

## MBSMAI Phase 1 Recommended MADe Modeling Techniques & Tips

In order to model a system in MADe, hierarchical structures and characterizations are required to constitute the model in order to support reliability activities and generate risk-based artifacts. Therefore it is recommended that the following Techniques and Tips be followed.

MADe's main interface (Figure A1) includes a Project Explorer and supporting libraries (i.e., Failure Concepts, generic Palette, and a Local Library of user defined components), relational diagrams (functional and failure), and continuous error notification (Problem/Connection Viewer).

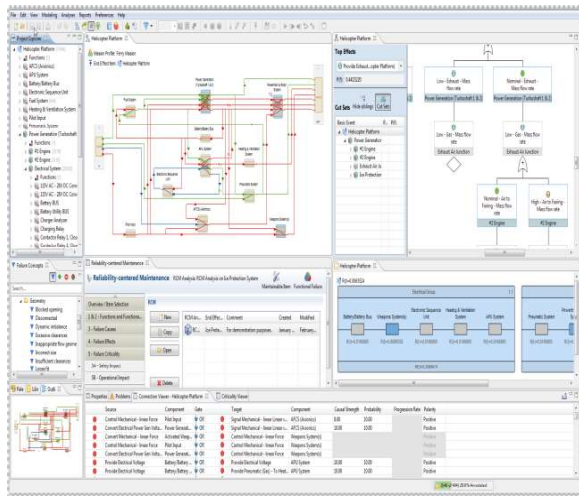


Figure A1: MADe Interface

Modelers should begin modeling a system in MADe by first **creating a new project and defining the "Mission Profile"** (Step 1). A new project is created by selecting the New Project from the File menu. Mission Profile should be accessed from the main toolbar under modeling or by right-clicking the newly created project in the project explorer pane. In the "Mission Profile" window, the modeler should define mission details and attach related documents, if any, and define key mission parameters: mission length, mission phases and their length, and phase segments. Mission Success Criteria should also be established in accordance to mission assumptions and requirements. The "Mission Profile" (Figure A2) can also be updated during the modeling process with individual component's duty cycle, numerical values, and functional limits at the component level.

For example the Sounding Rocket Mission profile consists of a 30-minute mission with four main phases: Launch, Calibration, Science Collection, and Recovery. The Launch phase has two segments for Engine 1 and Engine 2 burns. The mission success criterion defined for this system is to "Exceed minimum mission success criteria requirement," and a duty cycle of 100% has been considered for the nominal operation.

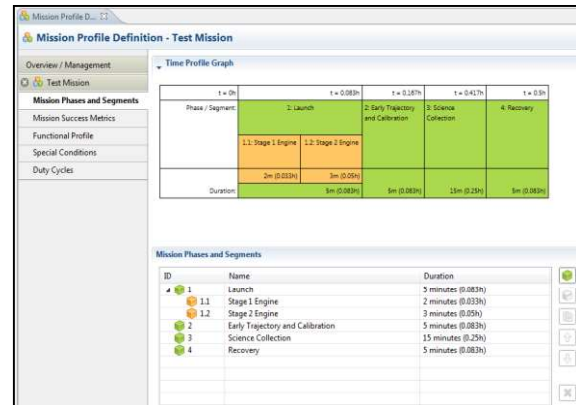


Figure A2: MADe Mission Profile Interface

Once the project has the "Mission Profile" defined, the modeler is ready to start the modeling process by **creating the system hierarchy in Project Explorer (Step 2)** and subsequently creating the functional block diagrams (Step 3). Modelers must bear in mind that the "Project Explorer" must be used to create the system and subsystem level hierarchy or 'skeleton' of the model (Figure A3). This is done by simply right-clicking on the "New Project" created earlier and selecting "New" Subsystem or Component.

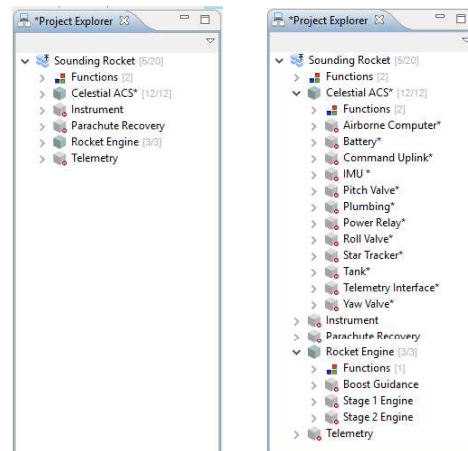


Figure A3: System Hierarchy Skeleton (Image on Left) and Completed Hierarchy with underlying components (Image on Right)

Once the system and subsystems are established, the modeler should then create functional block diagrams at the system and subsystem levels first and then decompose the elements of those diagrams into their own functional block diagrams as needed. The block diagrams defined (customized) for every subsystem and component are the basis for the tool to generate hardware Fault Tree Analysis (FTA) and Failure Modes Effects and Criticality Analysis (FMECA) results.

To create each Functional Block Diagram (Step 3) the modeler should use either the predefined components from the Palette or the user library to populate the block diagrams (e.g., Figure B4) via a drag-and-drop action that will also autonomously populate the project explorer accordingly, or use a custom component (created via the Optional Step shown below) from the project explorer. The non-custom items will come populated with general functions (MADe's designated functions), flows, and failure diagrams and might need modifications/enhancements later to define the subsystem/component role in the system (Step 4), while custom items should be populated manually during the creation process.

