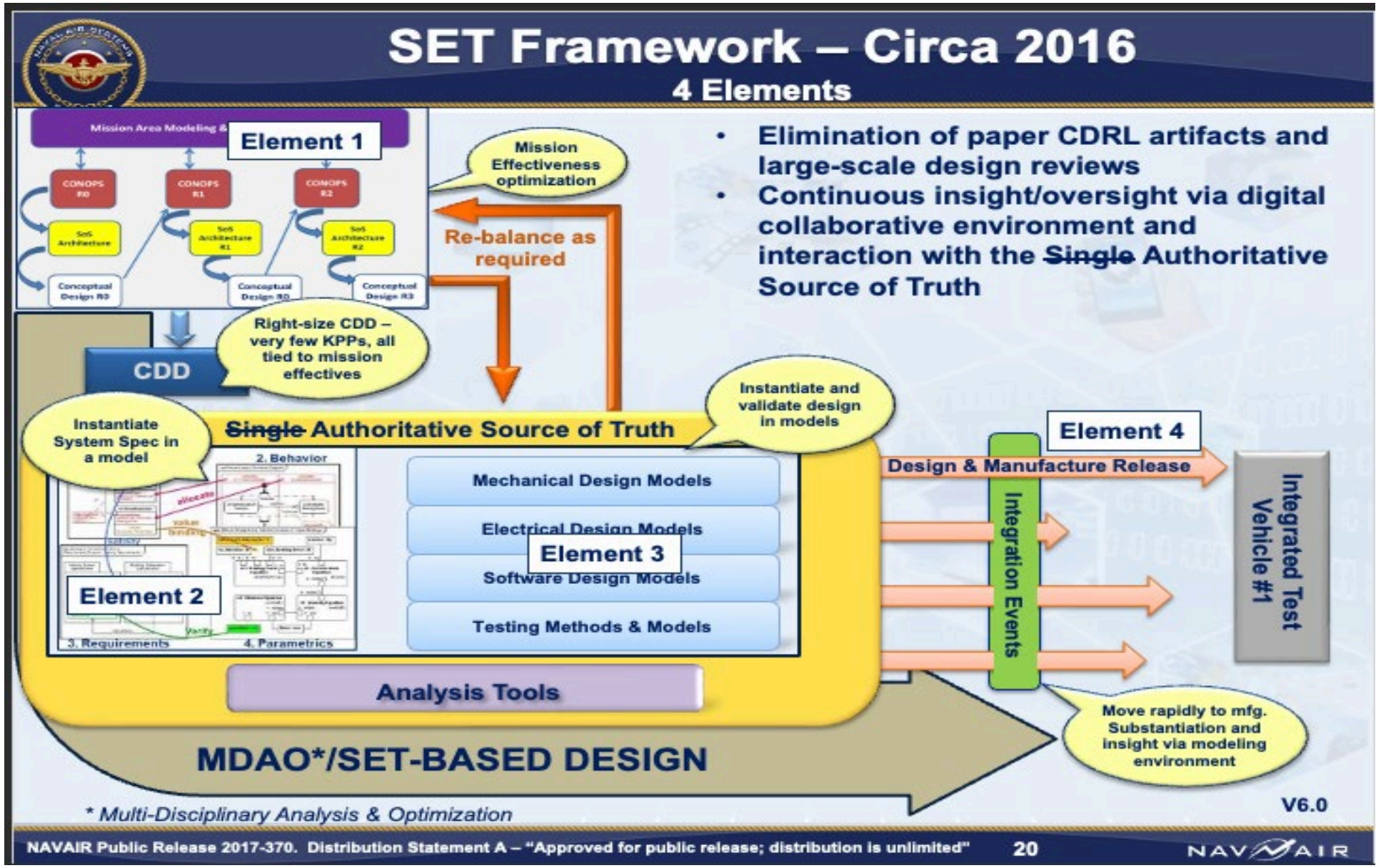


10 YEARS AGO: LEADERS WERE EMBRACING CHANGE AND ADAPTING TO USE DIGITAL STRATEGIES FASTER THAN OTHERS

⇩ 2013: Global Scan of Most Advanced and Holistic DE

1. Enabling digital technologies are changing how companies are doing business using model-centric engineering (now Digital Engineering)
2. They use model-centric environments for customer engagements, and also for design analysis and review sessions
3. They use commercial technologies and have developed a significant amount of infrastructure on their own
4. We heard about mission-level simulations that are being integrated with system simulations, digital assets & products providing a new world of services

CONCEPT FOR NEW OPERATIONAL PARADIGM FOR NAVAIR SET



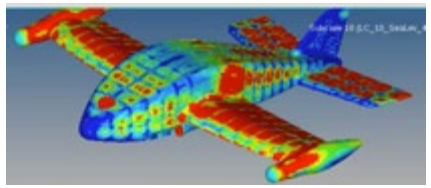
RESEARCH AND SURROGATE EXPERIMENT CONTRIBUTES BROADLY TO NAVAIR SET FUNCTIONAL AREAS

Surrogate Pilot Scenario: UAS Search/Rescue Mission

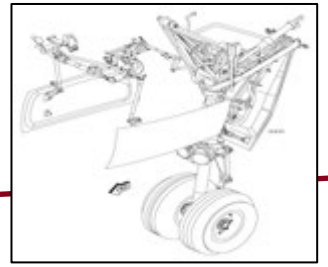
2015 Concept of Operation for SE Transformation demonstrates new Operational Paradigm

Deep Dives by Phases

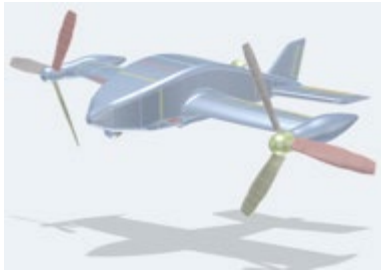
Graphical CONOPS Scenario: Search & Rescue



P1: Multi-physics



P2: Airworthiness



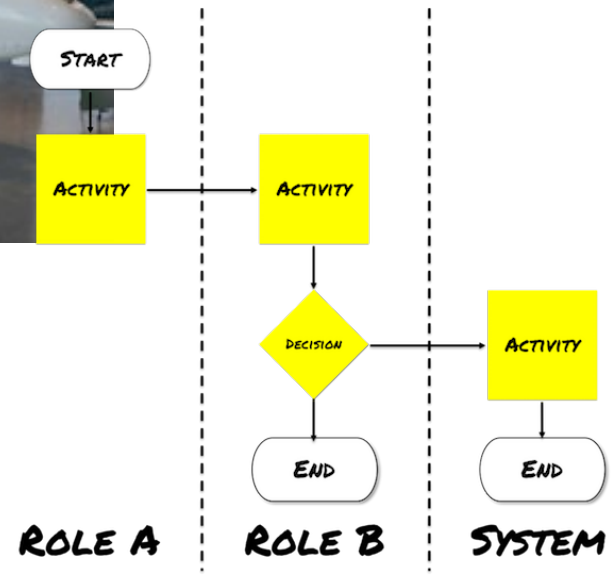
P3: Cost Modeling

Performance constraints force Multi-physics Design considerations

–

Similar to Bell Eagle Eye

Conform to NAVAIR Systems Engineering Method (NAVSEM)



