



Reliability Analysis of Complex NASA Systems with Model Based Engineering

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Model-based System Engineering for Reliability Analysis

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SESSION – 12

MBSMA



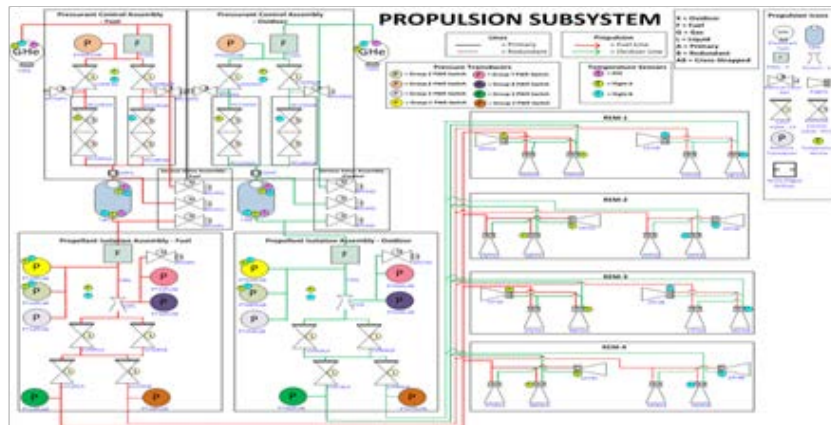
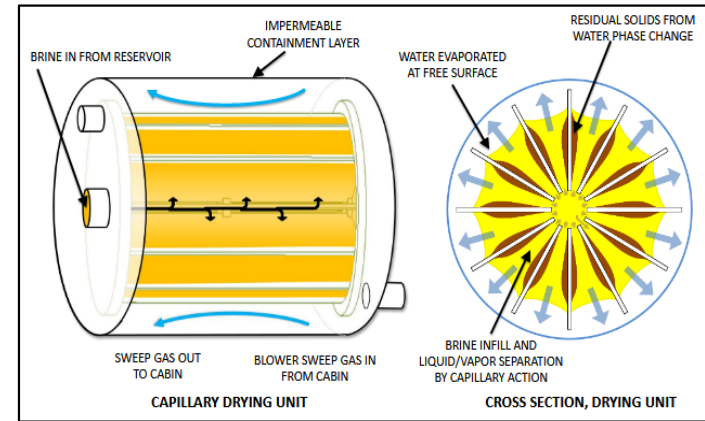
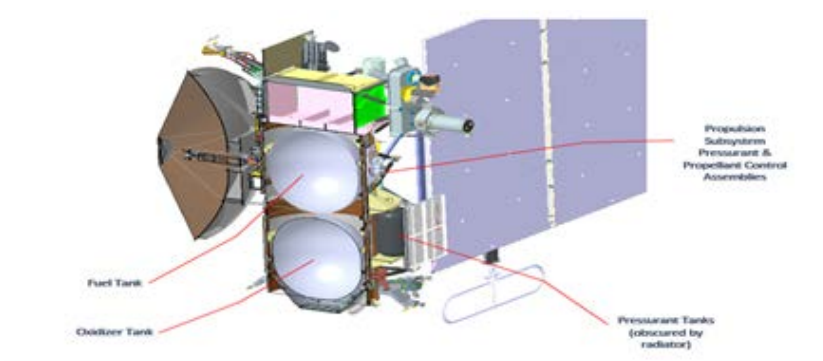
MBSMA Initiative Pathfinder Partner Project Objectives

- Investigate methodologies for the deployment of Model Based SMA/MA:
 - Reliability (e.g., FMECA, LLA, FTA, PRA, Maintainability, Availability)
 - System Safety (e.g., MSPSP, Hazard Analysis)
 - Software Assurance (e.g., Control/Testing Plans, Process/Supplier Risks, Software FMECA/FTA)
 - Quality Assurance (e.g., Control/Testing Plans, Process/Supplier Risks, Parts/Materials Approvals, Mission Assurance Requirements, PRACA/FRACAs)
- Provide Recommendations, Guidance, and Risk-Based Strategies for MBSMA/MA and MBSE Collaboration

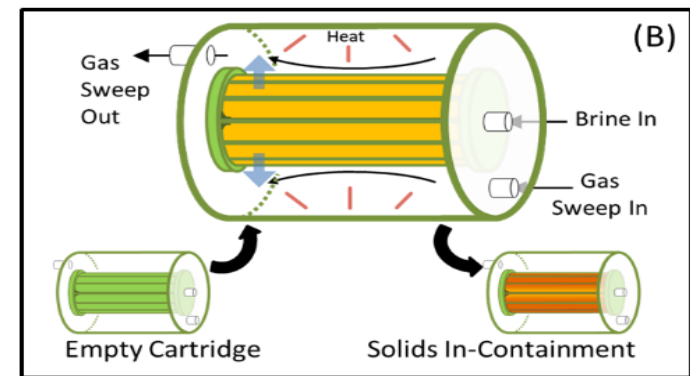
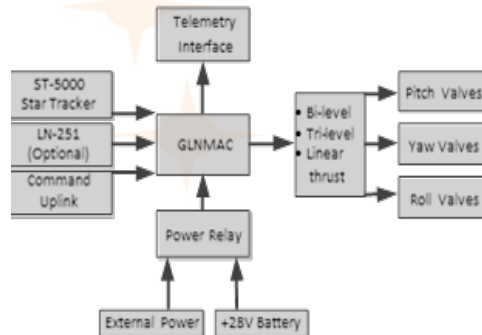
Is Model-Based Engineering valid and useable for Reliability Engineering for NASA mission Safety and Mission Assurance ?

MBSMAI Methodology

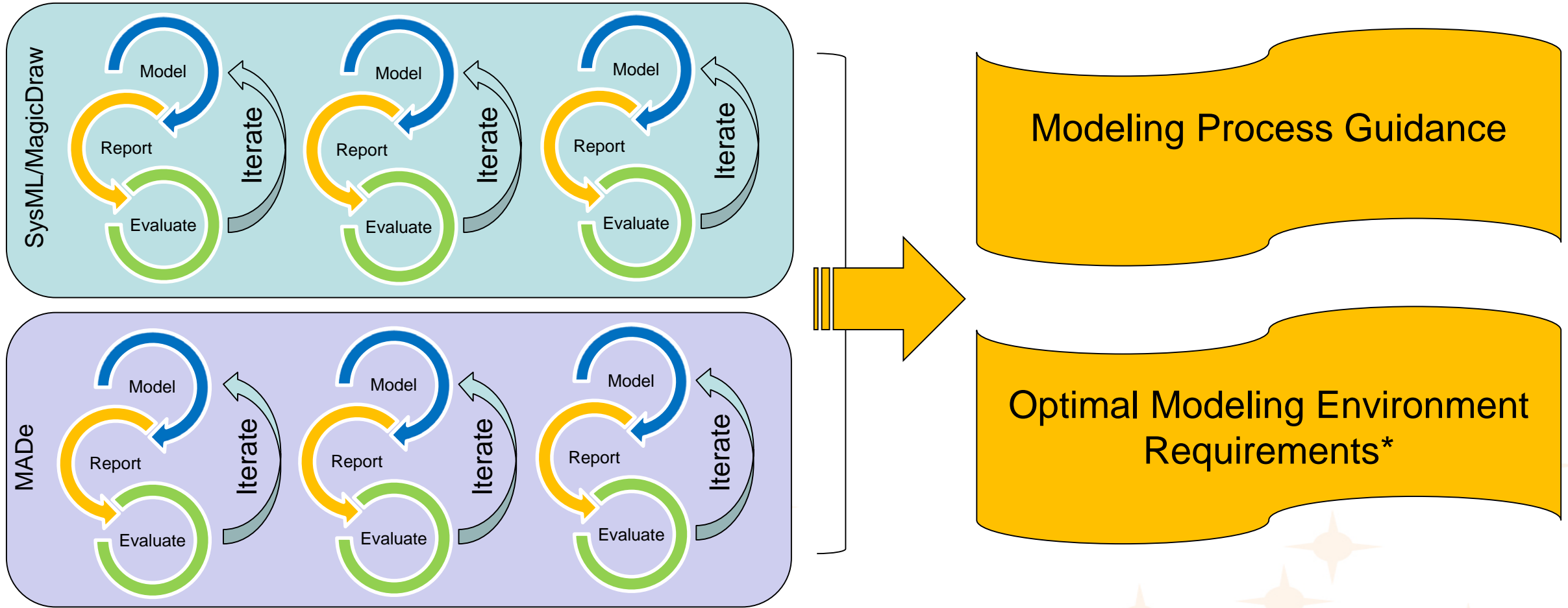
Use three mission test cases to evaluate the ability of Model-Based Engineering to support Reliability Analyses of Probability Analysis (PA) Failure Mode Effects and Criticality Analysis (FMECA), Fault Tree Analysis (FTA), and Limited Life Analysis (LLA).



Celestial ACS Block Diagram



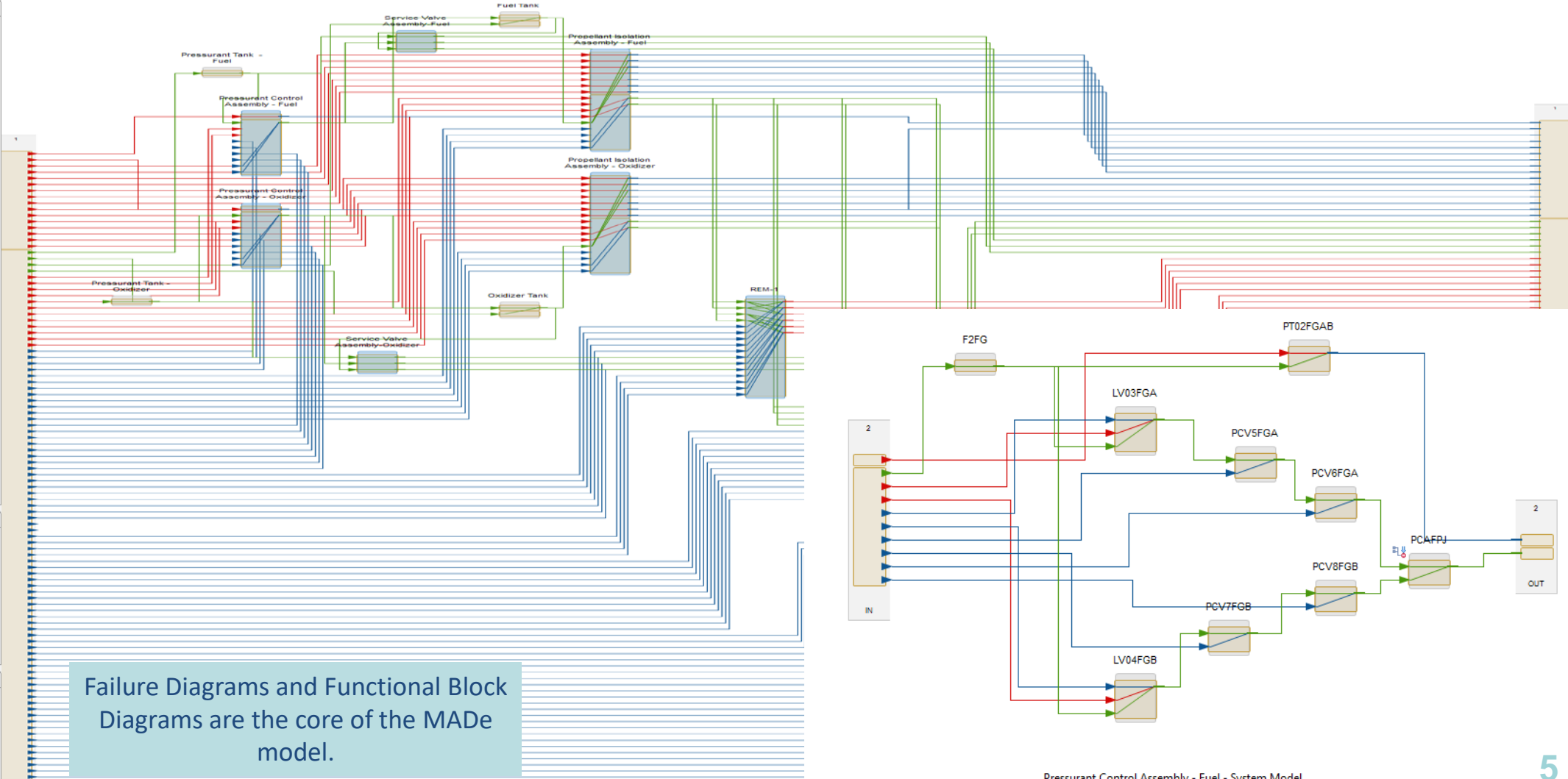
MBSMAI Methodology



* Tool readiness was also assessed.

