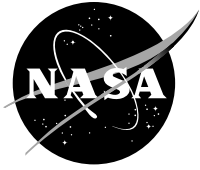


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Software Users Manual (SUM) Extended Testability Analysis (ETA) Tool

*William A. Maul and Christopher E. Fulton
QinetiQ North America, Cleveland, Ohio*

November 2011

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*William A. Maul and Christopher E. Fulton
QinetiQ North America, Cleveland, Ohio*

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National Aeronautics and
Space Administration

Glenn Research Center
Cleveland, Ohio 44135

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Change Record

Extended Testability Analysis (ETA) Tool Software Users Manual

Revision	Effective Date	Description of Change
Draft	12/15/2010	Initial draft of Users manual
Version 1.3	01/07/2011	Draft for formal RHC Technical Review
Version 1.4	01/10/2011	Updated draft—added error code messages to Section 5.4
Version 1.5	01/21/2011	Small modifications based on updated error codes and compiler information
Version 1.6	02/22/2011	Incorporated initial reviews from the two principle reviewers to both the User guide and the software package. As a result of some of the software modifications, several of the figures and some of the text discussions required modification
Version 2.0	04/25/2011	Draft completed peer review
Version 2.1	06/02/2011	Draft completed Branch Chief review
Version 2.2	06/07/2011	Approved by NASA management for publication as NASA TM

1.0 Scope

1.1 Identification

This document applies to the Extended Testability Analysis (ETA) Tool software, Version 6.7, release 1.0.

1.2 System Overview

The purpose of the ETA Tool software is to process the testability analysis results from the Testability Engineering And Maintenance System (TEAMS) Designer program and provide the user with detailed documentation of the results. The TEAMS Designer is commercial-off-the-shelf software with the capability to analyze a diagnostic model of the system under study. The diagnostic model is a directed graph representation of the failure effect propagation paths within the system's physical architecture. The ETA Tool extracts information from the TEAMS Designer analysis output and the associated diagnostic model to provide a detailed set of reports highlighting aspects of the system's diagnostic performance. The ETA Tool was developed under the NASA Constellation Program to support the Functional Fault Analysis (FFA) team for the Ares I Launch Vehicle.

The ETA Tool software was initially developed in response to system engineering requests to summarize the testability results from the diagnostic model and was extended to incorporate specific system information captured within the diagnostic model. The ETA Tool relies on the testability analysis output from TEAMS Designer and the diagnostic modeling conventions established by the Ares I FFA team (Appendix A). However, the version of the tool associated with this user manual was generalized for public distribution and application to a broad spectrum of systems requiring testability analysis.

1.3 Document Overview

This user manual describes the implementation and use of the ETA Tool software. The manual first provides an overview of the software package. It then provides directions for software installation, setup, and execution. The ETA Tool is a command line process with several user-selectable report output options. Example reports used to demonstrate the output options were generated for a generic system, the details of which are provided in Appendix B. The intent of this manual is to provide the user the information needed to operate the ETA Tool successfully and generate specific testability analysis reports. This manual is not intended to educate the user in the operation of the TEAMS Designer software package nor in the broader context of diagnostic analysis and assessment.

1.4 Formats and Conventions

Sans-serif	Directory names, file names, function names and screen output are displayed in this font. For example: <code>xls2csv.exe</code>
<i>Italics</i>	Book or report titles and names of book or report sections, mathematical symbols and notation, and the introduction of new terms. For example: <i>Introduction</i>

2.0 Referenced Documents

Documents referenced in this report are listed below

Document number	Title
NPR 7150.2	<i>NASA Software Engineering Requirements</i>
GLPR 7150.1	<i>GRC Software Engineering Requirements</i>
GRC-TPLT-SUM	<i>Software Users Manual Template</i>
MIL-STD-1629A	<i>Military Standard Procedures for Performing a Failure Mode, Effects and Criticality Analysis</i>
<TBD>	<i>NASA Constellation Program Fault Management Terminology Report</i> , Johnson, S.B.; and Day, J.C.: September 10, 2010 (unpublished).