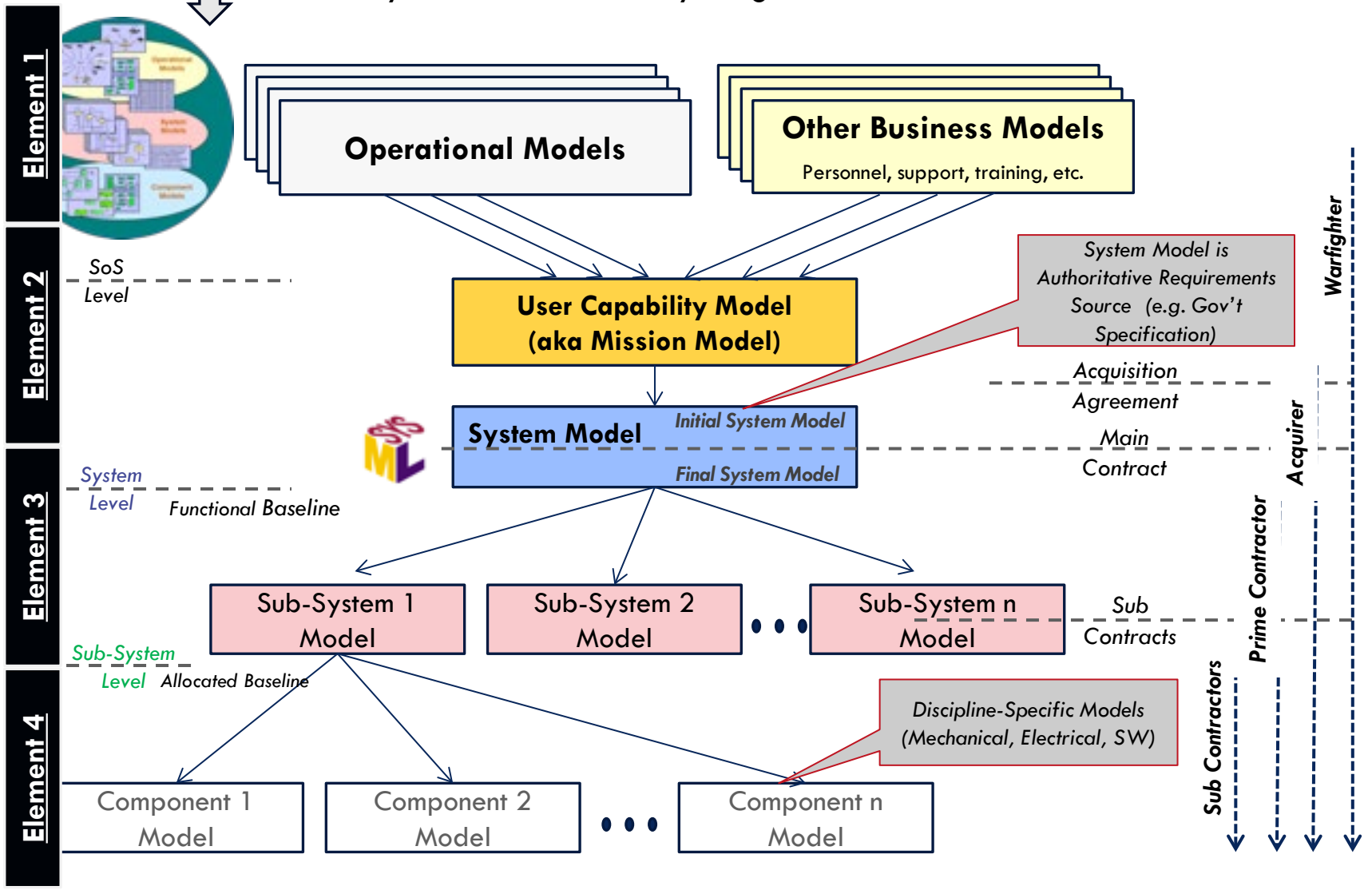
Doing Everything in Models to Demonstrate Art-of-the-Possible

SKYZER DEMONSTRATES MODELING AT DIFFERENT ABSTRACTION LEVELS

2016: Skyzer Modeled Everything in "Full Stack" to Demonstrate the Art-of-the-Possible