MBSMAI Phase 1: EUROPA Propulsion Modeling

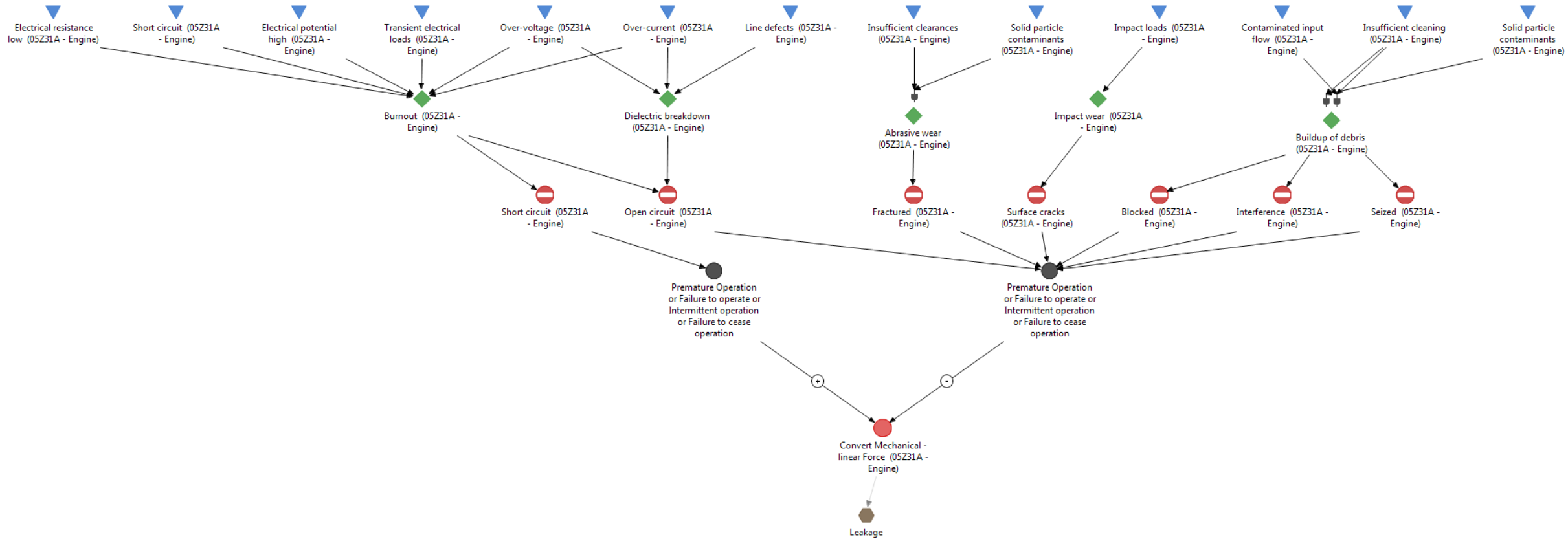
The Project Explorer panel on the left shows a hierarchical tree structure for the 'Propulsion' system. It includes sub-panels for 'Functions' (listing items like F3XL, F3X, Refine, Failure Diagram, Cause, Mechanism, Fault, Failure Condition) and 'Failure Concepts' (listing categories like Assembly and reassembly, Design, Maintenance, Manufacturing, Operation, Transportation). A 'Palette' and 'Library' panel at the bottom shows 'Components [107]' and 'Parts [134]'.



Failure Diagrams and Functional Block Diagrams are the core of the MAde model.

Pressurant Control Assembly - Fuel - System Model

MBSMAI Phase 1: EUROPA Propulsion Modeling



05Z31A - Engine - Failure Diagram

Failure Diagrams and Functional Block Diagrams are the core of the MADe model.



MBSMAI Phase 1: EUROPA Propulsion Modeling

The screenshot displays the RAMS software interface for modeling the propulsion system of the Europa lander. The main workspace shows a complex network of components and their interconnections, including Fuel Tanks, Pressurant Control Assemblies, and Propellant Isolation Assemblies. A central text box states: "The inherent error checking capability of MADe was able to alert the modeler of any discrepancy in the design."

The **Properties** window for the **Fuel Tank** component is visible, showing the following settings:

- General:** Duration of Operation (hrs): 653.6
- Bond:** Mean Time To Repair (hrs): 15.0
- Functional Failures:** Delay Time (hrs): 0.0
- Reliability:** Turn Around Time (hrs): 0.0
- Exponential:** Spares on Hand: 0
- Failure Distribution Type:** Exponential

The **Problems** window lists 42 warnings, including:

Name	Model
⚠ The 'LV02XGB' failure concept is disconnected	LV02XGB -> Surface cracks
⚠ The 'PCV3XGB' failure concept is disconnected	PCV3XGB -> Surface cracks
⚠ The In Flow, Control Gas (LV01XGA), contains flow properties that	LV01XGA -> Control (In Flows) -> G...
⚠ The In Flow, Control Gas (LV02XGB), contains flow properties that	LV02XGB -> Control (In Flows) -> Gas
⚠ The In Flow, Control Gas (LV03FGA), contains flow properties that	LV03FGA -> Control (In Flows) -> Gas
⚠ The In Flow, Control Gas (PCV1XGA), contains flow properties that	PCV1XGA -> Control (In Flows) -> ...
⚠ The In Flow, Control Gas (PCV2XGA), contains flow properties that	PCV2XGA -> Control (In Flows) -> ...
⚠ The In Flow, Control Gas (PCV3XGB), contains flow properties that	PCV3XGB -> Control (In Flows) -> ...
⚠ The In Flow, Control Gas (PCV4XGB), contains flow properties that	PCV4XGB -> Control (In Flows) -> ...
⚠ The In Flow, Control Gas (PCV5FGA), contains flow properties that	PCV5FGA -> Control (In Flows) -> ...
⚠ The In Flow, Control Gas (PCV6FGA), contains flow properties that	PCV6FGA -> Control (In Flows) -> ...
⚠ The In Flow, Control Gas (PCV7FGB), contains flow properties that	PCV7FGB -> Control (In Flows) -> G...
⚠ The In Flow, Control Gas (PCV8FGB), contains flow properties that	PCV8FGB -> Control (In Flows) -> G...
⚠ The In Flow, Control Liquid (LV05XLA), contains flow properties th	LV05XLA -> Control (In Flows) -> Li...
⚠ The In Flow, Control Liquid (LV06XLB), contains flow properties th	LV06XLB -> Control (In Flows) -> Li...

MBSMAI Phase 1: EUROPA Propulsion Modeling

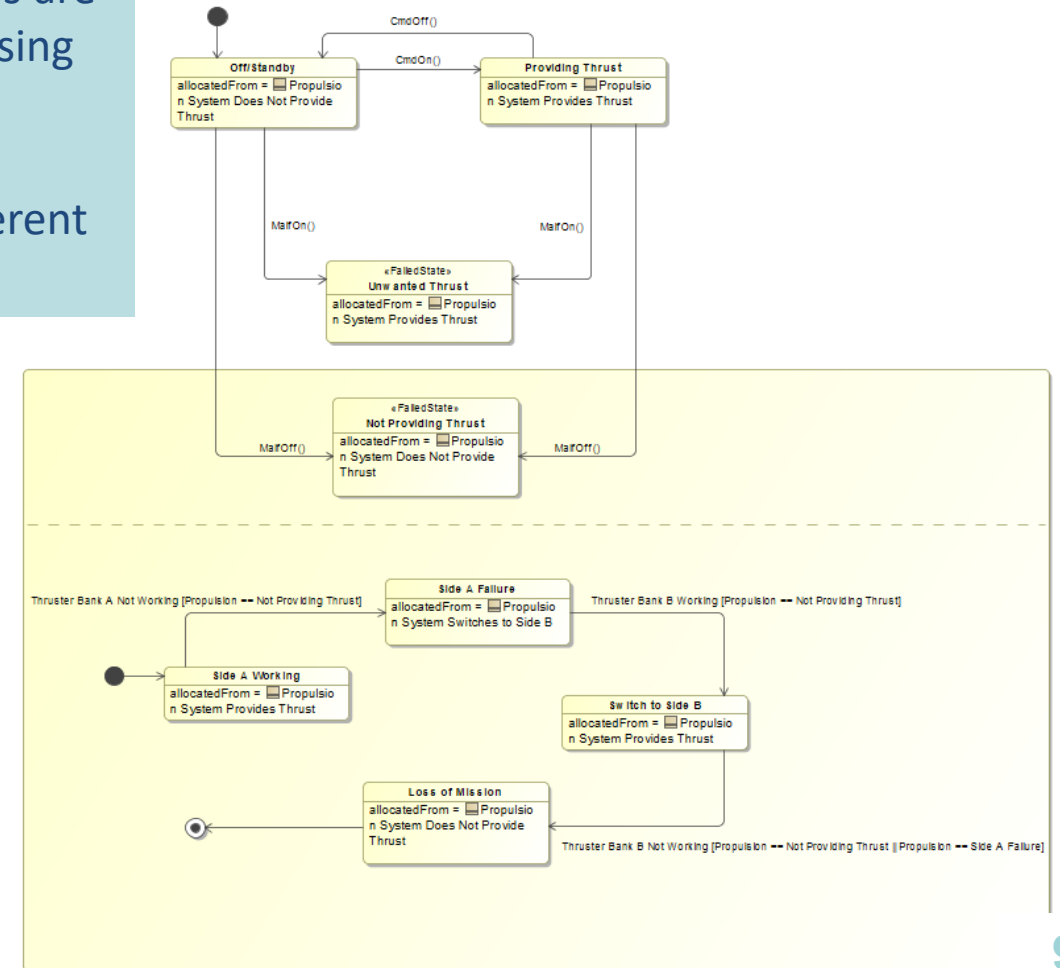
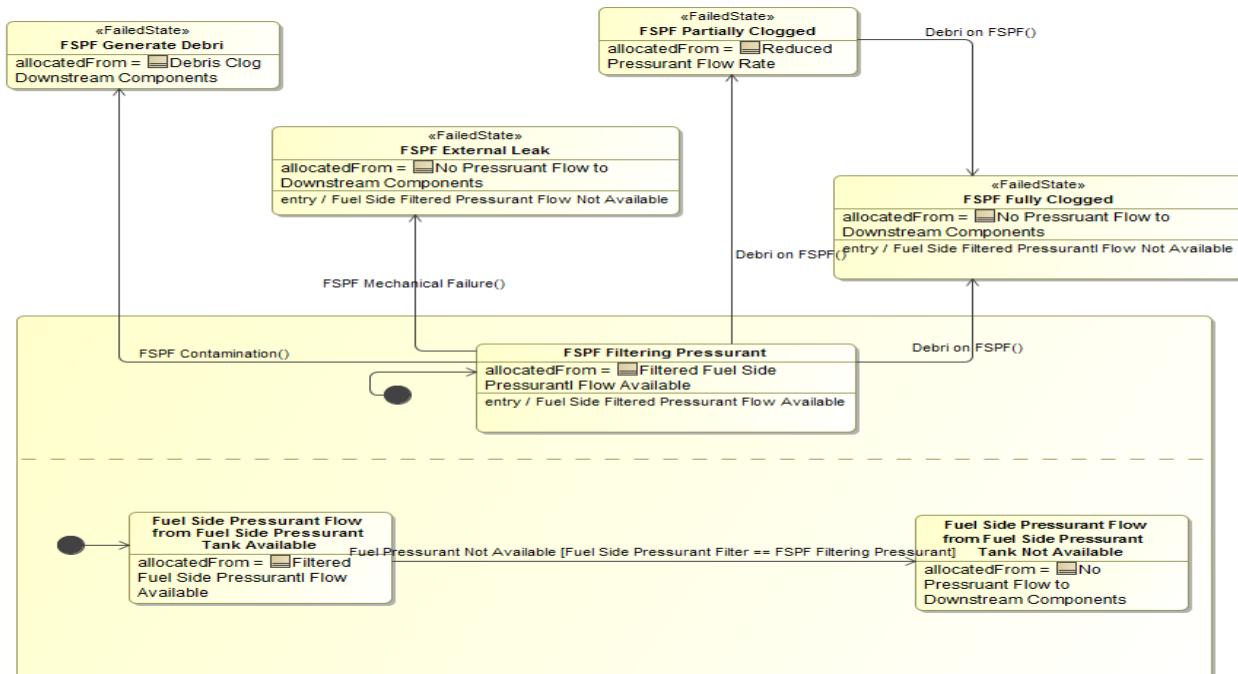
The screenshot displays the MBSMAI Phase 1 software interface. The main workspace shows a detailed block diagram of a propulsion system, including components like pressure transducers, tanks, filters, and valves. The left sidebar contains a 'Containment' tree with a hierarchical view of the model's structure. The top toolbar includes various modeling tools, and the right sidebar features 'Create Element' and 'Create Diagram' menus. A text box in the center of the interface provides context for the modeling process.