3.0 Software Summary

3.1 Software Application

The ETA Tool extracts information from the TEAMS Designer analysis output and the associated diagnostic model to provide a detailed set of reports highlighting aspects of the system's diagnostic performance. Here, diagnostic performance implies the system's ability to detect the effects propagated from failure modes and to isolate system faults or faulty components. The TEAMS testability analysis is performed on a diagnostic model of a physical system. The testability results and the diagnostic model are accessed by the ETA Tool so that further processing can extend the testability analysis. The extended analysis provides failure effect detection and fault isolation information in a consistent report format. The ETA Tool is capable of generating the following extended analysis reports:

- **Detectability Report** provides details that show how each tested failure mode was detected
- **Test Utilization Report** identifies all failure modes detected by each system test.
- **Failure Mode Isolation Report** demonstrates the ability of the system to discriminate between failure modes.
- **Component Isolation Report** demonstrates the ability of the system to discriminate between failure modes relative to the components containing the failure modes.
- **Effect Mapping Report** identifies failure modes that result in user specified system-level effects.
- **Sensor Sensitivity Analysis Reports** describes the impact of the loss of a sensor on the ability of the system to detect and isolate the various failure modes.

The ETA Tool reports can be converted into printable formats or viewed directly from computer Internet browsers.

3.2 Software Inventory

The following files are included in the ETA Tool, Version 6.7—Release 1.0 package

Basic_System <directory>

- Contains files for the example diagnostic model, including an example testability output cycle for TEAMS Designer which can be used to demonstrate the ETA Tool.

Sample Output <directory>

- Contains the output file from an ETA Tool example case for the Basic_System model.

Basic_System_sensor_file.csv <file>

- Example sensor file in comma separated variable (CSV) format
- Required for any ETA Tool analysis.

Basic_System_Sensor_Sensitivity_Study.csv <file>

- Example instrumentation information file in CSV format
- Required for the sensor sensitivity analysis option

ETAT_v6_7.c <file>

- ETA Tool source code written in the C programming language

ETAT_v6_7.exe <file>

- Windows executable version of the ETA Tool
- Compiled with GCC version 4.5.0 compiler using MinGW headers and libraries (10/30/2010 released package)

makefile <file>

- Contains compiler directives used to compile, link, and create executable software
- Tested using GCC version 4.5.0 compiler using MinGW headers and libraries (10/30/2010 released package)

README File.docx <file>

- Lists contents of the ETA Tool zip-file
- Provides a brief example showing how to run the program
- Contains code revision history

set-env.bat <file>

- Example DOS batch file to set a DOS environment variable for the highest-level directory used by the ETA Tool

xls2csv.exe <file>

- Windows executable program used by the ETA Tool internally to convert the EXCEL file to a comma-separated variable (CSV) file during processing

XLStoCVS.vbs <file>

- Visual basic script used to convert an EXCEL file to a CSV-formatted file.
- Pre-compiled code for previously described **xls2csv.exe** executable.
- Can be run from a command window

The software release package contains two directories: **Basic_System** and **Sample Output**. The first directory, named **Basic_System**, contains the diagnostic model from an example system. Under the **Basic_System** directory structure are two subdirectories; a **model** subdirectory that contains the TEAMS diagnostic model and a **description** subdirectory which contains two documents that detail the general design and operation of the example system modeled. The **description** directory in this package also contains an example output report set from the ETA Tool for the **Basic_System** model. The **Sample Output** directory contains sample analysis output files from a single processing cycle of the ETA Tool.

3.3 Software Environment

This section identifies the hardware and software resources that are required for a user to install and run the ETA Tool. The software is intended to be multi-platform operational. However, at this time, the software has only been tested with an Intel Processor-based Windows XP system. The program requires the following external software program:

- The included executable has been compiled with the GCC (version 4.5.0) compiler using MinGW headers and libraries (10/30/2010 released package)

The software has been developed and tested on the following platform:

- Operating System: Microsoft Windows XP Professional 2002, Service Pack 3
- Operating Platform: Q37 XPPro Multi Platform Load Intel® Core™ 2 Duo CPU T7500, 2.20 GHz, 3.5 GB RAM

3.4 Software Organization and Overview of Operation

The ETA Tool executable and the `xls2csv.exe` file should be located in the same directory. The ETA Tool program is operated from the command line. The ETA Tool assumes that the system environmental variable `TEAMS` is defined prior to ETA Tool execution. This variable is used to define the location of the `TEAMS` diagnostic model on the hard drive of the user's computer. The model information and testability reports used by the ETA Tool are stored by `TEAMS` in pre-defined subdirectories under the `TEAMS` directory. During execution, the ETA Tool will copy certain testability analysis output files to the local directory containing the ETA Tool executable and further process them. The program will also remotely access certain diagnostic model files to extract design information. Files containing final analysis reports from the ETA Tool will also be placed in the directory containing the ETA Tool executable. The types of reports generated will depend on the command line syntax used by the user to run the ETA Tool software.