MBSE tools & languages applicable

MBE tools & languages applicable



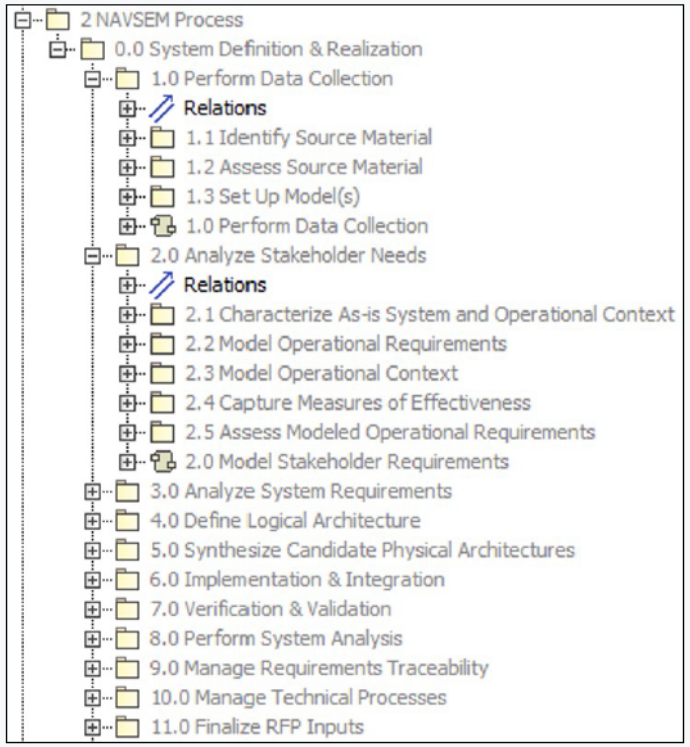
ORGANIZE THE MODEL TO THE SE PROCESS

2023: Spacer replicates "Full Stack" Pattern using NAVSEM ⇩

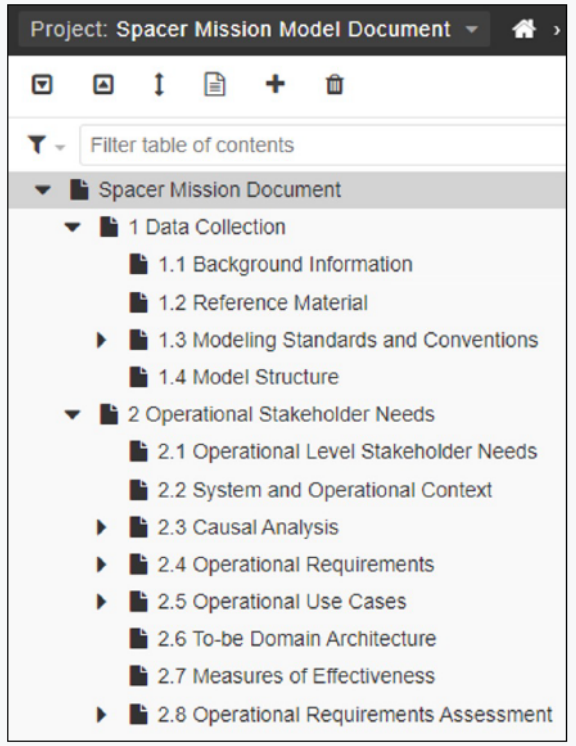
Model's Setup and Compliance with NAVSEM

- Using NAVSEM, models can be setup and organized more efficiently
- Document Models can be used to keep track of compliance with NAVSEM
  - The outline of the Document model is consistent with the NAVSEM process steps
  - If information is missing from an element within the outline, then this tells us model information is missing and thus not yet fully compliant with NAVSEM

Process Steps shown in MagicDraw Containment Tree



DocGen Output in OpenMBEE View Editor web-app



- Spacer Mission Model shown for example
- Spacer Mission Model covers Steps 1 and 2 in NAVSEM

"FULL STACK" OF SKYZER MODELS ENABLES ACQUISITION ANALYSIS

Skyzer links MBSE Cost Model to "Full Stack"

Generalization of Previous Mission/Systems

- Mission Reference Models
- System Reference Models

Using and Tailoring Reference Models

Reference models characterize reusable information and process

- NAVSEM Model
- Airworthiness Model
- CBT&E / MBTD Model
- Cyber Model
- Reliability and Maintainability
- Cost Model
- More…

NAVSEM Compliant

"Full Stack" Skyzer

- Mission Model
- Skyzer System Model

Project Usage

L&R Sys Model

Contractor RFP Response Model

Avionics M…

Airframe

Landing-Gear Subsystem Model

…

Stakeholder Analysis Models

- Instance of CBT&E / MBTD Model
- Instance of Airworthiness Model
- Instance of Cost Model

Criteria focused on Capability-based Test & Evaluation (CBT&E) and Mission-based Test Design (MBTD)

Criteria needed and evidence provided for getting a flight clearance

Cost Modeling approach based on using MBSE artifacts

How to model to develop Authoritative Source of Truth

Demo

SYSTEMS ENGINEERING RESEARCH CENTER

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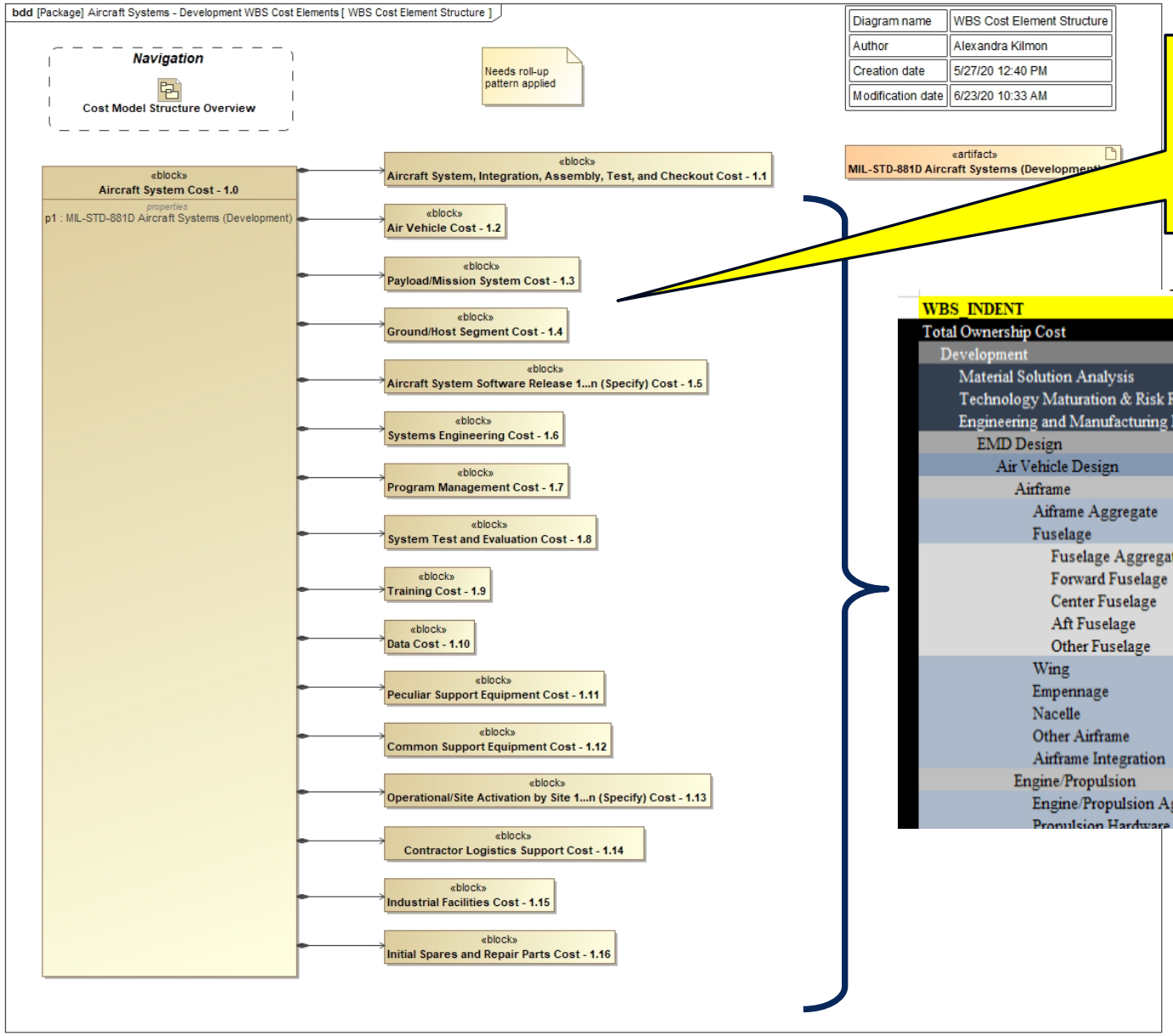
AIRCRAFT SYSTEM COST MODEL – STRUCTURE ALIGNS WITH MIL-STD 881



Cost Reference Model Aligns with Work Breakdown Structure from MIL-STD 881(F)