Defining the model required the modeler to use different elements i.e. Block, Operation, Signal, etc.) and different diagrams (i.e. State Machine Diagram).

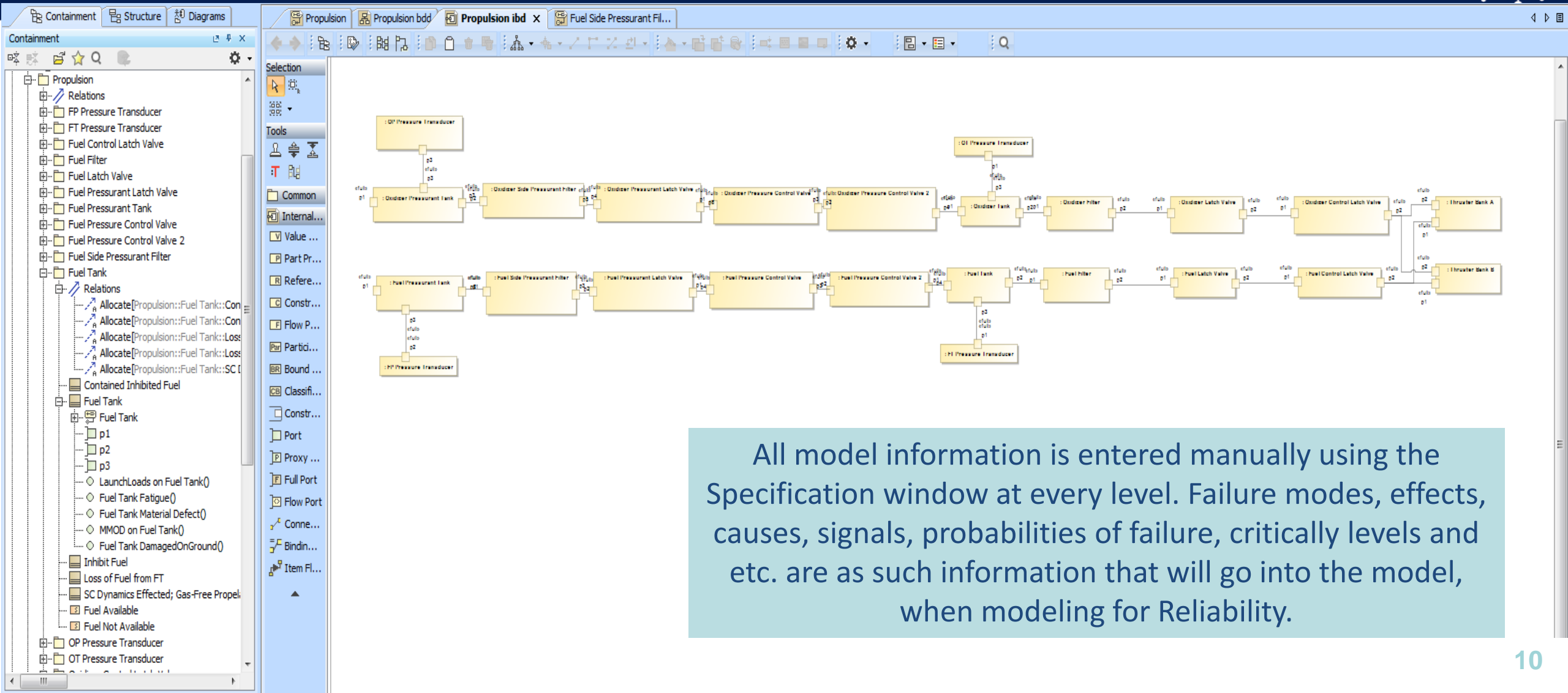
MBSMAI Phase 1: EUROPA Propulsion Modeling

Defining Orthogonal State Machines with appropriate Guard Conditions are required in order to define Redundancy in SysML/MagicDraw when using Tietronox Plugin.

Appropriate signal were defined in order to connect the model at different levels.



MBSMAI Phase 1: EUROPA Propulsion Modeling



All model information is entered manually using the Specification window at every level. Failure modes, effects, causes, signals, probabilities of failure, critically levels and etc. are as such information that will go into the model, when modeling for Reliability.

MBSMAI Phase 1: EUROPA Model Probability Analysis Evaluation

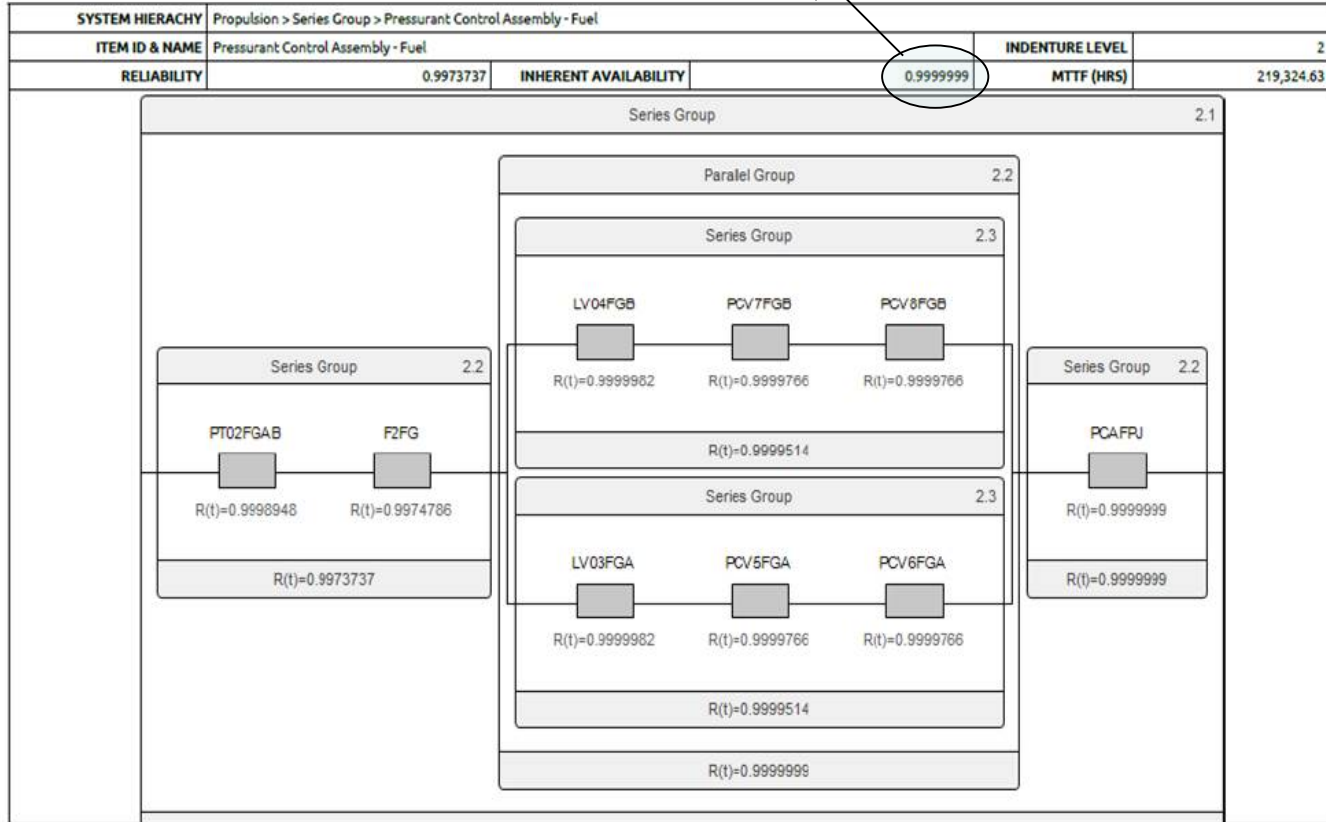
Europa Propulsion 7-3-2018

Reliability Block Diagram Report

Jul 12, 2018 1:44:42 PM

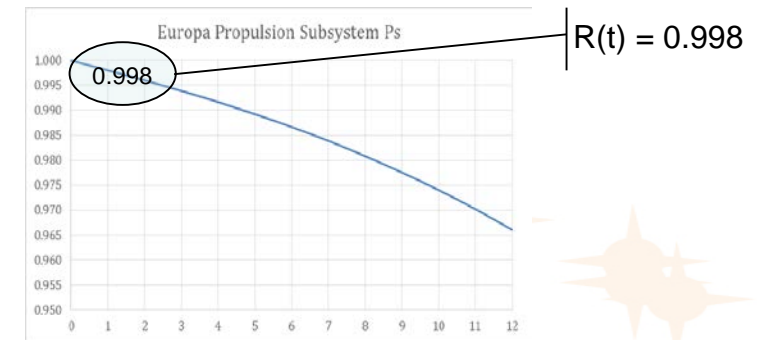
RBD DIAGRAMS

$$R(t) = 0.9999999$$



The Probability of failure reported for the entire Europa Propulsion Subsystem at 12 Yrs. (0.0387234) by the MADE fault tree module corresponds to the Probability of Success/Reliability reported by the MADE RBD module (0.9612766).

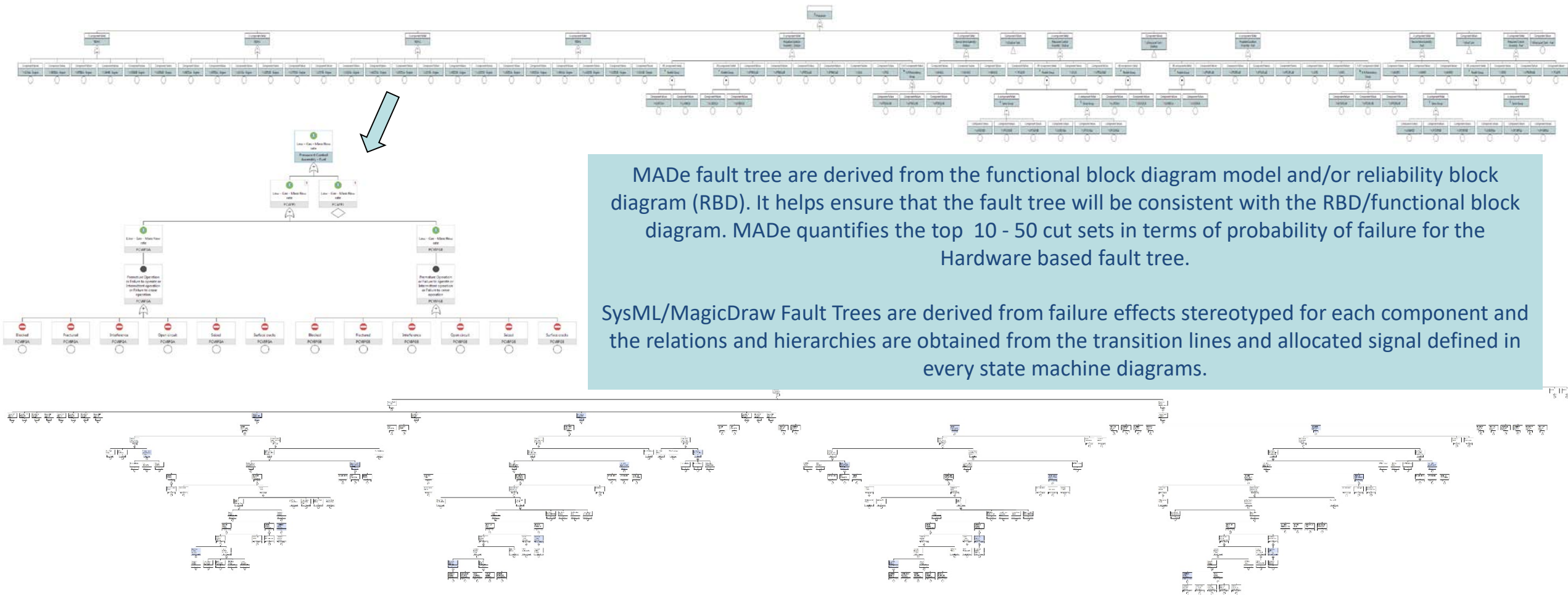
MADE RBD prediction results matches to about 5 decimal places to the traditional method on a component per component basis



SysML/MagicDraw with Tietronix plugins does not currently support Probability Analysis. However, custom Plugins have been developed by individual enterprises.