The creation of a custom component (Optional Step) should be done by right-clicking the system of interest (parent block) in the project explorer and manually adding the appropriate components or parts by name and assigning the appropriate functions from MADe's comprehensive list of generally designated functions, flows, and failure diagrams to each element of the model.

Where general/common parts and components are already available in the generic Palette or user library, it's best that the modeler uses those or chooses similar ones to develop a custom component from, so that preset functions, flows, and failure diagrams are attached. These should then be customized for the component or project specific application. This strategy allows the modeler to have a starting-point advantage that will help save time and increase the efficiency of the modeling process.

*For example, in the Sounding Rocket (SR) model a "Solenoid" from the MADe library was used to represent valves in the Celestial Attitude and Control Subsystem (CACS), a "Switch" was used to represent Power Relay, and a "Pipe (Pneumatic)" component was selected to represent the Plumbing portion of the CACS subsystem. These elements were updated according to the functionality of their components in the SR system, and their failure diagrams were also modified to represent the proper failures of these components for the specific mission profile defined earlier. Then, according to their functions, they were linked to their upstream and downstream components to form the functional block diagram. For instance, in this case the function of the Valve would be to "Convert" power from*

*the Battery and collects Static Pressure from the Gas Tank to "Regulate" the mass flow rate.*

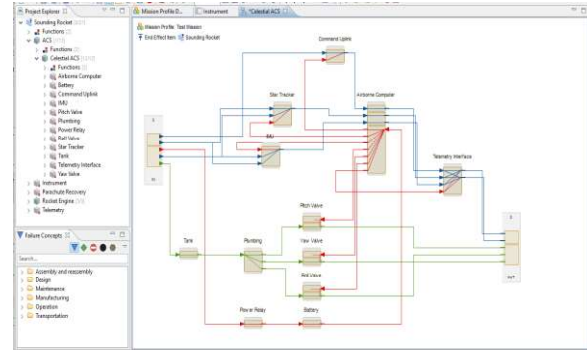


Figure A4: MADe System Hierarchy Interface and Functional Block Diagram

Modelers should note that they can also save their own designs at any level to a local or cloud "Library" and use this library (contained within the "Palette" pane on a different tab (Figure B5)) to simplify their modeling efforts.

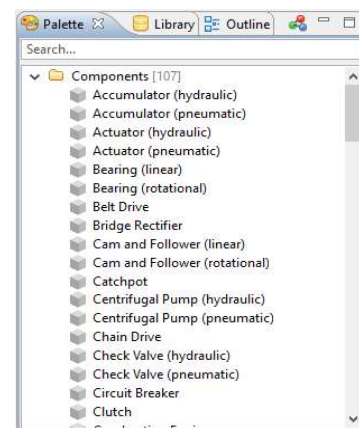


Figure A5: MADe Palette and Library Pane

The modeler should then **assign/refine, connect, and validate functions, flows, and failure diagrams to capture the behavior of each element of the model (Step 4).**

In order to **assign/refine the item's functions and characterizing in-flows and out-flows (Step 4a)**, the modeler should select "Functions" from the Modeling menu or by directly right-clicking on the item being developed. This action will open the "Functions and Flows" window (Figure A6), and the modeler should select the appropriate functions for the item from that window's tabs. Then, appropriate in-flows and out-flows should be connected together by dragging a line from the in-flow to out-flow option of interest to visually define the functionality of that item, as shown in Figure A7.



Figure A6: MADe Functions and Flows Window

After the functions and flows are defined for all the components, the block diagram will automatically show input and output nodes in the model (Figure A8). These nodes are color coded by type (**Material**, **Energy**, and **Data**) and the model should have the same number of inputs as it does outputs for each type to be connected. The modeler should use the cursor to drag and **connect the appropriate input/output nodes (Step 4b)** to each other in order to have a functionally interconnected model (Figure A8).

It's recommended the modeler pauses at this point to adjudicate any errors (See Step 5) and **review/validate the model (Step 4c)** content with fellow and other discipline engineers, including designers and Systems Engineering, as well as peer review with fellow modelers to minimize modeling errors.

*For example, the Sounding Rocket Pitch Valve's functionality (Figure A7) was represented by the "Convert" and "Regulate" functions chosen from the "Functions" tab, using the same Drag-n-Drop feature as in the "Flows" tab. Electrical Current and Gas Static Pressure were selected as inputs (in-flows), and correspondingly they will be processed and yield "Gas Mass Flow Rate" as the component final output (out-flow). Also, as shown in Figure A8, electrical power (red line) is in-flowed to the airborne computer and distributed from out-flow nodes to other boards in the system. High pressure gas in-flow and mass flow rate out-flow from the pitch valve are shown in green and the blue lines represents different forms of data transmission within the system.*