3.5 Security and Privacy

The ETA Tool is Class E software as defined in Glenn Procedural Requirement (GLPR) 7150.1 GRC Software Engineering Requirements, developed with U.S. government funding. As such, it is free and available without restriction for use by the general public. The user accepts any risks to their system or damage or loss of data with the operation of this software program.

3.6 Assistance and Problem Reporting

This software is officially unsupported. If there are any issues or questions concerning the software, the user may contact the principal developer, but an immediate response should not be expected. Further, the government makes no guarantees regarding compatibility with operating system software or compilers with which the ETA Tool software has not been test.

4.0 Software Operations

4.1 Installation and Setup

ETA Tool version 6.7 is packaged in a compressed file. The contents can all be extracted into a file directory that will be hence forth named `ETAT_HOME` directory. A list of files included in the compressed file is given in Section 3.2.

A pre-compiled version of the ETA Tool is included for Windows-based computers. The makefile provides the user with an example that demonstrates the process for generating the ETA Tool executable. The file will need to be modified to reflect the available C compiler, compiler options and compiler location on the user's computer.

The ETA Tool expects a system environmental variable to be set prior to ETA Tool execution that defines the location of the `TEAMS` diagnostic model. The process for setting the environmental variable will be dependent on the computer platform and operating system. The `'set-env.bat'` file included with the distribution package contains an example of syntax required to define the environmental variable for a DOS shell session. Also, it sets the environmental variable to reference the example model included in the package to allow exercising the ETA tool without requiring a `TEAMS` installation. However, during normal use of the ETA tool, this command should be modified to reference the installed `TEAMS` diagnostic model. For example,

```
>> set TEAMS=C:\TEAMS\Basic_System\model
```

Setting the environmental variable by running the batch file at the command line or by directly typing the `'set'` commands, should define the variable for the current DOS shell session. Environmental variables can also be defined in Microsoft Windows in the `'Control Panel'` under the `'System'` icon.

Two instrumentation files are required as inputs for the ETA Tool processing and must be created by the user prior to processing. In order for the ETA Tool to access these files, they must be placed in the same directory as the ETA Tool executable. These files contain basic design information that requires updating only if the instrumentation in the system under analysis is changed.

The first file is the sensor input file. This file, in a CSV format, is required for every ETA Tool analysis report. The sensor input file developed for the example system is provided as a template for use in creating customized sensor input files for user applications. The sensor input file for the example problem is named `Basic_System_sensor_file.csv` and is located in the `ETAT_HOME` directory. Table 1 displays a portion of this file. The following information is contained in the sensor input file:

- **Measurement Identifier**—Required unique string that is used to identify the sensor. Within the diagnostic model, the test name should contain this string (see Appendix A—Diagnostic Modeling Conventions). The ETA Tool attempts to match these values to the “Measurement Identifier” field used in the test naming conventions of the diagnostic model.
- **Other Measurement Identifier**—Optional measurement identifier that could be used in future reporting needs. The ETA Tool will also check to see if this string is utilized in the diagnostic model test naming convention field for “Measurement Identifier”. Often within a program instrumentation can have multiple identifiers that various groups employ.
- **Schematic Identifier**—Optional identifier that represents the schematic design representation of the sensor. The ETA Tool uses this field to align the sensor to the proper hierarchical module within the diagnostic model. Reported if available.
- **3rd Measurement Identifier**—Optional identifier that could be used in future reporting needs. Often within a program instrumentation can have multiple identifiers that various groups employ.
- **Subsystem**—Optional. Portion of the system where the sensor resides. Currently not used by the ETA Tool.
- **Component**—Optional. Lower level portion of the system where the sensor resides. Currently not used by the ETA Tool.
- **Short Description**—Optional. Brief description of the sensor.

If there are no entries for any of the optional columns, then the ‘None’ string is required. This file can have any name and can be specified as part of the command line syntax. If the naming convention, `<Model Name>_sensor_file.csv` is used, where the model name is the diagnostic model being evaluated, the ETA Tool will access the file from the current directory without command line specification.

TABLE 1.—PORTION OF THE SENSOR INPUT FILE REQUIRED BY THE ETA TOOL PROCESSING

Measurement Identifier	Other Measurement Identifier	Schematic Identifier	3rd Measurement Identifier	Subsystem	Component	Short Description
SEN0001	SEN0001	SS1	None	Hydraulic Pump Assembly	Turbine	Pitch Turbine Speed Sensor
SEN0002	SEN0002	SS2	None	Hydraulic Pump Assembly	Turbine	Yaw Turbine Speed Sensor
SEN0003	SEN0003	PV11	None	Hydraulic Pump Assembly	PSV	Pitch Propellant Supply Valve Position
SEN0004	SEN0004	PV12	None	Actuator	PSV	Pitch Pressure Selector Valve Position
SEN0005	SEN0005	PV21	None	Hydraulic Pump Assembly	PSV	Yaw Propellant Supply Valve Position
SEN0006	SEN0006	PV22	None	Actuator	PSV	Yaw Pressure Selector Valve Position

TABLE 2.—Concluded.

