SYSTEMS ENGINEERING RESEARCH CENTER

STEVENS INSTITUTE of TECHNOLOGY
THE INNOVATION UNIVERSITY®

Integrating Digital Engineering Technical Models with MBSE Cost Models

Sponsors: NAVAR, CCDC-AC

Presented by: Dr. Mark Blackburn SET Research, SERC, Stevens
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  - Dr. John Dzielski
  - Jake Sisavath
  - Sahil Panchal
  - Gabriel Rizzo
  - Dr. Russell Peak (PI – Georgia Tech)

Organization

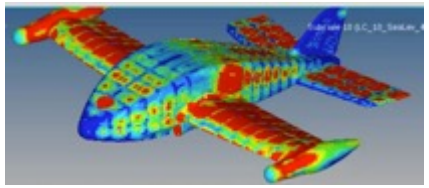
- **INTRO:** Context and Scope of NAVAIR SE Transformation & Skyzer Pilot
- **WHAT:** Integrating Digital Engineering Technical Models with MBSE Cost Models
- **HOW:** Surrogate Pilot & Experiments to Demonstrate Art-of-the-Possible
  - Authoritative Source of Truth
  - ”Full Stack” Graphical CONOPS, Mission, System, Multi-physics, Ontologies, Ref. Architectures
  - Stakeholder Analysis Models such as MBSE Cost Model
  - Modeling Methods
  - Digital Signoffs – Transformation From CDRLs
- **HOW WELL:** Contributing Modeling Examples transitioning to Support Workforce Development demonstrating Art-of-the-Possible
  - Video of demonstration coming soon: https://www.youtube.com/c/SERCUARC

Surrogate Pilot Scenario: Skyzer UAS Search and Rescue Mission

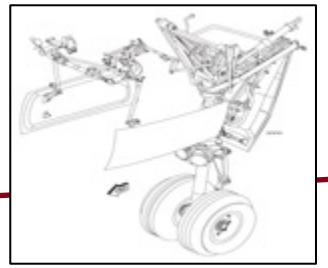
Doing Everything in Models to Demonstrate Art-of-the-Possible

Graphical CONOPS Scenario: Search & Rescue

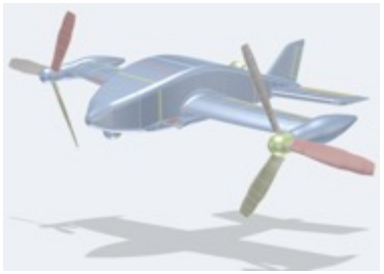
Deep Dives by Phases



P1: Multi-physics



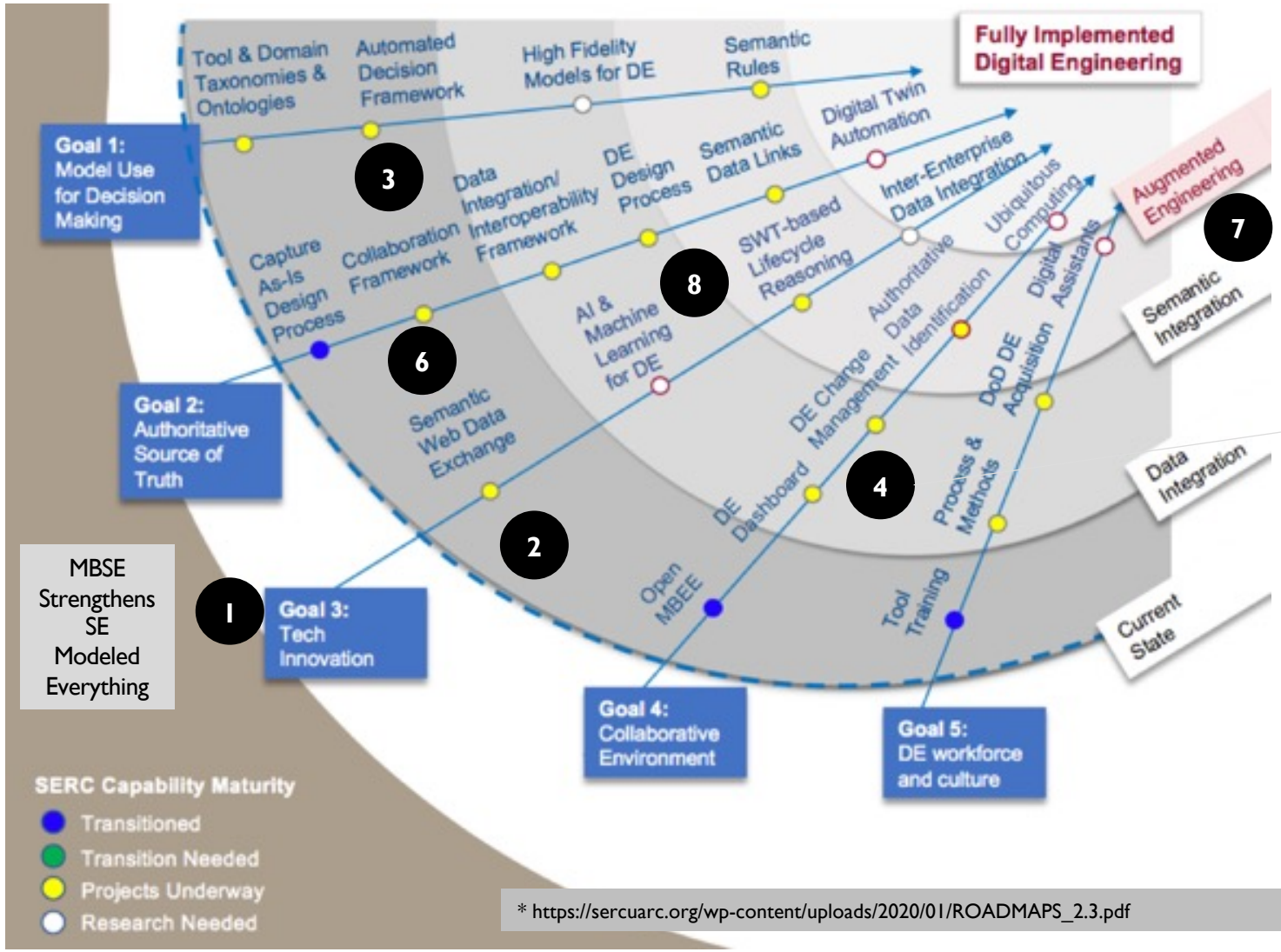
P2: Airworthiness



P3: Cost Modeling

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

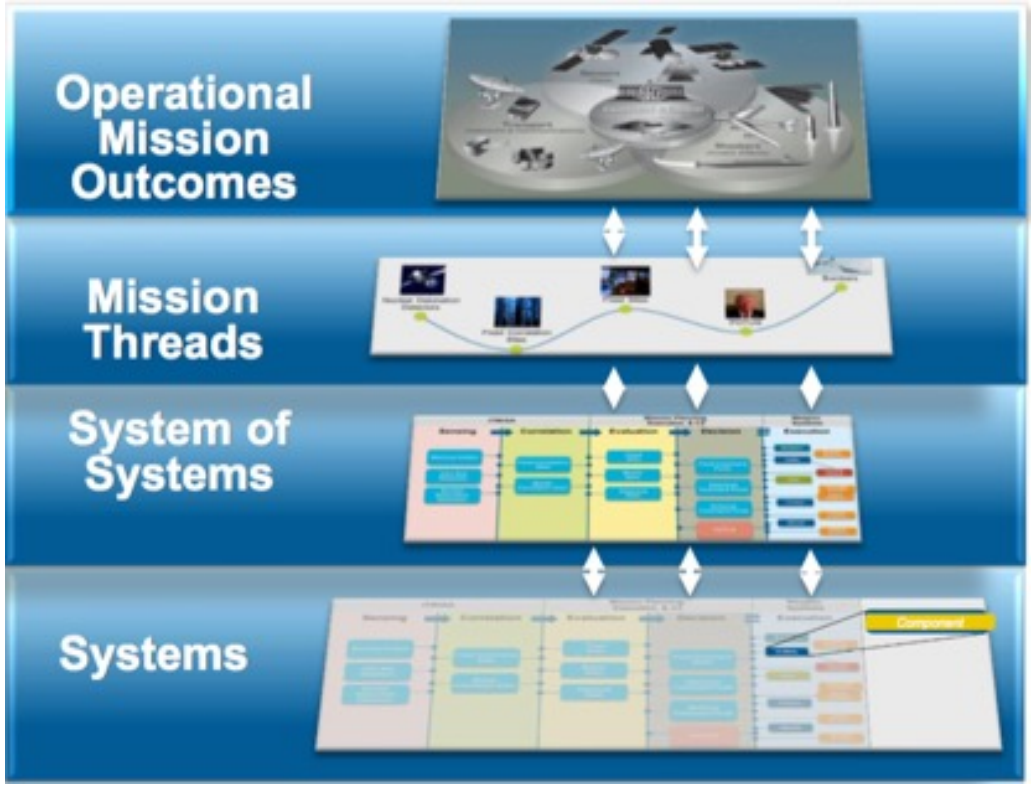
Digital Engineering for Systems Engineering Roadmap



* https://sercuarc.org/wp-content/uploads/2020/01/ROADMAPS_2.3.pdf

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)
- Skyzer models are unclassified examples and are being transformed to support workforce development (Goal 5)

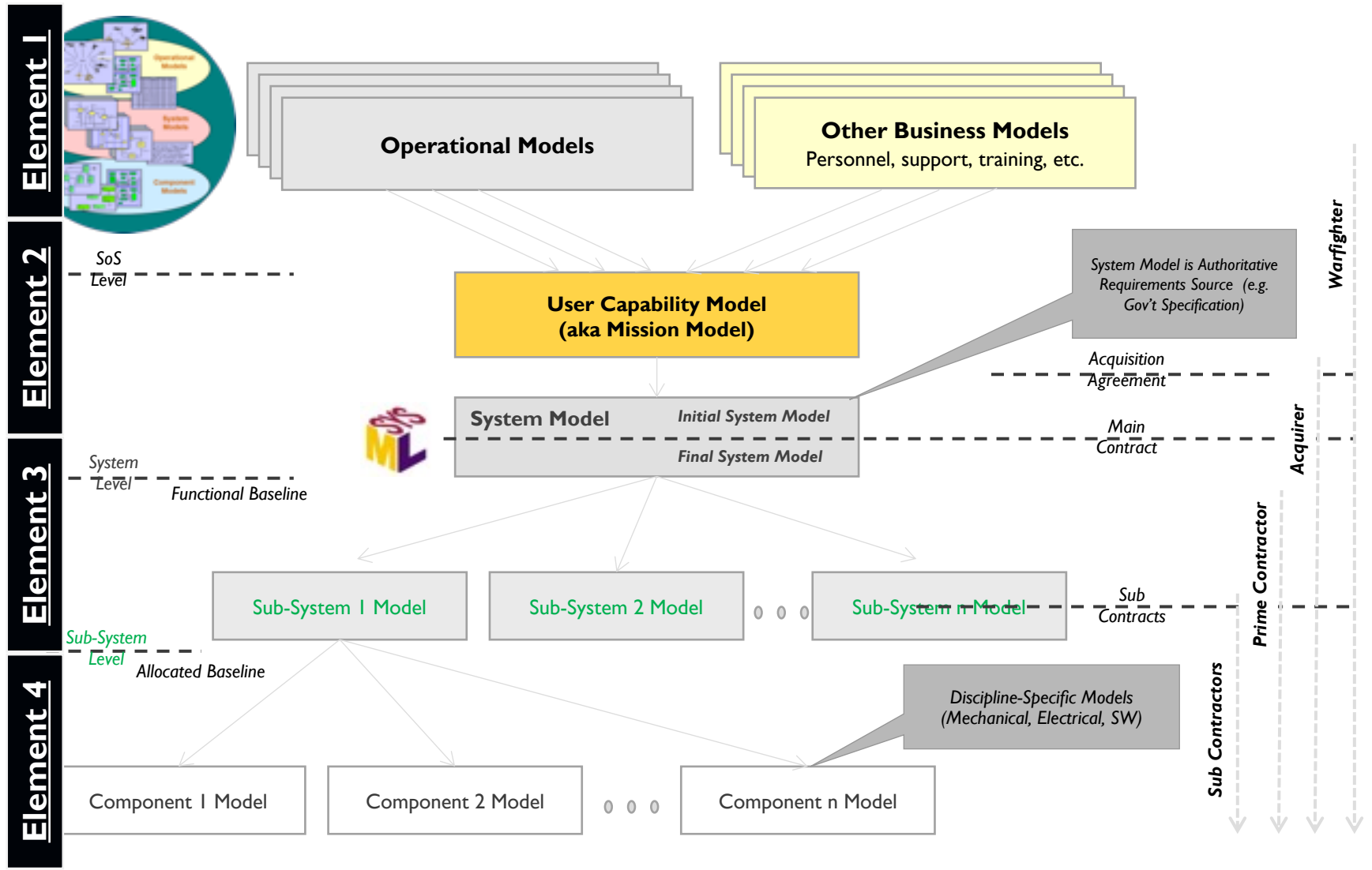


Extending the DoD Digital Engineering Strategy to Missions, Systems of Systems, and Portfolios
P. Zimmerman, T. Gilbert, J. Dahmann
22nd Annual NDIA Systems and Mission Engineering Conference Tampa, FL| 23 October 2019