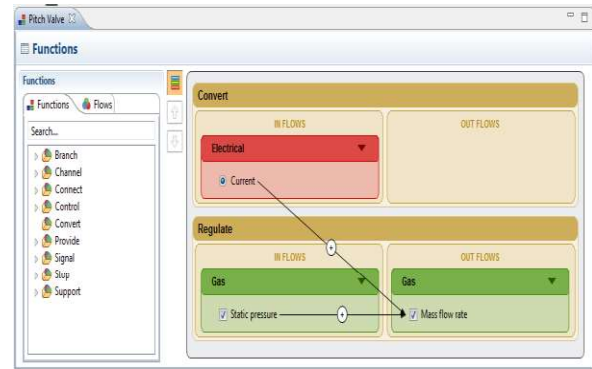


Figure A7: MADe Functional Definition Interface

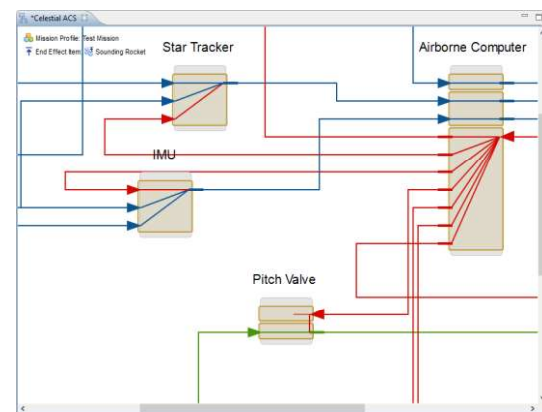


Figure A8: Model blocks input and output nodes

Then to complete each modeling element (manually created or provided/customized library elements), the modeler should **populate (or refine) the failure diagrams (Step 4b)** (Figure A9) connected to each component. This is done by simply dragging and dropping failure causes, mechanisms, and faults from the library of "Failure Concepts" provided within the software tool, and mapping them to the corresponding symptoms and failure modes. Note: Those items/components that were previously selected from the Pallet already come with a preset failure diagram that can be customized to reflect needs.

*For example the failure diagram for the Sounding Rocket "Pitch Valve" (Figure A9), shows the chain of events for each cause (blue triangles), with various mechanisms (green diamonds), that would result in faulty operation (red circles), which would end up with possible failure conditions (black circles) that effect the valve's "Regulate Gas Mass Flow Rate" function.*

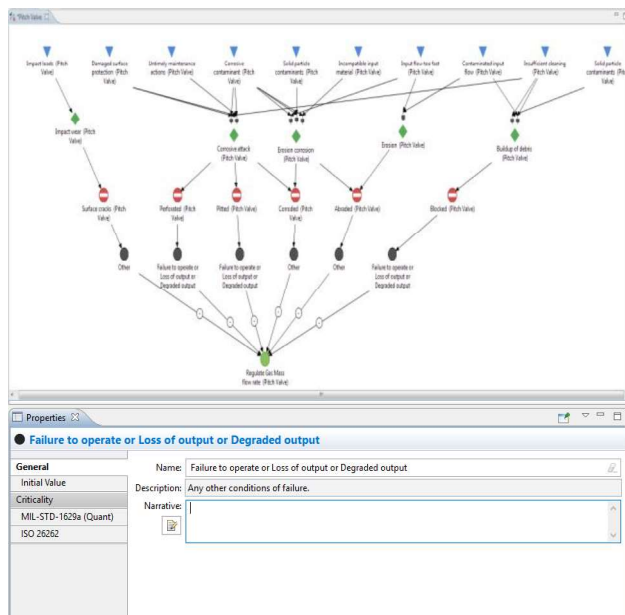


Figure A9: MADe Failure Diagram and Properties Section

The purpose of a “Failure Diagram” is to visually represent the chain of corresponding causes, mechanisms, faults, and failure conditions for every function and outline possible symptoms for failure of that function. The “Failure Diagrams” defined (customized) for every system component are also the basis from which the tool generates FMECA results. Therefore the diagrams should again be peer reviewed with fellow modelers and validated with the designers, Systems Engineering, and Fault Management at this stage.

As shown in Figure A9, the failure concepts available in the software tool are very general, but the user has the option to change the names and add supplementary narrative, in the properties tab, to improve the detail and quality of the model and eventually the reliability reports.

Once the system is completely modeled, the modeler should **adjudicate errors (Step 5)** in the instantaneous and live model problem reporting tab (Figure A10) that have not been addressed previously. The problems reported can be connection errors within in-flows and out-flows or between part/component/subsystem blocks. Once errors are resolved, this is a good time to validate the model with system designers and/or other discipline engineers again in advance of further population.

*For Example the Sounding Rocket Problem Pane, Figure A10, shows that 10 nodes, including 5 out-flows and 5 in-flows are missing connections. This problem reporting section can also be used to verify if the right numbers and types of flows have been modeled during earlier modeling stages.*

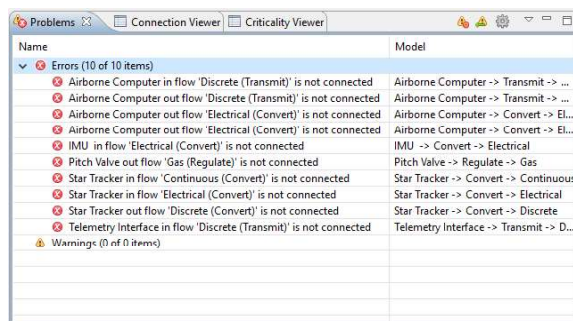


Figure A10: MADe Problem Reporting Window

After the model is error free, modelers should **enter failure condition parameters (Step 6)** (i.e., Detection Methods, Compensating Provisions, Occurrence Probability, and Criticality/Severity of the occurrence), which will enable generation of a complete FTA, FMECA and Risk Priority Number (RPN) analysis. Detection Methods and Compensating Provisions are used in their respective columns in the FMEA report, Occurrence Probability is used to calculate failure rate and reliability values for Reliability Block Diagram (RBD) and Quantitative FTA, and criticality/severity of the occurrence values are used in the FMEA report for RPN calculations.

