Failure Modes and Effects Analysis (FMEA) Assistant Tool Feasibility Study

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ABSTRACT

An effort to determine the feasibility of a software tool to assist in Failure Modes and Effects Analysis (FMEA) has been completed. This new and unique approach to FMEA uses model based systems engineering concepts to recommend failure modes, causes, and effects to the user after they have made several selections from pick lists about a component’s functions and inputs/outputs. Recommendations are made based on a library using common failure modes identified over the course of several major human spaceflight programs. However, the tool could be adapted for use in a wide range of applications from NASA to the energy industry.

INTRODUCTION

In order for NASA to meet ambitious goals in space exploration using increasingly complex system designs, safety should be considered as early as possible in the design process. Program managers, design engineers, and systems safety and reliability practitioners recognize the need to identify risk early thus reducing lifecycle cost. However, current safety analysis methods are challenging to perform quickly enough to affect design, particularly when assessing rapidly occurring changes and large, complex systems.

This project investigated the feasibility of developing a software tool, or modifying an existing tool or suite of tools, to assist in Failure Modes and Effects Analysis (FMEA). This innovative tool uses a standardized systematic approach to failure analysis that makes it easy to capture model information while saving analysis time. This approach not only enables early risk mitigation by reducing cost and human error, but also produces a reusable system model. This model can help bridge the gap between system engineering and safety. Hardware criticality, which can drive cost and schedule due to testing and certification requirements, can be quickly and systematically identified. Undesirable consequences across subsystem interfaces can be mitigated or eliminated.

FMEA starts at the component level and evaluates what can go wrong, and how it can affect the system. It is a bottom-up and systematic method that is mostly qualitative. It is used to identify design strategies to prevent failures and improve reliability. The FMEA therefore provides input to risk assessment activities, assists in assessing compliance to safety requirements (e.g., identifying single point failures), and is used to compare the benefits of competing designs. FMEAs are required for a wide range of products designed and built by NASA from Government Furnished Equipment projects and payloads, to fully integrated human rated spacecraft or habitats. The energy industry could also benefit from mutual development and use of this tool.

In prior NASA programs, it was recommended that lists of standard “common” failure modes (CFM) be considered for use, but free text fields provided for database entry led to inconsistent failure mode identification. For example, to identify the mode where a valve “Fails to Close” some analysts would enter a failure mode of “Fails Open” while others wrote “Fails to Close”. A later problem report search for occurrences of this failure mode would miss occurrences of the mode, as they were identified differently. For this reason, more recent efforts have been to standardize a CFM list of about 100 selections for use in a database [1]. However, in practice it was observed that such a long list was unwieldy, and analysts often chose failure descriptions too general to be informative, such as “fails to function,” with the detailed description written in free form text. This negates the benefit of a CFM list.

The FMEA Assistant tool has been designed to overcome this problem while retaining, and even expanding, the use of the common failure mode list. The FMEA Assistant does this by guiding the analyst through a set of questions about component attributes, including subsystem type, kinds of resources used, and types of outputs. The chosen attributes narrows down the number of possible choices of failure modes that make sense for that component. The analyst need only consider a few small sets from the full list of common failure modes to
find the appropriate ones. The dialogue is dynamic, so that the choices of failure modes presented change if the analyst changes the attribute selections. The tool also extends the use of standardization by offering short lists of common failure causes and effects for each failure mode.

The approach extends a prototype tool suite, the Hazard Identification Tool, developed in collaboration between Johnson Space Center’s Safety and Mission Assurance (S&MA) and Engineering directorates, which uses semantic text analysis and extraction technology to create system models from requirements, FMEAs and hazard reports [2]. The requirements and safety information are integrated into system architecture visualizations for review of completeness, correctness, and consistency of the analyses. This technology was extended to generate the basis of a reliability block diagram (RBD) model from the master equipment list (MEL). The model from the extracted text shows components, connections, redundancy, and links to FMEAs.

This project addresses a recognized challenge in a FMEA competency that is needed for developing the analysis for human-rated spacecraft. This project is also relevant to analysis of reliable systems being developed for power, life support, re-entry and landing, and software systems. Early opportunities to design out failure modes prevent the need for re-design, and can save cost and schedule.

1. **MODELING APPROACH**

A trade study to evaluate five existing software tools against the project’s objectives was completed. The Hazard Identification Tool prototype was selected as a starting point. The FMEA Assistant tool models a system's components and their connective relationships, and then assists the design engineer or safety analyst (hereafter referred to as the user) in FMEA, and finally links the FMEA data back to the model for further analysis and review.