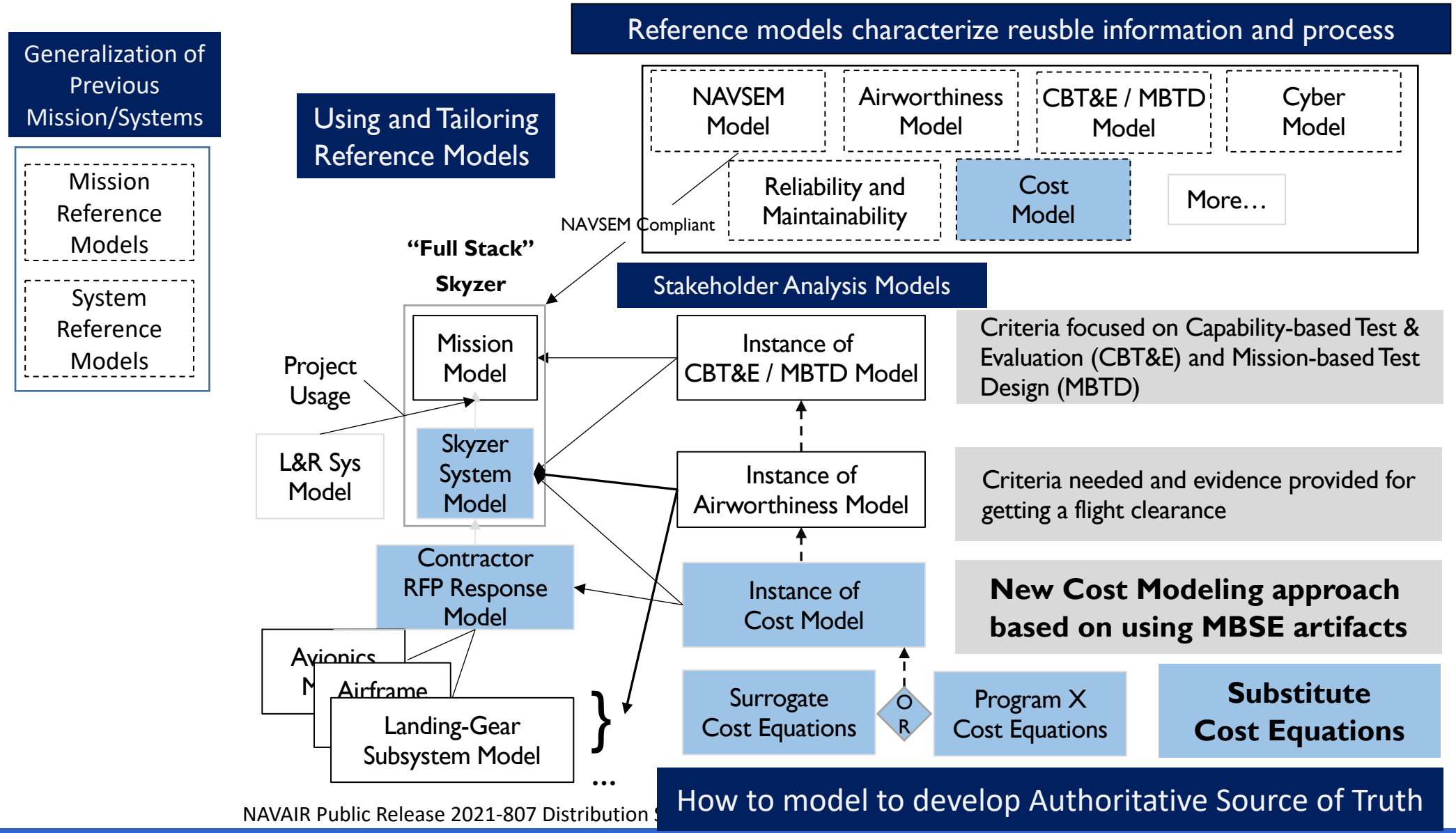
Skyzer Demonstrates Modeling Methods for SET Framework Elements at Different Abstraction Levels

MBSE tools & languages applicable

MBE tools & languages applicable



“Full Stack” of Skyzer Models



Cost Modeling

INPUTS

Cost Parameters
- Hours (Mfg, Tool, QC, Eng, etc.)
- Dollars (Mfg, Tool, QC, Eng, RM / PP,PE, etc.)
- Labor Rates (Direct, Indirect, OH, Wrap, etc.)
- Etc.

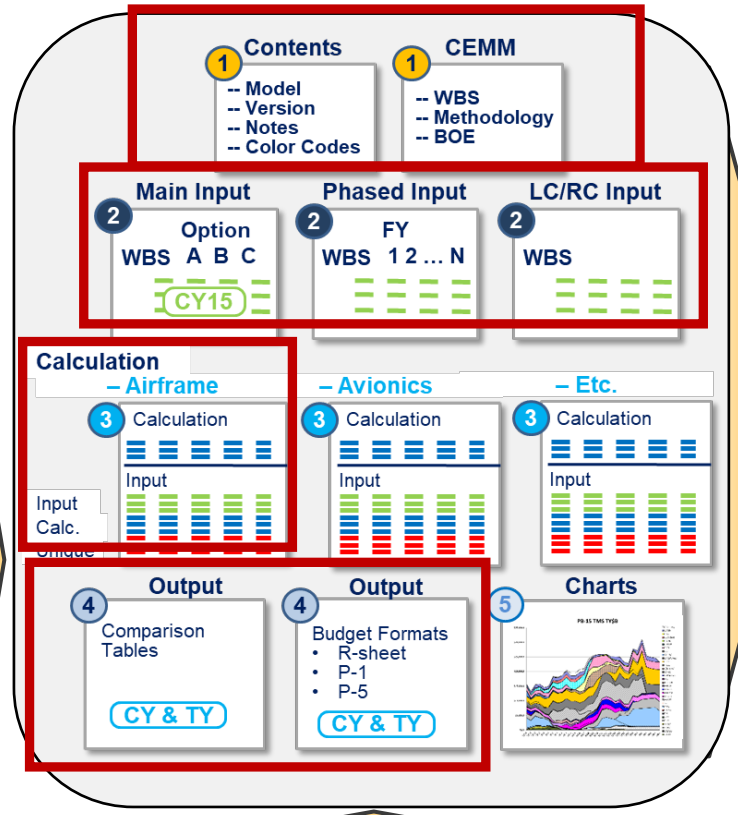
Technical Parameters (ETAB)
- Weight: WE, AUW, Structure, A/B Kit[lbs]
- Material Distribution :
  - Al, Steel, Ti, Composites, Other [%]
- Avionics:
  - CNI, EW, FC, Survivability, etc.
- Software: ESLOC, S/W language
- Propulsion: T/W Ratio , Airflow [lbs / sec]
- Flight Test: Hours, Points, Type
- Risk
- Etc.

Programmatic Parameters (ETAB)
- Acquisition Assumptions
- Prime / Sub Work Split
- Dates: Milestone, Contract Award, First Flight
- Schedules: Dev., Flight Test , Prod.
- ILS Elements: Data, Trainers, Spares
- O&S Assumptions
  - Maintenance Concept, Spares, Personnel, Reliability
- Risk
- Etc.

Input Suppliers
- PMAs
- IPTs
- AIR-00
- PEOs
- ASN
- OSD
- Industry
- Academia
- Etc.

Policy & Guidance
- DoDD 5000 Series
- CSDR Manual
- OSD Cost Guidebook
- ECNAV INST 5000.2B
- MIL-STD- 881D
- DoD ACQ Guidebook
- ETAB NAVAIRINST 5223.2
- Naval Systems Engineering Guide
- Etc.

Cost Model



Analytical Tools
- MS Excel, Cost Analysis ToolPak, NEMO, AIR-4.2 Regression Tool, ACEIT (ACE, CO$TAT), Tableau, Qlik,, Etc.

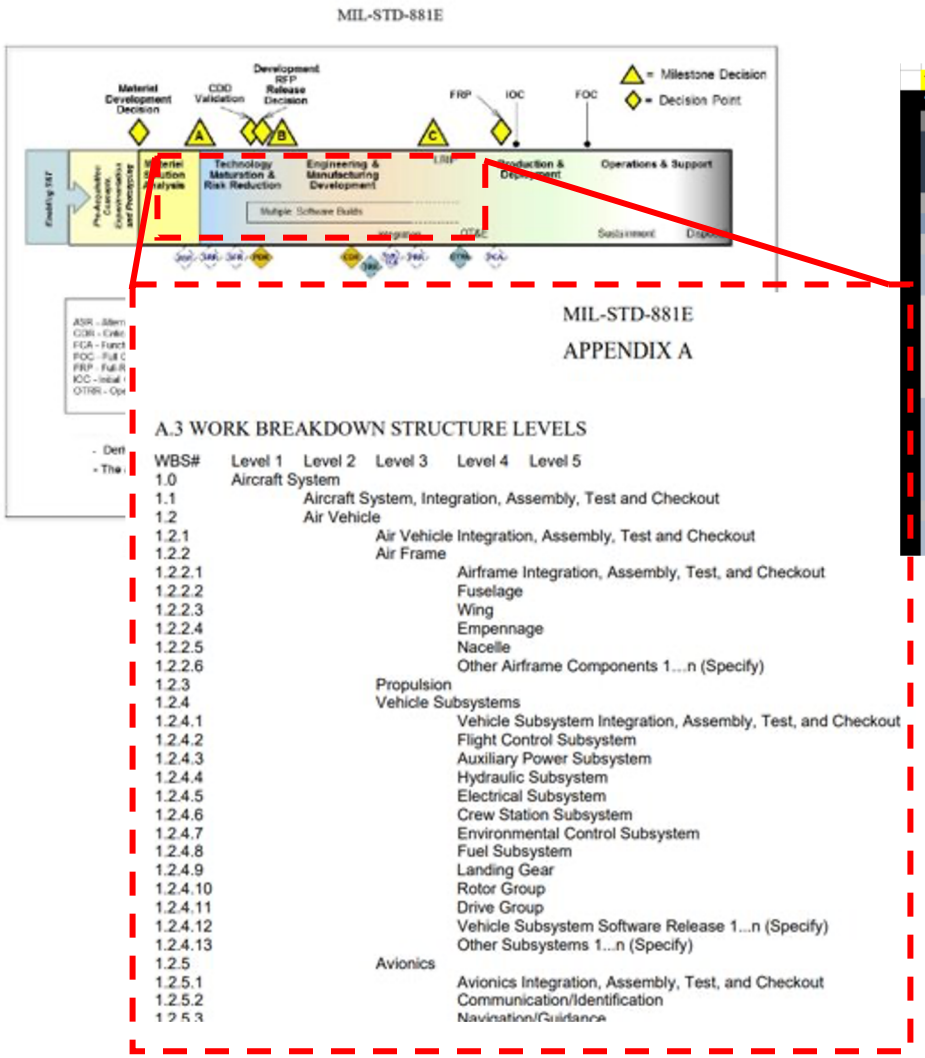
Data
- CADE (DAMIR, DACIMS, EVM), JCARD (CSDRs, Expenditures, Programmatic, Weights), BANK Datasets. eDocs, CBAR, Inflation (OSD, GI), Etc.

OUTPUTS

Products
- Budgets (DON, OSD, PB, POM)
- M/S LCC Estimates
- Naval Aviation Plan
- Will Cost / Should Cost
- Total Ownership Cost
- Special Studies (AOAs, CAIV, DAS, EAs, Trade Studies)
- Affordable Readiness
- What-if Drills
- Sensitivity Analysis
- Risk Analysis
- Briefings
- IBR's
- Claims / Litigation
- Negotiation Support

Customers
- PMAs
- PEOs
- AIR-00
- ASN
- NAVCOMPT
- NCCA
- OSD CAPE
- Etc.