The modeler should enter **Compensating provisions and detection methods (Step 6a)** by right-clicking on each failure of interest and either selecting from the list or noting a custom narrative (Figure A11).

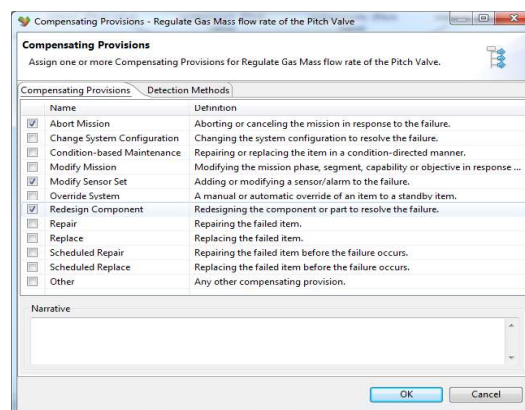


Figure A11: MADe Compensating Provisions & Detections Interface

It's important to note that the modeler should use “narratives” as appropriate during the entire modeling process. As shown in Figure A11, a preset list of provisions are provided within the software. In addition, the modeler can check “Other” and add other items of interest in the narrative box. The same scenario also applies to the failures. A narrative box is available for every cause, mechanism, fault, failure condition, and symptom. And the modelers should use these to

make their models and outputs specific to the system's purpose.

Using the “Criticality and Reliability Editor” feature of the tool, the modeler should **set Severity, Occurrence, and Detectability values for every given function loss (Step 6b)**. When the window (Figure A12) is open, the modeler should navigate the rulers or use the value box to set each of these values. A number from 1 to 10 should be selected for the high and low options. These values should be set using the model effects/values, a mission RPN table, and mission success requirements. For example, a severity/criticality of 4 might be set if a board fails due to low voltage; but if it fails due to high voltage (overvoltage), the severity may be set to 7 or 8 due to the possibility of other hazards, depending on system's sensitivity to the effect, as defined in the RPN Table or mission requirements.

Modelers should ensure that the selected occurrence magnitudes (a value between 1 and 10) are consistent with Fault Tree and/or RBD/prediction probability results (derived internal or external to the model and transferred to sliders manually), per the RPN Scale of the center/mission. Modelers should also ensure that the selected occurrence magnitudes are only for the function loss or failure mode selected. This may mean that the probability being correlated is only a portion of the component's failure probability, and it may need to be calculated externally. Alternatively, the appropriate failure probability for the function loss can be calculated using the “Failure Rate Prediction” option of the Analysis menu for that function flow (See optional step below).

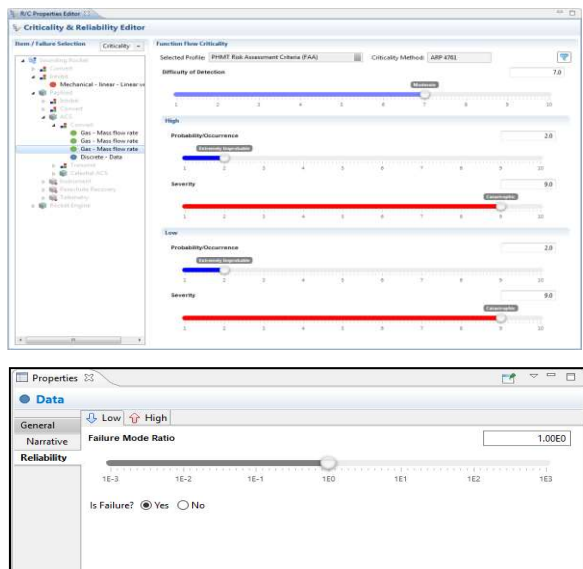


Figure A12: MADE Criticality and Reliability Editor & Properties Window

When the modeler chooses to **calculate failure rate using the “Failure Rate Prediction” capability of the software (Optional Step)**, the modeler should open the Failure Rate Prediction window from the Analyses main menu. Then the modeler will need to click “Create new failure rate analysis” and select the item of interest to be analyzed. The user should then add all applicable parts contributing to that specific function flow to obtain the appropriate reliability allotment. For each part, the modeler will then need to update the applicable factors (Figure A13) including base failure rate, quality factor, environmental factor, and all others required for a Handbook 217 calculation. Once completed, the modeler should ask the tool to calculate the probability and then transfer the results to the corresponding RPN ruler value manually. The modeler should not apply this value to the MTTF unless it represents the entire item's parts list since this will supersede any RBD work.

