Stevens Institute of Technology
&
Systems Engineering Research Center (SERC)

Systems Engineering Transformation Surrogate Pilot Experiments: Doing Everything in Models to Demonstrate the Art-of-the-Possible with Digital Signoffs

Research Collaborators:

Stevens Institute of Technology
Georgia Institute of Technology
Georgetown University
Massachusetts Institute of Technology
University of Maryland
University of Massachusetts

Sponsor: NAVAIR and CCDC-AC

SYSTEMS ENGINEERING
Research Center

Copyright and Disclaimer

SYSTEMS ENGINEERING
Research Center

Research Tasks and Collaborator Network

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

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

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

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

RT-170
- 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) – Univ. of Maryland
- Russell Peak – Georgia Tech.
- Stephen Edwards – Georgia Tech.
- Adam Baker (Grad) – Georgia Tech.
- Marlin Ballard (Grad) – Georgia Tech.

RT-168 – Phase I & II
- 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 Univ.
- Ian Grosse – Univ. of Massachucetts
- Tom Hagedorn – Univ. of Massachusetts
- Todd Richmond – Univ. of Southern California (Phase I)
- Edgar Evangelista – Univ. of Southern California (Phase I)

RT-195
- 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
- Mark Blackburn (PI), Stevens
- Mary Bone - 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.
- Gabe Rizzo (under Grad) – Georgia Tech.
- Donna Rhodes - MIT
- Mark Austin – Univ. Maryland
- Maria Coelho (Grad) – Univ. Maryland

ART-002
- Mark Blackburn (PI), Stevens
- Dinesh Verma (Co-PI) – Stevens
- Kunal Batra – Stevens
- Mary Bone - Stevens
- John Dzielski, Stevens
- Steven Hoffenson - Stevens
- Steve Hespelt - Stevens
- Roger Jones - Stevens
- Benjamin Kruse - Stevens
- Chris Snyder - Stevens
- Brian Chell (Grad) – Univ. Maryland
- Ian Grosse – Univ. of Massachucetts
- Tom Hagedorn – Univ. of Massachusetts

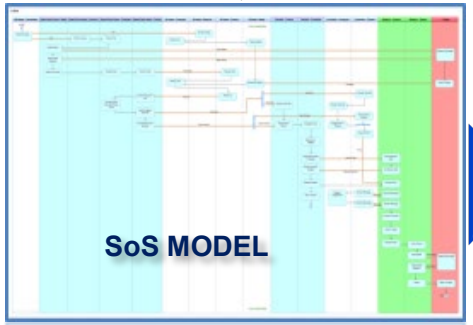
Outline

- Context on NAVAIR Systems Engineering Transformation
- Overview of using Digital Signoffs as a new type of Digital Engineering Competency
- Use Skyzer UAV for Search and Rescue Mission for use case
- Mechanics for using Digital Signoff in View Editor web browser
- How Digital Signoff created in a descriptive model (e.g., SysML)
- Measure and metrics using Digital Signoffs
- Example Digital Signoffs used in Video

Capability Based Acquisition - Outpacing the Threat
Digital Thread enables rapid delivery of Integrated Capabilities

Integration and Interoperability (I&I)

Integrated Warfare Analysis establishes CONEMPS and Effects-Chains

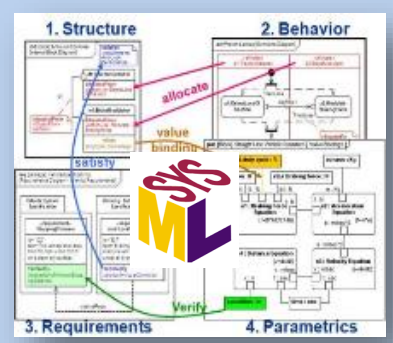


CONEMPS and Effects Chains are modeled at the System of Systems (SoS) level

System models form "Constructive" basis for LVC M&S environment

SE TRANSFORMATION

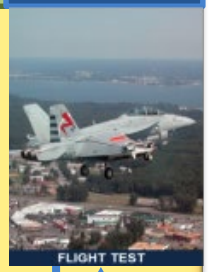
SYSTEM MODELS



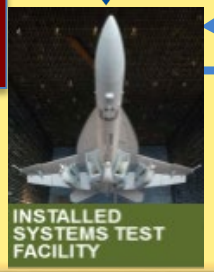
Systems are developed in a Model-Based environment

Capabilities-Based T&E

Constructive | Virtual | Live



Focus is Here

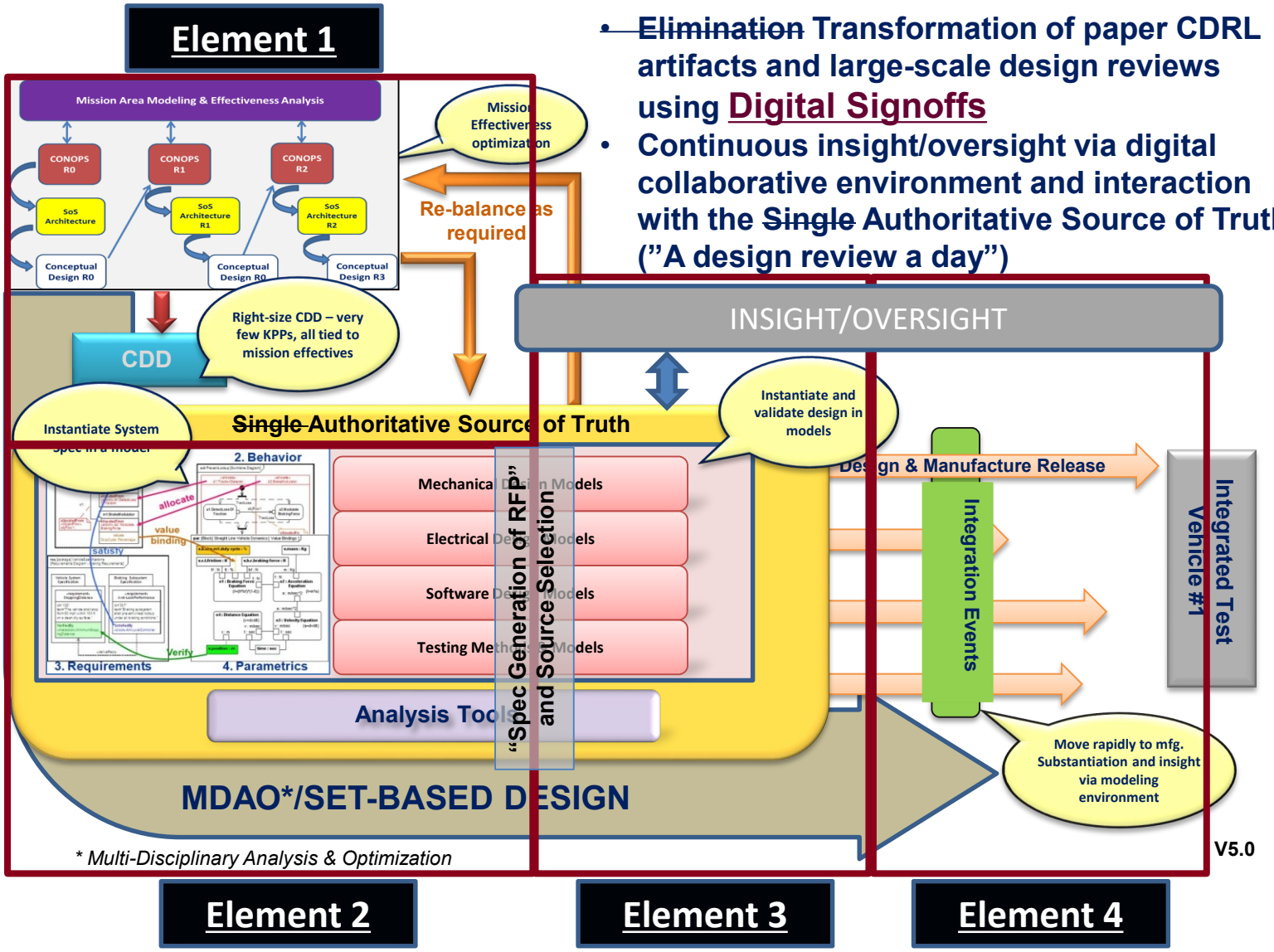


LVC-based Training
maximizes Fleet proficiency

Surrogate Pilot focused is on Characterizing Assessing, and Refining SET Framework for Model-Based Acquisition

SET Framework Concept Initially Rolled Out 2016 (D. Cohen)

- ~~Elimination~~ Transformation of paper CDRL artifacts and large-scale design reviews using Digital Signoffs
- Continuous insight/oversight via digital collaborative environment and interaction with the ~~Single~~ Authoritative Source of Truth ("A design review a day")