MBSMAI Phase 1: EUROPA Model Fault Tree Evaluation



MBSMAI Phase 1: Sounding Rocket Modeling

Project Explorer

- Sounding Rocket [2/22]
 - Functions [2]
 - Payload [4/17]
 - Functions [2]
 - ACS [1/13]
 - Functions [2]
 - Celestial ACS [12/12]
 - Functions [2]
 - Airborne Computer
 - Functions [3]
 - Transmit [1]
 - Transmit [2]
 - Convert [7]
 - Failure Diagram
 - Cause [22]
 - Mechanism [6]
 - Fault [8]
 - Failure Condition [36]
 - Battery
 - Command Uplink
 - IMU
 - Pitch Valve
 - Plumbing
 - Power Relay
 - Roll Valve
 - Star Tracker
 - Tank
 - Telemetry Interface
 - Yaw Valve
 - Instrument
 - Parachute Recovery
 - Telemetry
 - Rocket Engine [3/3]

Failure Concepts

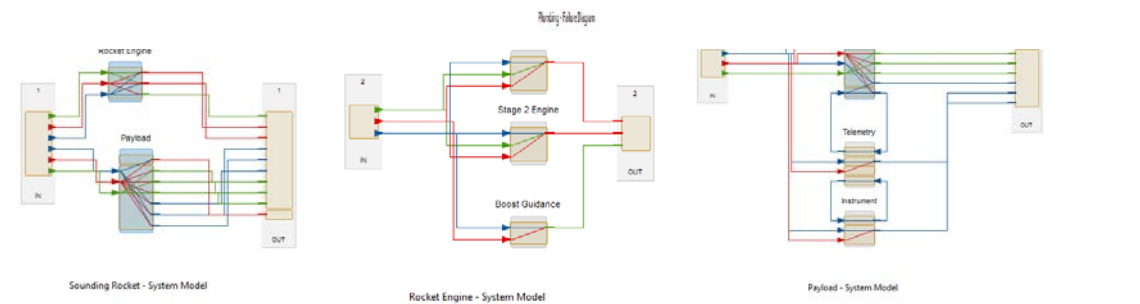
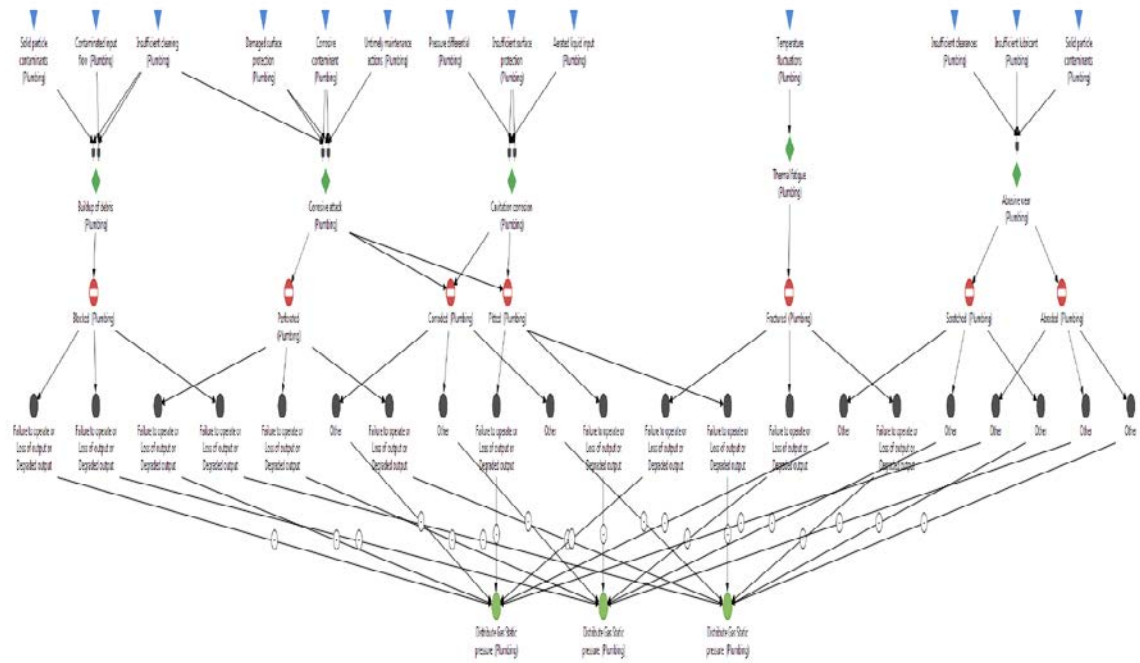
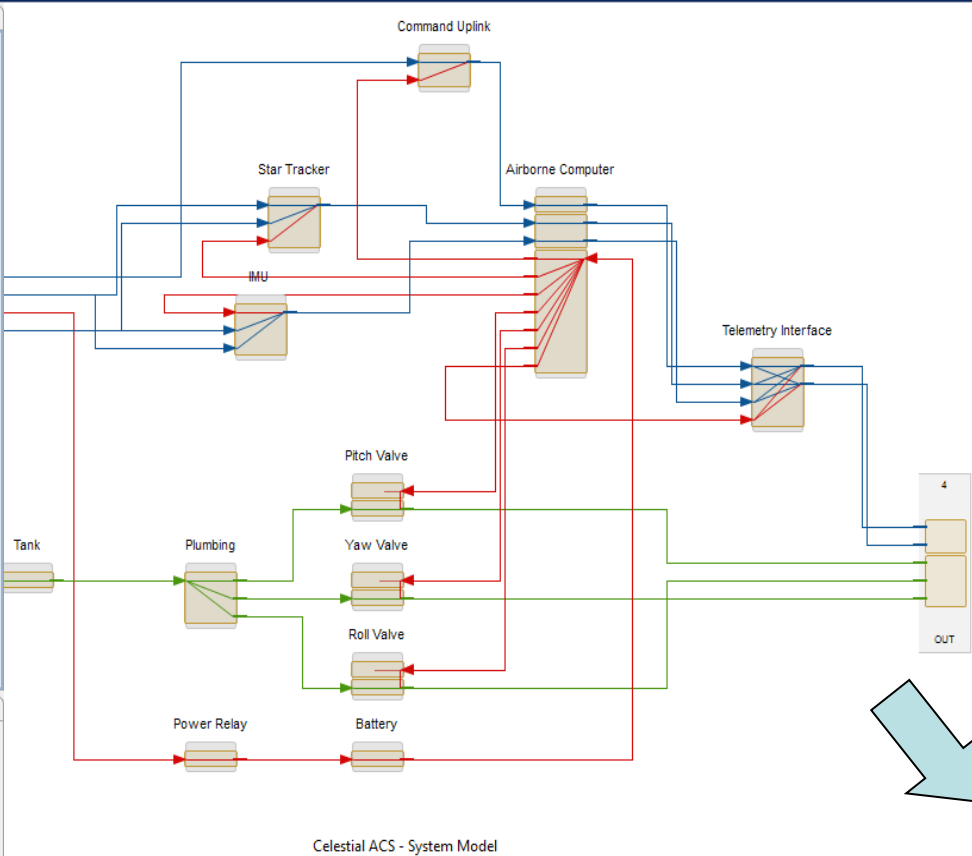
Search...

- Assembly and reassembly
- Design
- Maintenance
- Manufacturing
- Operation
- Transportation

Palette | **Library** | **Outline**

Search...

- Components [107]
- Parts [134]



MBSMAI Phase 1: Sounding Rocket Modeling

Compensating Provisions - Perforating of the Plumbing

Assign one or more Compensating Provisions for Perforating of the Plumbing.

Compensating Provisions	Detection Methods
<input checked="" type="checkbox"/>	<input type="checkbox"/>
<input checked="" type="checkbox"/> Abort Mission	Aborting or canceling the mission in response to the failure.
<input type="checkbox"/> Change System Configuration	Changing the system configuration to resolve the failure.
<input type="checkbox"/> Condition-based Maintenance	Repairing or replacing the item in a condition-directed manner.
<input checked="" type="checkbox"/> Modify Mission	Modifying the mission phase, segment, capability or objective in response
<input type="checkbox"/> Modify Sensor Set	Adding or modifying a sensor/alarm to the failure.
<input checked="" type="checkbox"/> Override System	A manual or automatic override of an item to a standby item.

Narrative

Reuired Narrative in case the options are not explanitory enough.

Criticality & Reliability Editor

Item / Failure Selection

- Sounding Rocket
 - Convert
 - Gas - Mass flow rate
 - Pneumatic - Mass flow rate
 - Pneumatic - Mass flow rate
 - Discrete - Data
 - Discrete - Data
 - Discrete - Data
 - Gas - Mass flow rate
 - Gas - Mass flow rate
 - Gas - Mass flow rate
 - Inhibit
 - Mechanical - linear - Linear velocity
 - Payload
 - Rocket Engine