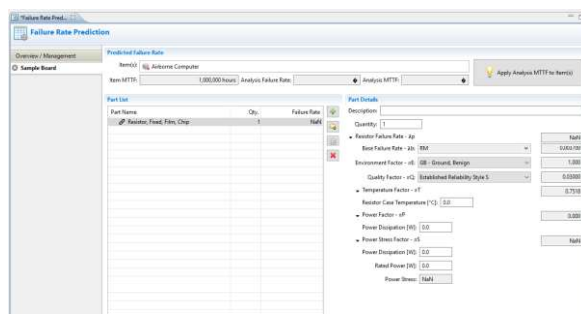


Figure A13: MADE Failure Rate Prediction Window

If the modeler needs to quantify the FT or generate probability numbers, the modeler should **define the reliability block diagram(s) for the model (Step 7)**. Reliability block diagrams (Figure A15) are attached to each element. These blocks are automatically generated along with the system hierarchy and should be organized in appropriate parallel, series, and/or standby groupings to accurately represent the model.

*Note: During this study, grouping caused unnecessary intermediate fault tree gates but this has been resolved in subsequent releases.*

RBD/Prediction results are obtained by manually entering the Exponential, Weibull, or Monte Carlo parameters (Figure A14) for each component. MADE will use these failure probabilities or MTTF values to perform the overall calculation based on the criteria defined in the mission profile and reports the results in a custom report (See Step 8) and use them to quantify the fault tree(s). The modeler can also use these values to select FMECA occurrence values if desired.

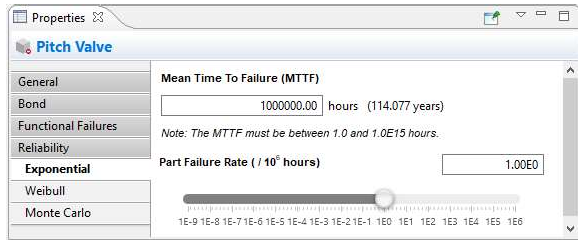


Figure A14: Item properties window for Failure Rate setting

An alternative to manual data entry would be to use the Failure Rate Prediction option mentioned earlier as an optional step. To use this tool for the RBD, the modeler will need to add the entire parts list of the item/component being evaluated to the Parts List section (Figure A13). And when the calculation is completed, the modeler should use the “Apply Analysis MTTF to Item(s)” button so that the calculation is automatically set to the item being reviewed.

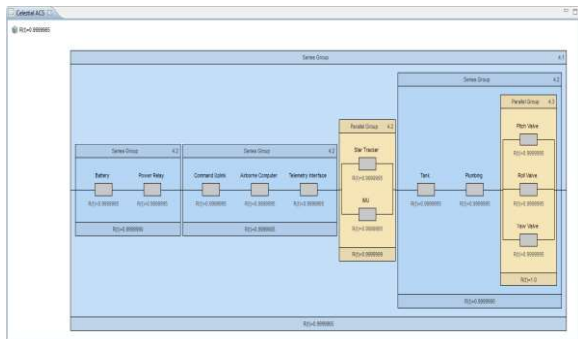


Figure A15: MADE REliability Block Diagram

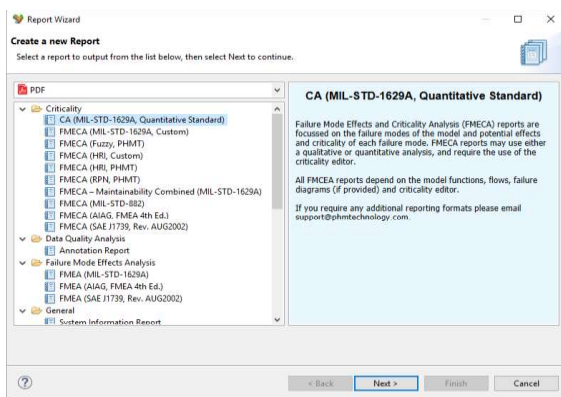


Figure A16: Report Wizard

A modeler can choose from several MADE report designs used to **generate reliability reports (Step 8)** from different analyses conducted on the system model. Report categories include Criticality, Data Quality Analysis, Maintainability, Mission Profile Definition, Reliability & Availability, Reliability-

Centered Maintenance (RCM), and Prognostics and Health Management. More information about each report is displayed in the Report Wizard description (Figure A16). FMECA and Reliability Block Diagram reports can be generated using this wizard, but the FTA, minimum cutsets, and Hardware Hierarchy reports should be obtained by going to the Analysis Menu and selecting the “Fault Tree” option.

For a report appropriate for NASA GSFC internal use, the modeler should use the “FMECA (MIL-STD-1629A, Custom)” report type, from the Report Wizard, and choose to get a PDF output or an Excel spreadsheet (recommended) output for further modification if needed (Figure A17).

For the RBD, the modeler should choose the “Reports Wizard” from the Reports main menu and select the “Reliability Block Diagram Report.” This report includes Failure Rates, MTTR, Grouping Types, and Reliability and Availability information, (Figure A18) and screenshots of the RBDs (Figure A19).

Since there is currently no specific FTA output report in MADE, the modeler should obtain Hardware or Functional FTAs within the software environment by selecting “Fault Tree” underneath the Analyses main menu and taking screenshots of the analysis of interest to use in other documents. The Functional FTAs (Figure A21) will capture all anomalies and issues modelled that may result in failure of a specific function. Although this is not a common way of performing FTA analysis at NASA, the results can be used to assist with scenario-based PRA analyses. MADE’s hardware-based FTAs (Figure A20) would best correlate to NASA GSFC needs and common practices.