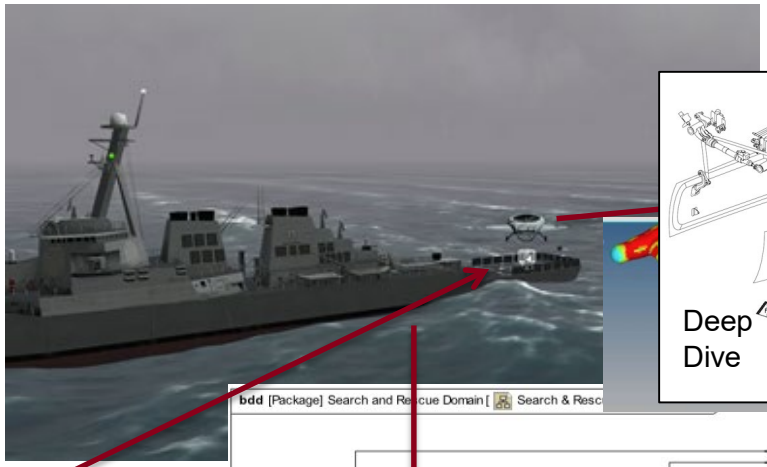
CDRL: Contract Data Requirements List

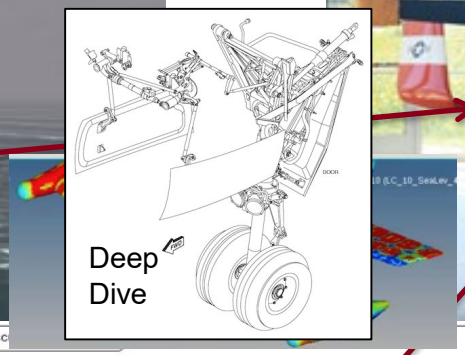
SYSTEMS ENGINEERING
Research Center

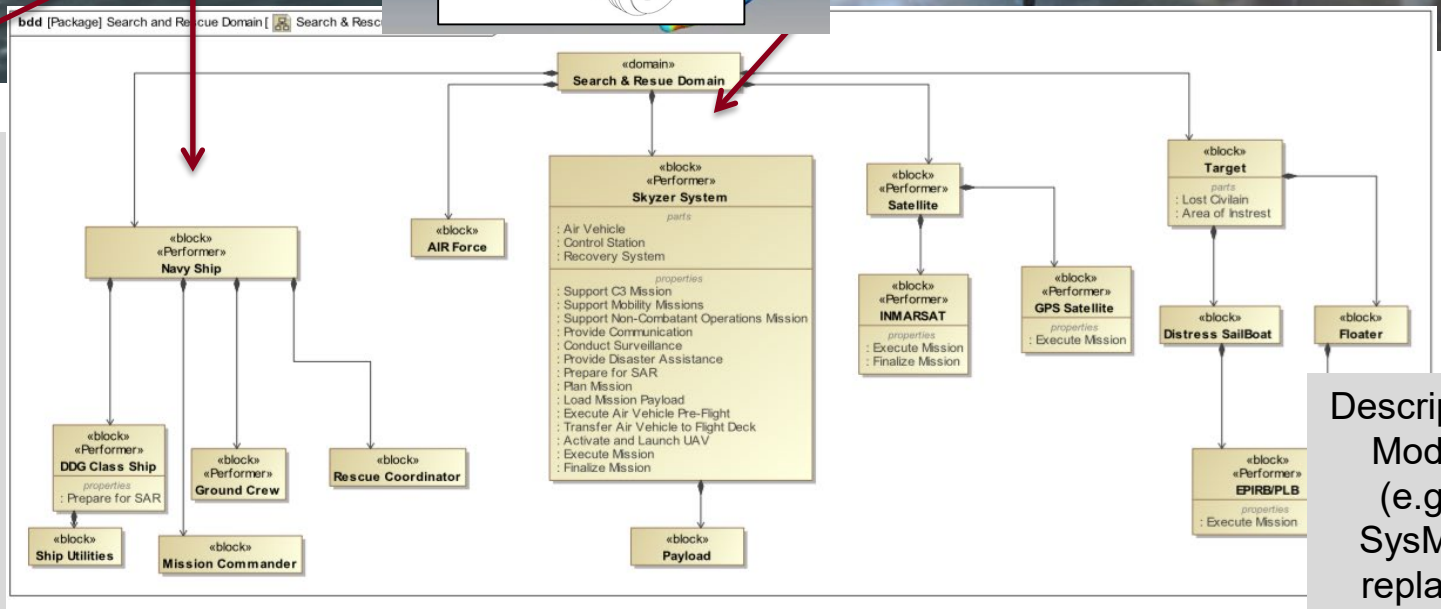
Surrogate Pilot Scenario: Skyzer UAS & Launch and Recovery for Landing Gear Deep Dive

Graphical CONOPS Scenario: Search & Rescue

Performance constraints force Multi-physics Design considerations - similar to Bell Eagle Eye







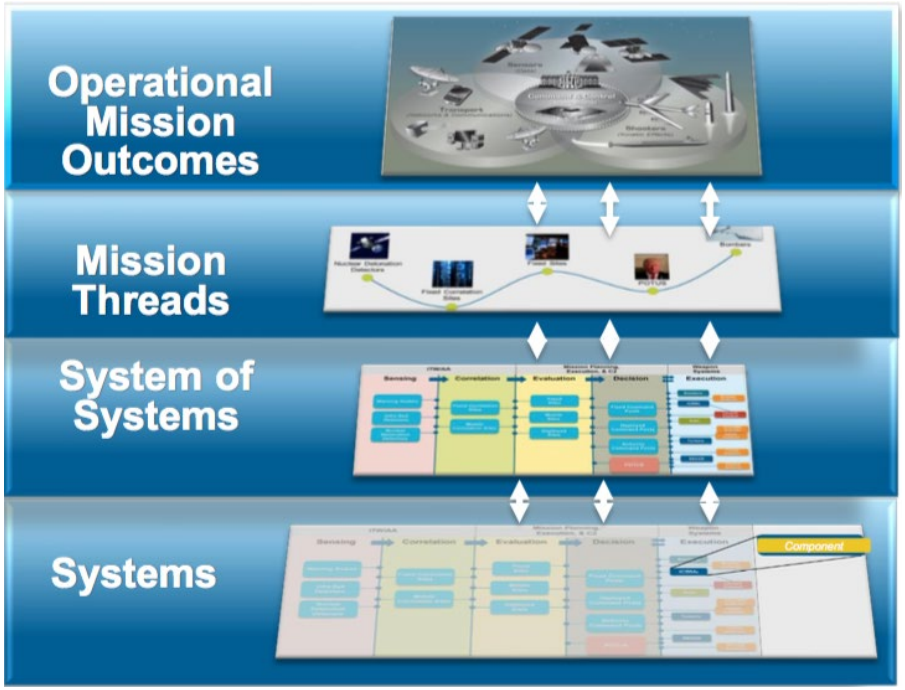
Phase II is adding ship-based Launch and Recovery (L&R) Capability & Deep Dive supports Airworthiness Use Case

Skyzer System & Mission Models developed using SysML

Descriptive Model (e.g., SysML) replace Documents

Context Related to DoD Digital Engineering Strategy Goals

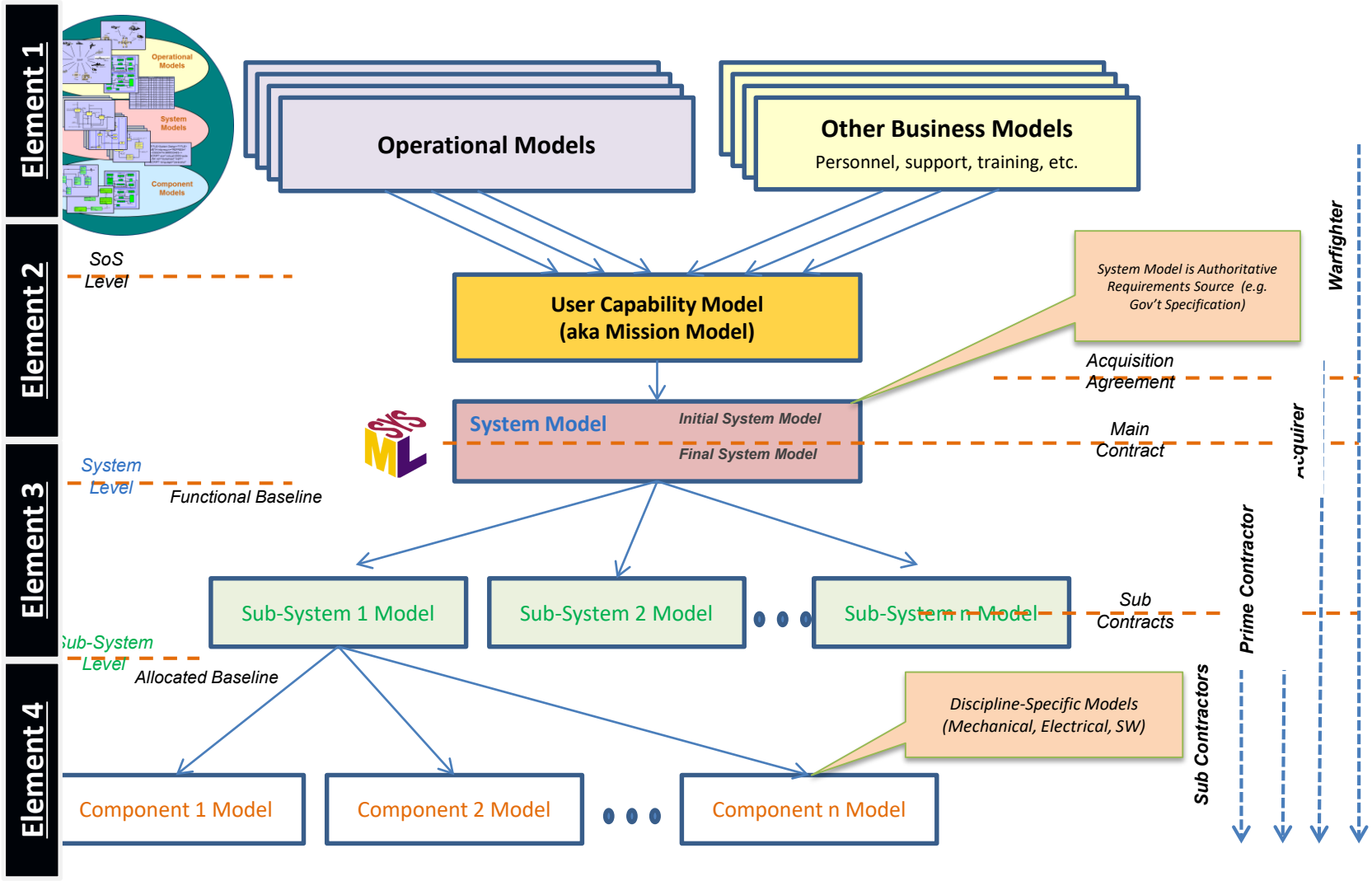
- MBSE Strengthens Systems Engineering (Goal 3)
  - Represent Structure, Behavior, Interfaces, Requirements and related interactions
  - Can characterize different levels of abstraction – Mission, System, Subsystem where different types of **methods** are needed
  - Can generate "documents/specifications" based on stakeholder-relevant views
- Need to formalize representation that links information in an Authoritative Source of Truth (Goal 2 – distributed like Internet)
- Need computing infrastructure to access and visualize on need-to-know basis (Goal 4)
- Need to semantically link information from different modeling levels and types to enable tradespace analyses and **decision making** (Goal 1)



Extending the DoD Digital Engineering Strategy to Missions, Systems of Systems, and Portfolios
P. Zimmerman, T. Gilbert, J. Dahmann
22nd Annual NDIA Systems and Mission Engineering Conference Tampa, FL| 23 October 2019