Total Ownership Cost – As-Is Process

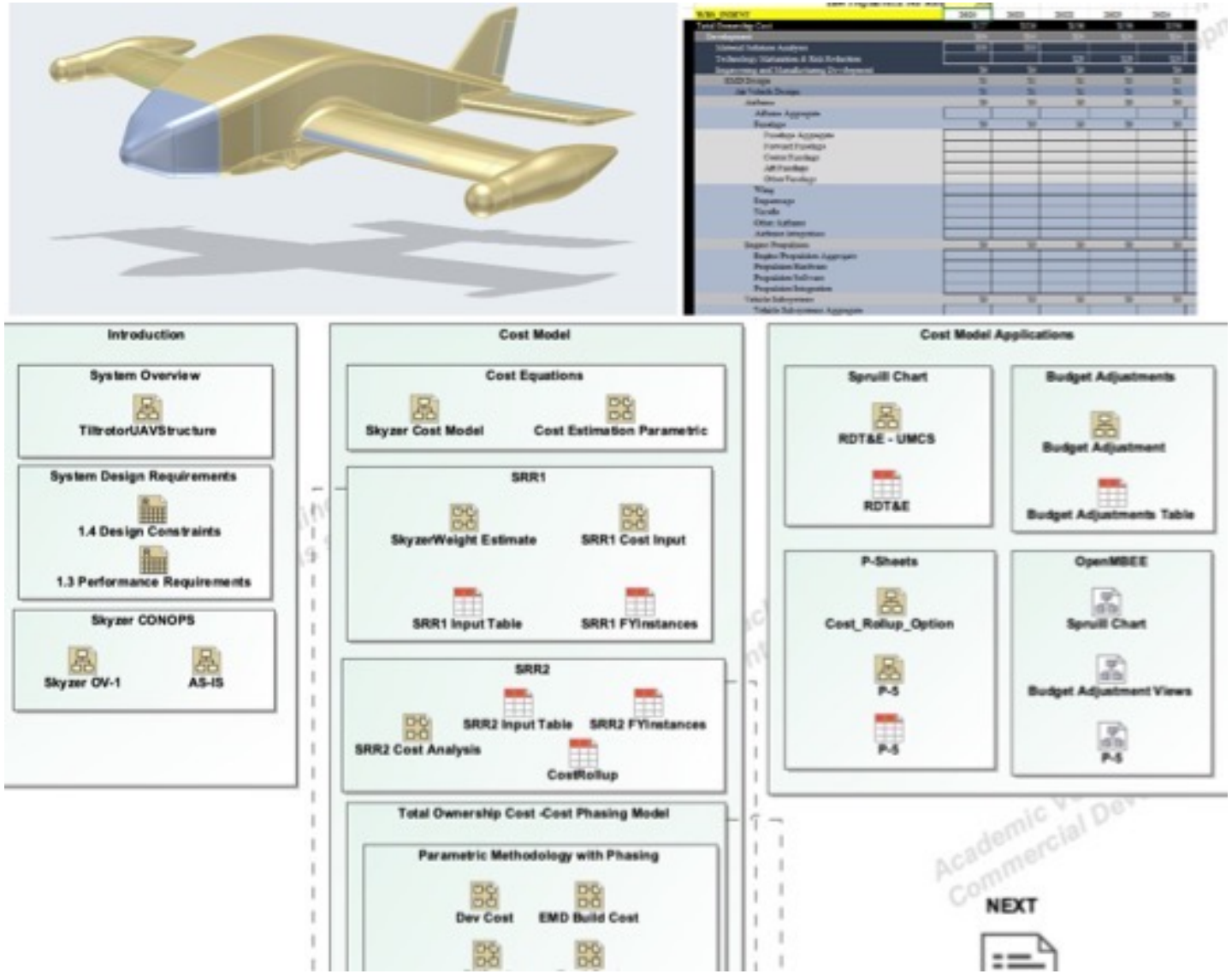


WBS_INDENT	2020	2021	2022	2023	2024
Total Ownership Cost	$127	$126	$136	$136	$136
Development	$14	$14	$24	$24	$24
Material Solution Analysis	$10	$10			
Technology Maturation & Risk Reduction			$20	$20	$20
Engineering and Manufacturing Development	$4	$4	$4	$4	$4
EMD Design	$1	$1	$1	$1	$1
Air Vehicle Design	$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					

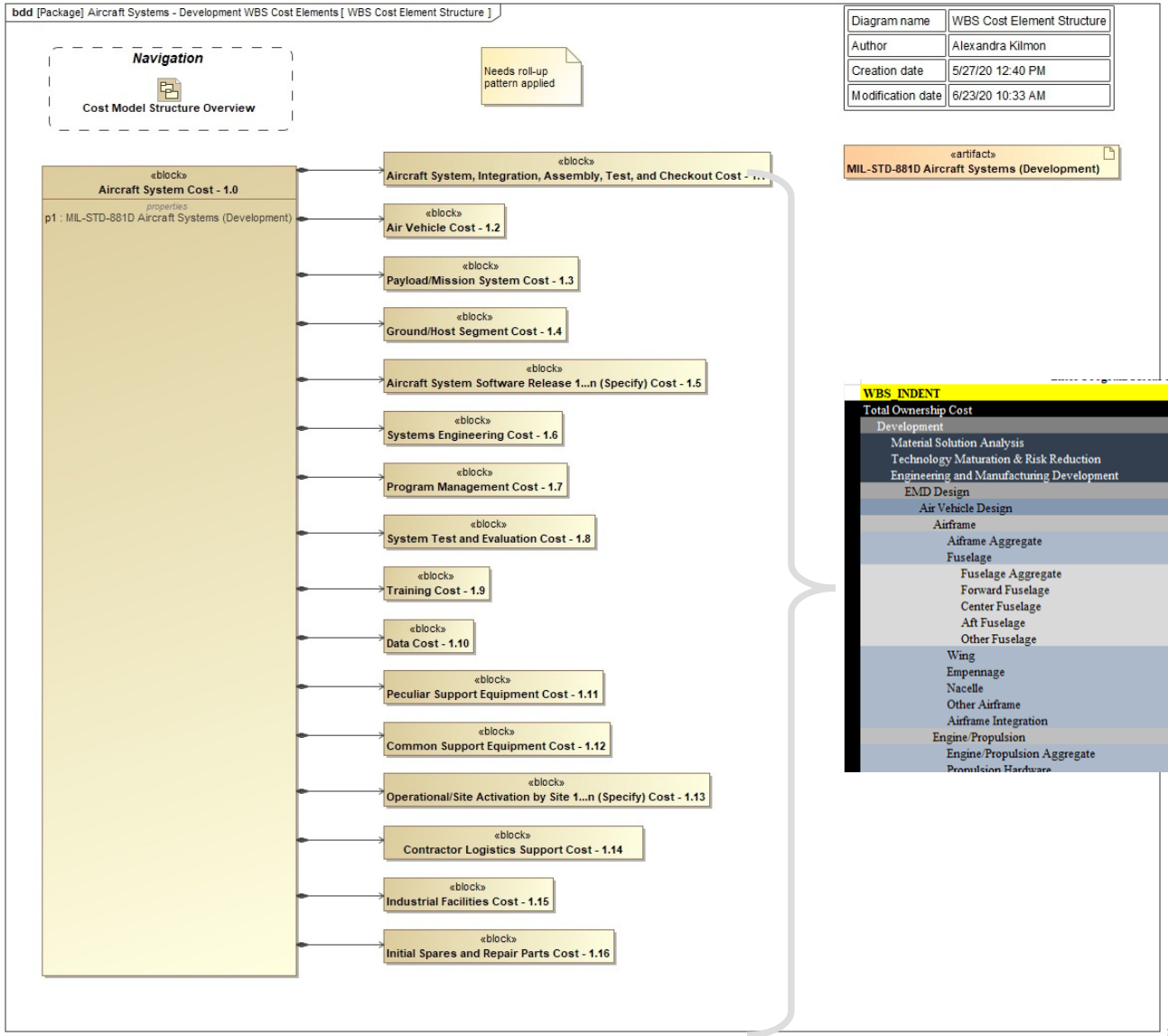
Standard WBS structure defined and leveraged to complete consistent cost and technical analysis

Cost Model Organization

Aircraft Characteristics Deep Dive



Aircraft System Cost Model – Structure Aligns with Mil-STD 881



WBS_INDENT	2020	2021	2022	2023	2024
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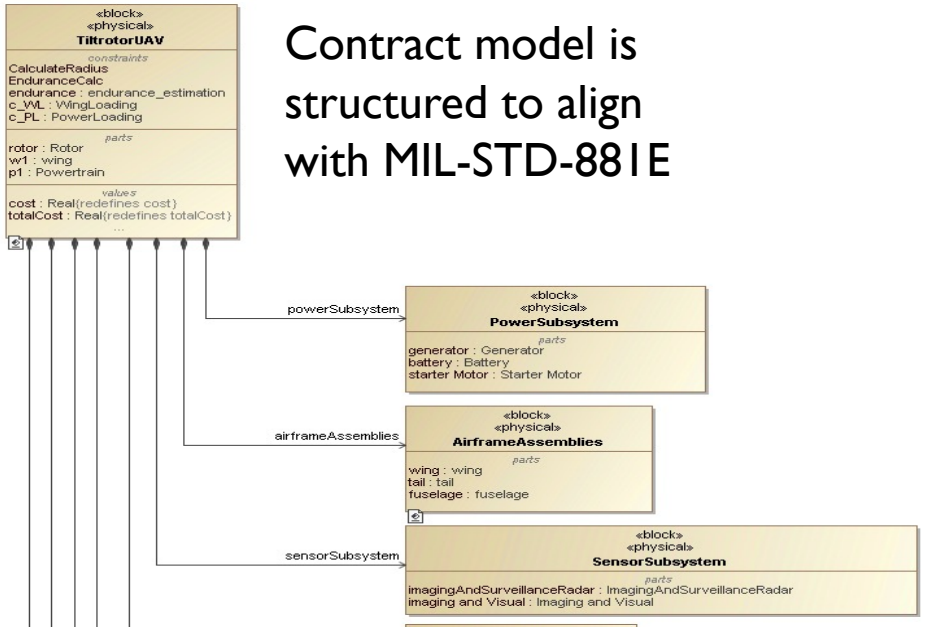
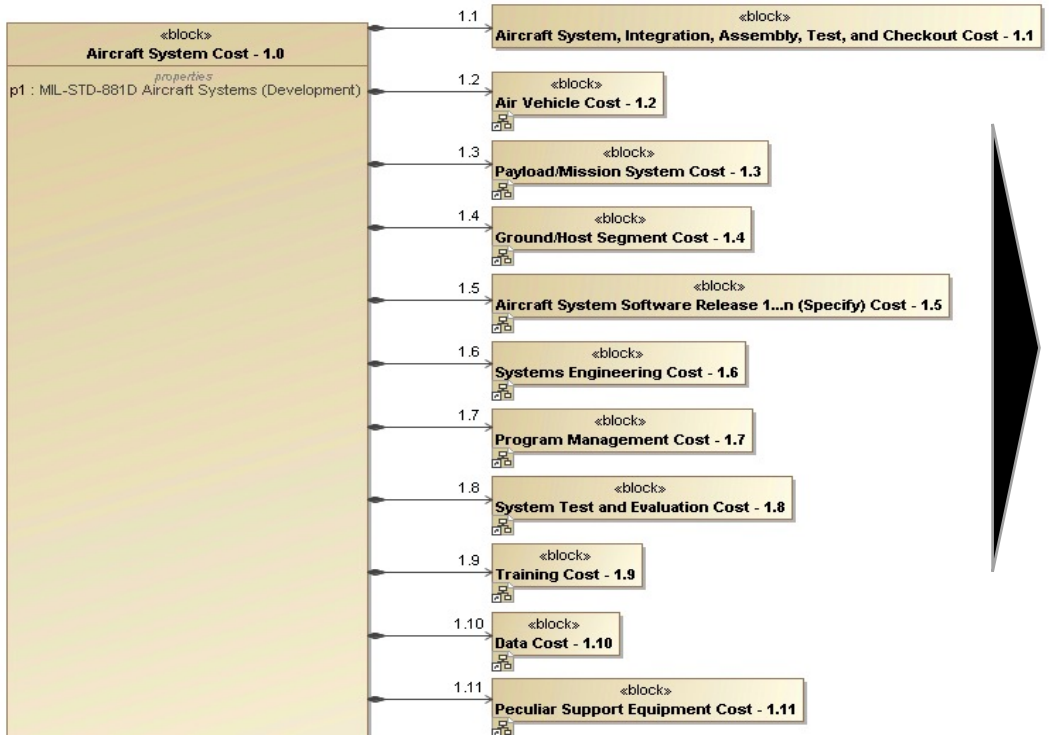
Air Vehicle Design	$1	$1	$1	$1	$1
Airframe	$0	$0	$0	$0	$0
Aiframe Aggregate					
Fuselage	$0	$0	$0	$0	$0
Fuselage Aggregate					
Forward Fuselage					
Center Fuselage					
Aft Fuselage					
Other Fuselage					
Wing					
Empennage					
Nacelle					
Other Airframe					
Airframe Integration					
Engine/Propulsion	$0	$0	$0	$0	$0
Engine/Propulsion Aggregate					
Propulsion Hardware					