In summary it is highly recommend the MADE Modeling Process described above and summarized below be followed so that accurate and value-needed results are produced:

1. Create new project and define Mission Profile
2. Create system hierarchy in Project Explorer
3. Create functional block diagrams
4. Assign/Refine, Connect, and Validate functions, flows, and failure diagrams of each element
5. Adjudicate errors
6. Enter failure condition parameters
7. Define the reliability block diagram for the model
8. Generate reliability reports

SR Model: 011320

FMECA (NLSI-STD-102A, Custom)

Aug 7, 2020 10:17:03 PM

SYSTEM: Sounding Rocket > ACS > Celestial ACS > Airborne Computer  
 IDENTIFICATION NUMBER: 4  
 REFERENCE DRAWING:  
 HISTORY:

DATE: Aug 7, 2020 10:17:03 PM  
 SHEET: 10 OF 64  
 COMPILED BY: mland  
 APPROVED BY:

IDENTIFICATION NUMBER	ITEM / FUNCTIONAL IDENTIFICATION (NOMENCLATURE)	FUNCTION	FAILURE MODES AND CAUSES	MISSION PHASE / OPERATIONAL MODE	SEVERITY CLASS	FAILURE PREDICTABILITY	FAILURE EFFECT PROBABILITY (P)	FAILURE MODE RATIO (R)	FAILURE RATE (λ)	OPERATING TIME (t)	FAILURE MODE COST C=C1+C2	ITEM COST C=C1/C2	COMPENSATING PROVISIONS	FAILURE DATA SOURCE
SLR-MAC	Airborne Computer	Convert Electrical Current	Low Electrical Current due to irregular distribution of the Airborne Computer as a result of overload caused by insufficient clearance and the failure resulting in Low Gas Mass Flow rate (Celestial ACS), Low Dynamic Data (Celestial ACS) and Low Dynamic Data (Sounding Rocket) Failure to operate or intermittent operation or Failure to receive operation or Loss of output or Degraded output Cloud Failure-Over/Short/Out of Range No valid telemetry. No power available from power node.	1 Launch 100% 2 Early Navigation and Guidance 100% 3 Science Collection 100% 4 Recovery 100%	1		1.00	0.000990	1.0E-4	0.5	2.98E10	5.2E10	Health Mission, Modify Sensor Set, Replace Software-Quality control	The team does not have a failure data source available
			Low Electrical Current due to irregular distribution of the Airborne Computer as a result of overload caused by insufficient clearance and the failure resulting in Low Gas Mass Flow rate (Celestial ACS), Low Dynamic Data (Celestial ACS) and Low Dynamic Data (Sounding Rocket) Failure to operate or intermittent operation or Failure to receive operation or Loss of output or Degraded output Cloud Failure-Over/Short/Out of Range No valid telemetry. No power available from power node.		1		1.00	0.000990	1.0E-4	0.5	2.98E10		Abort Mission, Replace Software-Quality control	
			Low Electrical Current due to irregular distribution of the Airborne Computer as a result of overload caused by insufficient clearance and the failure resulting in Low Gas Mass Flow rate (Celestial ACS), Low Dynamic Data (Celestial ACS) and Low Dynamic Data (Sounding Rocket) Failure to operate or intermittent operation or Failure to receive operation or Loss of output or Degraded output Cloud Failure-Over/Short/Out of Range No valid telemetry. No power available from power node.		1		1.00	0.000990	1.0E-4	0.5	2.98E10		Health Mission, Modify Sensor Set, Replace Software-Quality control	
			Low Electrical Current due to irregular distribution of the Airborne Computer as a result of overload caused by insufficient clearance and the failure resulting in Low Gas Mass Flow rate (Celestial ACS) and Low Gas Mass Flow rate (Sounding Rocket) Failure to operate or intermittent operation or Failure to receive operation or Loss of output or Degraded output Cloud Failure-Over/Short/Out of Range No valid telemetry. No power available from power node.		1		1.00	0.000990	1.0E-4	0.5	2.98E10		Health Mission, Modify Sensor Set, Replace Software-Quality control	
			Low Electrical Current due to irregular distribution of the Airborne Computer as a result of overload caused by insufficient clearance and the failure resulting in Low Gas Mass Flow rate (Celestial ACS) and Low Gas Mass Flow rate (Sounding Rocket) Failure to operate or intermittent operation or Failure to receive operation or Loss of output or Degraded output Cloud Failure-Over/Short/Out of Range No valid telemetry. No power available from power node.		1		1.00	0.000990	1.0E-4	0.5	2.98E10		Health Mission, Modify Sensor Set, Replace Software-Quality control	
			Low Electrical Current due to irregular distribution of the Airborne Computer as a result of overload caused by insufficient clearance and the failure resulting in Low Gas Mass Flow rate (Celestial ACS) and Low Gas Mass Flow rate (Sounding Rocket) Failure to operate or intermittent operation or Failure to receive operation or Loss of output or Degraded output Cloud Failure-Over/Short/Out of Range No valid telemetry. No power available from power node.		1		1.00	0.000990	1.0E-4	0.5	2.98E10		Health Mission, Modify Sensor Set, Replace Software-Quality control	
			Low Electrical Current due to short circuiting of the Airborne Computer as a result of faulted caused by electrical resistance low resulting in Low Gas Mass Flow rate (Celestial ACS) and Low Gas Mass Flow rate (Sounding Rocket) Failure to operate or intermittent operation or Failure to receive operation or Loss of output or Degraded output Cloud Failure-Over/Short/Out of Range No valid telemetry. No power available from power node.		1		1.00	0.117899	1.0E-4	0.5	3.99E10		Abort Mission, Replace Component Redundant path	