The following describes in more detail the step-by-step procedures and how they were implemented. The component to follow in this example is a motor safety device.

1. An initial model is generated from the MEL with some manual manipulation.
   
   1.a. Information about component names and quantities are extracted from a MEL table for the Appendix A. Constellation Common Failure Modes. The format of the table is shown in Table 1. User choices
of component attributes drive the selection of rows in the CFM library table that contain information for reuse in system modeling.

Figure 1. MEL example, with column added to indicate which components are to be added to the system model.

Figure 2. Model canvas populated from MEL.

Figure 3. Model after manual arrangement of components and addition of connections.
The table indicates the system types, functions, device features and sets of operating states that are probably associated with each failure mode. The Table of attributes for CFMs was developed using functions and operating states mentioned in each FM, or determining the meaning of the FM phrase and associating one or more probable general functions and state sets. This information drives much of the dialogue, working back from the attributes to narrow down to failure modes.
The user’s choice of the system type and other attributes determine the functional failures presented in the function pick list, which in turn determine the contents of the failure mode pick lists. Figure 6 shows a diagram indicating how the pick list choices offered as possible responses to dialogue queries depend on choices made for other queries, beginning with the choice of subsystem for the component.

<table>
<thead>
<tr>
<th>Recommended FM List</th>
<th>Function</th>
<th>Operating States</th>
<th>Device Features</th>
<th>System Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clogs</td>
<td>Transfer</td>
<td>Fluid</td>
<td>ECLSS, Thermal, Propulsion/Pyro</td>
<td></td>
</tr>
<tr>
<td>Closes at incorrect time</td>
<td>Lock</td>
<td>Open, Locked</td>
<td>Control Operation</td>
<td>Mechanisms, Structures</td>
</tr>
</tbody>
</table>

Table 1. Format of Table of Attributes associated with standard Common Failure Modes (Partial)

Figure 6. Diagram of Dialogue logic, illustrating how user responses determine offerings for queries

2. GENERATING THE PRELIMINARY FMEA

After selecting the set of failure modes in the dialogue page as shown in of Figure 5, the user opens a second dialogue by clicking a button at the bottom of that first dialogue. Here, the user can select types of failure mode causes and effects and can add descriptions and comments. An example of a completed second dialogue is shown in Figure 7, continuing with the motor safety component example. It contains a row for each failure mode selected in the first dialogue. Each failure mode “Description” on the far left can be extended with free form text to tailor the common failure mode with details specific to the particular component.
2.1 Selecting Causes and Effects

By clicking on “Causes” and “Effects” columns in a failure mode row, the user then selects causes and effects from lists of common causes and common effects. The user has the opportunity to enter comments on the far right of each row for adding more detail concerning the selected causes and effects for the particular component.

The “Causes” pick list is shown in . The field at the bottom allows the user to add a failure cause not on the pick list if there is a cause for the failure in the particular component that is not covered in the pick list.

The causes pick list was developed by reviewing existing FMEAs and categorizing causes into these primary categories: Failure internal to component; Manufacturing, installation, or assembly error; Input problem; Excessive natural environment (e.g. radiation); and Excessive induced environment (e.g. vibration).

*Figure 7. Second dialogue for refining and completing a component’s FMEAs*

*Figure 8. Causes Pick List*
Similarly, the effects list includes: Failed or delayed function; Premature function; Loss of output; Premature output; Erroneous output; Damage; and Leakage. The “Effects” pick list is shown in Figure 9. As with the Causes pick list, a field is provided that allows the user to select one or more failure effects and enter a new one if there is an effect of the failure of the particular component that is not covered in the pick list.

![Figure 9. Effects Pick List](image)

### 2.2 Criticality and Redundancy

The final fields that the user supplies in the dialogue of Figure 7 are criticality and redundancy for each failure mode. The criticality is typically assigned on the basis of worst-case potential failure effect assuming the loss of all redundancy (where applicable) [1]. Criticalities are defined as:

1 – Single failure that could result in loss of life or vehicle
2 – Single failure that could result in a loss of mission
1R# - Redundant hardware that, if all failed, could cause loss of life or vehicle. A number (#) is used to indicate the number of failures required for complete system failure
1S – Failure in a safety or hazard monitoring hardware item that could cause the system to fail to detect, combat, or operate when needed during a hazardous condition.