Total Ownership Cost – To-be Process

Contract model is structured to align with MIL-STD-881E



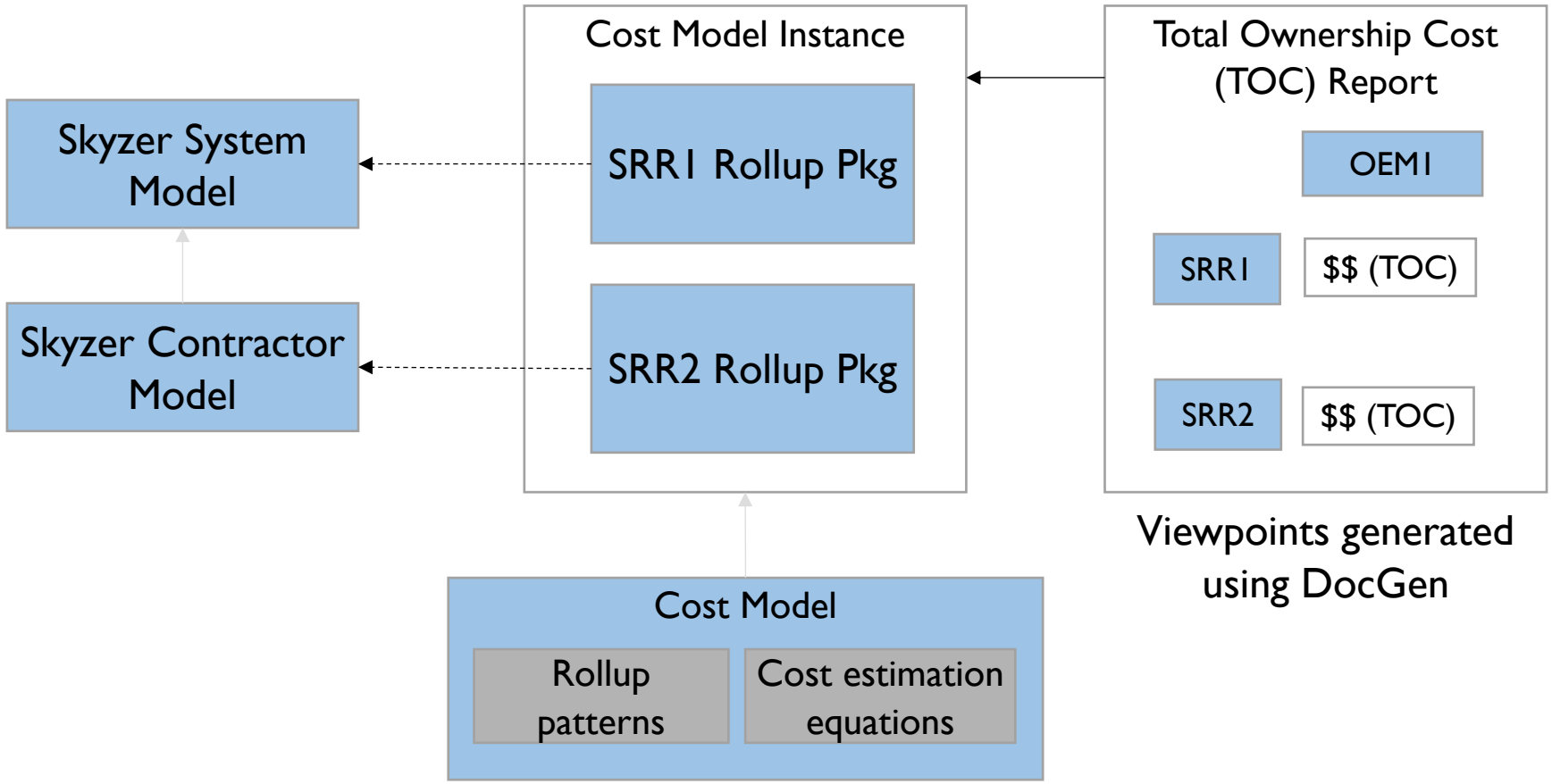
Government cost model rollup patterns MIL-STD-881E from AURA Cost Model



Benefits

- Improve ability to rapidly access change impacts in Authoritative Source of Truth
- Enable comparison of contractor model to government model
- Relate technical data to cost data

Generate Cost Data based on Airframe Weight Rollups



Goal: Leverage the system design data to gain insights into total ownership cost

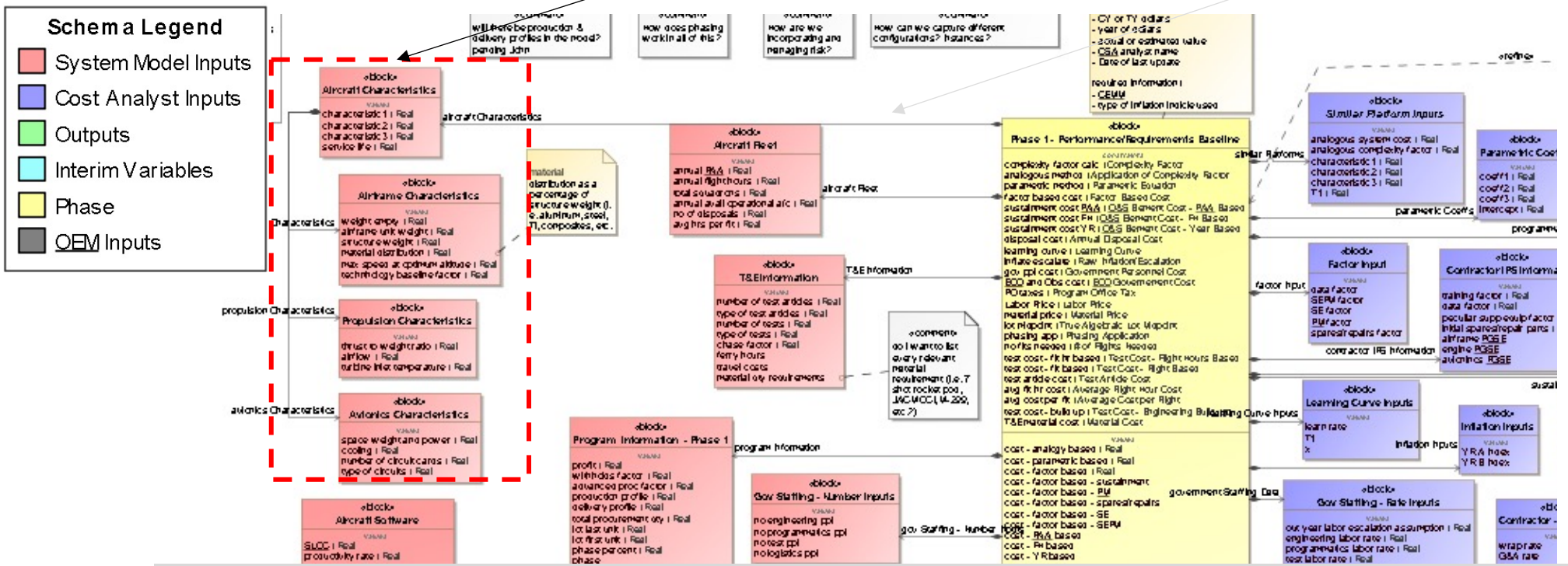
Goal: Reduce the burden to navigate the system model

Automate Cost Estimates as Technical Data Changes

- Cost rollup changes based on the fidelity of the data, generally related to overall program phase
  - Phase 1: Simple analogy and historical (SRR1)
  - Phase 2: Analogy and parametric (SRR2)
  - Phase 3: Engineering buildup (PDR/CDR)
  - Phase 4: Extrapolation of actuals (Prod)
- Approach
  - Use cost analysis patterns which relate to technical data fidelity, tracking contractor cost over the program lifecycle
  - Cost estimation approach is tailored by the fidelity of data on hand

Cost Model Schema (v58)

Deep Dive on Aircraft Characteristics
(see next slide for details)

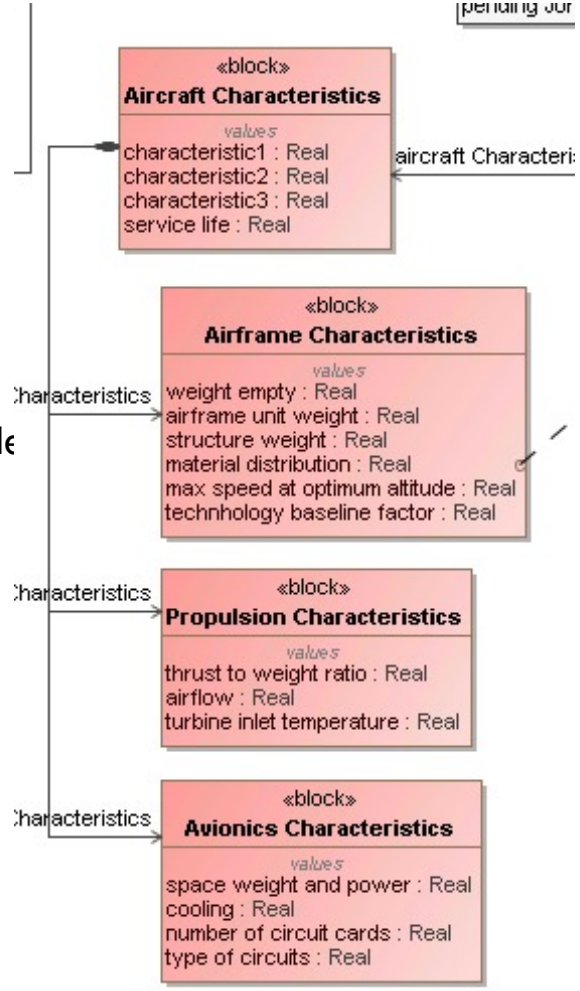


Observations based on Version #58 of AURA MBSE Cost Model

- Schema captured, identify cost analysis inputs, outputs, and phases
- Approach documented MIL-STD-881 relationships
- Rollup patterns were early in concept, not high in fidelity

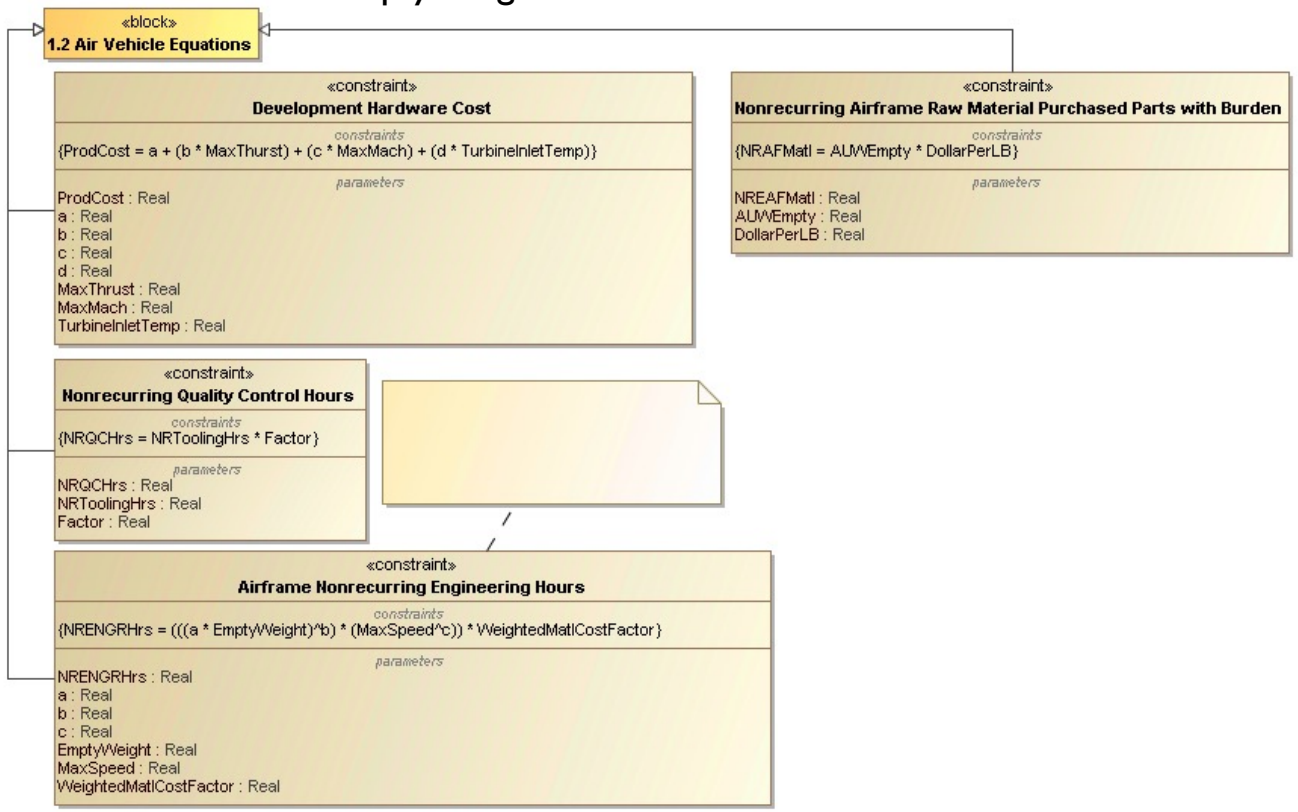
Deep Dive Focused on Aircraft Characteristics and Equations

- Airframe characteristics
  - Weight empty
  - Airframe unit weight
  - Structure weight
  - Material distribution
  - Max speed at optimum altitude
- Propulsion characteristics
  - Thrust to weight ratio
  - Airflow
  - Turbine inlet temperature
- Avionics characteristics
  - Space weight and power
  - Cooling
  - Number of circuit cards
  - Type of circuits