WBS_INDENT	2020	2021	2022	2023	2024
Total Ownership Cost	$127	$126	$136	$136	$136
Development	$14	$14	$24	$24	$24
Material Solution Analysis	$10	$10			
Technology Maturation & Risk Reduction			$20	$20	$20
Engineering and Manufacturing Development	$4	$4	$4	$4	$4
EMD Design	$1	$1	$1	$1	$1
Air Vehicle Design	$1	$1	$1	$1	$1
Airframe	$0	$0	$0	$0	$0
Aiframe Aggregate					
Fuselage	$0	$0	$0	$0	$0
Fuselage Aggregate					
Forward Fuselage					
Center Fuselage					
Aft Fuselage					
Other Fuselage					
Wing					
Empennage					
Nacelle					
Other Airframe					
Airframe Integration					
Engine/Propulsion	$0	$0	$0	$0	$0
Engine/Propulsion Aggregate					
Propulsion Hardware					

NOTICE: SPACER USES THE SAME MODELING PATTERN AS SKYZER & REFERENCE MODELS

Using and Tailoring Reference Models

Assumes standards and reference models exist or will exist

Determine where to start

Reference models characterize reusable information and process

Determine modeling needs

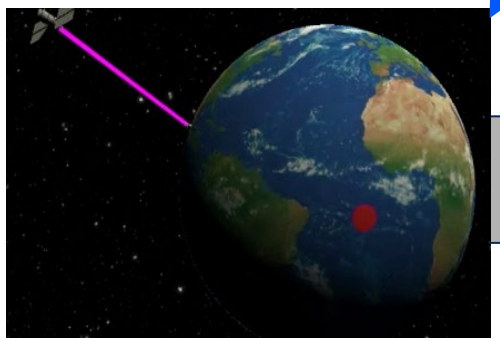
NAVSEM Model | Airworthiness Model | CBT&E / MBTD Model | Cyber Model | Reliability and Maintainability | Cost Model

More…

NAVSEM Compliant

"Full Stack" Spacer

Graphical CONOPs derived from publicly available sources FireSat



Project Usage

Mission Model

Ground System Model

Space Model

Contractor RFP Response Model (1..*)

- Payload
- Guidance & Navigation
- Communication
- Etc.

- Spacecraft Command
- Ground Equipment Control
- Communication
- Mission Data Processing
- Etc.

…

Stakeholder Analysis Models

Instance of CBT&E / MBTD Model

Criteria focused on Capability-based Test & Evaluation (CBT&E) and Mission-based Test Design (MBTD)

Instance of Cyber

Criteria needed and evidence provided for getting a flight clearance

Instance of Cost Model

New Cost Modeling approach based on using MBSE artifacts

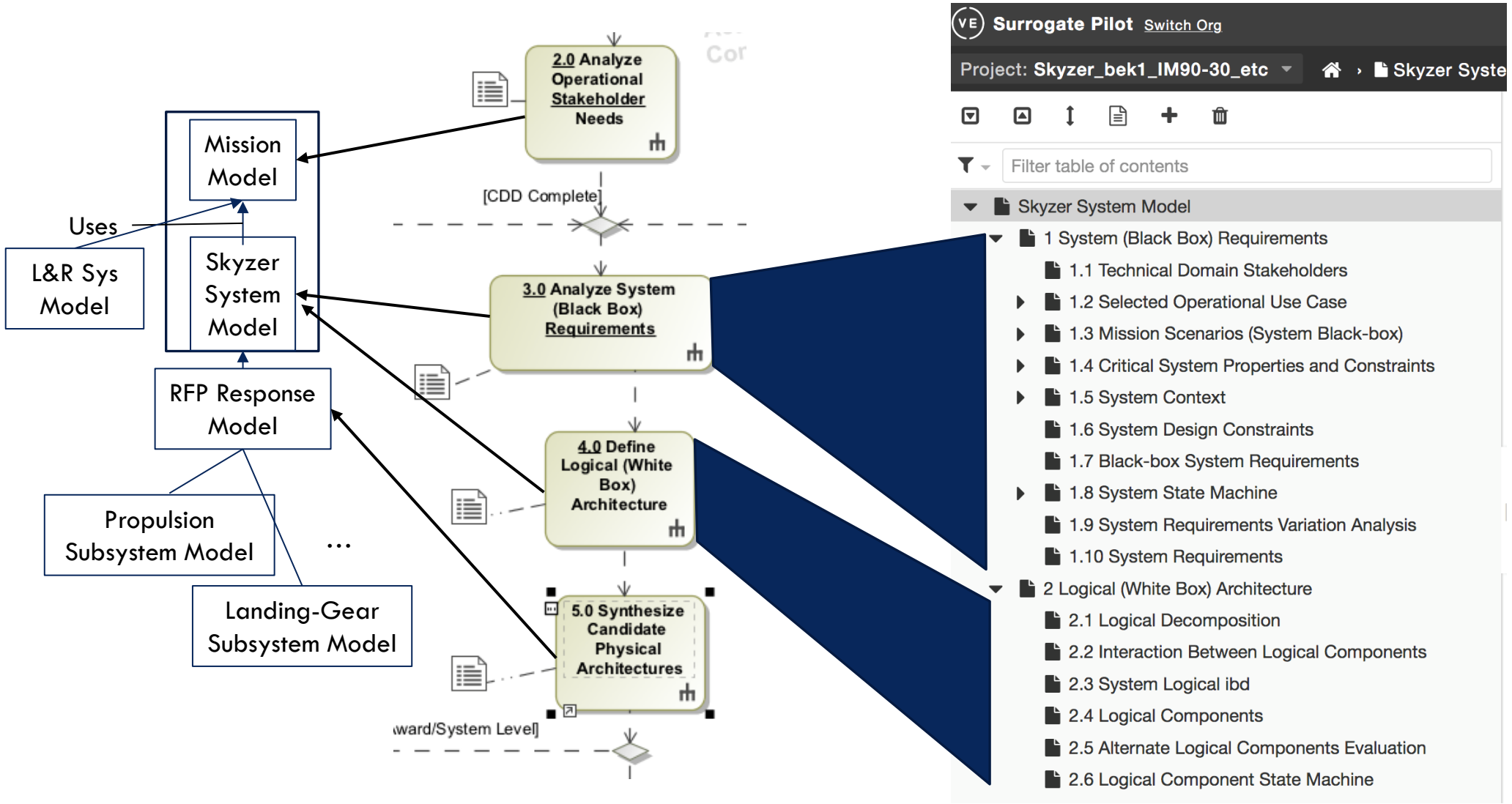
Evaluation Model

RFP Evaluation Model for Source Selection

How to model to develop Authoritative Source of Truth

Demo: Graphical CONOPS

DOCGEN GENERATED VIEW HIERARCHY TO COMPLY WITH NAVSEM STEP 3.0 AND 4.0



Demo

LINKING MISSION MODELS TO SYSTEM MODEL TO DEMONSTRATE AUTHORITATIVE SOURCE OF TRUTH

Surrogate Pilot Switch Org

Search selected

Project: Skyzer System Model Document › Skyzer System Model Documents › Skyzer System Requirements Analysis (Step 3)