2R – Redundant hardware item that if all failed, could cause a loss of mission.
3 – All other failures.

### 2.3 Generating a FMEA worksheet

Finally, a FMEA worksheet, as shown in Figure 10, is generated in Excel, with the following fields: Subsystem, Component, Function, Failure Mode, Failure Description, Failure Causes, Immediate Effects, Criticality, and Comments.

In addition to the FMEA worksheet, a table of the rows that have been selected from the Failure Modes attributes table during the analysis process can be output and reused for modeling system components in engineering.
3. CONCLUSION

The prototype FMEA Assistant tool has the potential to reduce cost and human error. It provides a standardized systematic approach to failure analysis while gathering model information. Without any tool, the user may repeatedly choose general failure modes such as “failure to function”. General failure modes are rarely adequate for FMEA worksheet development and subsequent systems and safety analysis. The tool helps drive out the complete and most descriptive choices of applicable common failure modes. With the FMEA Assistant tool, the user is invited to consider the component from several perspectives (subsystem, function, inputs, outputs, operating states, and hazard types). This encourages full consideration of potential failure modes and therefore more thorough and accurate analysis. The user is able to spend more time considering safety-related issues and less time repeatedly scanning a long list of common failure modes or searching for related historical or other information. This should result in a lower error rate, less overall time preparing the FMEA, and an improved product. Furthermore, this approach not only enables early risk mitigation, but also model reuse. Using the tool to derive a single model for reuse by systems engineers, safety analysts, and others helps reduce cost and human error. Identifying single point failures allows for early opportunities to design them out, preventing the need for re-design, and can save cost and schedule.

4. FORWARD WORK

In response to feedback from potential users, a capability to identify hazards associated with particular failure modes has recently been added. This capability was developed by mapping the common failure modes list with a common or standard hazards list. This helps the analyst either identify hazards at the vehicle level caused by the component, or can help with the currently manual task of cross-referencing the FMEA to hazards already documented.

Also in response to user suggestions, a selection of common components will be selected for identification of standard failure modes. This will demonstrate the concept of building a library of standard components with failure modes, causes, and effects already identified within the tool. Additionally, integration with the existing FMEA database used by the International Space Station Program has been studied and is feasible with the
proper data field mapping and funding to complete the task.

Evaluation of the benefit in time, accuracy and specificity compared to traditional FMEA practices is greatly desired. A relatively small scope NASA project would be ideal for an evaluation.

In the longer term, the FMEA Assistant tool capability could be integrated with other vehicle risk assessment tools in development at JSC for quantitative reliability assessment. It could also tie into other JSC model-based system and mission capability impact tools currently in development, as they all have the same goals of providing information on how a failure affects other systems, and how the effects propagate to affect the mission. Along those lines, the tool could be used in operational programs to help identify the potential cause(s) of a failure.

A recent effort [3] to integrate safety attributes and failure knowledge from FMEA Assistant into Systems Modeling Language (SysML) models has been initiated. This is another related area of potential forward work.

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REFERENCES


Appendix A. Constellation Common Failure Modes Attributes Table (Partial)