Very Low

High

Probability/Occurrence: 2.0

Extremely Improbable

Severity: 7.0

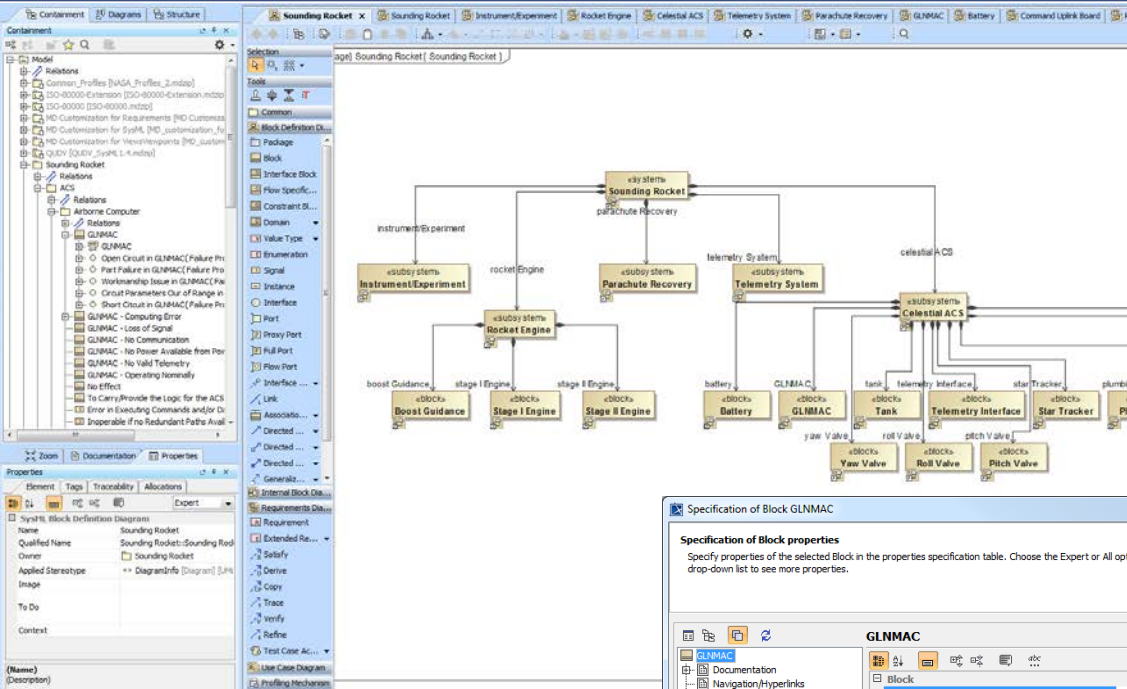
Severe Major

Low

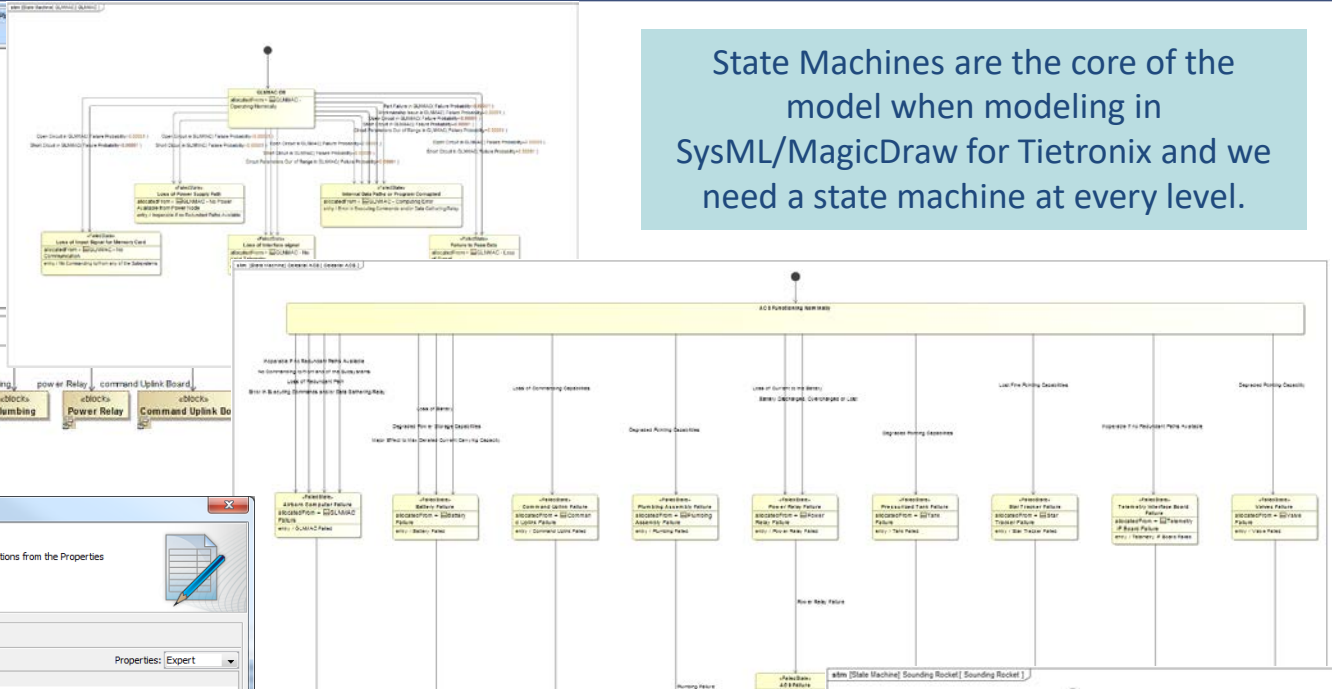
Probability/Occurrence: 4.0

Extremely Remote

MBSMAI Phase 1: Sounding Rocket Modeling



State Machines are the core of the model when modeling in SysML/MagicDraw for Tietronix and we need a state machine at every level.

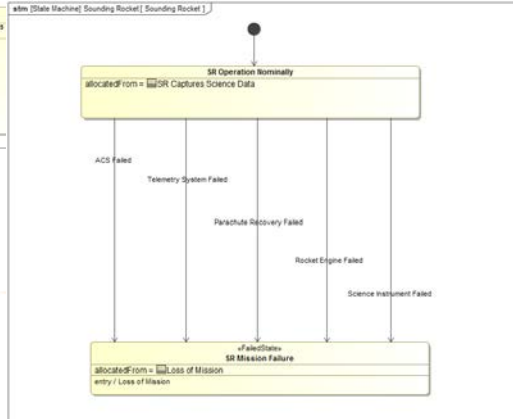


Specification of Block GLNMAC

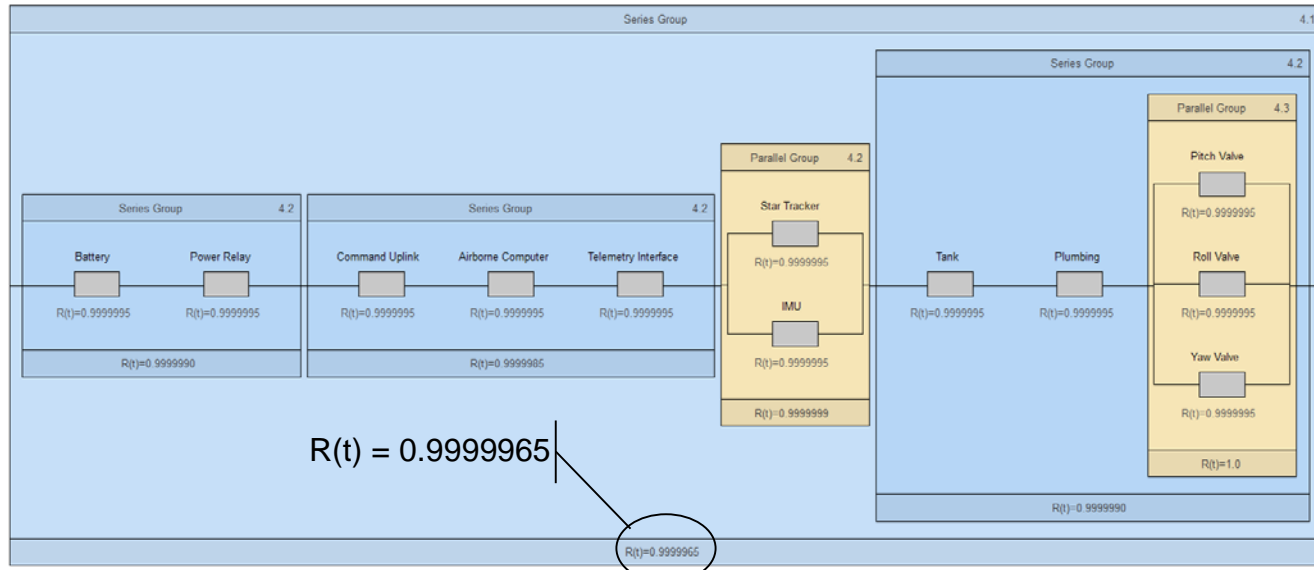
Specify properties of the selected Block in the properties specification table. Choose the Expert or All options from the Properties drop-down list to see more properties.

GLNMAC	Properties: Expert
Block	GLNMAC
Owner	Airborne Computer [Sounding Rocket:ACS]
Qualified Name	Sounding Rocket:ACS:Airborne Computer:GLNMAC
Is Encapsulated	<undefined>
Satisfies	
Applied Stereotype	Block [Class] [SysML::Block]
Is Active	false
Use Case	
Image	
Classifier Behavior	GLNMAC [Sounding Rocket:ACS:Airborne Comput...
Owned Behavior	GLNMAC [Sounding Rocket:ACS:Airborne Comput...
Base Classifier	
Realized Interface	
Name	The name of the NamedElement.

All model information was entered manually using the Specification window at every level. Failure modes, effects, causes, signals, probabilities of failure, critically levels and etc. are as such information that will go into the model, when modeling for Reliability.



MBSMAI Phase 1: Sounding Rocket Probability Analysis Evaluation



ACS												
Subsystem / Component Name	Qty	Model	MTTF/ Char Life / Lognormal Mean	Failure Rate / Shape / Lognormal Std Dev	Relative Duty Cycle	Component Reliability (for time in years)			Redundancy Configuration	Subsystem Reliability (for time in years)		
						5.70E-05	1	1		5.70E-05	1	1
Star Trackers	1			0.00000017	100%	0.99999915	0.998511908	0.998511908	Single String	0.99999915	0.998511908	0.998511908
Star Tracker Head (Mini Star Tracker)	1	E	38461538.46	0.00000026		0.999999987	0.999772266	0.999772266	Single String	0.99999915	0.998511908	0.998511908
Star Tracker Processor (Mini Star Tracker)	1	E	6944444.444	0.000000144		0.999999928	0.998739355	0.998739355				
Command Uplink	1			2.05538E-07	100%	0.999999897	0.998201111	0.998201111	Single String	0.99999897	0.998201111	0.998201111
Avionics Board - Medium Complexity	1	E	4865292.2	2.05538E-07		0.999999897	0.998201111	0.998201111				
Telemetry Interface	1			5.481E-07	100%	0.999999726	0.995210152	0.995210152	Single String	0.99999726	0.995210152	0.995210152
Avionics Board - High Complexity	1	E	1824484.5	5.481E-07		0.999999726	0.995210152	0.995210152	Single String	0.99999726	0.995210152	0.995210152
IMU	1			2.28654E-08	100%	0.999999889	0.999799719	0.999799719	Single String	0.99999889	0.999799719	0.999799719
NG Scalable SIRU	1	E	43734201.02	2.28654E-08		0.999999889	0.999799719	0.999799719	Single String	0.99999889	0.999799719	0.999799719
Airborne Computer	1			5.50045E-07	100%	0.999999723	0.995149609	0.995149609	Single String	0.99999723	0.995149609	0.995149609
Avionics Board - High Complexity	1	E	1824484.5	5.481E-07		0.999999726	0.995210152	0.995210152	Single String	0.99999723	0.995149609	0.995149609
Memory	1	E	218906859.7	4.56648E-09		0.999999996	0.999959998	0.999959998				
Power control circuit	1	E	420466859.9	2.37831E-09		0.999999999	0.999979166	0.999979166				
Power	1			1.40818E-08	100%	0.999999873	0.997776719	0.997776719	Single String	0.99999873	0.997776719	0.997776719
Relays	1	E	71013886.22	1.40818E-08		0.999999993	0.998878651	0.998878651	Single String	0.99999873	0.997776719	0.997776719
Battery in LEO (the entire battery; not technology specific)	1	E	4168668.687	0.00000024		0.99999998	0.99789808	0.99789808				
Delta V	1			1.67797E-07	100%	0.999999697	0.994693998	0.994693998	Single String	0.99999697	0.994693998	0.994693998
Tank	1	E	5959577.615	1.67797E-07		0.999999916	0.998531177	0.998531177	Single String	0.99999697	0.994693998	0.994693998
Plumbing	1	E	61103138.13	1.63658E-08		0.999999992	0.998656646	0.998656646				
Thruster Valve	3	E	7089554.5	1.41053E-07		0.999999789	0.9963	0.9963				
ACS Total						0.000057 years	1 years	1 years		0.99999882	0.97951332	0.97951332
Max Redundancy						0.99999882	0.97951332	0.97951332		0.99999882	0.97951332	0.97951332
Min Redundancy						0.99999882	0.97951332	0.97951332		0.99999882	0.97951332	0.97951332

R(t) = 0.9999965

R(t) = 0.9999965

R(t) = 0.999998923

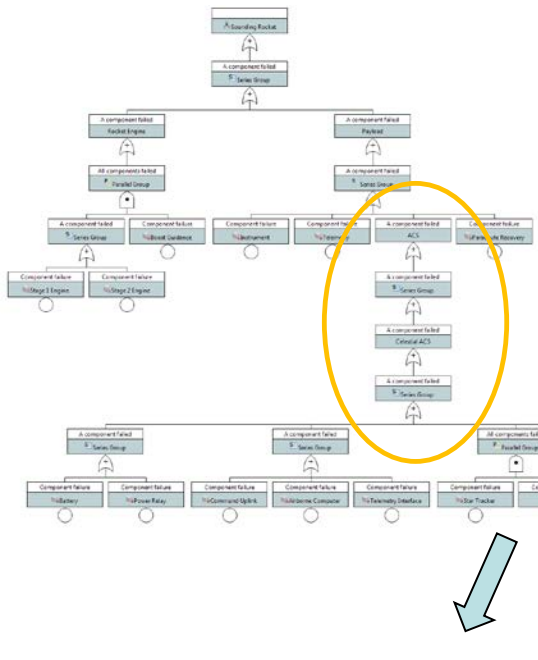
ACS Total

Max Redundancy	0.99999882	0.97951332	0.97951332
Min Redundancy	0.99999882	0.97951332	0.97951332

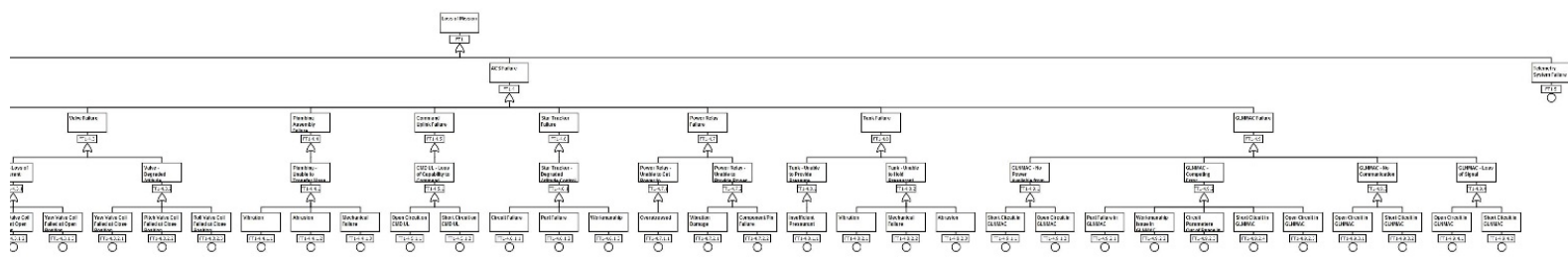
The Probability of failure reported for the Sounding Rocket MADe model corresponds to the Probability of Success/Reliability of the traditional method at the component level; mission life probabilities also compare favorably if the duration and duty cycles assumed for each are the same.