Filter table of contents

- Skyzer System Requirements Analysis (Step 3)
  - 1 Technical Domain Stakeholders
  - 2 Selected Operational Use Case
    - 2.1 Operational Use Case Signoff
  - 3 Mission Scenarios (System Black-box)
  - 4 Critical System Properties and Constraints
  - 5 System Context
    - 5.1 System Black-box ibd
      - § 5.1.1 1. Black Box Specifications
    - 5.2 System Interface Definitions
    - 5.3 System Context Signoff
  - 6 System Design Constraints
  - 7 Black-box System Requirements
  - 8 System State Machine
  - 9 System Failure Analysis
  - 10 System Requirements Variation Analysis

DOCLIB

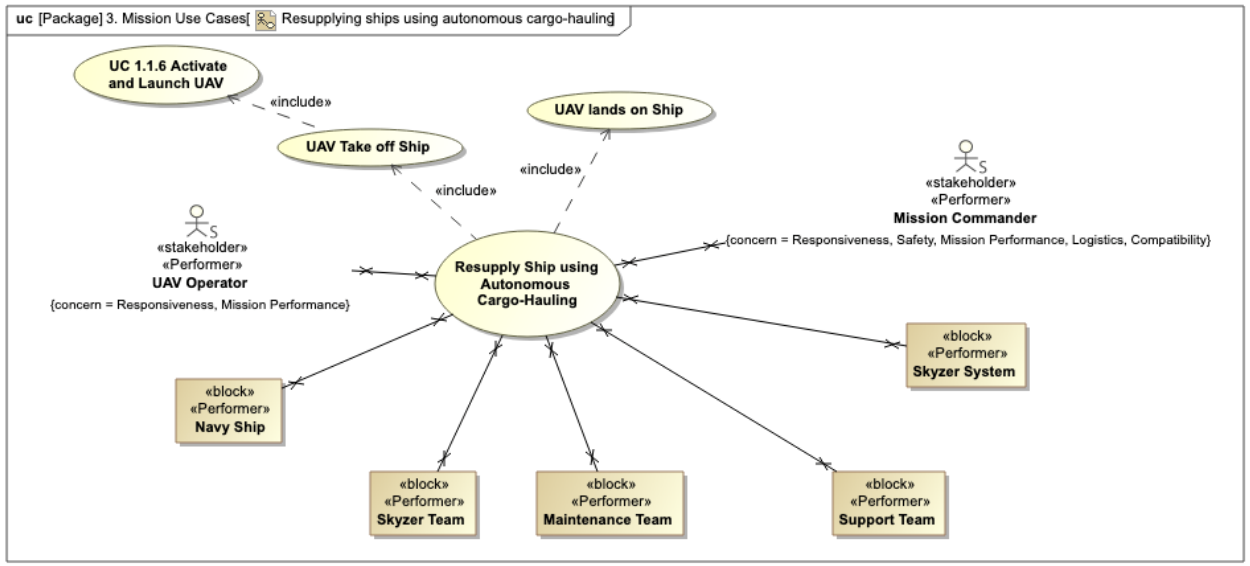


Figure 3. Resupplying ships using autonomous cargo-hauling

2.1 Operational Use Case Signoff

EXPORT CSV FILTER TABLE

Table 3. Operational Use Case Signoff

Approved Elements	Approval Status	Approved By (SME)	Approved By (Chief-Engineer)	Completeness	Comment
Selected Operational Use Case	approved	Mark Blackburn	-	100	-

We place the Digital Signoff with the associated modeling element(s) that provide evidence

We can Transform CDRLs

DIGITAL SIGNOFFS ARE TEMPLATE-BASED & TAILORABLE TO SUBJECT MATTER EXPERTS

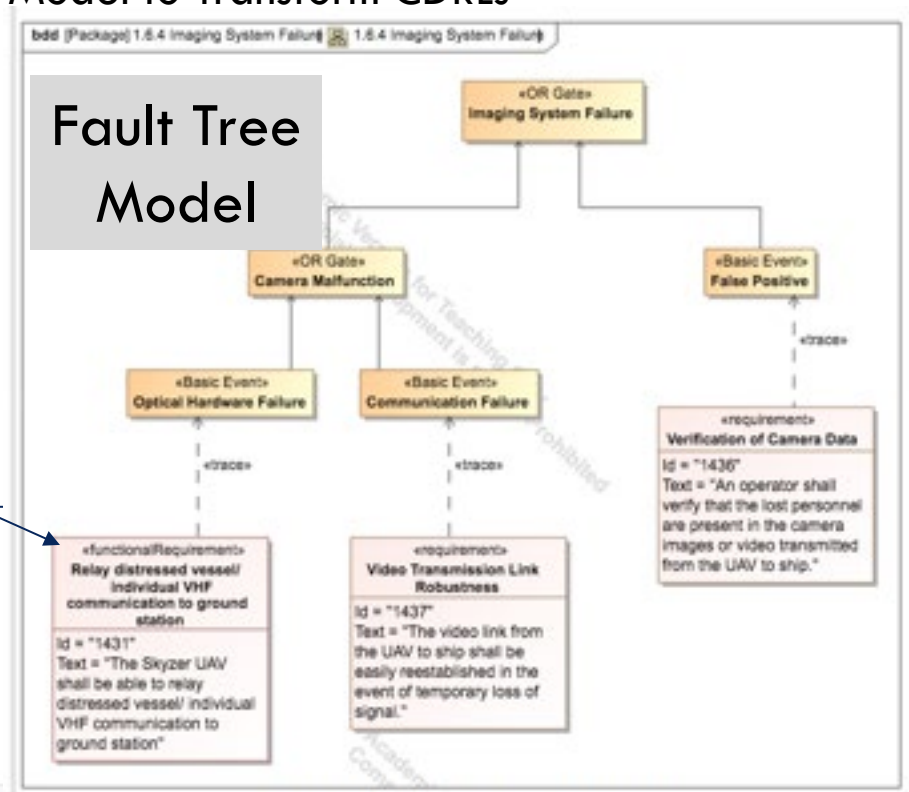
Demo: Digital Signoffs In the Model

Skyzer demos Digital Signoff in Model to Transform CDRLs

TABLE III. Risk assessment matrix

RISK ASSESSMENT MATRIX				
SEVERITY / PROBABILITY	Catastrophic (1)	Critical (2)	Marginal (3)	Negligible (4)
Frequent (A)	High	High	Serious	Medium
Probable (B)	High	High	Serious	Medium
Occasional (C)	High	Serious	Medium	Low
Remote (D)	Serious	Medium	Medium	Low
Improbable (E)	Medium	Medium	Medium	Low
Eliminated (F)	Eliminated			