Measurement Identifier	Other Measurement Identifier	Schematic Identifier	3rd Measurement Identifier	Subsystem	Component	Short Description
SEN0007	SEN0007	dP1	None	Hydraulic Fluid Assembly	Filter	Pitch Delta Pressure Filter Sensor
SEN0008	SEN0008	dP2	None	Hydraulic Fluid Assembly	Filter	Yaw Delta Pressure Filter Sensor
SEN0009	SEN0009	P11	None	Hydraulic Pump Assembly	Turbine	Pitch Turbine Propellant Inlet Pressure
SEN0010	SEN0010	P12	None	Hydraulic Fluid Assembly	None	Pitch Hydraulic Supply Pressure 1

The second sensor input file, the sensor sensitivity study input file, is only required when the sensor sensitivity analysis option is specified on the command line. The sensor sensitivity study input file for the example problem is named `Basic_System_Sensor_Sensitivity_Study.csv` and is located in the `ETAT_HOME` directory.

For illustrative purposes, a portion of the file is shown in Table 2. This file defines the sensor groupings for the analysis. The sensor sensitivity analysis cycles through the available sensors three times. The first pass removes individual sensors from the system and determines the diagnostic impact. During the second and third passes, groups of sensors are removed one group at a time. The first column in this file, **Measurement Identifier**, specifies the individual sensors to be analyzed in the sensor sensitivity analysis. The unique label must be identical to an entry in the basic sensor file, **Measurement Identifier** column, presented above. The second column in this sensor file, **Group 1 Identifier**, tags individual sensors with a group name that will be used to extract those sensors together during the second sensor sensitivity analysis cycle. The third column, **Group 2 Identifier**, performs the same function for the third sensor sensitivity analysis cycle. If a sensor is not involved in a group for the second or third analysis cycle, a 'None' entry is required in the respective columns. This file should be saved in a comma-separated-variable format.

TABLE 3.—PORTION OF THE SENSOR INFORMATION INPUT FILE REQUIRED BY THE ETA TOOL SENSOR SENSITIVITY ANALYSIS PROCESSING

Measurement Identifier	Group 1 Identifier	Group 2 Identifier
SEN0001	None	Turbine Speed Sensor
SEN0002	None	Turbine Speed Sensor
SEN0003	None	Propellant Supply Valve Position
SEN0004	None	Pressure Selector Valve Position
SEN0005	None	Propellant Supply Valve Position
SEN0006	None	Pressure Selector Valve Position
SEN0007	None	Delta Pressure Filter Sensor
SEN0008	None	Delta Pressure Filter Sensor
SEN0009	None	Turbine Propellant Inlet Pressure
SEN0010	Pitch Hydraulic Supply Pressure	Hydraulic Supply Pressure
SEN0011	Pitch Hydraulic Supply Pressure	Hydraulic Supply Pressure
SEN0012	None	Turbine Propellant Inlet Pressure
SEN0013	Yaw Hydraulic Supply Pressure	Hydraulic Supply Pressure
SEN0014	Yaw Hydraulic Supply Pressure	Hydraulic Supply Pressure
SEN0015	None	Propellant Supply Valve Current
SEN0016	None	Actuator Power Valve Solenoid Current

4.2 Basic Operation

The ETA Tool program is executed from the DOS command line with user-selectable options. The following text provides a description of the proper syntax for the ETA Tool version 6.7;

```
ETAT_v6_7 {-i ins_file.csv} {-d} {-s1 ss_file.csv} {-D} {-T} {-E} {-I} {-iso label}
```

where

- {-i ins_file.csv} Specifies the CSV-formatted sensor file to use in the ETA Tool analysis. If this option is not specified, the ETA Tool will attempt to access a default sensor file by the naming convention “<Model Name>_sensor_file.csv”
- {-d} Indicates a debugging option which turns on certain screen printing output for ETA Tool developers.
- {-s1 ss_file.csv} Indicates that the sensors sensitivity analysis is to be performed and the CSV-formatted file to use containing additional sensor information.
- {-D} Generates the Detectability Report
- {-T} Generates the Test Utilization Report
- {-E} Generates the Effect Mapping Report
- {-I} Generates the Failure Mode Isolation Report
- {-iso label} Generates the Component Isolation report and indicates the hierarchical label to be used in the component-isolation analysis