SysML/MagicDraw with Tietronix plugins does not currently support Probability Analysis. However, custom Plugins have been developed by individual enterprises.

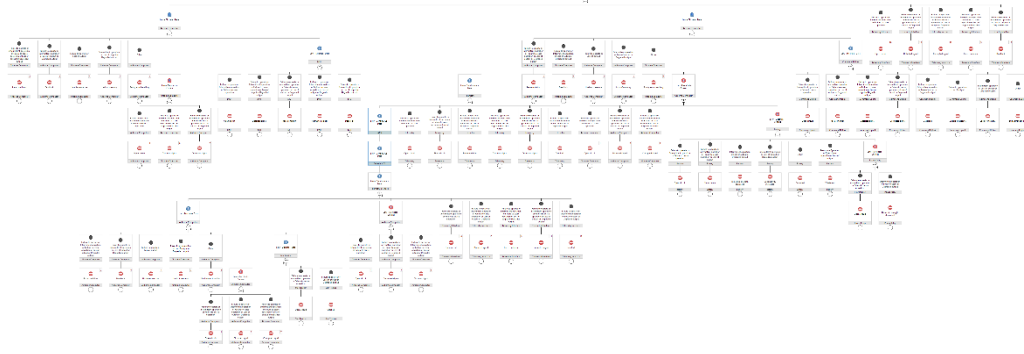
MBSMAI Phase 1: Sounding Rocket Fault Tree Evaluation



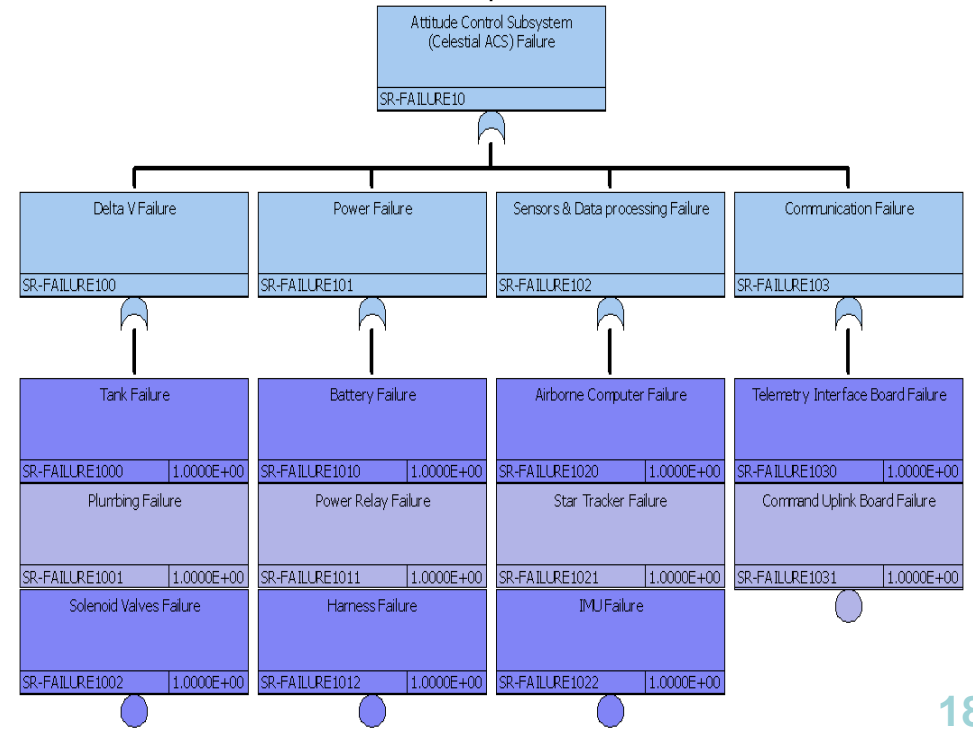
MADe, and Traditional Method Fault Trees show similar basic events.



SysML/MagicDraw Fault Trees also contain Boolean logic errors (i.e., events decomposed into subordinate events without a combining logic or gate, and logic gates with only one input) but perform accurate Boolean math.



SysML/MagicDraw FT output from the Tietronix Plugin shows immediate Failure Causes as the basic event not hardware failure since State Diagrams were optimized for the FMECA.



MBSMA Phase 1: Sounding Rocket Model Failure Modes Effects and Criticality Analysis (FMECA) Evaluation

B1 rows Failure Level: ALL Criticality Level: ALL End Effect: ALL

System	Subsystem	Item #	Item	Potential Failure M...	Immediate Failure Effect	End Effect	Potential Cause(s)	Fault Propagation Path (Explicit)
Sounding...	Sounding...	SR Mission Failure	Loss of Mission	Loss of Mission	Loss of Mission	1	ACS Failed	
Sounding...	Sounding...	SR Mission Failure	Loss of Mission	Loss of Mission	Loss of Mission	1	Telemetry System Failed	
Sounding...	Sounding...	SR Mission Failure	Loss of Mission	Loss of Mission	Loss of Mission	1	Parachute Recovery Failed	
Sounding...	Sounding...	SR Mission Failure	Loss of Mission	Loss of Mission	Loss of Mission	1	Rocket Engine Failed	
Sounding...	Sounding...	SR Mission Failure	Loss of Mission	Loss of Mission	Loss of Mission	1	Science Instrument Failed	
Sounding...	Celestial...	SR Mission Failure	Loss of Mission	Loss of Mission	Loss of Mission	3	Item in Escalating Command and/or B...	Celestial ACS Airborn Computer Failure >> Signal: GUMMAC Failure >> Celestial ACS ACS Failure >> Signal: ACS Failed >> Sounding Rocket SR Mission Failure
Sounding...	Celestial...	Airborn Computer F...	Loss of Mission	Loss of Mission	Loss of Mission	3	Propagable if no Redundant Paths Av...	Celestial ACS Airborn Computer Failure >> Signal: GUMMAC Failure >> Celestial ACS ACS Failure >> Signal: ACS Failed >> Sounding Rocket SR Mission Failure
Sounding...	Celestial...	Airborn Computer F...	Loss of Mission	Loss of Mission	Loss of Mission	3	Loss of Redundant Path	Celestial ACS Airborn Computer Failure >> Signal: GUMMAC Failure >> Celestial ACS ACS Failure >> Signal: ACS Failed >> Sounding Rocket SR Mission Failure
Sounding...	Celestial...	Airborn Computer F...	Loss of Mission	Loss of Mission	Loss of Mission	3	No Commanding to/from and of the Su...	Celestial ACS Airborn Computer Failure >> Signal: GUMMAC Failure >> Celestial ACS ACS Failure >> Signal: ACS Failed >> Sounding Rocket SR Mission Failure
Sounding...	Celestial...	Battery Failure	Loss of Mission	Loss of Mission	Loss of Mission	3	Celestial ACS Battery Failure >> Signal: Battery Failure >> Celestial ACS ACS Failure >> Signal: ACS Failed >> Sounding Rocket SR Mission Failure >> Signal: ACS Failed >> Sounding Rocket SR Mission Failure	
Sounding...	Celestial...	Battery Failure	Loss of Mission	Loss of Mission	Loss of Mission	3	Degraded Power Storage Capabilities	Celestial ACS Battery Failure >> Signal: Battery Failure >> Celestial ACS ACS Failure >> Signal: ACS Failed >> Sounding Rocket SR Mission Failure >> Signal: ACS Failed >> Sounding Rocket SR Mission Failure
Sounding...	Celestial...	Battery Failure	Loss of Mission	Loss of Mission	Loss of Mission	3	Major Effect to Max Demand Current	Celestial ACS Battery Failure >> Signal: Battery Failure >> Celestial ACS ACS Failure >> Signal: ACS Failed >> Sounding Rocket SR Mission Failure >> Signal: ACS Failed >> Sounding Rocket SR Mission Failure
Sounding...	Celestial...	Command Link Board	Loss of Mission	Loss of Mission	Loss of Mission	3	Loss of Commanding Capabilities	Celestial ACS Command Link Board >> Signal: Command Link Board Loss of Signal >> Celestial ACS ACS Failure >> Signal: ACS Failed >> Sounding Rocket SR Mission Failure
Sounding...	Celestial...	Plumbing Assembly Failure	Loss of Mission	Loss of Mission	Loss of Mission	3	Degraded Pointing Capabilities	Celestial ACS Plumbing Assembly Failure >> Signal: Plumbing Assembly Failure >> Celestial ACS ACS Failure >> Signal: ACS Failed >> Sounding Rocket SR Mission Failure
Sounding...	Celestial...	Power Relay Failure	Loss of Mission	Loss of Mission	Loss of Mission	3	Loss of Current to the Battery	Celestial ACS Power Relay Failure >> Signal: Power Relay Failure >> Celestial ACS ACS Failure >> Signal: ACS Failed >> Sounding Rocket SR Mission Failure
Sounding...	Celestial...	Power Relay Failure	Loss of Mission	Loss of Mission	Loss of Mission	3	Battery Discharged, Overcharged or Lost	Celestial ACS Power Relay Failure >> Signal: Power Relay Failure >> Celestial ACS ACS Failure >> Signal: ACS Failed >> Sounding Rocket SR Mission Failure
Sounding...	Celestial...	Pressurized Tank Failure	Loss of Mission	Loss of Mission	Loss of Mission	3	Degraded Pointing Capabilities	Celestial ACS Pressurized Tank Failure >> Signal: Tank Failure >> Celestial ACS ACS Failure >> Signal: ACS Failed >> Sounding Rocket SR Mission Failure
Sounding...	Celestial...	Star Tracker Failure	Loss of Mission	Loss of Mission	Loss of Mission	3	Lost Fine Pointing Capabilities	Celestial ACS Star Tracker Failure >> Signal: Star Tracker Failure >> Celestial ACS ACS Failure >> Signal: ACS Failed >> Sounding Rocket SR Mission Failure
Sounding...	Celestial...	Telemetry IF Board Failure	Loss of Mission	Loss of Mission	Loss of Mission	3	Inoperable if no Redundant Paths Av...	Celestial ACS Telemetry IF Board Failure >> Signal: Telemetry IF Board Failure >> Celestial ACS ACS Failure >> Signal: ACS Failed >> Sounding Rocket SR Mission Failure
Sounding...	Celestial...	Valve Failure	Loss of Mission	Loss of Mission	Loss of Mission	3	Degraded Pointing Capability	Celestial ACS Valve Failure >> Signal: Valve Failure >> Celestial ACS ACS Failure >> Signal: ACS Failed >> Sounding Rocket SR Mission Failure
Sounding...	Celestial...	ACS Failure	Loss of Mission	Loss of Mission	Loss of Mission	2	Battery Failure	Celestial ACS ACS Failure >> Signal: ACS Failed >> Sounding Rocket SR Mission Failure >> Signal: Loss of Mission
Sounding...	Celestial...	ACS Failure	Loss of Mission	Loss of Mission	Loss of Mission	2	Command Link Board	Celestial ACS ACS Failure >> Signal: ACS Failed >> Sounding Rocket SR Mission Failure >> Signal: Loss of Mission
Sounding...	Celestial...	ACS Failure	Loss of Mission	Loss of Mission	Loss of Mission	2	Pumping Failure	Celestial ACS ACS Failure >> Signal: ACS Failed >> Sounding Rocket SR Mission Failure >> Signal: Loss of Mission
Sounding...	Celestial...	ACS Failure	Loss of Mission	Loss of Mission	Loss of Mission	2	Power Relay Failure	Celestial ACS ACS Failure >> Signal: ACS Failed >> Sounding Rocket SR Mission Failure >> Signal: Loss of Mission
Sounding...	Celestial...	ACS Failure	Loss of Mission	Loss of Mission	Loss of Mission	2	Tank Failure	Celestial ACS ACS Failure >> Signal: ACS Failed >> Sounding Rocket SR Mission Failure >> Signal: Loss of Mission
Sounding...	Celestial...	ACS Failure	Loss of Mission	Loss of Mission	Loss of Mission	2	Star Tracker Failure	Celestial ACS ACS Failure >> Signal: ACS Failed >> Sounding Rocket SR Mission Failure >> Signal: Loss of Mission
Sounding...	Celestial...	ACS Failure	Loss of Mission	Loss of Mission	Loss of Mission	2	Telemetry IF Board Failure	Celestial ACS ACS Failure >> Signal: ACS Failed >> Sounding Rocket SR Mission Failure >> Signal: Loss of Mission
Sounding...	Celestial...	ACS Failure	Loss of Mission	Loss of Mission	Loss of Mission	2	Valve Failure	Celestial ACS ACS Failure >> Signal: ACS Failed >> Sounding Rocket SR Mission Failure >> Signal: Loss of Mission
Sounding...	Celestial...	ACS Failure	Loss of Mission	Loss of Mission	Loss of Mission	2	GUMMAC Failure	Celestial ACS ACS Failure >> Signal: ACS Failed >> Sounding Rocket SR Mission Failure >> Signal: Loss of Mission