Mitigation Requirement to address Basic Events that could lead to Mishap for the Hazard



9.2 System Failure Analysis Signoff

Last Modified: 5/13/20 9:36 AM by ben

EXPORT CSV FILTER TABLE

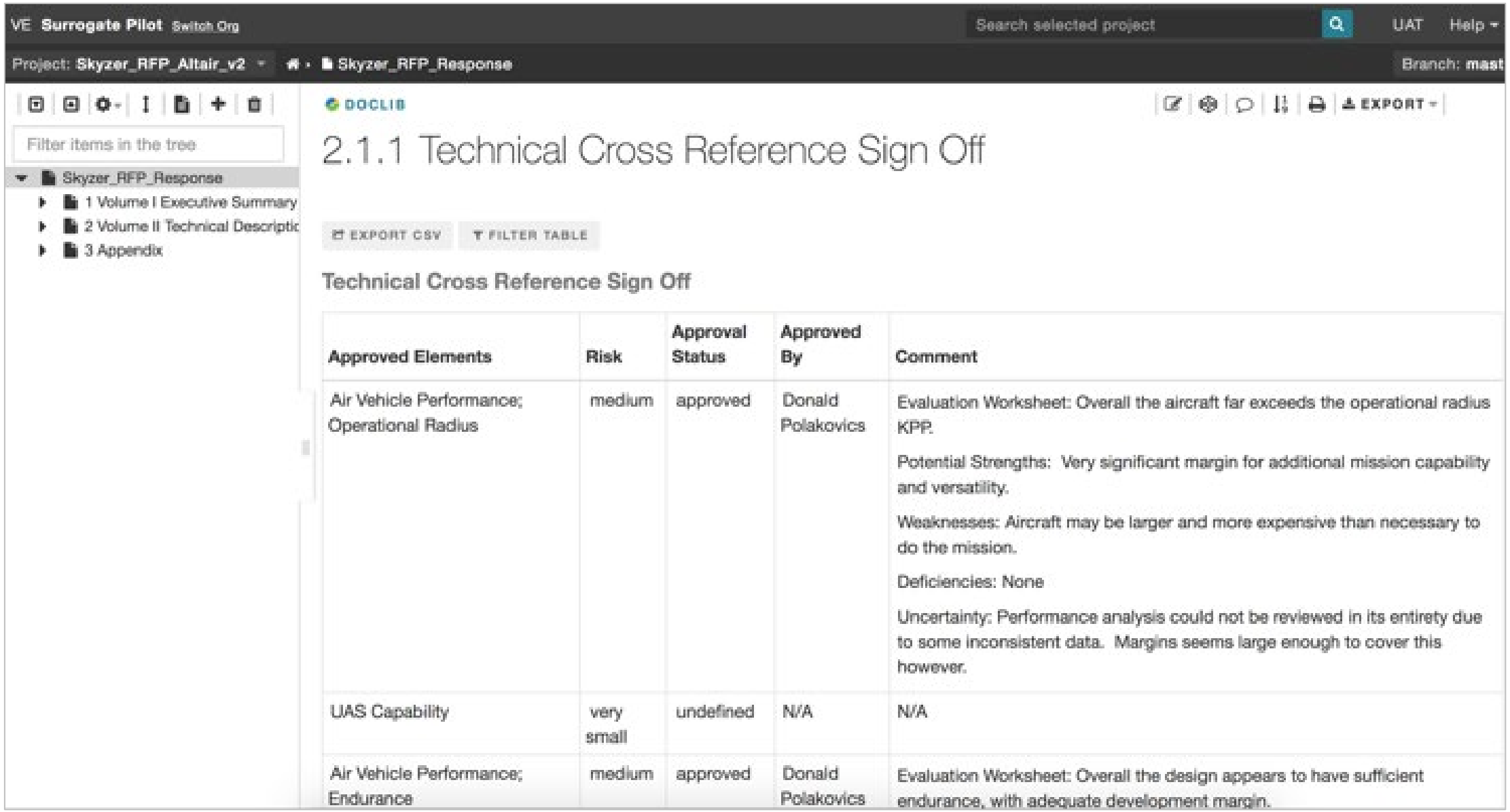
Table 176. System Failure Analysis Signoff

Approved Elements	Approval Status	Approved By	Completeness	Probability	Impact	Com
3.9 Fault Tree Analysis	Value : rejected ADD	Adam Baker	Value : 75 ADD	Value : 25 ADD	Value : 75 ADD	may need an extra basic event added

Fault Tree analysis is the Model Artifact being assessed for a potential hazard, and assessment of Completeness, Probability and Impact is captured with Approval Status for Digital Signoff by SME