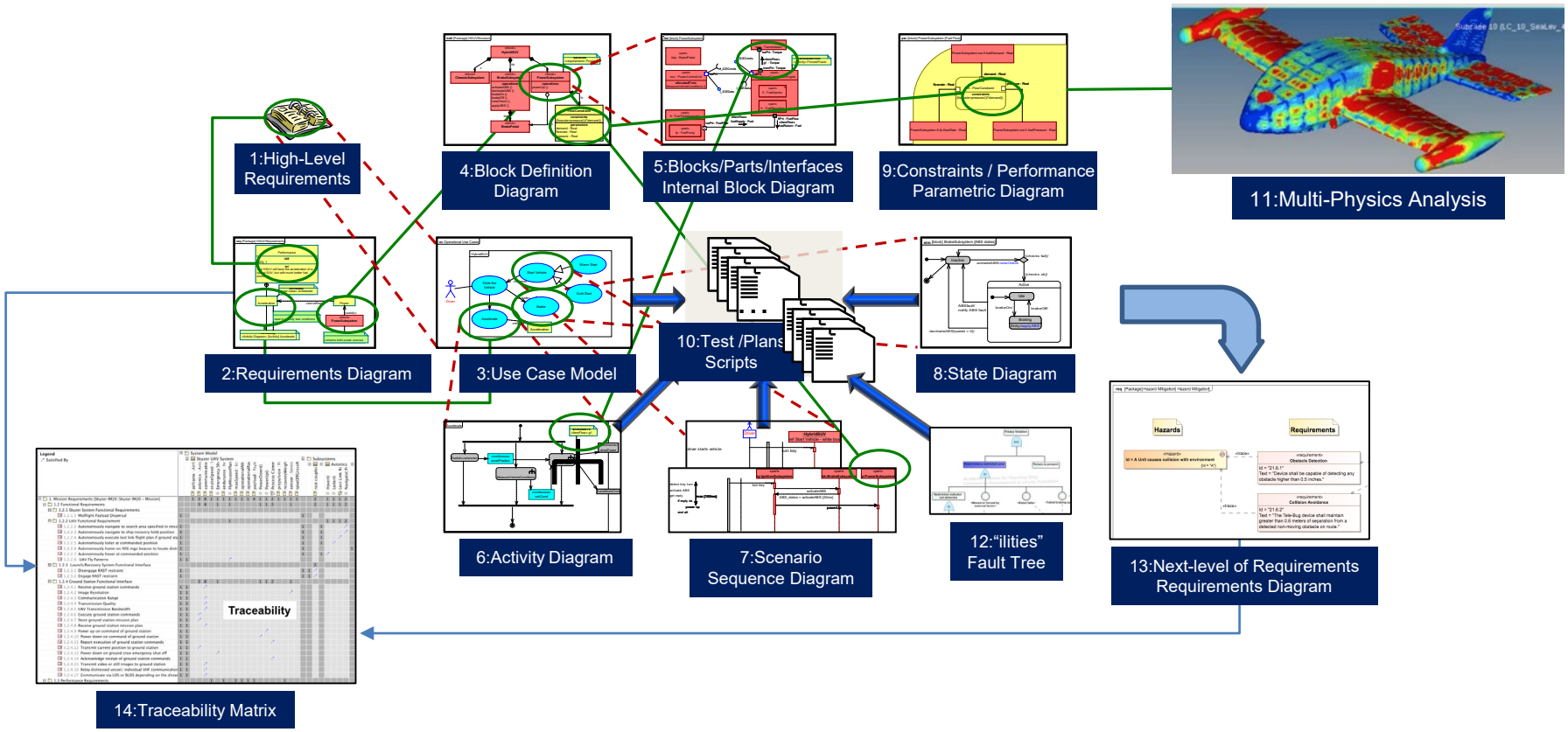
SYSTEMS ENGINEERING
Research Center

Skyzer Demonstrates Modeling Methods for SET Framework Elements at Different Abstraction Levels



SYSTEMS ENGINEERING
Research Center

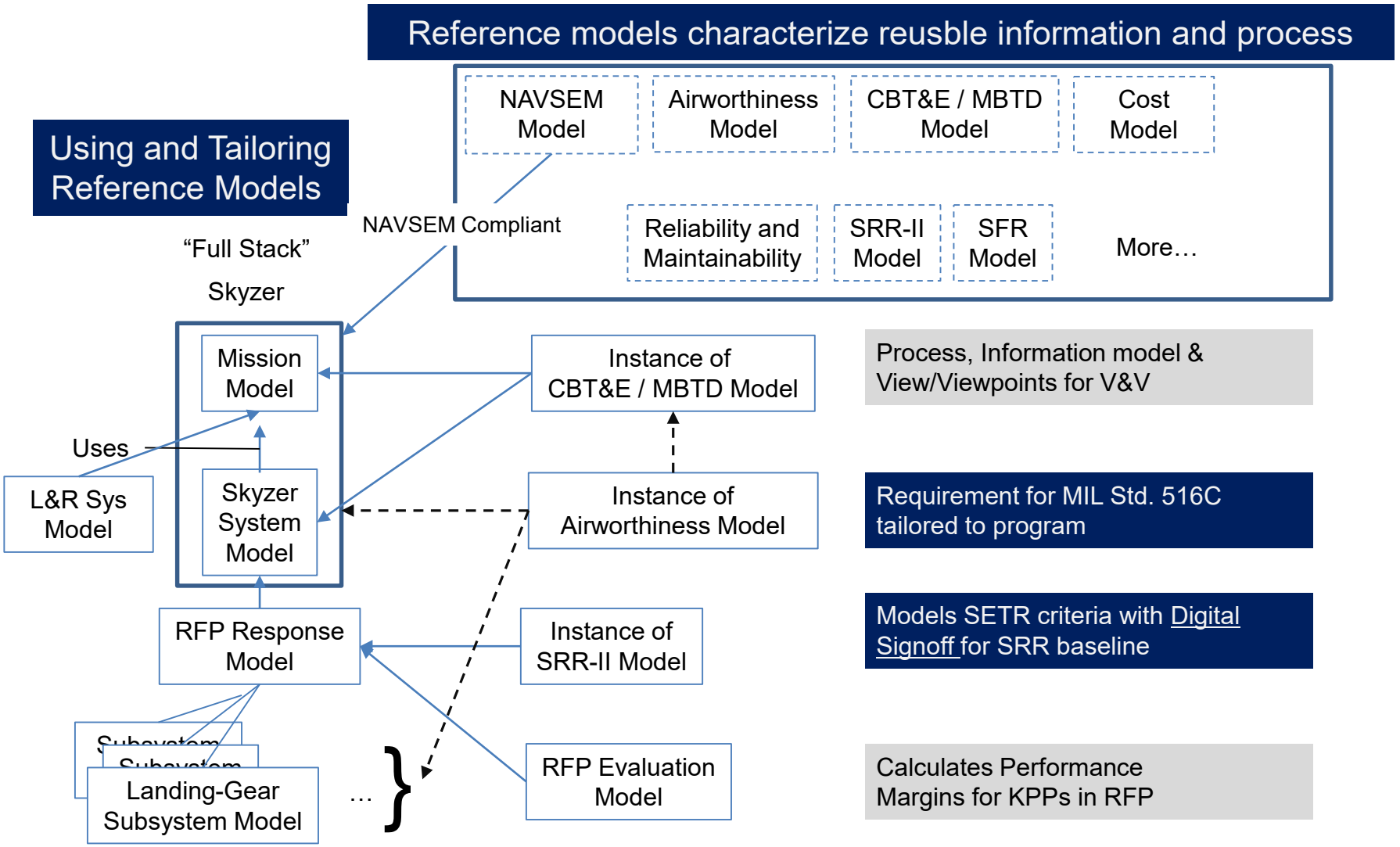
How MBSE Strengthens SE by Characterizing the Analysis of Structure, Behavior and Interfaces



MBSE Artifacts – More than just Requirements

SYSTEMS ENGINEERING
Research Center

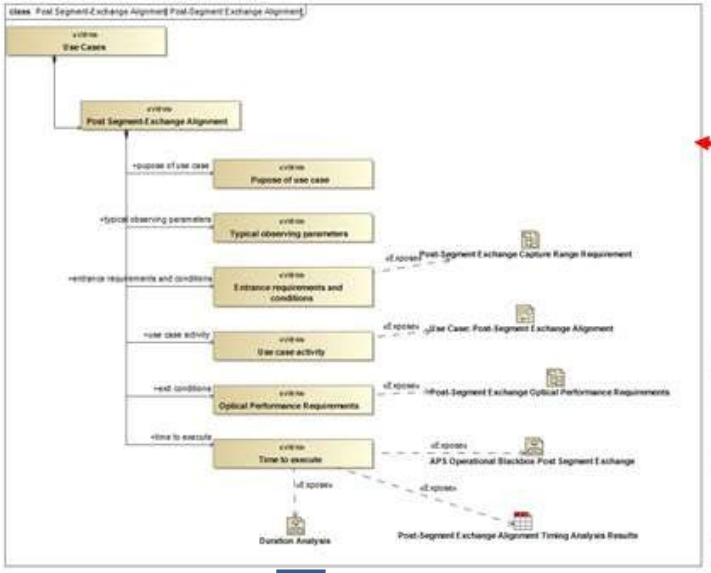
"Full Stack" of Models using Digital Signoff



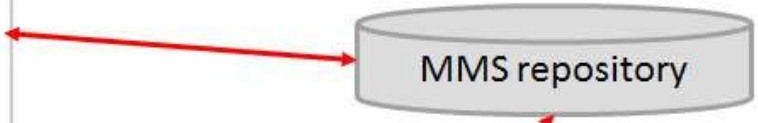
SYSTEMS ENGINEERING
Research Center

Digital Signoffs Leverage Capabilities of OpenMBEE

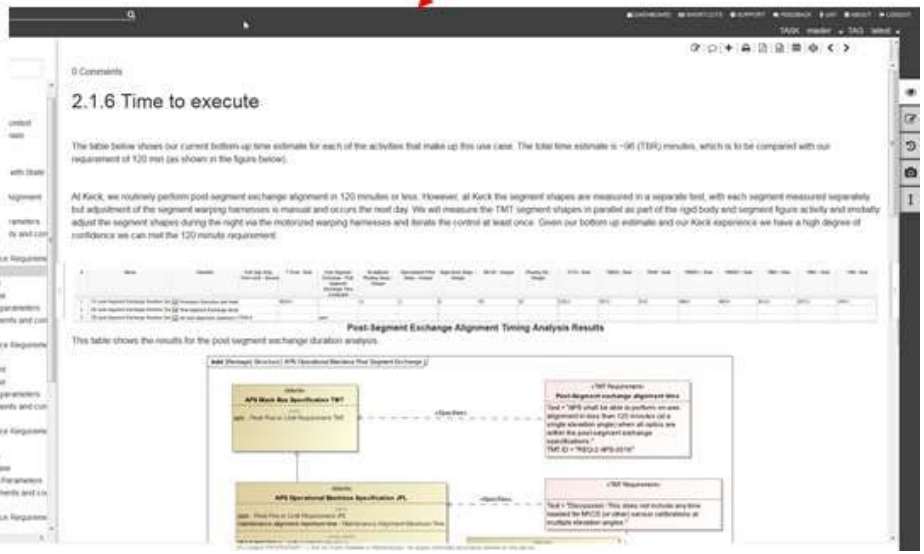
Model Development Kit/DocGen
View and Viewpoint Hierarchy