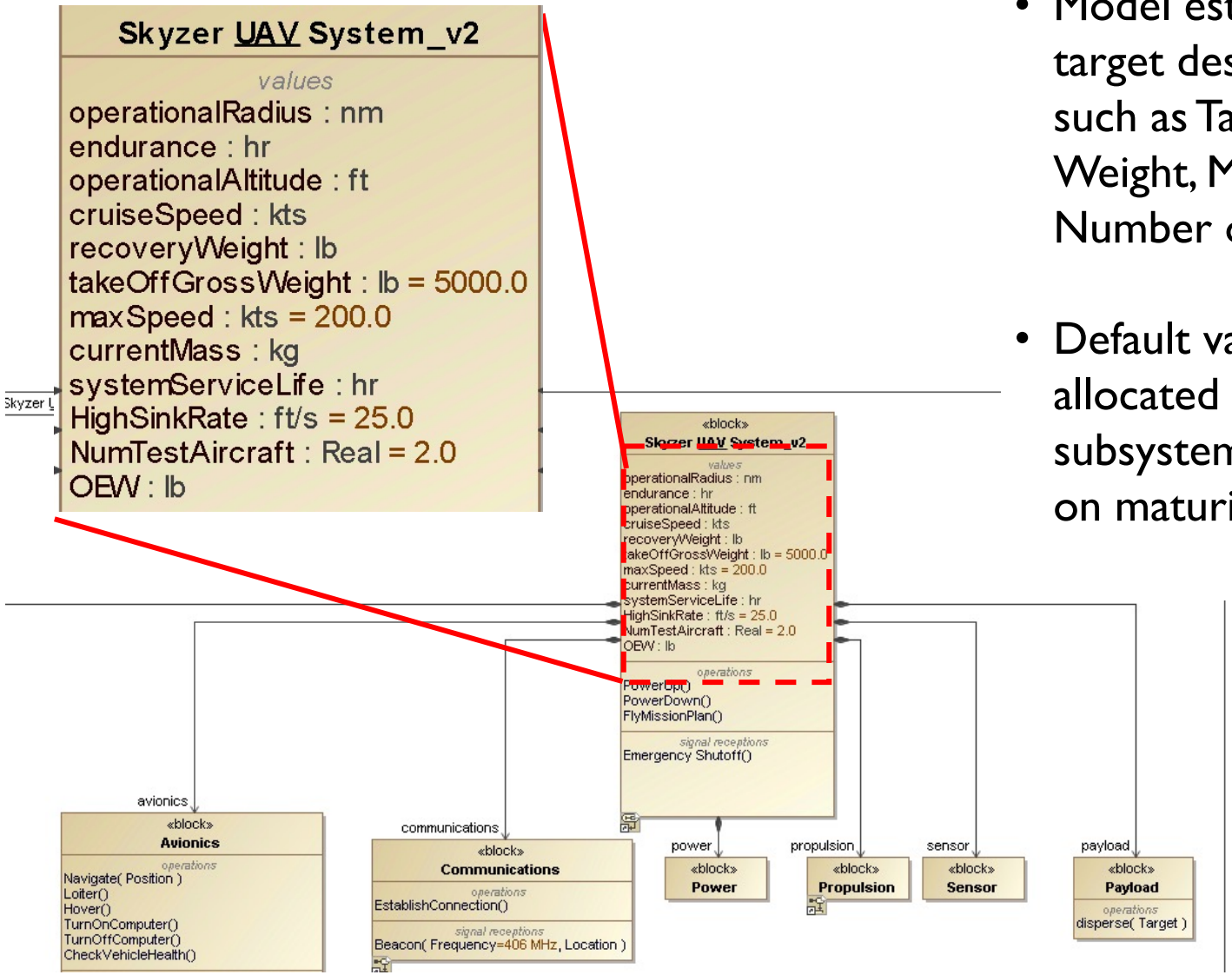


Air vehicle parameters of interest

- MaxMach
- MaxSpeed
- MaxThrust
- EmptyWeight

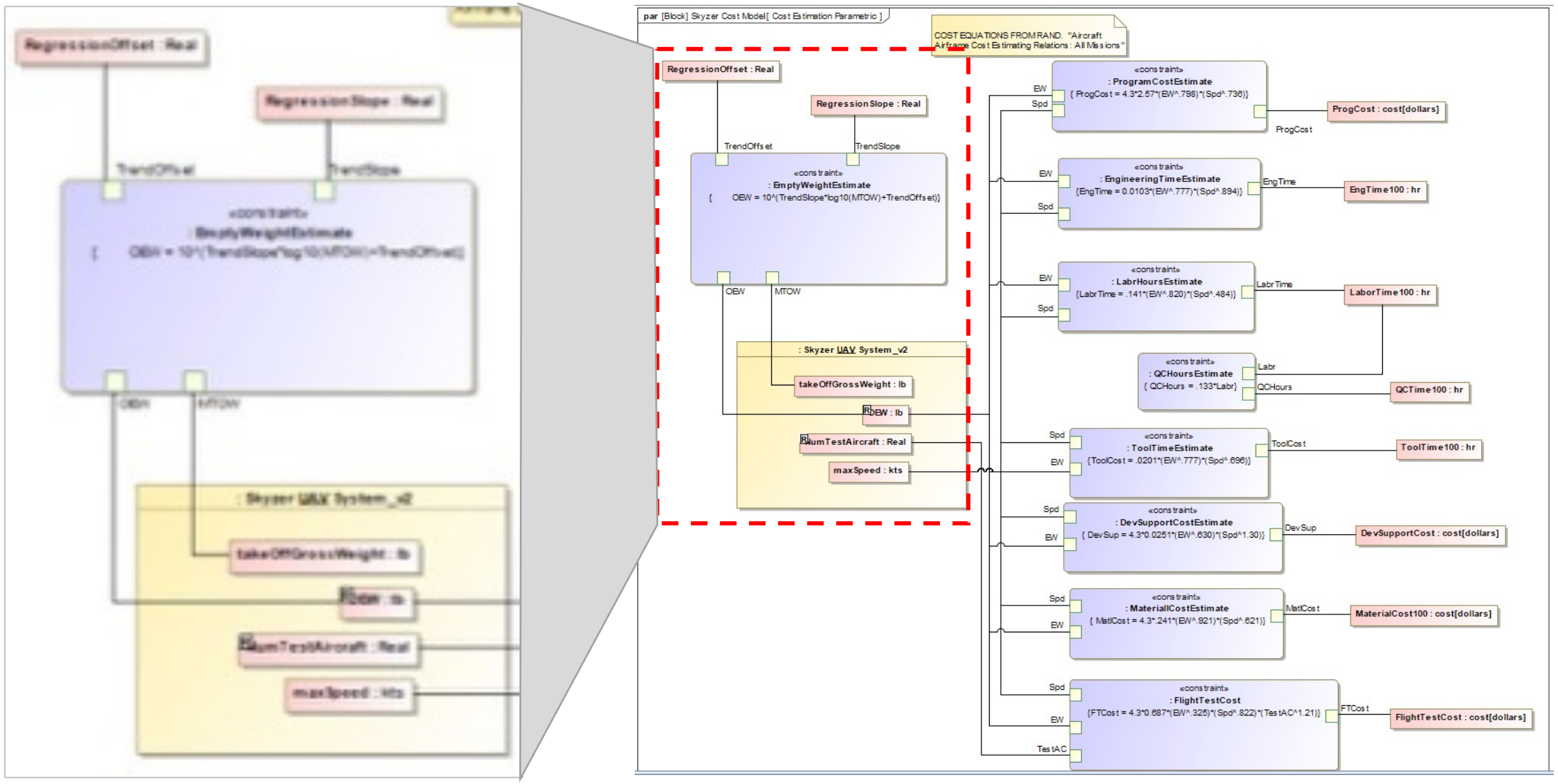


SRR1 - Model Development

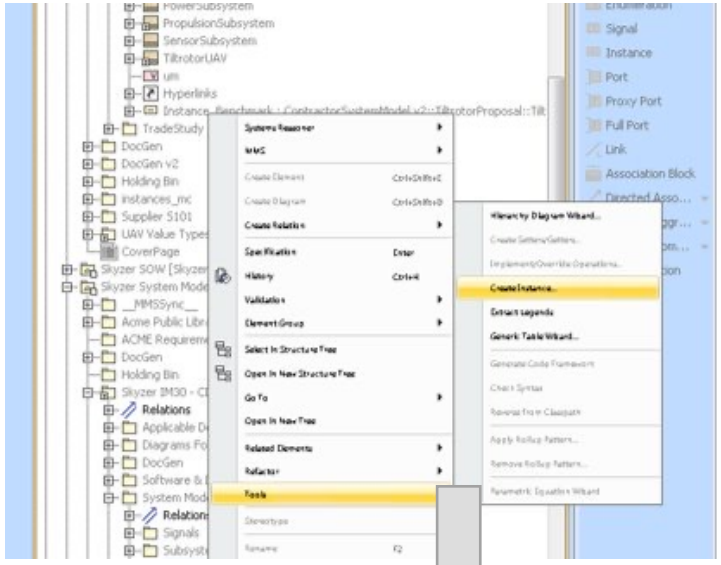


- Model established with target design constraints, such as Take Off Gross Weight, Max Speed, and Number of Test Aircraft
- Default values can be allocated or inherited from subsystem blocks, depending on maturity of the design

Cost Equations (Surrogate or Actual)



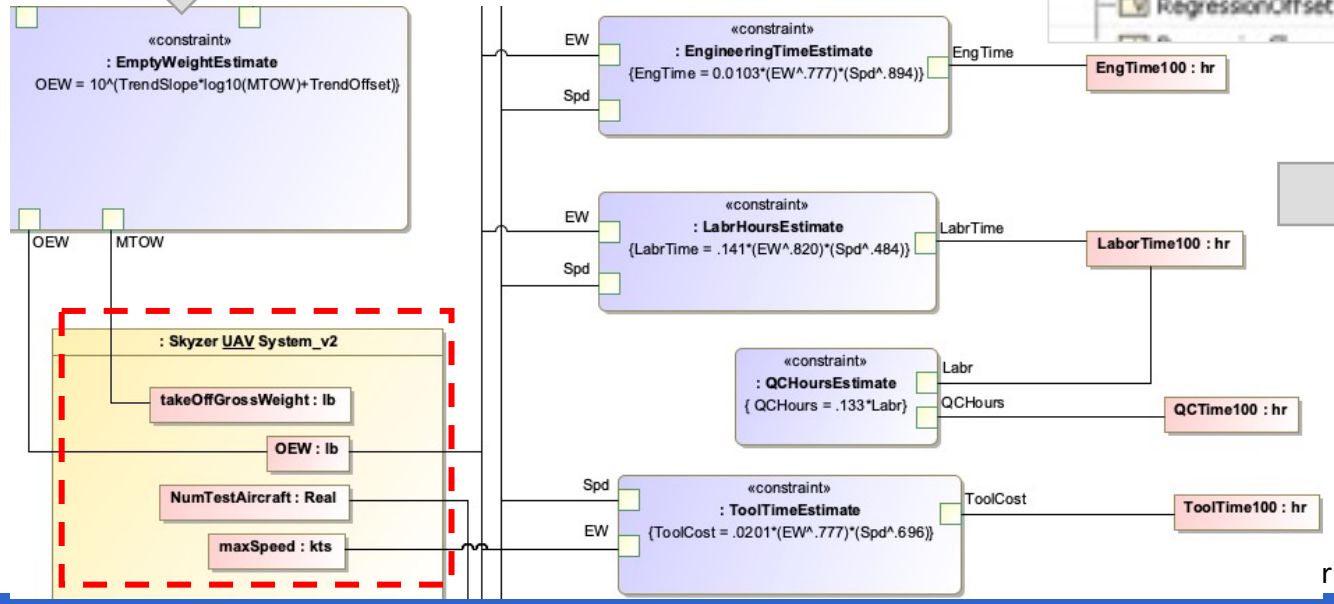
SRR1 – Model Instance in Cost Model



Create instances of for technical model in Cost Model, establishing source of truth data for cost model

Name	Value
Skyzer Cost Model	Skyzer Cost Model
DevSupportCost : cost[dollars]	14740.4671
EngTime100 : hr	517.9189
FlightTestCost : cost[dollars]	6794.6236
LaborTime100 : hr	1131.2535
MaterialCost100 : cost[dollars]	37913.4148
ProgCost : cost[dollars]	2.8362E5
QCTime100 : hr	150.4567
RegressionOffset : Real	-0.0870