<table>
<thead>
<tr>
<th>Recommended FM List</th>
<th>Function</th>
<th>Operating States</th>
<th>Device Features</th>
<th>System Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clogs</td>
<td>Transfer</td>
<td></td>
<td>Fluid</td>
<td>ECLSS, Thermal, Propulsion/Pyro</td>
</tr>
<tr>
<td>Closes at incorrect time</td>
<td>Lock</td>
<td>Open, Locked</td>
<td>Control Operation</td>
<td>Mechanisms, Structures</td>
</tr>
<tr>
<td>Closes at incorrect time</td>
<td>Close</td>
<td>Open, Closed</td>
<td>Control Path</td>
<td>ECLSS, Thermal, Propulsion/Pyro, Power/Energy</td>
</tr>
<tr>
<td>Closes at incorrect time</td>
<td>Regulate Timing</td>
<td>Open, Closed</td>
<td>Control Path</td>
<td>ECLSS, Thermal, Propulsion/Pyro, Power/Energy</td>
</tr>
<tr>
<td>Closes incorrectly</td>
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<td>Open, Closed</td>
<td>Control Path</td>
<td>ECLSS, Thermal, Propulsion/Pyro, Power/Energy</td>
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<td>Combustion instability</td>
<td>Control Vibration</td>
<td></td>
<td>Propulsion/Pyro</td>
<td>Propulsion/Pyro</td>
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<td>Activate</td>
<td>Inactive, Active</td>
<td>Control Operation</td>
<td>Any</td>
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<td>Regulate Timing</td>
<td>Inactive, Active</td>
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<td>Electrostatic discharge</td>
<td>Insulate</td>
<td>Electronics/Power</td>
<td>Power/Energy, Electronics</td>
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<td>Erroneous high indication</td>
<td>Indicate</td>
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<td>Any-with Sensor/Indicator</td>
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<tr>
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<td>Any-with Sensor/Indicator</td>
<td></td>
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<td>Erroneous Input</td>
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<td>Control Operation</td>
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<td>Control Operation</td>
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<td>Monitor</td>
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<td>Any-with Sensor/Indicator</td>
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<td>Fails low</td>
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<td>Sensor/Indicator</td>
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<td>De-activate</td>
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<td>Monitor</td>
<td>Off, Monitor</td>
<td>Sensor/Indicator</td>
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<td>Fails on</td>
<td>Activate</td>
<td>On, Off</td>
<td>Control Operation</td>
<td>Any</td>
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<td>Fails partially closed</td>
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<td>Motion/Separation</td>
<td>GN&amp;C, Propulsion/Pyro, Mechanisms, Robotics</td>
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<td>GN&amp;C, Propulsion/Pyro, Mechanisms, Robotics</td>
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<td>Off, Fired</td>
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<td>Fails to function</td>
<td>... other function</td>
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<td>Fails to ignite</td>
<td>Ignite</td>
<td>Off, Ignited</td>
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<td>GN&amp;C, Propulsion/Pyro, Mechanisms, Robotics</td>
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<td>ECLSS, Thermal, Propulsion/Pyro, Power/Energy</td>
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<td>Fails to operate</td>
<td>Off, Operating</td>
<td>Any</td>
<td></td>
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<td>Fails to reef</td>
<td>Reef</td>
<td>GN&amp;C, Propulsion/Pyro, Mechanisms, Robotics</td>
<td></td>
<td></td>
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<td>Fails to relieve</td>
<td>Relieve</td>
<td>ECLSS, Thermal, Propulsion/Pyro</td>
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<td>Fails to rotate</td>
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<td></td>
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<td>Run, Off</td>
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<td></td>
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<td>Seal</td>
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<td></td>
<td></td>
</tr>
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<td>Fails to separate</td>
<td>Mated, Separated</td>
<td>GN&amp;C, Propulsion/Pyro, Mechanisms, Robotics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fails to shutdown/stop</td>