Model Management System



View Editor

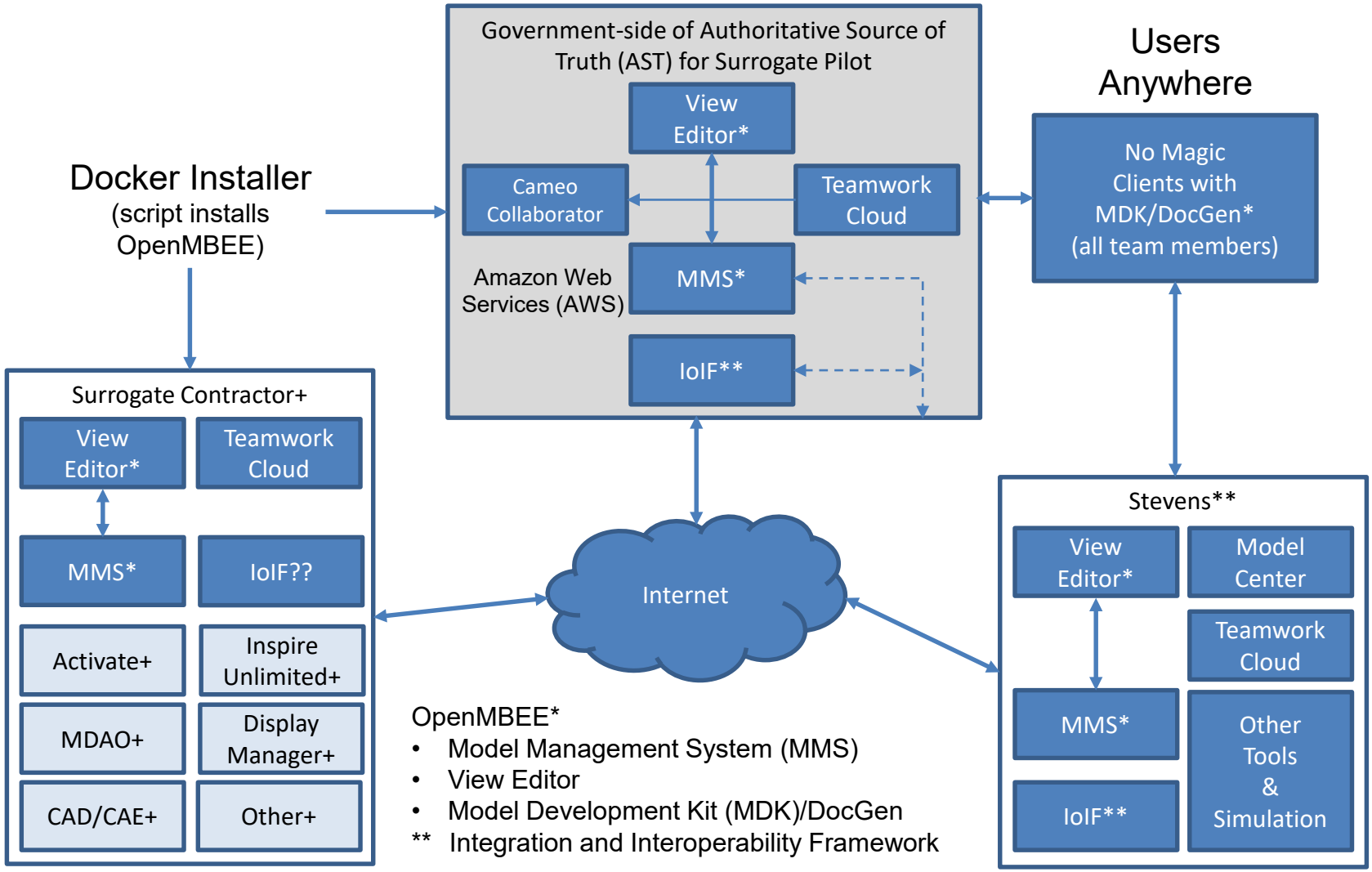


Visualization in View Editor
(allows edits to be pushed back into model)

NAVAIR Public Release 2017-370. Distribution Statement A – "Approved for public release; distribution is unlimited"

SYSTEMS ENGINEERING
Research Center

Enabling Elements of Authoritative Source of Truth



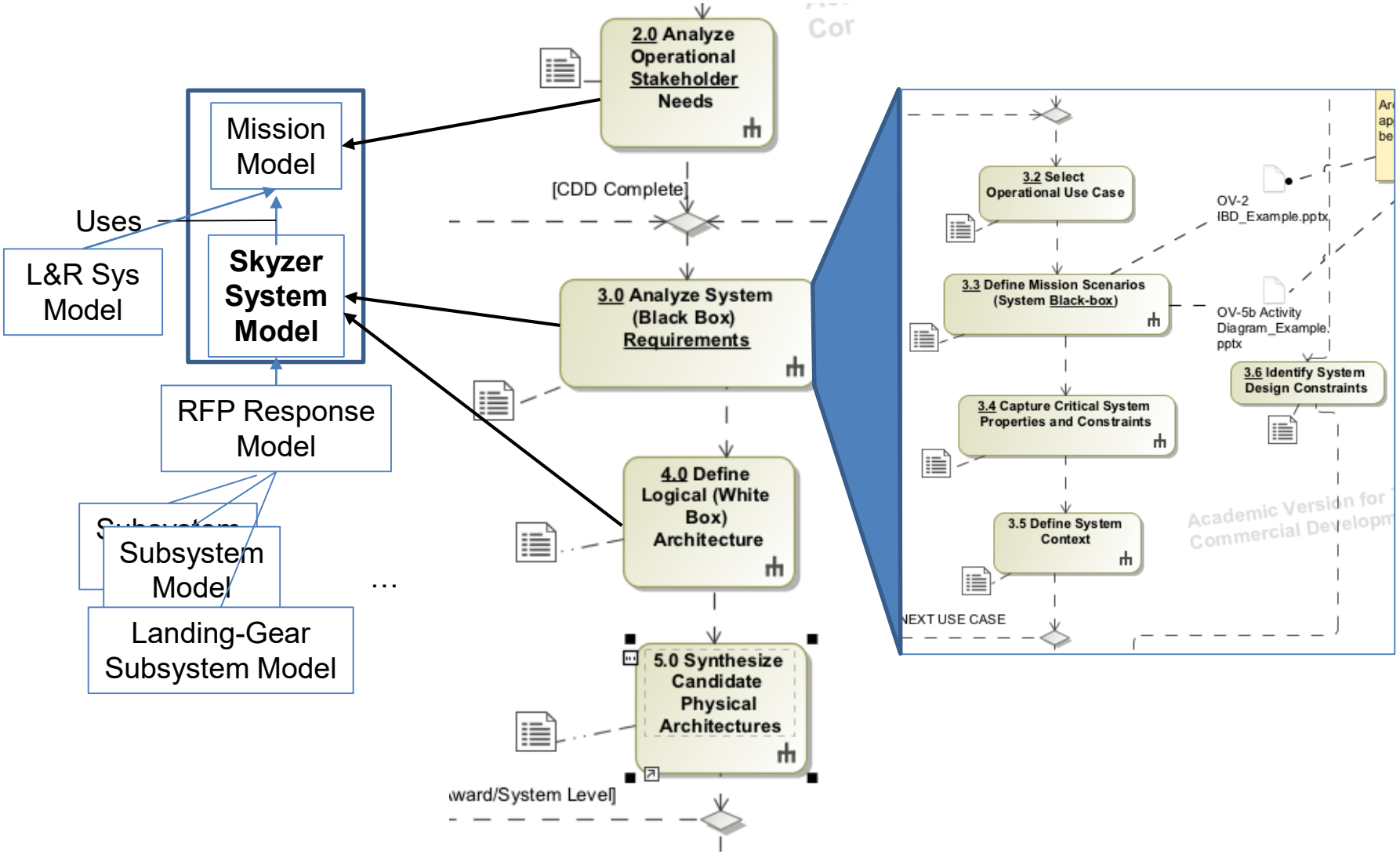
NAVAIR Public Release 2018-194. Distribution Statement A – "Approved for public release; distribution is unlimited"