Base Model 6-8-2018
 SYSTEM Sounding Rocket > Payload > ACS > Celestial ACS > Battery
 INDEPENDENT LEVEL 5
 REFERENCE DRAWING
 MISSION Test Mission

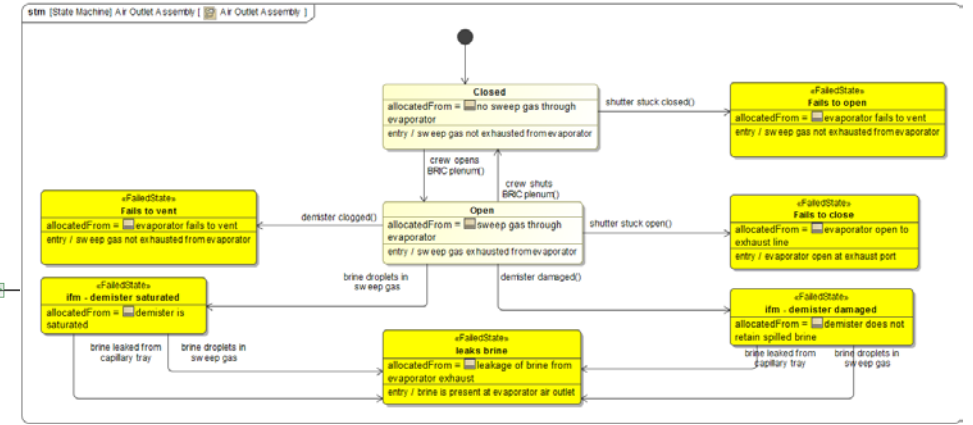
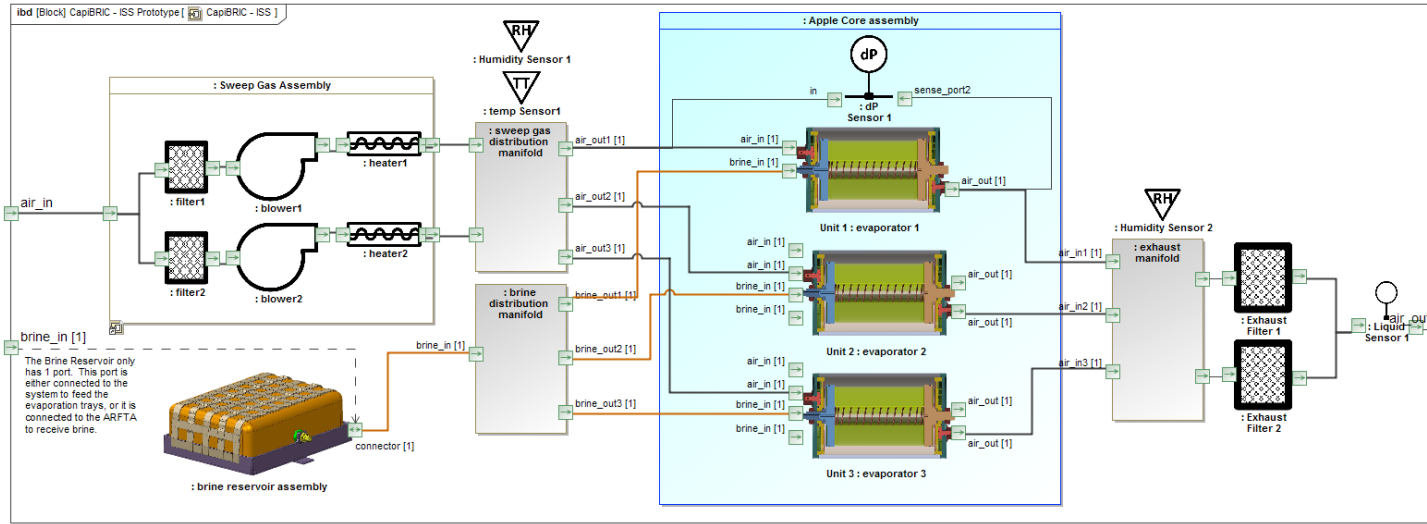
FMECA (RPN, PHMT)
 Aug 8, 2018 1:07:20 PM
 DATE Aug 8, 2018 1:07:20 PM
 SHEET 35 OF 111
 COMPILED BY Young Lu
 APPROVED BY

ITEM NO.	ITEM PHYSICAL DESCRIPTION	FUNCTION/ FUNCTIONAL NARRATIVE	FAILURE MODE		CAUSES OF FAILURE		FAILURE EFFECTS		DETECTION METHODS	COMPENSATING PROVISIONS		CRITICALITY				
			FUNCTIONAL FAILURE	FAULT	MECHANISM	CAUSE	NEXT HIGHER LEVEL	END EFFECTS		O	S	D	RPN			
	Battery	Supply Electrical Voltage	Supply Electrical Voltage Low	Short circuit	Dielectric breakdown	Item life-span exceeded	Transmit Discrete Data Low (Celestial ACS) AND Convert Gas Mass Flow rate Low (Celestial ACS) AND Convert Gas Mass Flow rate Low (Celestial ACS) AND Convert Gas Mass Flow rate Low (Celestial ACS) AND Transmitt Continuous Data Low (Celestial ACS) AND Convert Gas Mass Flow rate Low (Celestial ACS)	Convert Discrete Data Low (Sounding Rocket)	Operator Observation, Sensing Device	Abort Mission, Redesign Component	Quality Control and Robust Reliability Analysis	10.0	8.0	10.0	800	
	Battery	Modelled as an electrical storage device which converts stored chemical energy into electrical energy.	Cannot store power in failed string	No connection of battery power line	Short across battery connections	Failure to cease operation of failure to operate or intermittent operation or loss of power	Transmit Discrete Data Low (Celestial ACS) AND Convert Gas Mass Flow rate Low (Celestial ACS) AND Convert Gas Mass Flow rate Low (Celestial ACS) AND Transmitt Continuous Data Low (Celestial ACS) AND Convert Gas Mass Flow rate Low (Celestial ACS)	Convert Gas Mass Flow rate Low (Sounding Rocket)	Operator Observation, Sensing Device	Abort Mission, Redesign Component	Quality Control and Robust Reliability Analysis	10.0	9.0	10.0	900	
1.1	Airborn Computer	The GUMMAC can be used to provide stall navigation solution including position, velocity, attitude, and body rates to control engine operation and non-pumping rockets.	Failure to open circuit	Loss of signal	Computing error	Errors in executing commands and/or data gathering and relay	Loss of mission / remaining path fails.	No data signal	Redundant path	Operator Observation, Sensing Device	Abort Mission, Redesign Component	Quality Control and Robust Reliability Analysis	10.0	9.0	10.0	900
1.2	Battery	Power Harness Failure	Short Across	Loss of Mission	Power Harness Failed Short	Signal: Loss of Battery >> Celestial ACS Battery Failure >> Signal: Loss of Mission	Loss of power supply path	Inoperable if no redundant path	Loss of Mission	Current reading drop at different points	Redundant string	5				
1.3	Power Relay	Failed Open	Power Relay - Unable to...	Loss of Mission	Power Relay - Failed Open	Signal: Loss of Current to the Battery >> Celestial ACS Power Relay Failure >> Signal: Loss of Mission	Loss of power supply path	Inoperable if no redundant path	Loss of Mission	Current reading drop at different points	Redundant string	5				
1.4	Star Tracker	Inoperable	Star Tracker - Degraded...	Loss of Mission	Star Tracker - Inoperable	Signal: Loss of Fine Pointing Capabilities >> Celestial ACS Star Tracker Failure >> Signal: Loss of Mission	Loss of input signal for master-ctrl	No communication	Loss of Mission	No current or fluctuation detected at different points	Quality control and robust reliability analysis	5				
2.1	Valve	Failed Close	Valve - Degraded Attn...	Loss of Mission	Valve - Failed Close	Signal: Degraded Pointing Capability >> Celestial ACS Valve Failure >> Signal: Loss of Mission	Loss of an electrical battery in a combination of one or more electrochemical cells used to convert stored chemical energy into electrical energy.	Loss of a battery string	Current reading drop at different points	Redundant string	5					
2.2	Plumbing	Cracked	Plumbing - Unable to Tr...	Loss of Mission	Plumbing - Cracked	Signal: Degraded Pointing Capabilities >> Celestial ACS Plumbing Assembly Failure >> Signal: Loss of Mission	Breakage of wire	Vibration damage	Reduction of max demand current carrying capacity	Major effect to max demand current carrying capacity	Loss of Mission	Current reading drop at different points	5			
2.3	Power Harness	Failed Open	Power Relay - Unable to...	Loss of Mission	Power Relay - Failed Open	Signal: Loss of Current to the Battery >> Celestial ACS Power Relay Failure >> Signal: Loss of Mission	Power harness fails open	Component failure or vibration damage	Short across battery connections	Discharge of battery	Loss of Mission	No current or fluctuation detected at different points	5			
2.4	Command Link Board	Loss of Signal	Command Link Board - Loss of Signal	Loss of Mission	Command Link Board - Loss of Signal	Signal: Loss of Commanding Capabilities >> Celestial ACS Command Link Board Loss of Signal >> Signal: Loss of Mission	Power harness fails short	Component failure or vibration damage	Short across battery connections	Discharge of battery	Loss of Mission	No current or fluctuation detected at different points	5			
3.1	Command Link Board	Loss of Signal	Command Link Board - Loss of Signal	Loss of Mission	Command Link Board - Loss of Signal	Signal: Loss of Commanding Capabilities >> Celestial ACS Command Link Board Loss of Signal >> Signal: Loss of Mission	Open or short on any signals	Loss of commanding to computer	Loss of Mission	Verification of commanding from telemetry stream	Quality control and robust reliability analysis	5				
5.1	Plumbing	Cracked	Plumbing - Unable to Tr...	Loss of Mission	Plumbing - Cracked	Signal: Degraded Pointing Capabilities >> Celestial ACS Plumbing Assembly Failure >> Signal: Loss of Mission	Fracture or crack in threaded pneumatic flow into sub-filters	Mechanical failure/vibration abrasion	Degraded tolerance adjustment capability	Degraded pointing capability	Short life of mission, Loss of Mission.	Degraded tolerance, Pressure sensor.	Inspection, Quality control	4		
6.1	Power Relay	Failed Open	Power Relay - Unable to...	Loss of Mission	Power Relay - Failed Open	Signal: Loss of Current to the Battery >> Celestial ACS Power Relay Failure >> Signal: Loss of Mission	Power relay fails open	Component failure or vibration damage	Loss of current to the battery	Loss of Mission	No current detected at different points	Redundant lines to maintain derating requirements.	5			
6.2	Power Relay	Failed Open	Power Relay - Unable to...	Loss of Mission	Power Relay - Failed Open	Signal: Loss of Current to the Battery >> Celestial ACS Power Relay Failure >> Signal: Loss of Mission	Power relay fails short	Overstressed	Short across battery connections	Discharge of battery	Loss of Mission	No current or fluctuation detected at different points	5			
7.1	Star Tracker	Inoperable	Star Tracker - Degraded...	Loss of Mission	Star Tracker - Inoperable	Signal: Loss of Fine Pointing Capabilities >> Celestial ACS Star Tracker Failure >> Signal: Loss of Mission	Star Tracker inoperable	Part failure, circuit failure, or workmanship	Significantly reduced attitude determination ability	Fine pointing loss.	Short life of mission, Loss of Mission.	Inability to command resources, Degraded telemetry.	Quality control and robust reliability analysis	4		
8.1	Tank	Responsible for containing the pressurized des...	Fracture or crack in threaded des...	Loss of Mission	Fracture or crack in threaded des...	Signal: Degraded Pointing Capabilities >> Celestial ACS Pressurized Tank Failure >> Signal: Loss of Mission	Fracture or crack in threaded des...	Mechanical failure/vibration abrasion	Degraded tolerance adjustment	Degraded pointing capability	Short life of mission, Loss of Mission.	Degraded tolerance, Pressure sensor.	Inspection, Quality control	4		