Demo

DIGITAL SIGNOFF OF SOURCE SELECTION TECHNICAL EVALUATION DONE IN MODEL

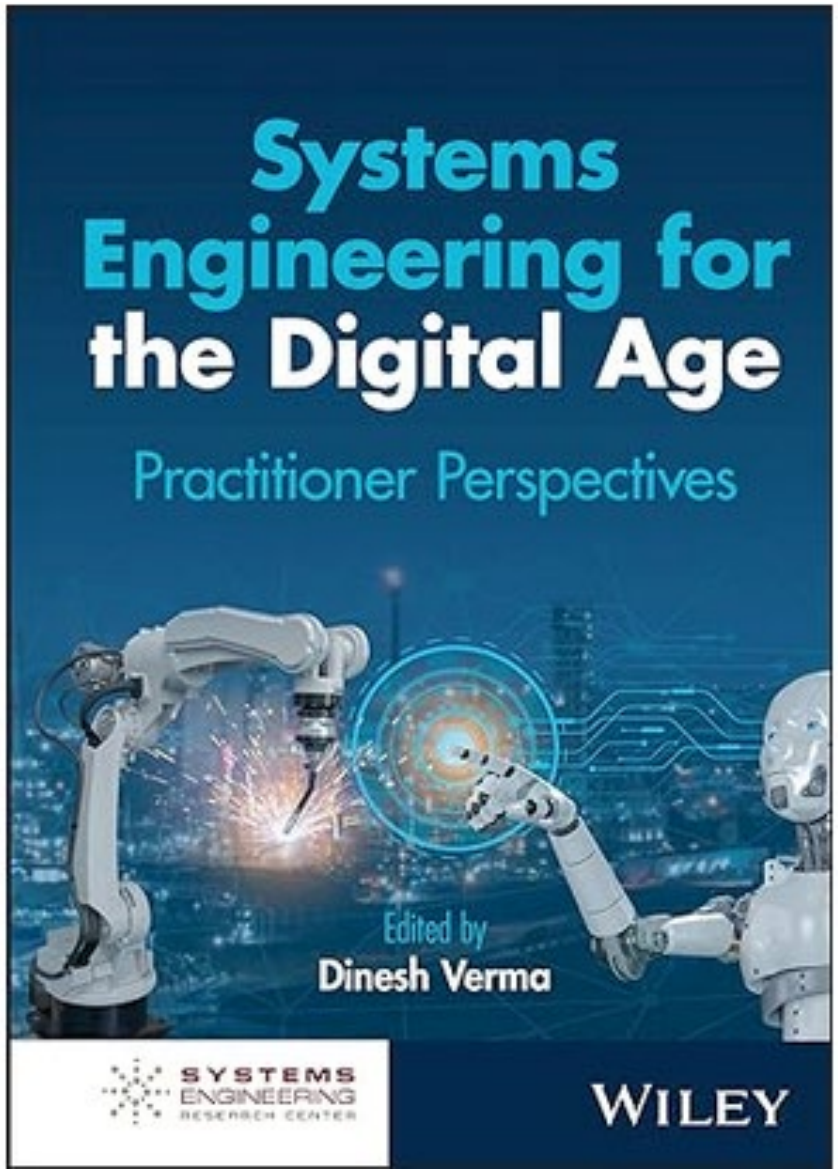


Approved Elements	Risk	Approval Status	Approved By	Comment
Air Vehicle Performance; Operational Radius	medium	approved	Donald Polakovics	Evaluation Worksheet: Overall the aircraft far exceeds the operational radius KPP. Potential Strengths: Very significant margin for additional mission capability and versatility. Weaknesses: Aircraft may be larger and more expensive than necessary to do the mission. Deficiencies: None Uncertainty: Performance analysis could not be reviewed in its entirety due to some inconsistent data. Margins seems large enough to cover this however.
UAS Capability	very small	undefined	N/A	N/A
Air Vehicle Performance; Endurance	medium	approved	Donald Polakovics	Evaluation Worksheet: Overall the design appears to have sufficient endurance, with adequate development margin.

Book Chapters Summarize Research

First four chapters reflect on research over the past 10 years

Provide guidelines related to topics covered in course modules



DIGITAL ENGINEERING USING COMPUTATIONAL ONTOLOGIES

Semantically Rich Interface Exchange to Authoritative Source

We formalized tradespace analysis methodology using SysML models, ontologies and semantic technologies with ***Armaments Interoperability and Integration Framework (IoIF)*** and workflows for US Army Armaments Center

Details discussed in NDIA talk: ***A Digital Engineering Methodology for Interoperability Using Ontologies***

Advanced Data Exploitation & Analysis

(AI, Data Analytics, Machine Learning, MDAO…)

RESEARCH TASKS AND COLLABORATOR NETWORK

RT-48 (2013)
- Mark Blackburn (PI), Stevens
- Rob Cloutier (Co-PI) - Stevens
- Eirik Hole - Stevens
- Gary Witus – Wayne State

RT-118 (2014)
- Mark Blackburn (PI), Stevens
- Rob Cloutier - Stevens
- Eirik Hole - Stevens
- Gary Witus – Wayne State

RT-141 (2015)
- Mark Blackburn (PI), Stevens
- Mary Bone - Stevens
- Gary Witus – Wayne State

RT-157 (2016)
- Mark Blackburn (PI), Stevens
- Mary Bone - Stevens
- Roger Blake - Stevens
- Mark Austin – Univ. Maryland
- Leonard Petnga – Univ. of Maryland

RT-170 (2016)
- Mark Blackburn (PI), Stevens
- Mary Bone - Stevens
- Deva Henry - Stevens
- Paul Grogan - Stevens
- Steven Hoffenson - Stevens
- Mark Austin – Univ. of Maryland
- Leonard Petnga – Univ. of Maryland
- Maria Coelho (Grad) – UMD
- Russell Peak – Georgia Tech.
- Stephen Edwards – Georgia Tech.
- Adam Baker (Grad) – Georgia Tech.
- Marlin Ballard (Grad) – Georgia Tech.

RT-168 – Phase I & II (2016)
- Mark Blackburn (PI), Stevens
- Dinesh Verma (Co-PI) – Stevens
- Ralph Giffin
- Roger Blake - Stevens
- Mary Bone – Stevens
- Andrew Dawson – Stevens (Phase I)
- Rick Dove
- John Dzielski, Stevens
- Paul Grogan - Stevens
- Deva Henry – Stevens (Phase I)
- Bob Hathaway - Stevens
- Steven Hoffenson - Stevens
- Eirik Hole - Stevens
- Roger Jones – Stevens
- Benjamine Kruse - Stevens
- Jeff McDonald – Stevens (Phase I)
- Kishore Pochiraju – Stevens
- Chris Snyder - Stevens
- Gregg Vesonder – Stevens (Phase I)
- Lu Xiao – Stevens (Phase I)
- Brian Chell (Grad) – Stevens
- Luigi Ballarinni (Grad) – Stevens
- Harsh Kevadia (Grad) – Stevens
- Kunal Batra (Grad) – Stevens
- Khushali Dave (Grad) – Stevens
- Rob Cloutier – Visiting Professor
- Robin Dillon-Merrill – Georgetown
- Ian Grosse – UMass
- Tom Hagedorn – UMass
- Todd Richmond – USC
- Edgar Evangelista – USC

RT-195 (2018)
- Mark Blackburn (PI), Stevens
- Mary Bone - Stevens
- Ralph Giffin - Stevens
- Benjamin Kruse - Stevens
- Russell Peak – Georgia Tech.
- Stephen Edwards – Georgia Tech.
- Adam Baker (Grad) – Georgia Tech.
- Marlin Ballard (Grad) – Georgia Tech.
- Donna Rhodes - MIT
- Mark Austin – Univ. Maryland
- Maria Coelho (Grad) – Univ. Maryland

WRT-1008 (2019)
- Mark Blackburn (PI), Stevens
- Mary Bone - Stevens
- John Dzielski- Stevens
- Benjamin Kruse - Stevens
- Bill Rouse – Stevens/Georgetown
- Russell Peak – Georgia Tech.
- Selcuk Cimtalay – Georgia Tech.
- Adam Baker (Grad) – Georgia Tech.
- Marlin Ballard (Grad) – Georgia Tech.
- Alanna Carnevale (Grad) – Georgia Tech.
- William Stock (Grad) – Georgia Tech.
- Michael Szostak (Grad) – Georgia Tech.
- Donna Rhodes - MIT
- Mark Austin – Univ. Maryland
- Maria Coelho (Grad) – Univ. Maryland

WRT-1025 (2020)
- Mark Blackburn (PI), Stevens
- Mark Austin (Co-PI) – Univ. Maryland
- Maria Coelho (Grad) – Univ. Maryland