Digital Signoff Uses and Scenarios

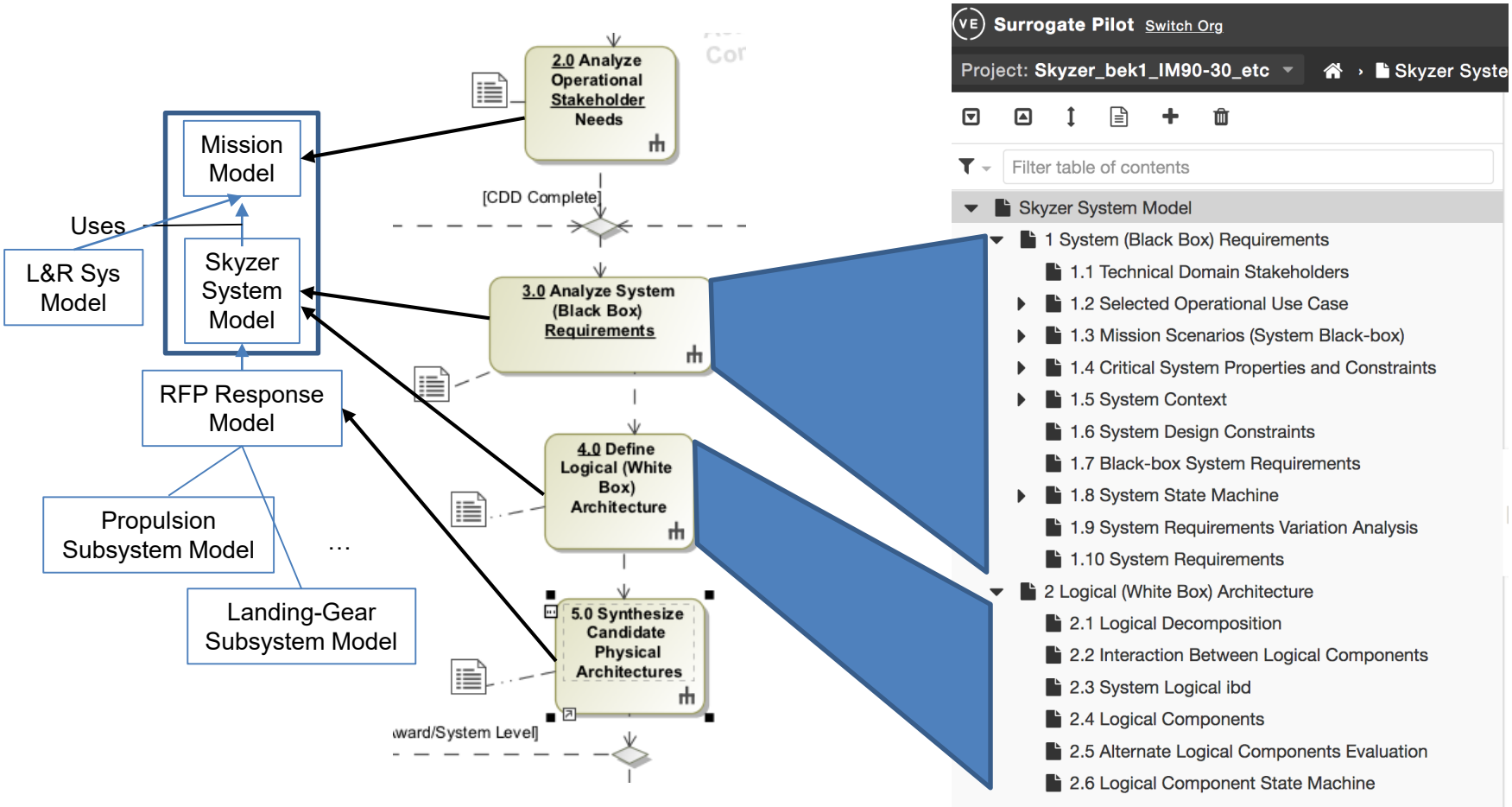
- Digital Signoffs provide a means to continuously and asynchronously approve the developed **model artifacts** that comply with recommend methods for MBSE
- Digital Signoffs provide a means to transform from traditional document-based reviews and signoff processes by locating signoff with **modeling artifacts** that satisfy analysis or design criteria
- Digital Signoffs can be approved by Subject Matter Experts (SME) directly in web-based browsers (e.g., View Editor) reducing the need for SME to have expertise in a model-authoring client (tool)
- Digital Signoffs are template-based allowing for tailoring such as having two approvals
- Digital Signoff measures & metrics can be collected automatically

SYSTEMS ENGINEERING
Research Center

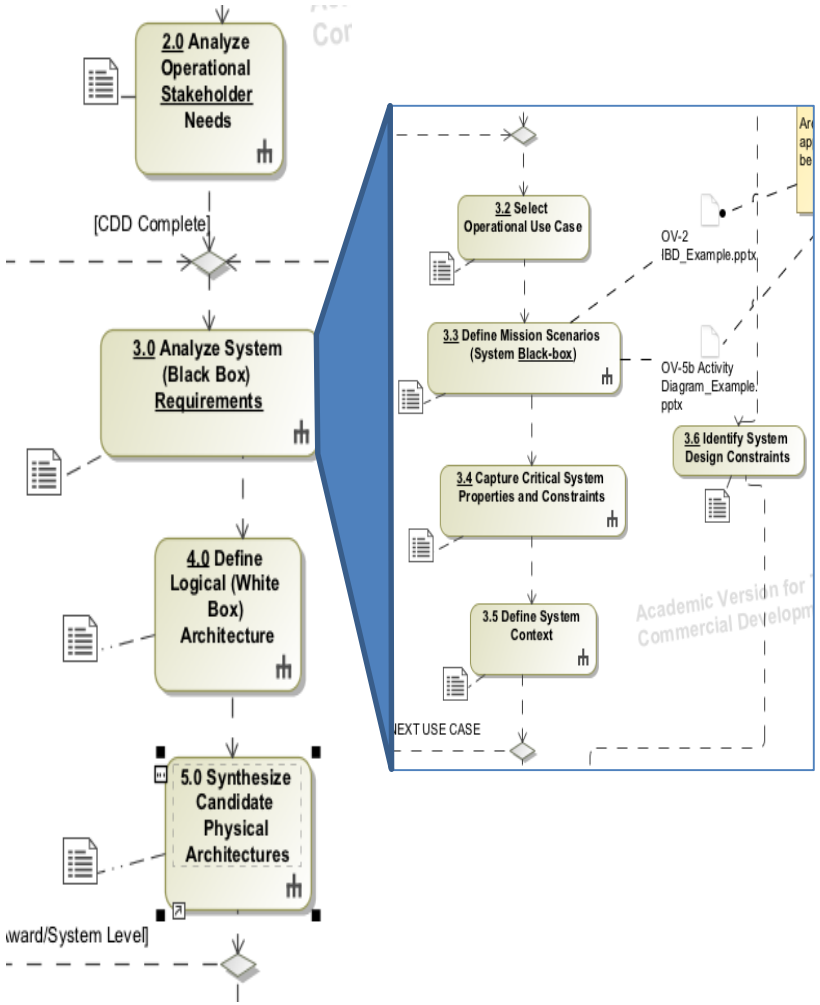
Models Methods Guide Production of Artifacts/Work Products for NAVSEM Method

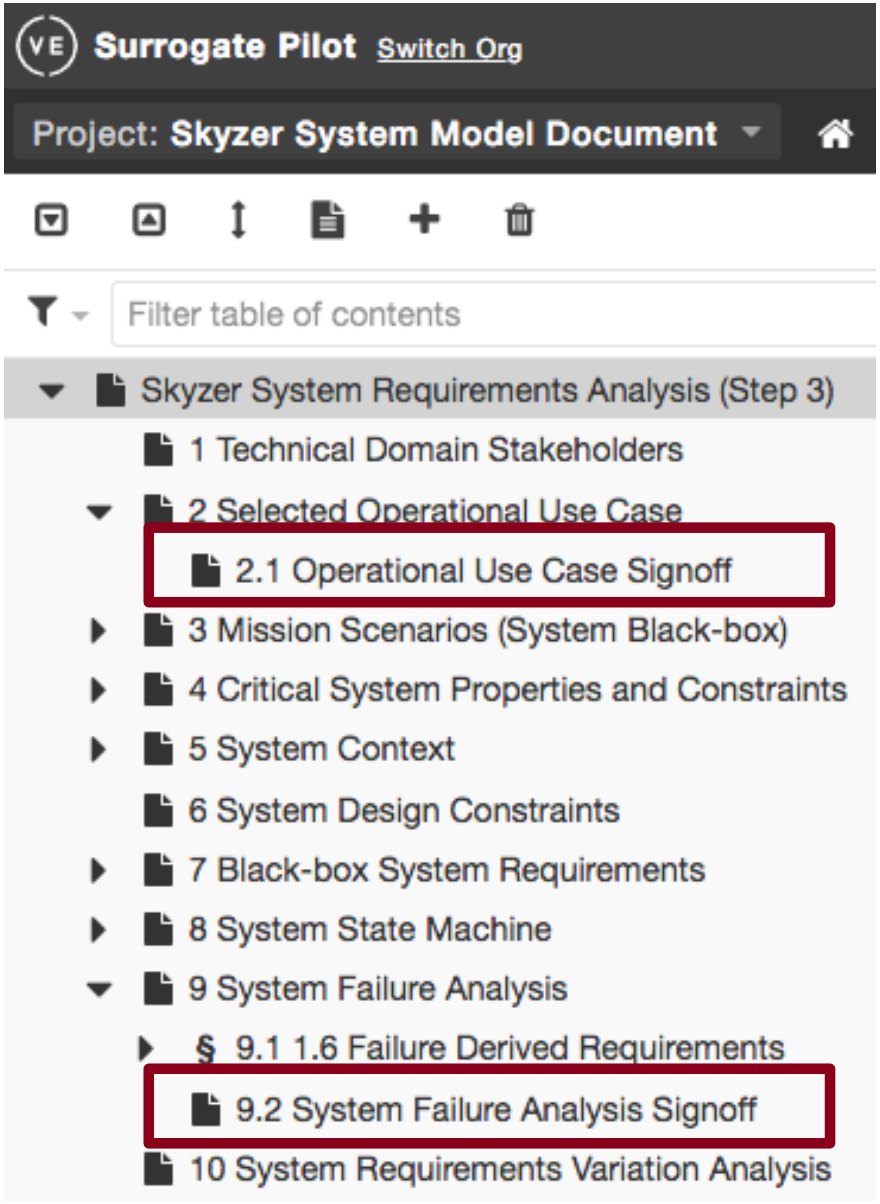


DocGen Generated View Hierarchy to Comply with NAVSEM System Model Step 3.0 and 4.0