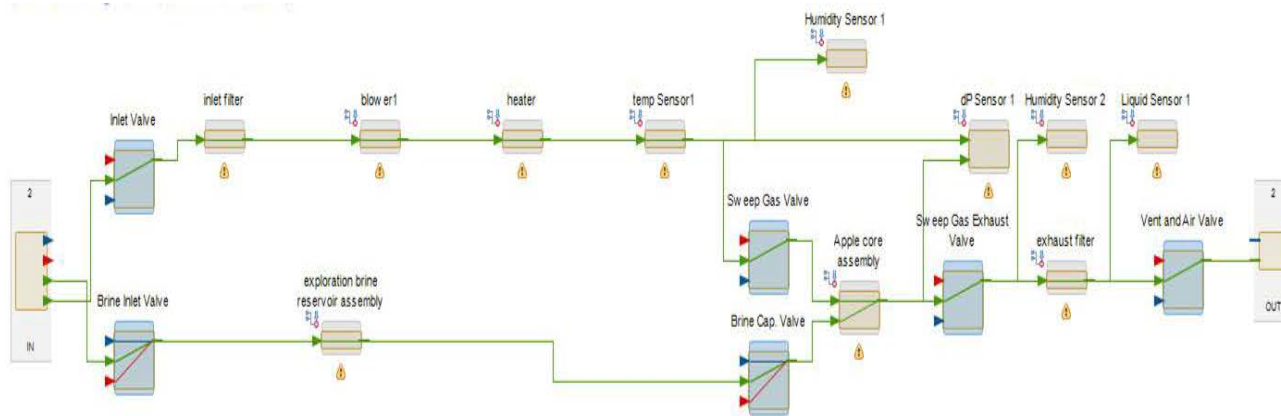
SysM/MagicDraw Severity and Likelihood values are entered manually and can correlate to the GSFC Risk definitions. To have a complete FMECA all thinking and data entry for to calculate RPN would be done at manually at the modeling stage and the plugin will extract the data and tabulate it for the user.

Narrative additions were used to clarify MA De FMECA outputs but tool modifications may be required to synthesize/input mission consequences more autonomously.

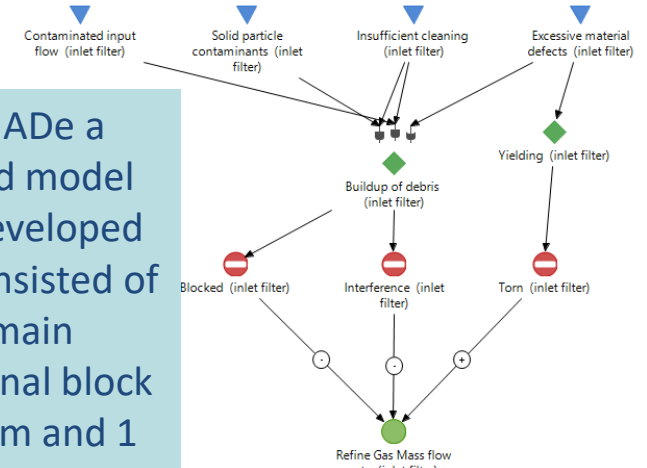
MBSMAI Phase 1: HUMAN SYSTEM – CapiBRIC Modeling



The CapiBRIC SysML model in SysML/MagicDraw provided by JSC consisted of a Block Definition Diagram, a wiring Diagram and 13 state machines

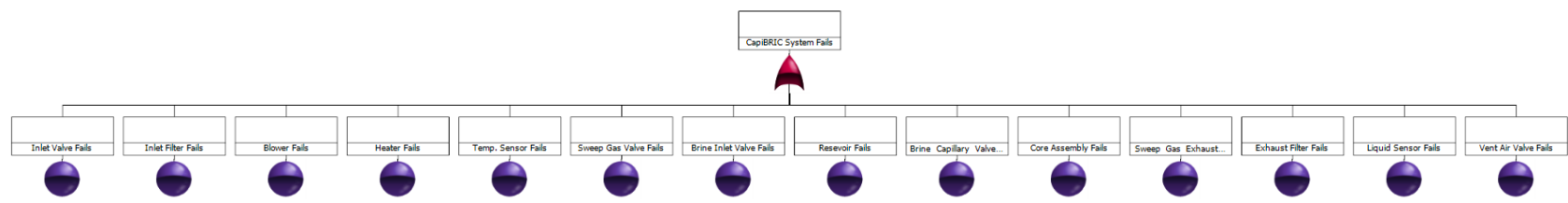
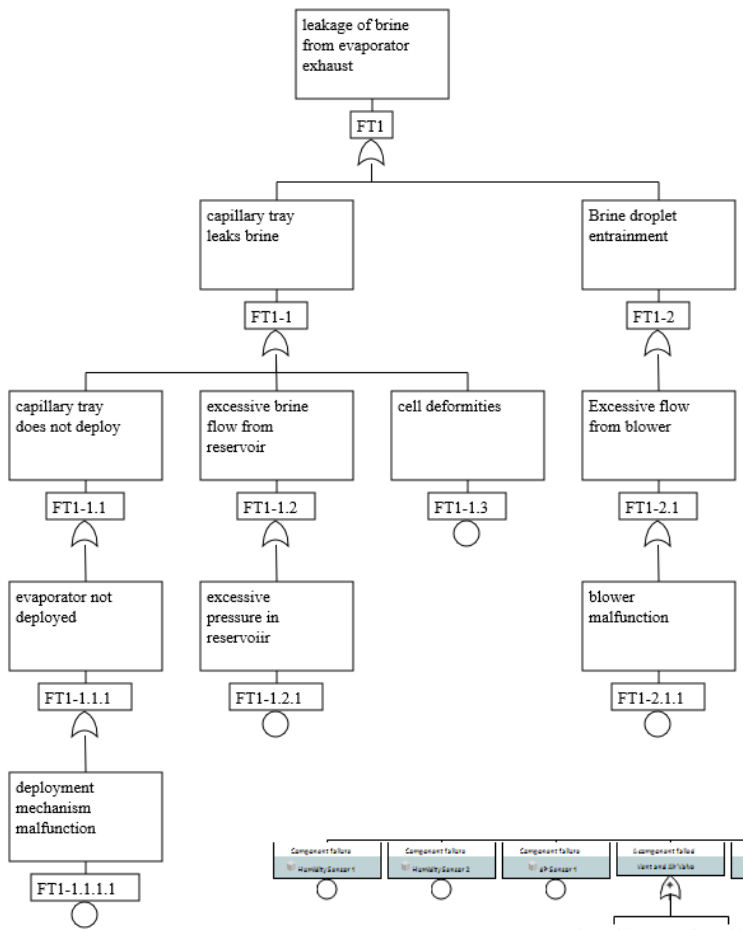


In MADE a limited model was developed that consisted of 1 main functional block diagram and 1 failure diagram.

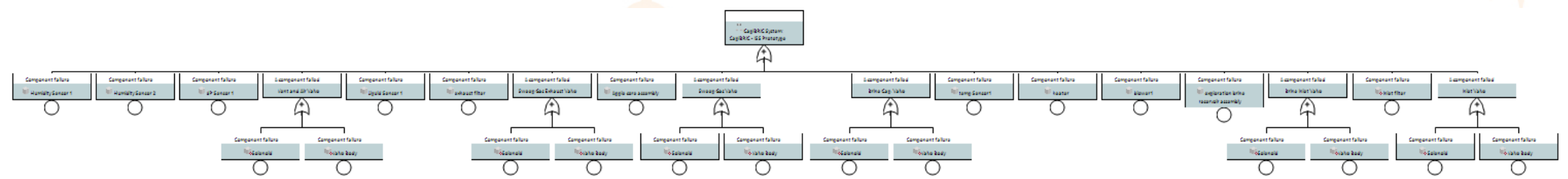


MBSMAI Phase 1: CapiBRIC Model Fault Tree Evaluation

Traditional fault tree method was used to confirm that the hardware fault tree quantification in MADE was equivalent to those in traditional software tool.



The SysML/MagicDraw CapiBRIC model was provided to the MBSMAI model development and evaluation team and not developed internally so the model structure is similar but not exactly the same as that in MADE or traditional analysis performed by the team



IS MODEL-BASED ENGINEERING VALID AND USEABLE FOR RELIABILITY ENGINEERING?

Model-Based Engineering is found to be valid and useable for Reliability Engineering for NASA Safety and Mission Assurance, if adequate modeling processes and environment are established.



Recommended Process Guidance for Cross-Discipline Model-Based Engineering

Pre- Requisite: Establish Modelling process and controls

- 1) Establish a multi-discipline modeling team (Systems Engineering (SE) and SMA at a minimum);
- 2) Establish modeling responsibilities (e.g., SE's model requirements, Designer's model structure (Functional Block Diagram/Wire Diagram), REs model failure behaviors and characteristics) and controls;
- 3) Complete modeling and share common data between modelling elements;
- 4) Produce Reliability artifacts and share resulting data between modelling elements;
- 5) Verify and refine modelling (and designs) until a final and acceptable result is achieved;
- 6) Share modeling with future missions.

Recommended Optimal Modeling Environment Requirements for Cross-Discipline Model-Based Engineering

The Modeling environment/tool shall:

- Be easily mastered structure and interface for efficiency.
- Support for the development of models from the traditional reliability artifacts rather than only deriving the artifacts from the models for efficiency via model re-use.
- Have the ability to create a functional model of the systems for efficiency and clarity.
- Have the ability to ensure that changes to one diagram (e.g., adding a component) propagates to other parts/diagrams of the model automatically or at least shows as an error that needs to be resolved by the modeler.
- Have the ability to allocate requirements to a functional diagram/element for consistent and accurate effect assessment.
- Include modeling diagrams that connect hierarchically to each other for efficiency and clarity which will allow non-modelers to easily traverse and drill down within the model for understanding and accuracy validation.
- Have Libraries of standard components with baseline failure and function data for consistency and accuracy.
- Have Libraries of standard failure mechanisms and causes for consistency and efficiency.
- Have the ability to combine models and duplicate modeling for efficiency.
- Include Model component and system error checking for accuracy.
- Include Model change control/reporting for accuracy.
- Have performance that shortens analysis time while maintaining consistency and accuracy between models.
- Have the ability to add models of systems or portions of systems to a library of shareable models for efficiency.

Recommended Optimal Modeling Environment Requirements for Cross-Discipline Model-Based Engineering

The Modeling environment/tool shall:

- Have the ability to produce a FMECA with NASA defined levels and characterization factors, a Fault tree with precise Boolean logic for accuracy, life assessments at the component and system level, and availability assessments at the component and system level.
- Have the ability to perform maintainability assessments interconnected with maintenance/sparing plans at the component and system level.
- Have the ability to import requirements, CAD and BOM/part lists type data to create modeling elements or as supporting data for efficiency.
- Have the ability to select requirements allocated to each element as the effects and functions for accuracy and efficiency.
- Include an export function to other modeling formats and reliability tools (e.g., Windchill Prediction tool (formerly Relex), Sapphire, QRAS, etc.)
- Have the ability to perform probability analysis using at least 217F, Telecordia, FIDES, PRISM, and/or enterprise custom databases (SEAM). Or import data from reliability tools (e.g., Windchill Prediction tool, etc.) for accuracy and efficiency.
- Have the ability to import results (e.g., radiation effects, life expectancy data, traditional analysis data) from other models or sources for efficiency and accuracy.

Conclusion and Path Forward

Conclusions

- Model-Based Organizations, including NASA, must decide for themselves how to implement model-based engineering in a way that makes sense for all their engineering, assurance, operational, and production elements. Therefore it is essential to the subject matter experts from each element as early as possible.
- Not all tools are ready to support all disciplines.

Path Forward

- Conduct Phase 2 of this study in which evaluations and testing will consist of follow-on Reliability evaluations with more complex system/model (e.g., Cubesat Mission) and Safety Analyses.
- Work with tool vendor's to customize tools for even more compatibility with SMA disciplines.
- Conduct Phase 3 of this study which will evaluate Software Assurance and Quality Engineering Analysis compatibility.