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Figure A17: Sample FMECA Output

Base Model 6-4-2018

Reliability Block Diagram Report

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RELIABILITY & AVAILABILITY

SYSTEM HIERARCHY Sounding Rocket										INDENTURE LEVEL	1
ITEM NAME Sounding Rocket										ITEM ID	SR1
PHYSICAL DESCRIPTION A rocket consisting of a stage 1 engine, stage 2 engine, instrument, telemetry, boost guidance, ACS, and parachute recovery system.											
RELIABILITY 0.999990										INHERENT AVAILABILITY	0.999990
										MTTF (HRS)	55,700.36
										MTR (HRS)	1
GROUP	ITEM ID & NAME	RELIABILITY	MTTF (HRS)	INHERENT AVAILABILITY	INHERENT UNAVAILABILITY	OPERATIONAL AVAILABILITY	MTTR (HRS)	MTR (HRS)			
1.1 Series Group (Series)	Rocket Engine	0.999999	1,166,666.57	0.999999	0.0	0.999999		1			
	Payload	0.999990	98,168.49	0.999990	0.000010	0.999990		1			
SYSTEM HIERARCHY Sounding Rocket > Series Group > Rocket Engine										INDENTURE LEVEL	2.0
ITEM NAME Rocket Engine										ITEM ID	
PHYSICAL DESCRIPTION An engine attached to the payload of the sounding rocket.											
RELIABILITY 0.999999										INHERENT AVAILABILITY	0.999999
										MTTF (HRS)	1,166,666.57
										MTR (HRS)	1
GROUP	ITEM ID & NAME	RELIABILITY	MTTF (HRS)	INHERENT AVAILABILITY	INHERENT UNAVAILABILITY	OPERATIONAL AVAILABILITY	MTTR (HRS)	MTR (HRS)			
2.1 Parallel Group (Parallel)	S19 Boost Guidance	0.999995	999,999.9	0.999999	0.0000010	0.999999		1			
2.2 Series Group (Series)	Stage 1 Engine	0.999995	999,999.9	0.999999	0.0000010	0.999999		1			
	Stage 2 Engine	0.999995	999,999.9	0.999999	0.0000010	0.999999		1			
SYSTEM HIERARCHY Sounding Rocket > Series Group > Payload										INDENTURE LEVEL	2.0
ITEM NAME Payload										ITEM ID	
PHYSICAL DESCRIPTION A system that provides the capabilities of telemetry data acquisition, tracking, power timing, protection, mechanical configuration, stability, and recovery.											
RELIABILITY 0.999990										INHERENT AVAILABILITY	0.999990
										MTTF (HRS)	98,168.49
										MTR (HRS)	1
GROUP	ITEM ID & NAME	RELIABILITY	MTTF (HRS)	INHERENT AVAILABILITY	INHERENT UNAVAILABILITY	OPERATIONAL AVAILABILITY	MTTR (HRS)	MTR (HRS)			
2.1 Series Group (Series)	Instrument	0.999995	999,999.9	0.999999	0.0000010	0.999999		1			
	Parachute Recovery	0.999995	999,999.9	0.999999	0.0000010	0.999999		1			
	Telemetry	0.999995	999,999.9	0.999999	0.0000010	0.999999		1			
	ACS	0.999995	137,878.78	0.999990	0.0000070	0.999990		1			
SYSTEM HIERARCHY Sounding Rocket > Series Group > Payload > Series Group > ACS										INDENTURE LEVEL	3.0
ITEM NAME ACS										ITEM ID	
PHYSICAL DESCRIPTION Attitude Control Systems available for telescope and spectrometer payloads depend on the science target.											
RELIABILITY 0.999995										INHERENT AVAILABILITY	0.999990
										MTTF (HRS)	137,878.78
										MTR (HRS)	1
GROUP	ITEM ID & NAME	RELIABILITY	MTTF (HRS)	INHERENT AVAILABILITY	INHERENT UNAVAILABILITY	OPERATIONAL AVAILABILITY	MTTR (HRS)	MTR (HRS)			
3.1 Series Group (Series)	Celestial ACS	0.999995	137,878.78	0.999990	0.0000070	0.999990		1			

Figure A18: Sample Reliability Block Diagram Output (Part A)