DocGen Generated View for Skyzer System Model with Digital Signoffs

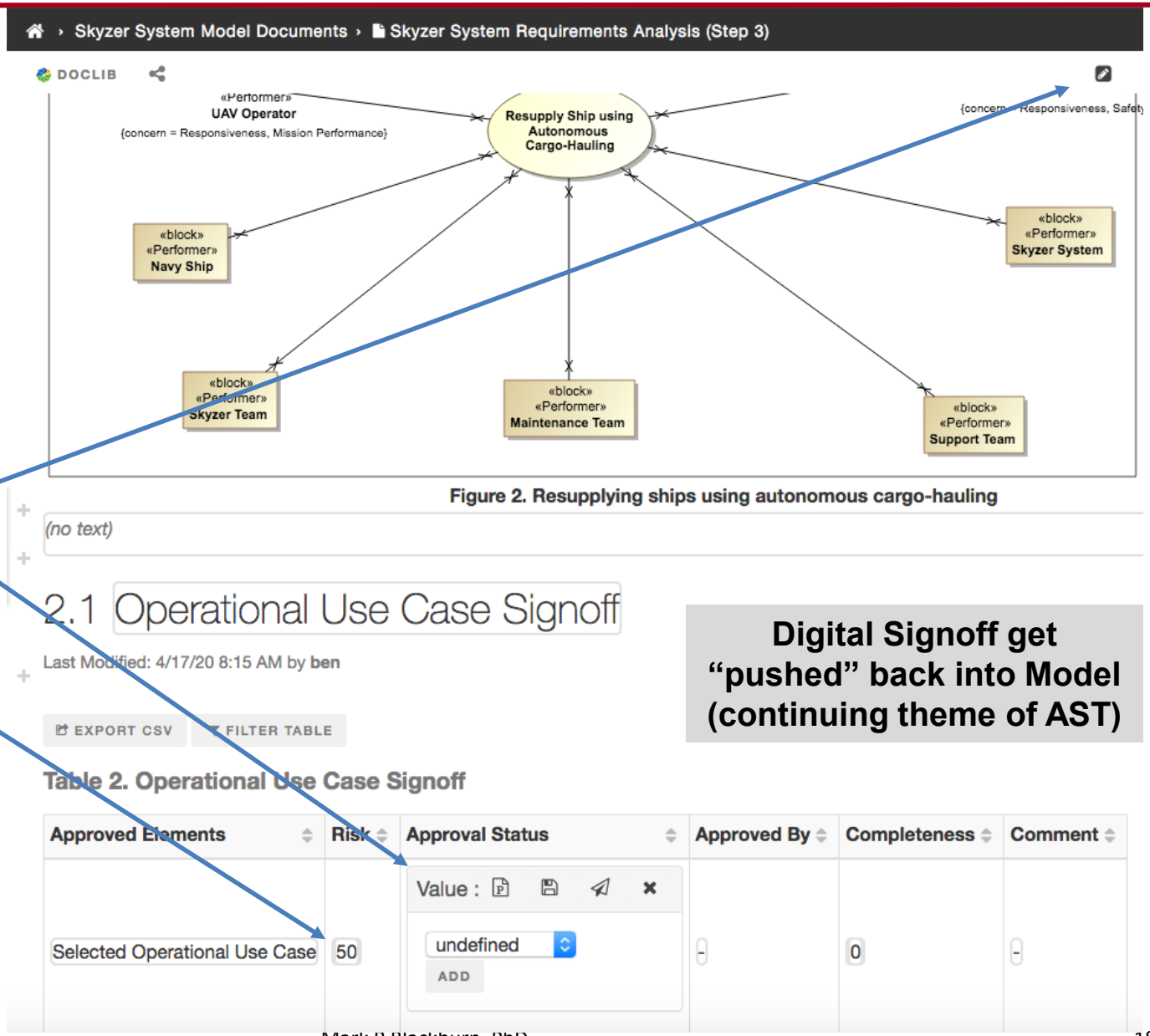




SYSTEMS ENGINEERING
Research Center

Digital Signoff for Operational Scenario Applicable to System

1) Enable Editing
2) Add Approval Status
3) Add Risk



Digital Signoff get "pushed" back into Model (continuing theme of AST)

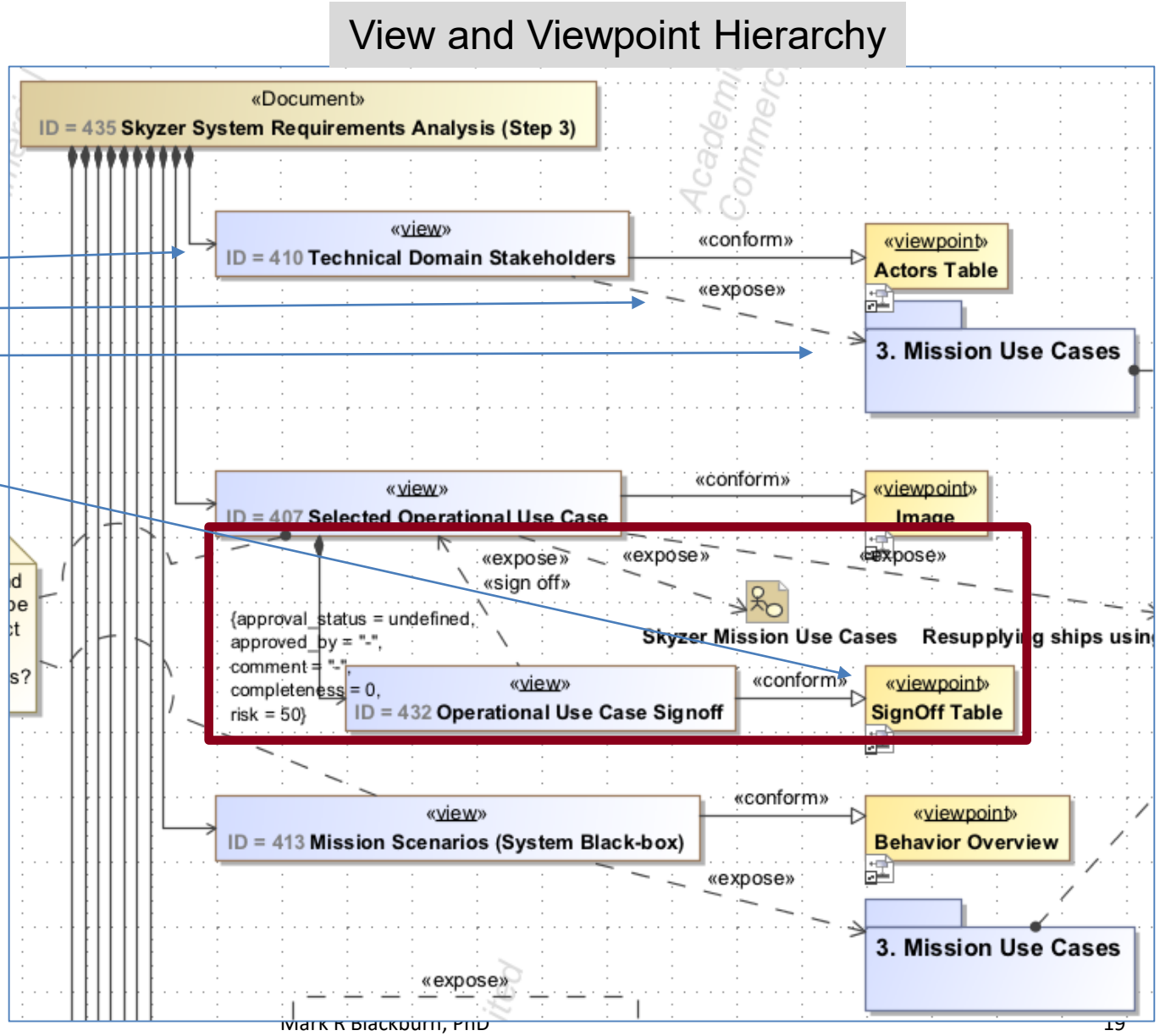
SYSTEMS ENGINEERING
Research Center

Digital Signoff Are Placed in View Hierarchy With Model Artifacts that Should be Exposed

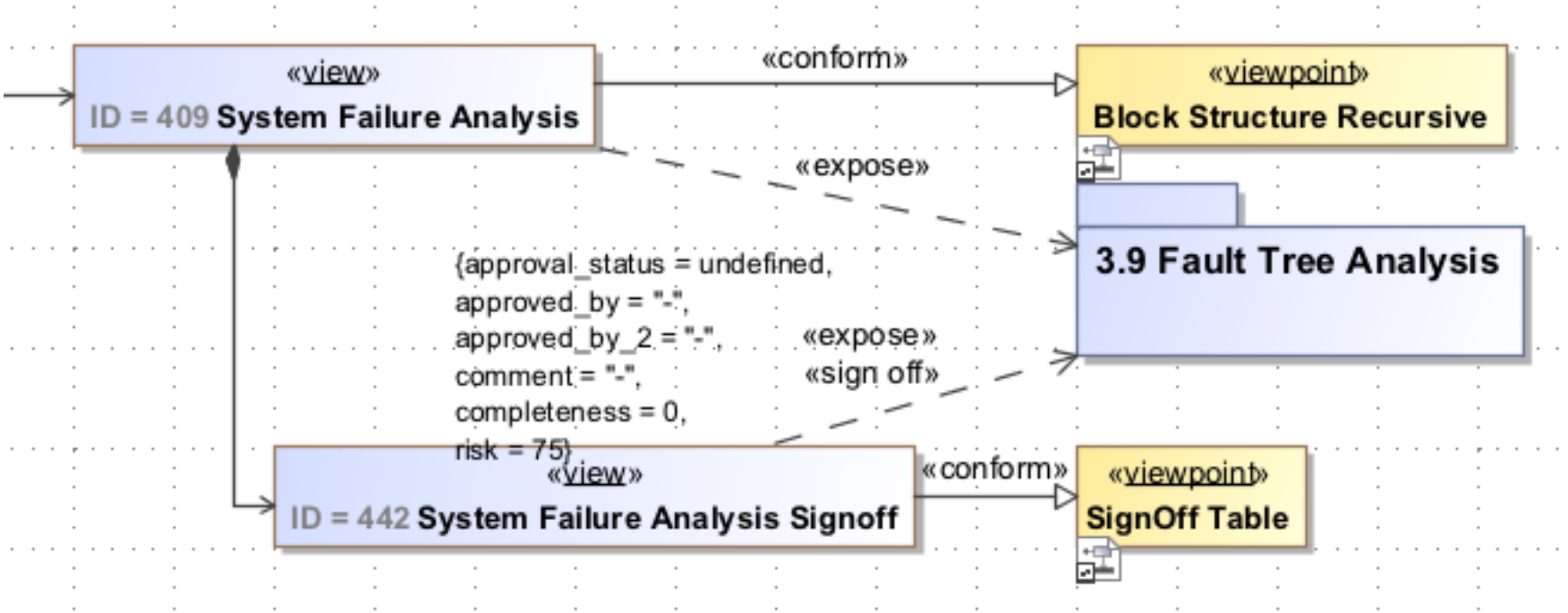
Views define "Document" Structure

View exposes Model Elements

Viewpoints is "program" to extracts specific information from exposed model element to generate View



Digital Signoff for Subject Matter Experts



Digital Signoff In View Editor for Subject Matter Experts

Risk Matrix						
Likelihood	Near Certainty	E				
	Highly Likely	D				
	Likely	C				
	Low Likelihood	B				
	Not Likely	A				
			1	2	3	4	5
			Very Low	Low	Moderate	High	Very High
			Consequence				