ART-002 (2018) – ART-022 (2021/23)
- Mark Blackburn (PI), Stevens
- Dinesh Verma (Co-PI) – Stevens
- Kunal Batra – Stevens
- Mary Bone - Stevens
- John Dzielski, Stevens
- Steven Hoffenson - Stevens
- Steve Hespelt – Stevens
- Tom Hagedorn – Stevens
- Roger Jones – Stevens
- Philip Odonkor – Stevens
- Annie Yu – Stevens
- Benjamin Kruse – Stevens/VT
- Chris Snyder - Stevens
- Brian Chell – Stevens
- Chuck Colllard– Stevens
- Daniel Dunbar (PhD) – Stevens
- Josh Maccoby (PhD) – Stevens
- Renee Blatchley (PhD) – Stevens
- Maximillian Vierlboeck (PhD) - Stevens
- Andrew Underwood (Ungrad) – Stevens
- Benjamin Steinwurtzel (Ungrad)
- Ariela Litvin (Ungrad)
- Aughdon Breslin (Ungrad)
- Joshua Bernstein (Ungrad)
- Cory Phillipe (Grad) - Stevens
- Ian Grosse – Univ. of Massachucetts
- Doug Eddy – Univ. of Massachucetts
- Joe Gabbard – Virginia Tech
- Kyle Tanous– Virginia Tech
- Jared Van Dam (PhD) – Virginia Tech
- Kelsey Quinn (PhD) – Virginia Tech

WRT-1036 (2020)
- Mark Blackburn (PI), Stevens
- John Dzielski- Stevens
- Russell Peak – Georgia Tech.
- Selcuk Cimtalay – Georgia Tech.
- Taylor Fields – Georgia Tech.
- William Stock (Grad) – Georgia Tech.
- Sahil Panchal – Georgia Tech
- Jake Sisavath – Georgia Tech
- Gabriel Rizzo – Georgia Tech

WRT-1054 (2022)
- Mark Blackburn (PI), Stevens
- John Dzielski- Stevens
- Tom Hagedorn – Stevens
- Steve Hespelt – Stevens
- Chuck Collard– Stevens
- Daniel Dunbar (PhD) – Stevens
- Kevin Morrill)– Stevens
- Russell Peak – Georgia Tech.
- Selcuk Cimtalay – Georgia Tech.
- Taylor Fields – Georgia Tech.
- Adam Baker – Georgia Tech.
- Avik Banerjee – Georgia Tech.
- Vanessa J. Nuhn – Georgia Tech.
- Cole A. Sherling – Georgia Tech.

WRT-1084 (2023)
- Mark Blackburn (PI), Stevens
- Tom Hagedorn – Stevens
- Steve Hespelt – Stevens
- Chuck Collard– Stevens
- Daniel Dunbar – Stevens
- Steve Jenkins – Stevens

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SERC/AIRC University Network

AFIT Air Force Institute of Technology

Carnegie Mellon University

NPS Naval Postgraduate School

The George Washington University Washington, DC

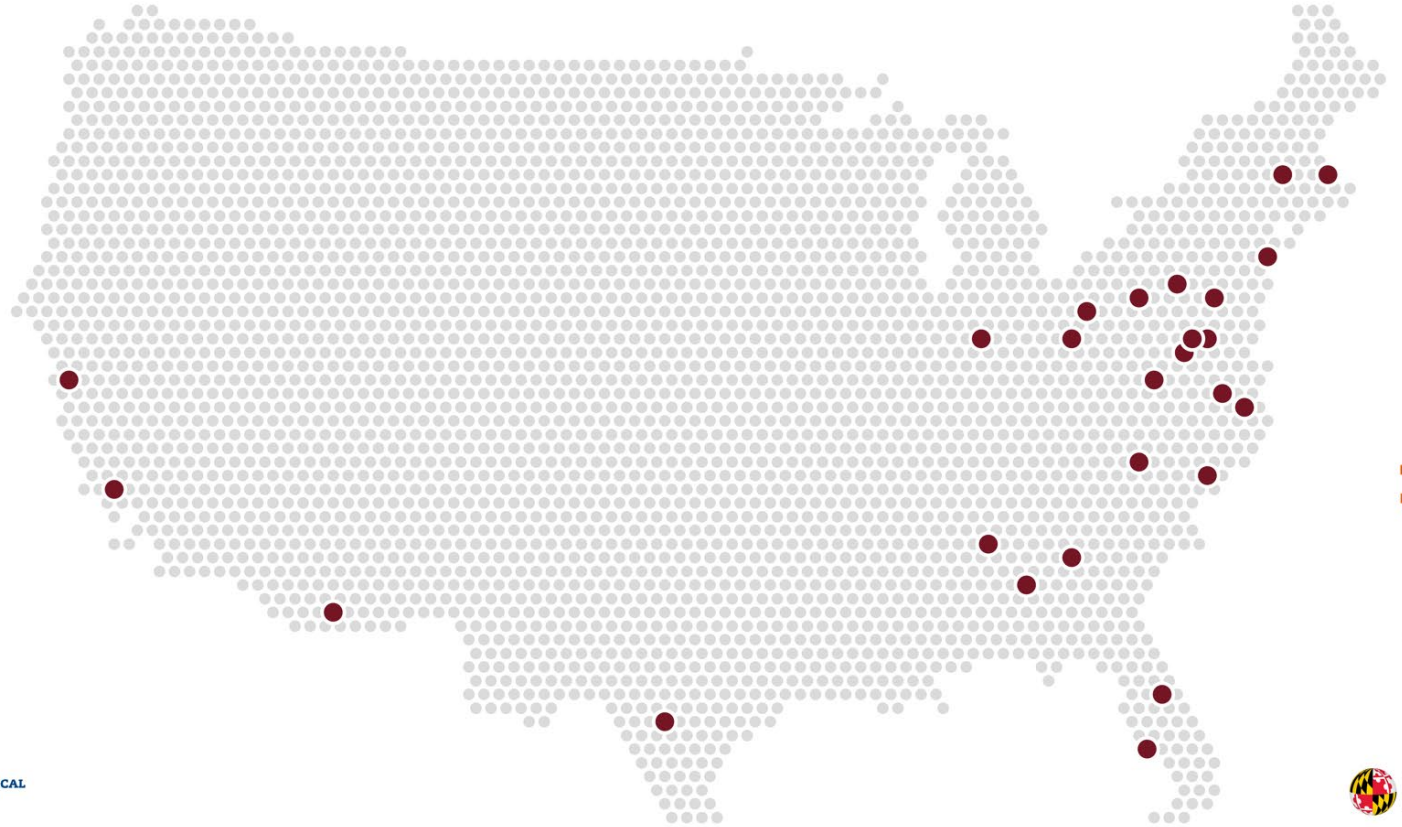
Georgetown University

Stevens Institute of Technology

PennState

The University of Arizona

University of Massachusetts Amherst



Massachusetts Institute of Technology

Old Dominion University

University of Virginia

USC

Virginia Tech

Purdue University

Auburn University

Georgia Tech

George Mason University

North Carolina Agricultural and Technical State University

University of Maryland

The Ohio State University

Texas A&M University

The University of Alabama in Huntsville

NC State University

UCF

University of South Florida

QUESTIONS AND DISCUSSION

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