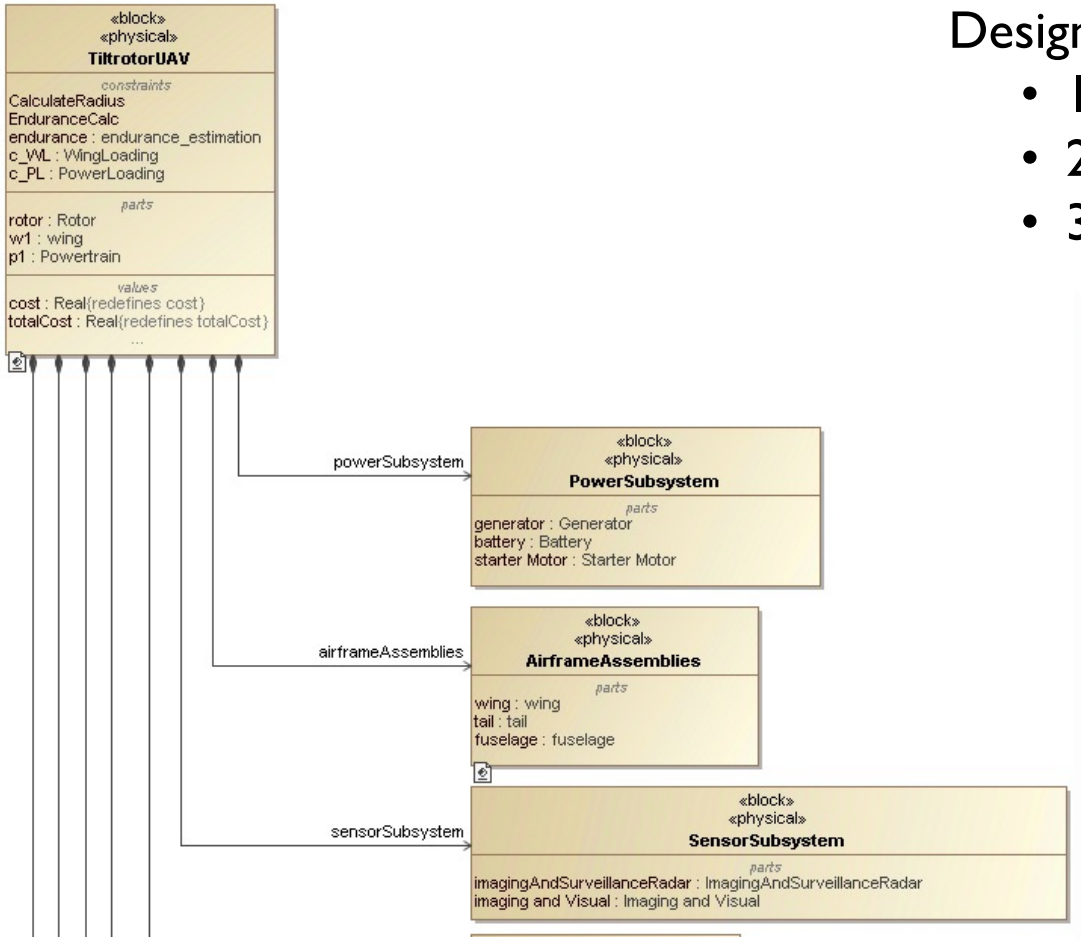
Parametric Rollup



Run parametric simulation for cost methodology model to determine system cost estimates, such as development support cost

ribution is unlimited"

SRR2 – Cost Rollup Pattern based on RFP Model



Design trades

- 1) Subsystem/component cost data organization
- 2) Project use relationship
- 3) Rollup cost pattern ownership

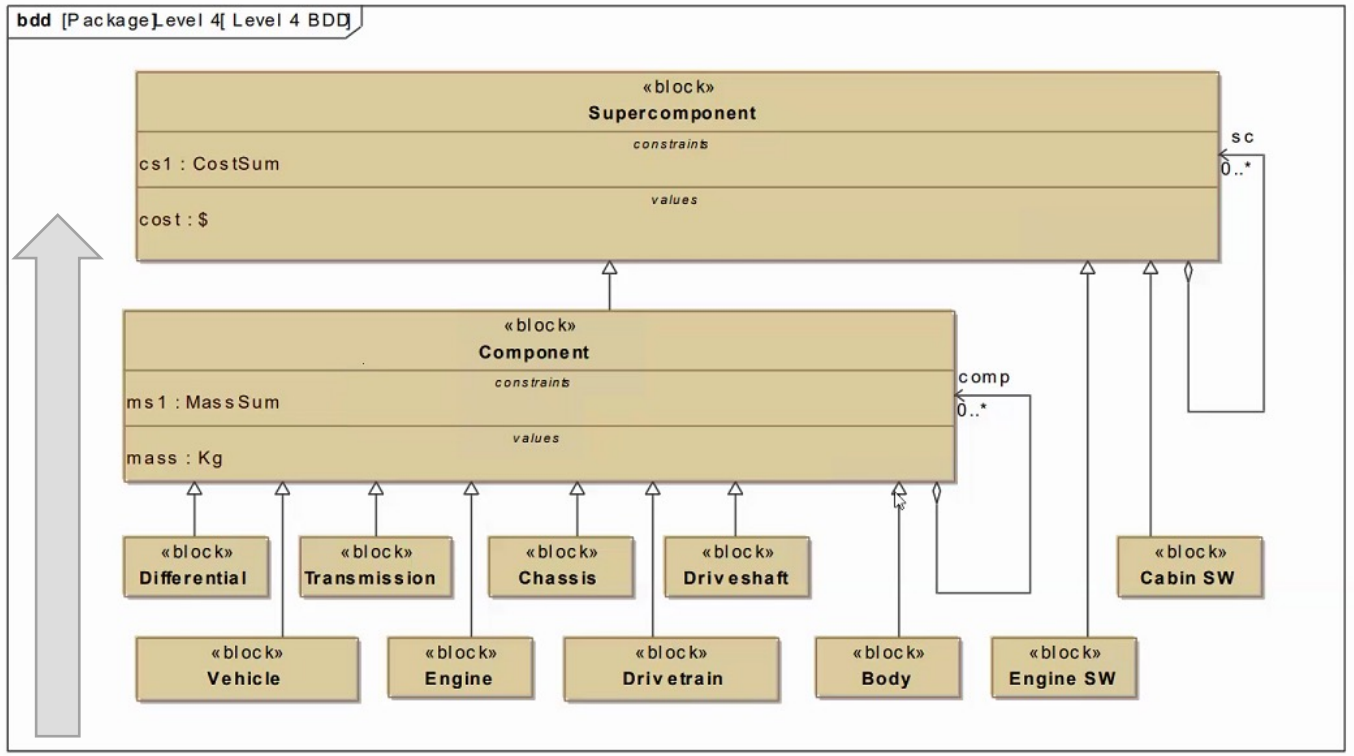
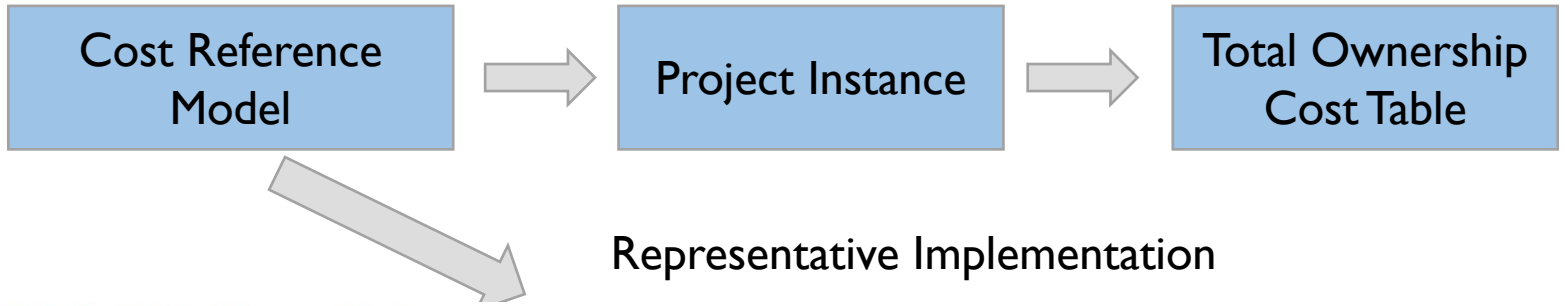


Figure 16 Two levels of Inheritance for Roll-up Calculations

Total Ownership Cost Approach



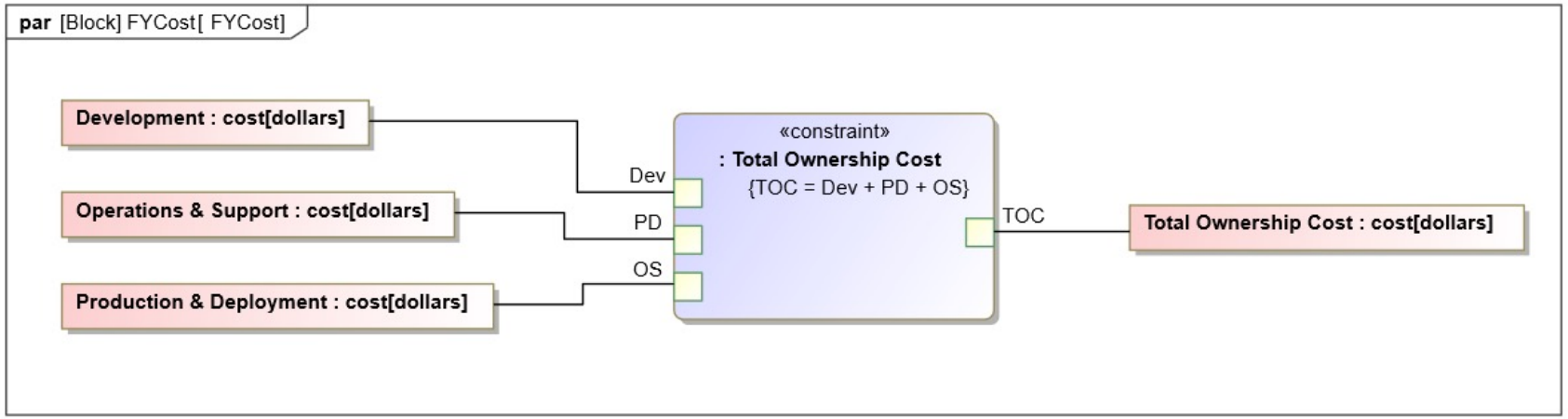
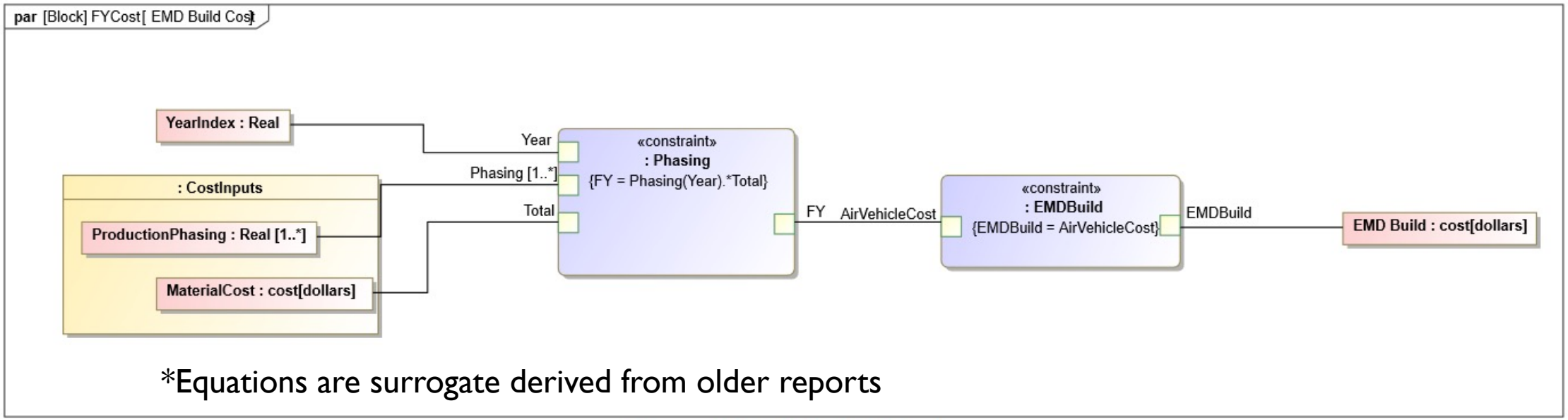