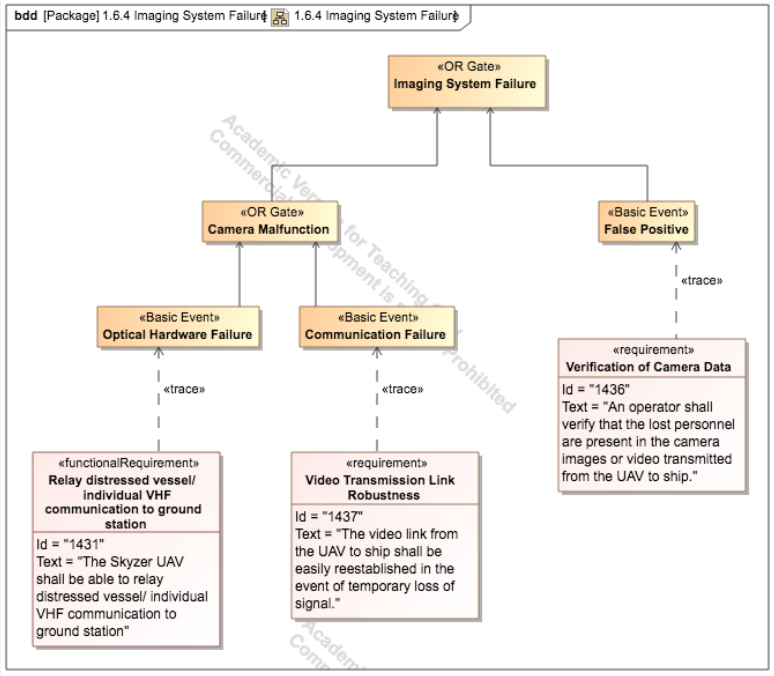


Figure 43. 1.6.4 Imaging System Failure

9.2 System Failure Analysis Signoff

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

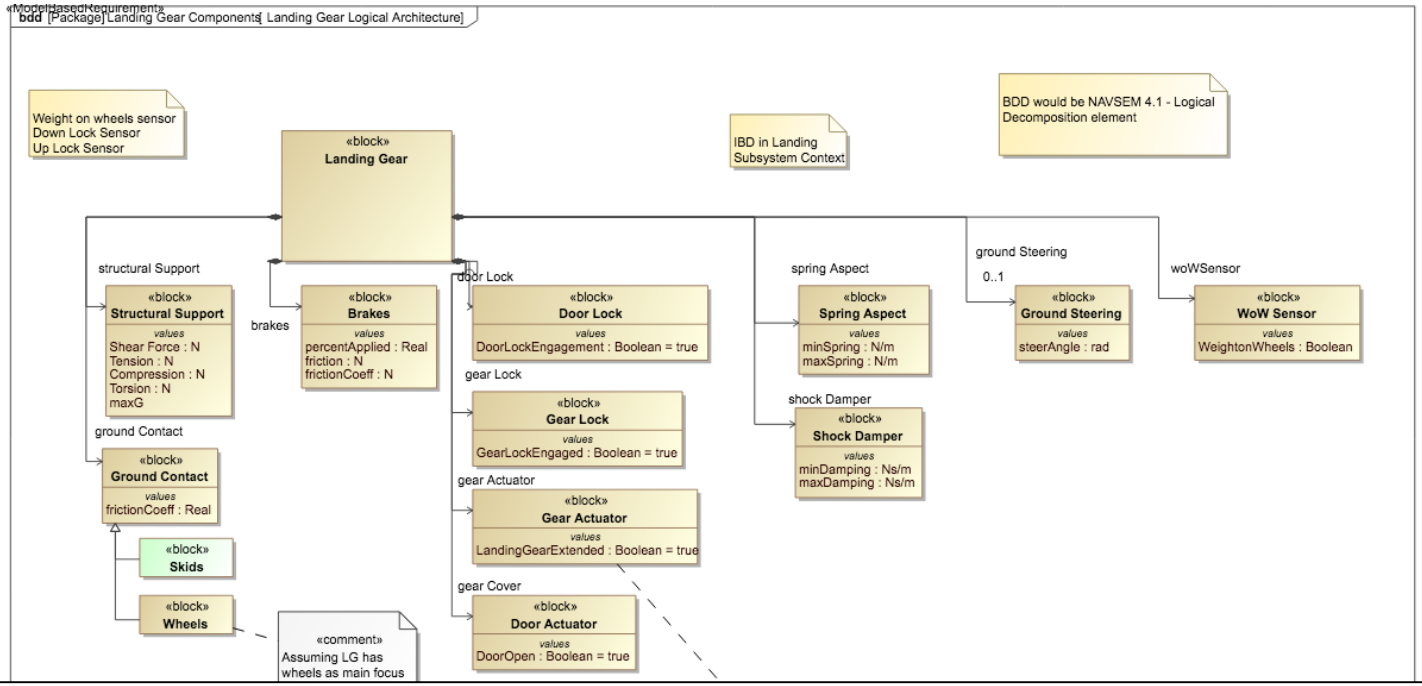
EXPORT CSV FILTER TABLE

Table 176. System Failure Analysis Signoff

Approved Elements	Approval Status	Approved By	Completeness	Probability	Impact	Comment
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

SYSTEMS ENGINEERING
Research Center

Digital Signoff are Template-Based and Can Have Multiple Approvals



1.1 Logical Decomposition Signoff

Last Modified: 4/17/20 2:44 PM by **ben**

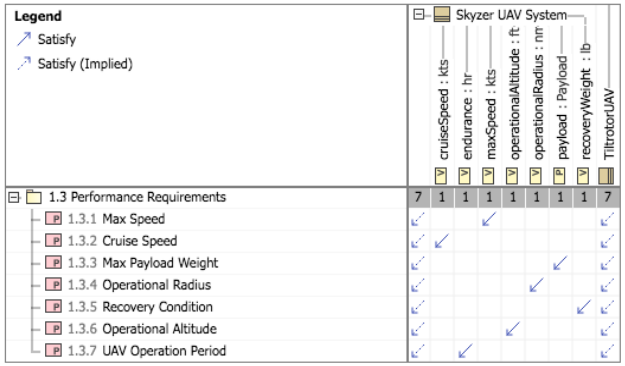
EXPORT CSV FILTER TABLE

Table 1. Logical Decomposition Signoff

Approved Elements	Risk	Approval Status	Approved By (SME)	Approved By (Class-Desk)	Completeness	Comment
Landing Gear Logical Architecture	50	undefined	-	-	0	-
Skyzer UAV System_v2	50	undefined	-	-	0	-

SYSTEMS ENGINEERING
Research Center

Digital Signoff Can Align with Traditional Baseline Criteria (SRR-II) in Skyzer RFP View



Model artifact provides evidence for SETR criteria

PerformanceRequirements

+ ADD

Performance parameters are used in Evaluation model. To maintain the evaluation process, these value can't be redefined in contractor's system model. Therefore, this performance table inherits the value properties defined in Skyzer UAV System.

+ ADD

2.5.3.1 Performance Requirements SignOff

Last Modified: 12/7/18 11:47 AM by ben

+ ADD

Criteria in existing NAVAIR Systems Engineering Technical Review (SETR) for SRR (can Digital Signoff subsume SETR)

EXPORT CSV | FILTER TABLE

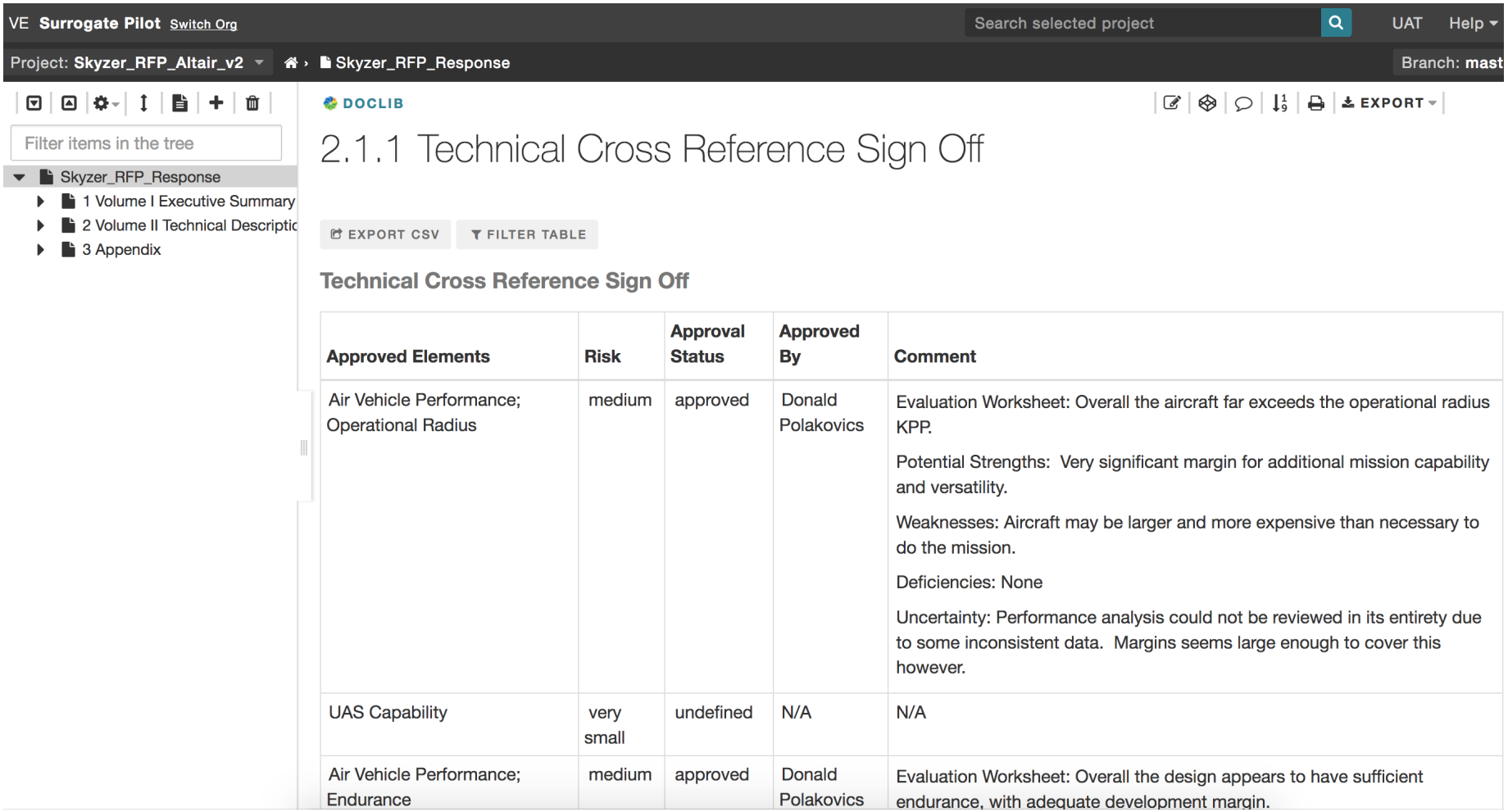
Performance Requirements SignOff

Approved Elements	Risk	Approval Status	Approved By	Comment
PerformanceRequirements	medium	Value : to be defined / ✓ undefined / approved / rejected	-	Criteria SRR-II 1.f. - Requirements traceability from the CDD to the requirements baseline has been documented

RFP: Request for Proposal
SRR-II: System Requirement Review

SYSTEMS ENGINEERING
Research Center

Digital Signoff for Source Selection Technical Evaluation Done In the 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.