RBD DIAGRAMS

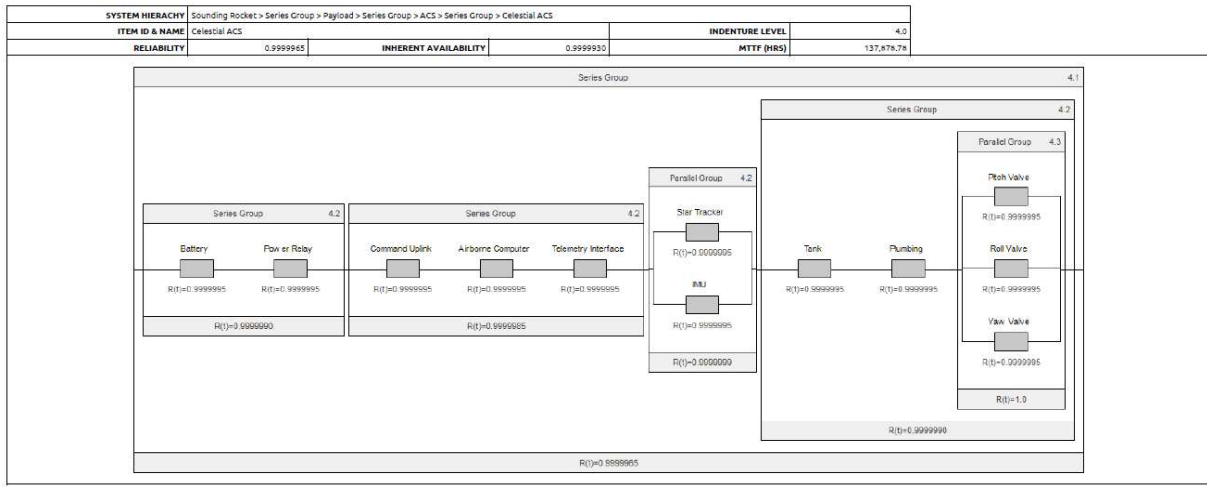


Figure A19: Sample Reliability Block Diagram Output (Part B)

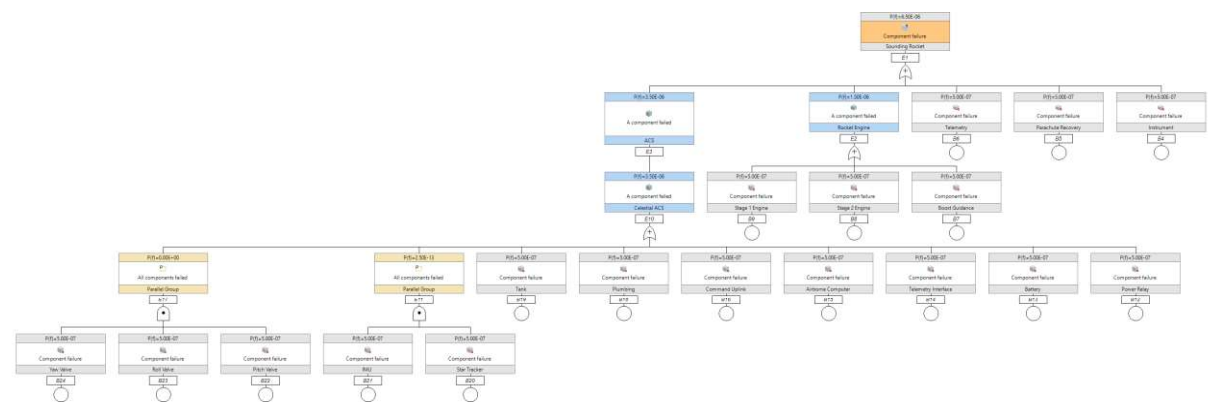


Figure A20: Sample Hardware Fault Tree Output

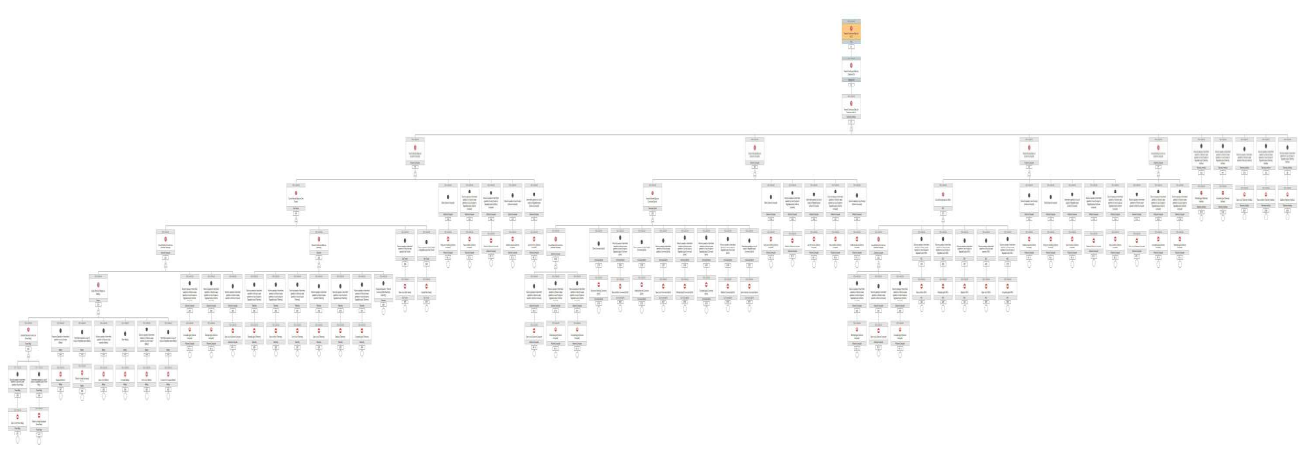


Figure A21: Sample Functional Fault Tree Output