<td>Started, Stopped</td>
<td>Any</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fails to stop</td>
<td>Stop</td>
<td>Any</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fails to switch</td>
<td>Closed, Open</td>
<td>ECLSS, Thermal, Propulsion/Pyro, Power/Energy</td>
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</tr>
<tr>
<td>Fails to switch</td>
<td>Off</td>
<td>Any</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fails to switch</td>
<td>On, Off</td>
<td>Any</td>
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<td>3_or_More_States</td>
<td>Any</td>
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<td>Transfer</td>
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<tr>
<td>Fails to trip</td>
<td>Trip; Control Overcurrent</td>
<td>Power/Energy, Electronics</td>
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<td>Flow blockage</td>
<td>Transfer</td>
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<td>Flow restriction</td>
<td>Transfer</td>
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<td>High input</td>
<td>Receive Input</td>
<td>Control Amount</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High output</td>
<td>Supply Output</td>
<td>Control Amount</td>
<td></td>
<td></td>
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<tr>
<td>Inadvertant output</td>
<td>Supply Output</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Inadvertant output</td>
<td>Regulate Timing</td>
<td>ECLSS, Thermal, Propulsion/Pyro, C&amp;DH, C&amp;T, GN&amp;C, Power/Energy, Mechanisms</td>
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<td></td>
</tr>
<tr>
<td>Inadvertantly fires</td>
<td>Fire</td>
<td>Propulsion/Pyro</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inadvertantly fires</td>
<td>Regulate Timing</td>
<td>Propulsion/Pyro</td>
<td></td>
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</tr>
<tr>
<td>Incorrect timing</td>
<td>Regulate Timing</td>
<td>Control Operation</td>
<td>Any</td>
<td></td>
</tr>
<tr>
<td>----------------------------------</td>
<td>-----------------</td>
<td>-----------------------</td>
<td>------------------------------</td>
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</tr>
<tr>
<td>Internal leakage</td>
<td>Contain/Isolate</td>
<td>Fluid</td>
<td>ECLSS, Thermal, Propulsion/Pyo</td>
<td></td>
</tr>
<tr>
<td>Loss of adhesion-cohesion</td>
<td>Attach</td>
<td>Structure</td>
<td>Any</td>
<td></td>
</tr>
<tr>
<td>Loss of input - data/cmd/signal</td>
<td>Receive Input</td>
<td>I/O</td>
<td>ECLSS, Propulsion/Pyo, C&amp;DH, C&amp;T, GN&amp;C, Power/Energy</td>
<td></td>
</tr>
<tr>
<td>Loss of input - general</td>
<td>Receive Input</td>
<td>I/O</td>
<td>ECLSS, Propulsion/Pyo, C&amp;DH, C&amp;T, GN&amp;C, Power/Energy</td>
<td></td>
</tr>
<tr>
<td>Loss of input - power</td>
<td>Receive Input</td>
<td>I/O</td>
<td>ECLSS, Propulsion/Pyo, C&amp;DH, C&amp;T, GN&amp;C, Power/Energy</td>
<td></td>
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<tr>
<td>Loss of insulation capability</td>
<td>Insulate</td>
<td>Thermal</td>
<td>Any</td>
<td></td>
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<tr>
<td>Loss of output - data/cmd/signal</td>
<td>Supply Output</td>
<td>I/O</td>
<td>ECLSS, Propulsion/Pyo, C&amp;DH, C&amp;T, GN&amp;C, Power/Energy</td>
<td></td>
</tr>
<tr>
<td>Loss of output - general</td>
<td>Supply Output</td>
<td>I/O</td>
<td>ECLSS, Propulsion/Pyo, C&amp;DH, C&amp;T, GN&amp;C, Power/Energy</td>
<td></td>
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<tr>
<td>Loss of output - power</td>
<td>Supply Output</td>
<td>I/O</td>
<td>ECLSS, Propulsion/Pyo, C&amp;DH, C&amp;T, GN&amp;C, Power/Energy</td>
<td></td>
</tr>
<tr>
<td>Loss of preload/loading</td>
<td>Attach</td>
<td>Structure</td>
<td>Any</td>
<td></td>
</tr>
<tr>
<td>Low input</td>
<td>Receive Input</td>
<td>Control Amount</td>
<td>ECLSS, Thermal, Propulsion/Pyo, C&amp;DH, C&amp;T, GN&amp;C, Power/Energy, Mechanisms</td>
<td></td>
</tr>
<tr>
<td>Low output</td>
<td>Supply Output</td>
<td>Control Amount</td>
<td>ECLSS, Thermal, Propulsion/Pyo, C&amp;DH, C&amp;T, GN&amp;C, Power/Energy, Mechanisms</td>
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<tr>
<td>No indication</td>
<td>Indicate</td>
<td>Sensor/Indicator</td>
<td>Any-with Sensor/Indicator</td>
<td></td>
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<tr>
<td>Nonconforming flow</td>
<td>Control Flow</td>
<td>Fluid</td>
<td>ECLSS, Thermal, Propulsion/Pyo</td>
<td></td>
</tr>
<tr>
<td>Nonconforming start</td>
<td>Start</td>
<td>Stopped, Started</td>
<td>Control Operation</td>
<td>Any</td>
</tr>
<tr>
<td>Nonconforming stop</td>