Figure 12. Methodology

EMD Build Cost – Example Parametric Equation*

Inputs link back to contractor model



*Equations are surrogate derived from older reports

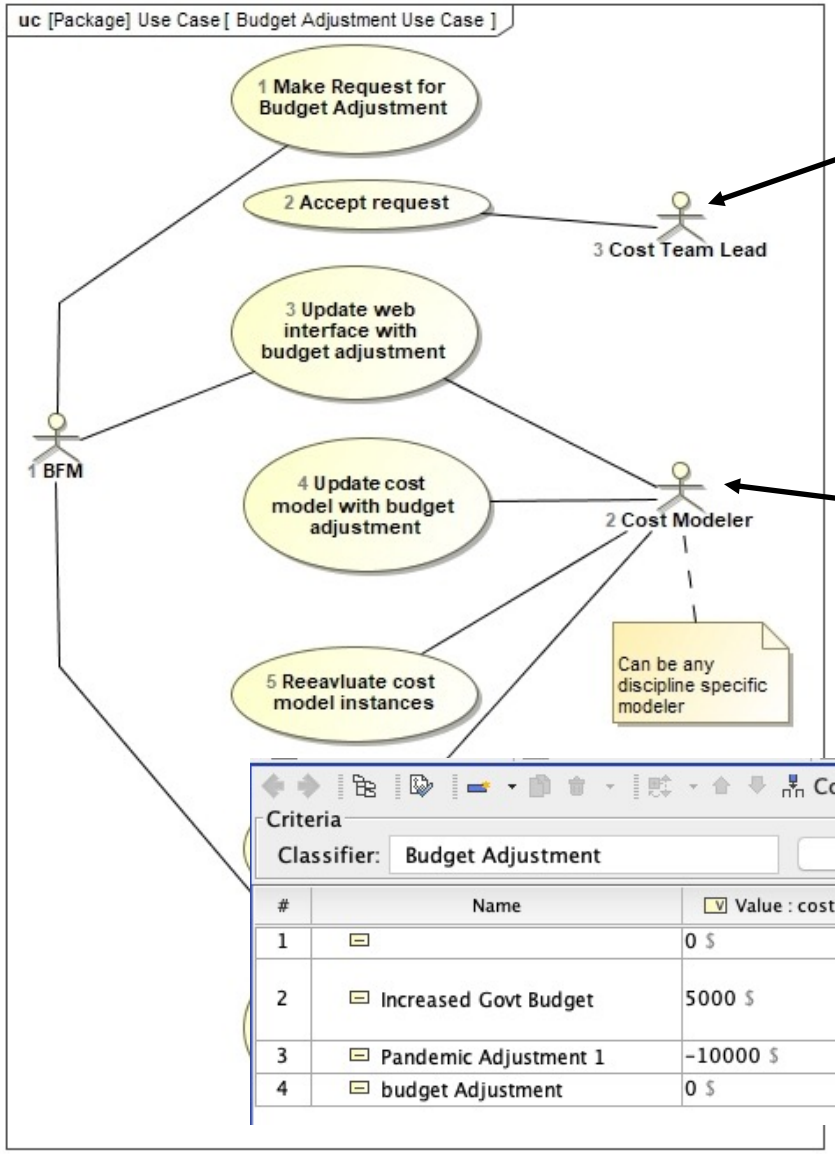
Figure 14. EMD Build Cost

Generation of Total Ownership Cost Table

#	Name	Total Ownership Cost : cost[dollars]	Development : cost[dollars]	EMD Design : cost[dollars]	EMD Build : cost[dollars]	Production & Deployment : cost[dollars]	Test & Evaluation : cost[dollars]	Operations & Support : cost[dollars]
1	FY2020	69411.66 $	31109.62 $	29003.46 $	1516.54 $	38302.05 $	589.62 $	0 $
2	FY2021	173529.15 $	77774.04 $	72508.65 $	3791.34 $	95755.11 $	1474.05 $	0 $
3	FY2022	240877.15 $	106819.99 $	101512.11 $	5307.88 $	134057.16 $	0 $	0 $
4	FY2023	275288.17 $	122079.99 $	116013.84 $	6066.15 $	153208.18 $	0 $	0 $
5	FY2024	275288.17 $	122079.99 $	116013.84 $	6066.15 $	153208.18 $	0 $	0 $
6	FY2025	240877.15 $	106819.99 $	101512.11 $	5307.88 $	134057.16 $	0 $	0 $
7	FY2026	189260.62 $	83929.99 $	79759.52 $	4170.48 $	105330.62 $	0 $	0 $
8	FY2027	120438.58 $	53410 $	50756.06 $	2653.94 $	67028.58 $	0 $	0 $
9	FY2028	86027.55 $	38150 $	36254.33 $	1895.67 $	47877.56 $	0 $	0 $
10	FY2029	51616.53 $	22890 $	21752.6 $	1137.4 $	28726.53 $	0 $	0 $

TOC reviewable from ViewEditor, removing stakeholder navigation of containment tree (NOT Actual Data)

Budget Adjustment Use Case - (See Video)



The Actors are Roles

(Discipline-Specific Modeler)

Walkthrough scenario for demo

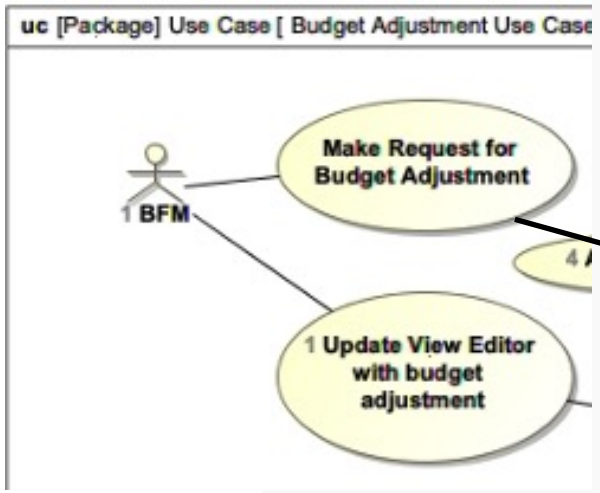
Columns | Export

Criteria

Classifier: Budget Adjustment ... Scope (optional): Budget Adjustment Instances ... Filter:

#	Name	Value : cost[dollars]	Reasoning : String	Date : String	Adjustor : String	From : String	To : String
1		0 $					
2	Increased Govt Budget	5000 $	Increased Government Spending	2022	Program	2024	2026
3	Pandemic Adjustment 1	-10000 $	COVID-19 Pandemic	2020	Taylor Fields	2020	2022
4	budget Adjustment	0 $					

Budget Financial Manager



Surrogate Pilot Switch Org | Search selected project | UAT

oject: Skyzer Cost Model › Budget Adjustments | Branc

Filter table of contents

- Budget Adjustments
  - 1 Adjustment Summary Table

DOCLIB

Document Last Modified: 2/11/21 5:04 PM

Budget Adjustments

Last Modified: 2/9/21 2:40 PM by **taylor.fields**

1 Adjustment Summary Table

Last Modified: 2/11/21 5:04 PM by **taylor.fields**

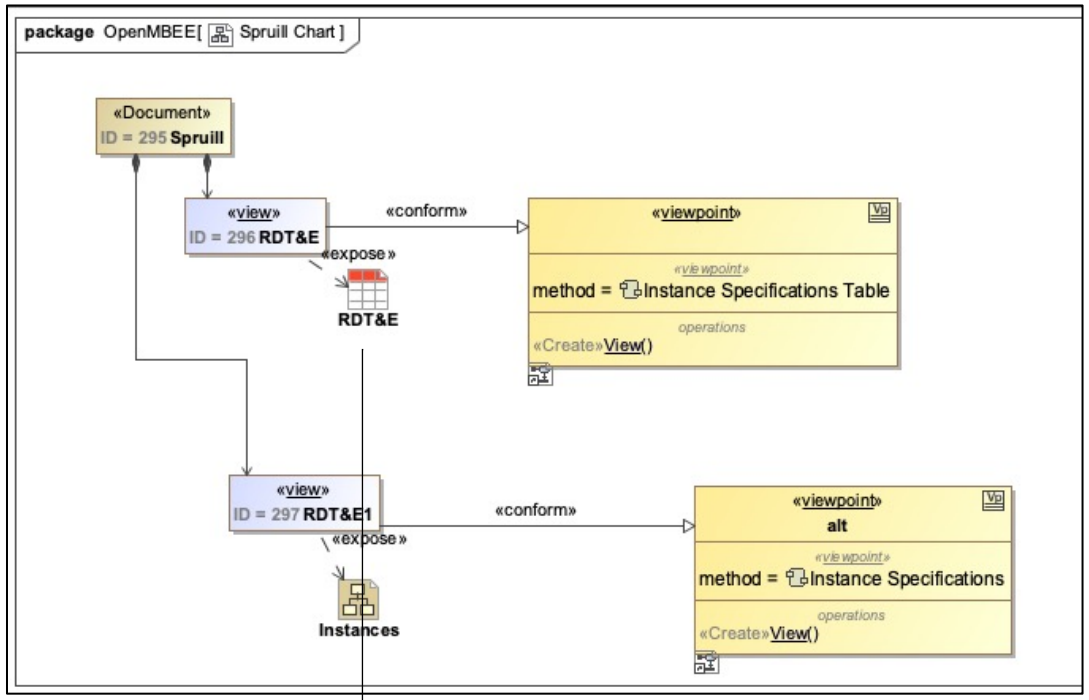
EXPORT CSV | FILTER TABLE

Table 1. <>

Budget Adjustment	Adjustor	Date	Reasoning	Value	From	To
(no name)	(no value)	(no value)	(no value)	0.0		
budget Adjustment	(no value)	(no value)	(no value)	0.0	(no value)	(no value)
Increased Govt Budget	Program	2022	Increased Government Spending	5000.0	Value : 2024 ADD	2026
Pandemic Adjustment 1	Taylor Fields	2020	COVID-19 Pandemic	-10000.0	2020	2022

Used DocGen and Excel for Synchronization

OpenMBEE DocGen/Cameo Publisher



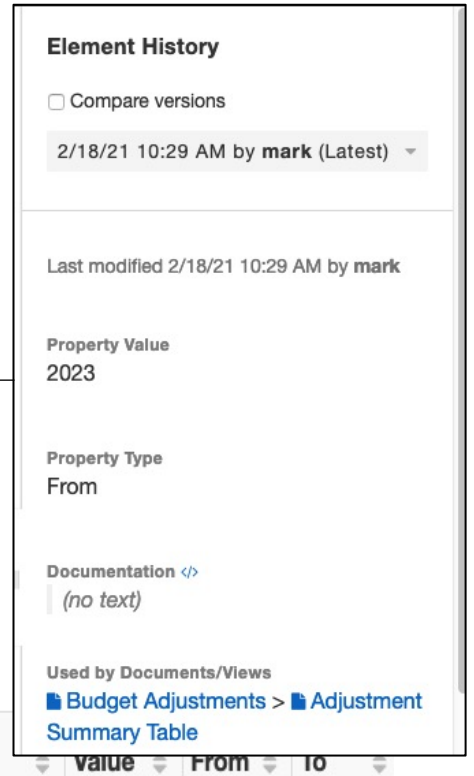
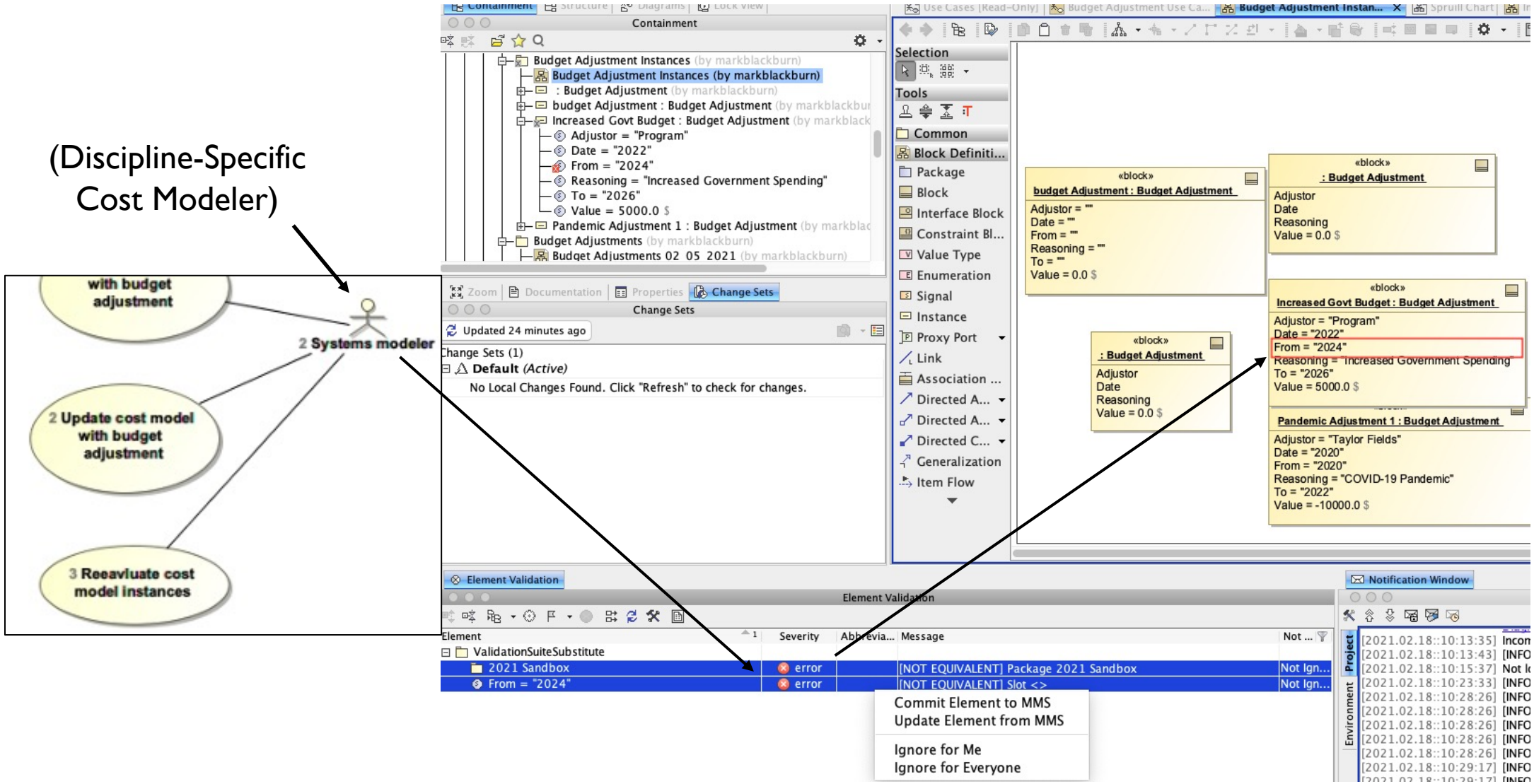