Used Hyperlinks to Discipline-Specific Models and Researching How to Create Digital Signoffs for these Analyses & Tools

VE **Surrogate Pilot** Switch Org — Search selected project — UAT — Help — M

Project: **Skyzer_RFP_Altair_v2** › Skyzer_RFP_Response — Branch: **master**

DOCLIB — EXPORT

Filter items in the tree

- Skyzer_RFP_Response
  - 1 Volume I Executive Summary
    - 1.1 ES-1 Offeror Summary Table
    - 1.2 Technical Summary
  - 2 Volume II Technical Description
    - 2.1 Technical Cross Reference Ma
    - 2.2 Design Overview - Diagram
      - 2.2.1 Propulsion Subsystem
      - 2.2.2 Airframe Subsystem
      - 2.2.3 Sensor Subsystem
    - 2.3 Design Analysis
      - 2.3.1 EagleEye Surrogate Ben
        - 2.3.1.1 Aerodynamic Analy
        - 2.3.1.2 Endurance Study
        - 2.3.1.3 Maximum Speed a
      - 2.3.2 Sizing Study and Initial V
      - 2.3.3 Conceptual Trades - Tilt
        - 2.3.3.1 Tiltrotor Design
        - 2.3.3.2 Ducted Fan Design
        - 2.3.3.3 Rotor Selection Tab
      - 2.3.4 T
      - 2.3.5 A
      - 2.3.6 S
      - 2.3.7 S
      - 2.3
      - 2.3
      - 2.3.8 V
      - 2.3.9 M
    - 2.4 Perfor
  - 3 Appendix
    - 3.1 Altair
    - 3.2 Altair

Engineering Activity Checklist

ENGINEERING ACTIVITY	DELIVERABLES	Offeror's Proposal System Model Element or Documentation Base Vol/Annex and Associated Page Number
Eagle Eye Surrogate Benchmark	Engineering system model, supporting CAE models and performance results to satisfy the "Requirement Model" or "System Model" (IM30) and KPP metrics.	EagleEye Surrogate Benchmark
Sizing Study	Take off weight, empty weight, fuel fraction, warm up, take off, and landing weight fraction. Mission segment fractions.	Sizing Script @ Altair365
Conceptual Trades - Tilt Rotor vs Ducted Fan	Airframe CFD models, co-efficient's of lift and drag, respective propulsive performance results for both concepts.	Conceptual Trades - Tiltrotor vs Ducted Fan
Initial Weight Targets	Targets set from task 1C.	WeightBudgetScript@Altair365
Vehicle CAD and packaging	Vehicle package space definition and major system locations. Technical Data Package.	Vehicle CAD and packaging
Thrust/Weight Wing Loading	Airframe load case matrix	Thrust/Weight Wing Loading Calculation

Applications Places System — Thu Nov 29, 13:54

Untitled - HyperWorks 2017.2

File Edit View Model Results Annotations Tools Preferences Applications Help

Contour Plot
Element Stresses (2D & 3D)(vonMises, Max)
Analysis system
1.214E+07
1.000E+06
8.750E+05
7.500E+05
6.250E+05
5.000E+05
3.750E+05
2.500E+05
1.250E+05
9.565E-06
Max = 1.214E+07
Min = 9.565E-06

1: Model
Subcase 10 (LC_10_SeaLev_45_deg) : Static Analysis : Frame 25

Files — Model 1
Subcase 10 (LC_10_SeaLev_45_deg)
Static Analysis
Entities
Assembly Hierarchy
Components (27)
Load Cases
Notes (1)
Plot Styles (3)
Sets (7)
Views (1)
Measures (2)
Results
Name Value
0 entities selected

Result type: Element Stresses (2D & 3D) (t) — vonMises — Layers: Max
Selection: Components — Resolved in: Analysis System — System
Averaging method: None — Averaging Options...
Value filter: None
Envelope trace plot:
Display Legend Result — Max: Min: Multiplier: 1 Offset: 0 — Edit Legend...
Cache — Apply

Need for Further Maturity/Assessment

- We still have to formulate the various categories of Digital Signoffs – and associated templates to support them
- We have to formulate the set of Digital Signoffs that would represent classical baselines at key review points such as the SRR, PDR, CDR, TRR, and so on
- We have to investigate the measures used to create Digital Signoff Metrics

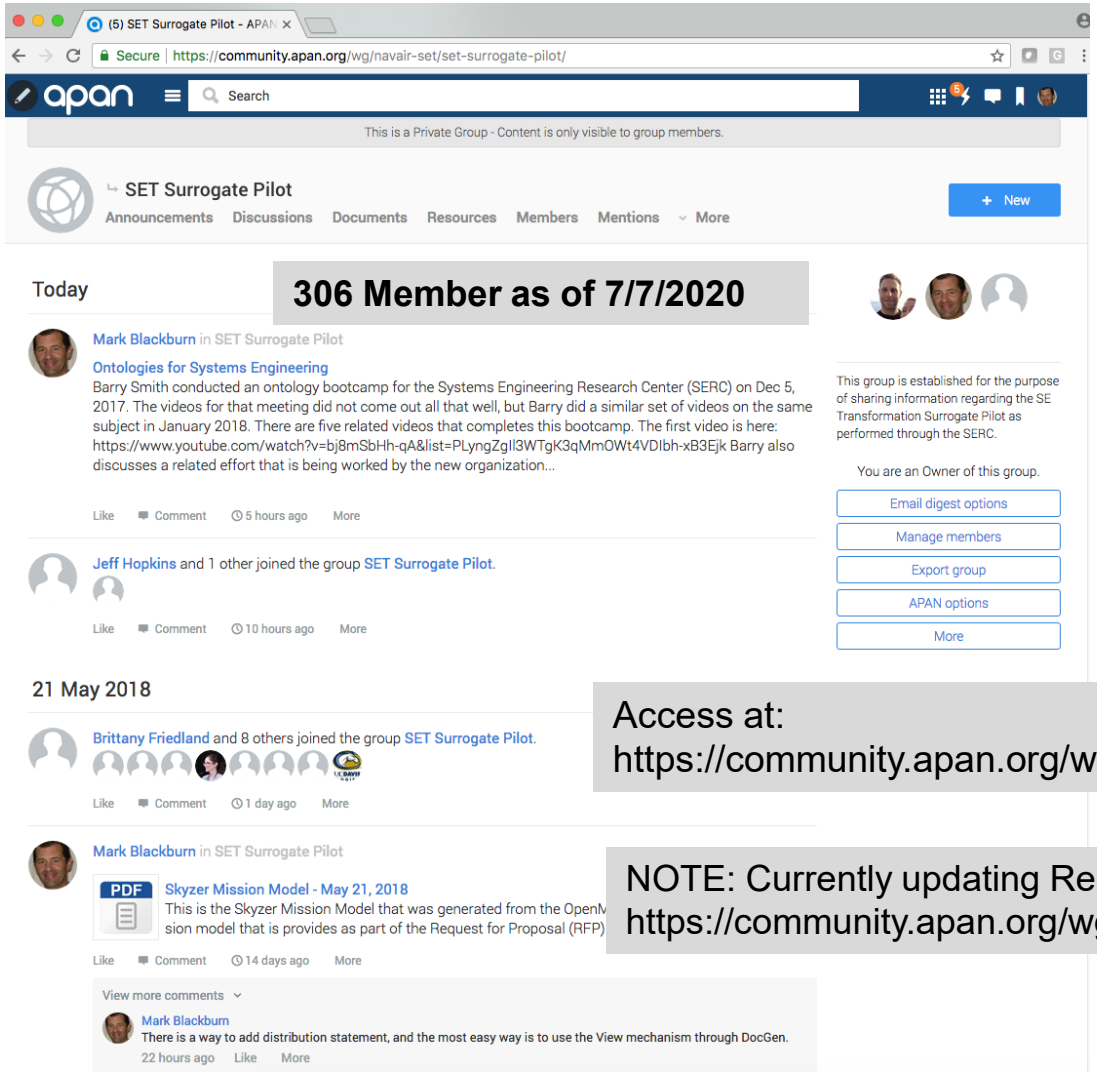
2 Signoff Metrics

#	Date	Number Of Sign Offs	Number Of High Risk Sign Offs	Ratio Of Approved Sign Offs	Ratio Of Rejected Sign Offs	Average Risk
1	2020.04.17 13.44	5	1	0	0	55
2	2020.04.29 16.54	5	1	0.6	0.2	40

Figure 6. Signoff Metrics

SYSTEMS ENGINEERING
Research Center

Continuous Updates of Discussion Threads Provided on Public All Partners Network



- Briefings
- Videos
- Models
- Discussion threads
- Instructs to see models on AWS

Access at:
https://community.apan.org/wg/navair-set/set-surrogate-pilot/

NOTE: Currently updating Research Group for Phase II
https://community.apan.org/wg/navair-set/research/

Digital Signoff Video with Overview: http://www.markblackburn.com/MBSE/WRT_1006_Digital_Signoff_Video_4_29_2020.mp4
Digital Signoff Video Example: http://www.markblackburn.com/MBSE/Digital_Signoff_Example_July_2020.mp4

Thank you!

Dr. Mark Blackburn
Dr. Benjamin Kruse
Dr. Cliff Whitcomb
Marlin, Ballard, PhD Candidate
Adam Baker, PhD Candidate
Wil Stock, Graduate Student
Systems Engineering Research Center
Stevens Institute of Technology
Naval Postgraduate School
Georgia Institute of Technology