<td>Stop</td>
<td>Started, Stopped</td>
<td>Control Operation</td>
<td>Any</td>
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<tr>
<td>Open circuit</td>
<td>Protect Circuit</td>
<td>Electronics/Power</td>
<td>ECLSS, Thermal, Electronics</td>
<td></td>
</tr>
<tr>
<td>Opens at incorrect time</td>
<td>Open</td>
<td>Closed, Open</td>
<td>Control Path</td>
<td>ECLSS, Thermal, Propulsion/Pyo, Power/Energy</td>
</tr>
<tr>
<td>Opens at incorrect time</td>
<td>Regulate Timing</td>
<td>Closed, Open</td>
<td>Control Path</td>
<td>ECLSS, Thermal, Propulsion/Pyo, Power/Energy</td>
</tr>
<tr>
<td>Opens incorrectly</td>
<td>Open</td>
<td>Closed, Open</td>
<td>Control Path</td>
<td>ECLSS, Thermal, Propulsion/Pyo, Power/Energy</td>
</tr>
<tr>
<td>Overcurrent</td>
<td>Control Overcurrent</td>
<td>Electronics/Power</td>
<td>Power/Energy, Electronics</td>
<td></td>
</tr>
<tr>
<td>Overheats</td>
<td>Control Heat</td>
<td>Thermal</td>
<td>Any</td>
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<tr>
<td>Parameter drift</td>
<td>Condition Data</td>
<td>Sensor/Indicator</td>
<td>Any-with Sensor/Indicator</td>
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<tr>
<td>Passes contaminates</td>
<td>Control Contaminants</td>
<td>Fluid</td>
<td>ECLSS, Thermal, Propulsion/Pyo</td>
<td></td>
</tr>
<tr>
<td>Premature actuation</td>
<td>Actuate</td>
<td>Off, Actuated</td>
<td>Control Operation</td>
<td>Any</td>
</tr>
<tr>
<td>Premature actuation</td>
<td>Regulate</td>
<td>Off, Actuated</td>
<td>Control Operation</td>
<td>Any</td>
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<tr>
<td></td>
<td>Timing</td>
<td>Control Operation</td>
<td>Any</td>
<td></td>
</tr>
<tr>
<td>----------------------</td>
<td>-------------------------</td>
<td>-------------------</td>
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<tr>
<td>Premature de-activation</td>
<td>De-Activate</td>
<td>Active, Inactive</td>
<td>Control Operation</td>
<td>Any</td>
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<tr>
<td>Premature operation</td>
<td>Operate/Run</td>
<td>Off, Operating</td>
<td>Control Operation</td>
<td>Any</td>
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<tr>
<td>Regulates high</td>
<td>Regulate</td>
<td>Control Amount</td>
<td>ECLSS, Thermal, Propulsion/Pyro, C&amp;DH, C&amp;T, GN&amp;C, Power/Energy, Mechanisms</td>
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<tr>
<td>Regulates low</td>
<td>Regulate</td>
<td>Control Amount</td>
<td>ECLSS, Thermal, Propulsion/Pyro, C&amp;DH, C&amp;T, GN&amp;C, Power/Energy, Mechanisms</td>
<td></td>
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<tr>
<td>Reverse polarity</td>
<td>Protect Circuit</td>
<td>Electronics/Power</td>
<td>Power/Energy, Electronics</td>
<td></td>
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<tr>
<td>Separates prematurely</td>
<td>Separate</td>
<td>Mated, Separated</td>
<td>Motion/Separation</td>
<td>GN&amp;C, Propulsion/Pyro, Mechanisms, Robotics</td>
</tr>
<tr>
<td>Separates prematurely</td>
<td>Regulate Timing</td>
<td>Mated, Separated</td>
<td>Motion/Separation</td>
<td>GN&amp;C, Propulsion/Pyro, Mechanisms, Robotics</td>
</tr>
<tr>
<td>Short circuit</td>
<td>Control Overcurrent</td>
<td>Electronics/Power</td>
<td>Power/Energy, Electronics</td>
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<tr>
<td>Short to ground</td>
<td>Control Overcurrent</td>
<td>Electronics/Power</td>
<td>Power/Energy, Electronics</td>
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<tr>
<td>Structural failure - debond</td>
<td>Attach</td>
<td>Structure</td>
<td>Power/Energy, Electronics</td>
<td></td>
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<tr>
<td>Structural failure - debris</td>
<td>Contain/Isolate</td>
<td>Structure</td>
<td>Power/Energy, Electronics</td>
<td></td>
</tr>
<tr>
<td>Structural failure - deform</td>
<td>Protect Structure</td>
<td>Structure</td>
<td>Power/Energy, Electronics</td>
<td></td>
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<tr>
<td>Structural failure - fracture</td>
<td>Protect Structure</td>
<td>Structure</td>
<td>Power/Energy, Electronics</td>
<td></td>
</tr>
<tr>
<td>Structural failure - general</td>
<td>Protect Structure</td>
<td>Structure</td>
<td>Power/Energy, Electronics</td>
<td></td>
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<tr>
<td>Structural failure - loss of containment</td>
<td>Contain/Isolate</td>
<td>Structure</td>
<td>Power/Energy, Electronics</td>
<td></td>
</tr>
<tr>
<td>Structural failure - mounting</td>
<td>Attach</td>
<td>Structure</td>
<td>Power/Energy, Electronics</td>
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</tbody>
</table>