Table 1. <>

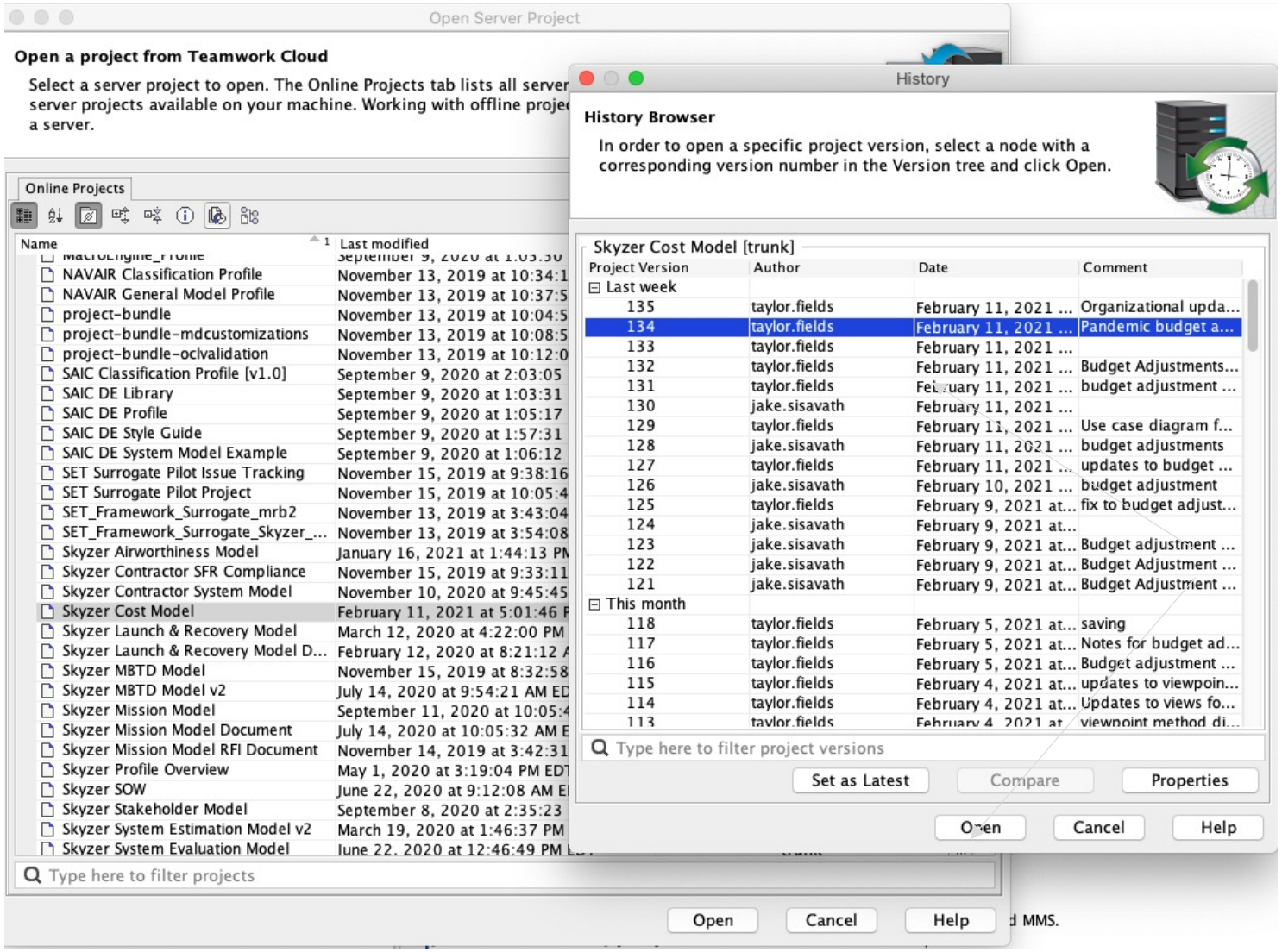
Budget Adjustment	Adjustor	Date	Reasoning	Value	From	To
(no name)	(no value)	(no value)	(no value)	0.0		
budget Adjustment	(no value)	(no value)	(no value)	0.0	(no value)	(no value)
Increased Govt Budget	Program	2022	Increased Government Spending	5000.0	2023	2026
Pandemic Adjustment 1	Taylor Fields	2020	COVID-19 Pandemic	-10000.0	2020	2022

Final Synchronization Done in Model to Establish Authoritative Source of Info

(Discipline-Specific Cost Modeler)



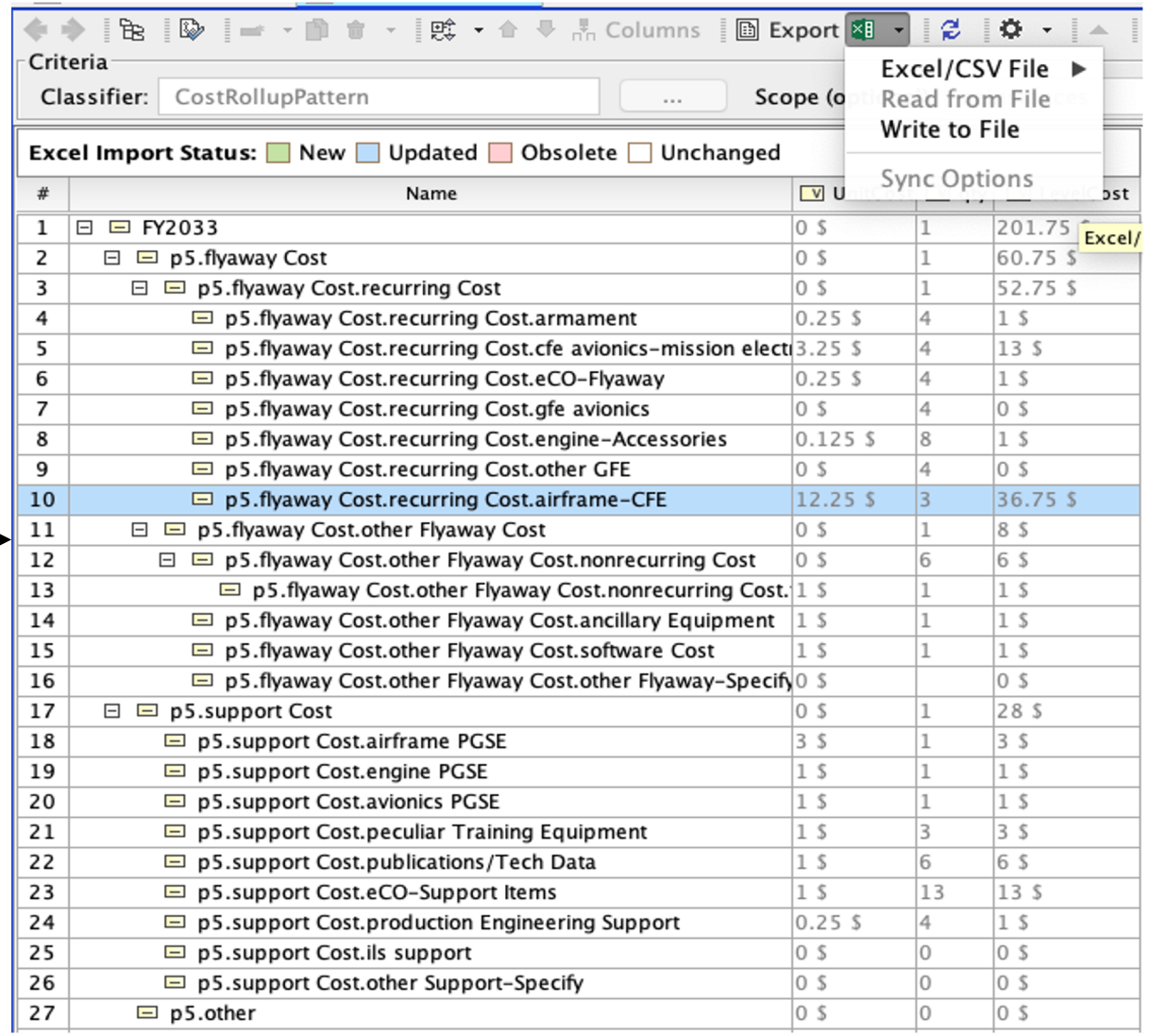
Actual Commit by Role With Additional/Appropriate Privileges



We can rollback

Update to P-5 Rollup

Can do updates in exported Excel Spreadsheet and Synchronize back into Model for Commit



#	Name	U		ost
1	FY2033	0 $	1	201.75 $
2	p5.flyaway Cost	0 $	1	60.75 $
3	p5.flyaway Cost.recurring Cost	0 $	1	52.75 $
4	p5.flyaway Cost.recurring Cost.armament	0.25 $	4	1 $
5	p5.flyaway Cost.recurring Cost.cfe avionics-mission electi	3.25 $	4	13 $
6	p5.flyaway Cost.recurring Cost.eCO-Flyaway	0.25 $	4	1 $
7	p5.flyaway Cost.recurring Cost.gfe avionics	0 $	4	0 $
8	p5.flyaway Cost.recurring Cost.engine-Accessories	0.125 $	8	1 $
9	p5.flyaway Cost.recurring Cost.other GFE	0 $	4	0 $
10	p5.flyaway Cost.recurring Cost.airframe-CFE	12.25 $	3	36.75 $
11	p5.flyaway Cost.other Flyaway Cost	0 $	1	8 $
12	p5.flyaway Cost.other Flyaway Cost.nonrecurring Cost	0 $	6	6 $
13	p5.flyaway Cost.other Flyaway Cost.nonrecurring Cost.	1 $	1	1 $
14	p5.flyaway Cost.other Flyaway Cost.ancillary Equipment	1 $	1	1 $
15	p5.flyaway Cost.other Flyaway Cost.software Cost	1 $	1	1 $
16	p5.flyaway Cost.other Flyaway Cost.other Flyaway-Specify	0 $		0 $
17	p5.support Cost	0 $	1	28 $
18	p5.support Cost.airframe PGSE	3 $	1	3 $
19	p5.support Cost.engine PGSE	1 $	1	1 $
20	p5.support Cost.avionics PGSE	1 $	1	1 $
21	p5.support Cost.peculiar Training Equipment	1 $	3	3 $
22	p5.support Cost.publications/Tech Data	1 $	6	6 $
23	p5.support Cost.eCO-Support Items	1 $	13	13 $
24	p5.support Cost.production Engineering Support	0.25 $	4	1 $
25	p5.support Cost.ils support	0 $	0	0 $
26	p5.support Cost.other Support-Specify	0 $	0	0 $
27	p5.other	0 $	0	0 $

Video Shows Demonstration for Several Scenarios

- Walkthrough Skyzer Cost Model
- Discuss Model Organization and Navigation
- Look at a few scenarios
  - Cost roll-up pattern
  - Mechanisms that allow subject matter experts to adjust cost values through using Export/Import spreadsheet that are synchronized back into the Cost Model
  - Automated cost equation substitution
- Check *Systems Engineering Research Center YouTube* for Video to be posted

Accomplishments

- Demonstrated Cost Model Stakeholder Analysis Model linked to Skyzer technical models for cost model criteria, relationships and to generate various reports
- Demonstrated how standard cost-estimating relationships (CERS) and methodologies (CEMs) are applied to these models
- Used technical data for parametric total ownership cost (TOC) estimates
- Aligned MBSE Cost Model with with MIL-STD-881E
- Automatically generated reports (e.g., P-5 sheet, Spruill Charts)
- Demonstrated approach for Cost Model modularization (e.g., Project Usages) for access and control
- Ready to initiate on small number of DoD programs as trials

Thank you!

- Dr. Mark Blackburn
- Senior Research Scientist
- Principal Investigator
- Member of SERC Research Council
- Member of OpenMBEE Leadership Team
- School of Systems & Enterprises
- Systems Engineering Research Center
- Stevens Institute of Technology