Upon completion of the ETA Tool processing, a main output file is generated. The main output file is in HyperText Markup Language (HTML) format and is displayable within any of the common Internet browsers. It has been tested and is known to work correctly with Internet Explorer, 7.0, Mozilla Firefox 3.6.13, Google Chrome 9.0, Safari 5.0 and Opera 11.0 browsers. The naming convention for the main output file is as follows:

```
<TEAMS diagnostic model name>_TestAnalysis_Main.htm
```

The main output file for the example problem is:

```
.\ ETAT_HOME \Basic_System_TestAnalysis_Main.htm
```

The main output file has three sections separated by blue horizontal lines. The top section contains testability conditions for the analysis conducted by TEAMS. The second section contains hyper-linked documents from the TEAMS Designer testability analysis. These documents are not modified by the ETA Tool and are provided to the user for reference information. The last section contains hyper-linked documents of reports generated by the ETA Tool based on the options selected by the user at run time. Note that only the reports specified by the user as part of the command line syntax will be linked by the main report. Figure 1 illustrates an example of the ETA Tool main report file.

ETAT Analysis Summary

Model Version: Basic_System

Testability Run Date: Mon Jan 03 15:41:12 2011

Test Conditions

TEAMS Model Analyzed:

Basic_System

Ambiguity Isolation Level:

Failure_mode

System Modes:

Phase-B

Switches

Phase-B

Technology Labels:

Crit-1R_Phase-B

Crit-3_Phase-B

Crit-1S_Phase-B

Crit-1_Phase-B

Test Labels:

Effect

Flight

TEAMS Analysis Links

[TEAMS Testability Figures of Merit \(TFOM\) Report](#)

[TEAMS Ambiguity Report](#)

[TEAMS Fault Detection & Isolation Report](#)

ETAT Output Reports

[Detectability Report](#)

[Test Utilization Report](#)

[Effect Mapping Report](#)

[Failure Mode Isolation Report](#)

[Component Isolation Report](#)

[Sensor Sensitivity Analysis by Individual Sensors](#)

[Sensor Sensitivity Analysis by Measurements](#)

[Sensor Sensitivity Analysis by Measurement Groups](#)

Figure 1.—Main output report file generated by the ETA Tool software.

5.0 Processing Reference Guide

This section provides a demonstration and explanation for each of the six ETA Tool reports. In addition, the output from a simple TEAMS model is used to demonstrate and explain the processes that generate each of the available ETA Tool reports. As part of the example, command line syntax for the various reports is discussed.

5.1 Capabilities

Each report output option is independent of the others. The user may select any or all of the options during a single processing cycle.

5.2 Processing Procedures

The command line syntax for each report will be discussed individually in subsequent subsections by describing any special input requirements and the resulting output report. In each case, the example system provided was utilized to generate the reports for illustration.

5.2.1 Generation of the ETA Tool Detectability Report

Syntax for generating a Detectability Report:

```
>> ETAT_v6_7.exe -D
```

Special Input Requirements:

None

Output Report Description:

The Detectability report generated for the example system provided in the software package is named:

```
.\ETAT_HOME \Basic_System_Detectability_Report.htm.
```

The report can be either opened directly into an Internet browser or accessed by the “Detectability Report” link on the main output file, `Basic_System_TestAnalysis_Main.htm`.

The Detectability report provides details regarding the detection or missed detection of failure modes using the available suite of detection tests. This analysis and reporting capability proved useful during the design phase of NASA’s Ares I Project, when verifying the ability of subsystem designs to meet requirements regarding the detection of specific failure modes. The Detectability report identified the sensors and tests capable of providing detection of effects propagated by the failure mode.

The Detectability report generated by this command line syntax may be found in the `ETAT_HOME` directory. Figure 2 illustrates the ETA Tool Detectability report for the example diagnostic model. The report contains three sections separated by a blue horizontal line. The top section lists the testability conditions for the analysis conducted by TEAMS.

The second section contains metrics generated by the ETA Tool during the detectability analysis.

- Number of Failure Modes—the number of failure modes that are active for the specified testability analysis conditions.
- Number of Tests—the number of tests available for the specified testability analysis
- Overall Detection Coverage—a calculated metric that is equal to the number of detected failure modes divided by the total number of failure modes

This section also lists the failure modes, if any, that were not detected by any test during this analysis. For large lists of undetected failures (greater than 10 failure modes), a separate report is generated and hyper-linked to this section.

The last section of this report presents information for each detected failure mode where results for the individual failure modes are separated by a green horizontal line. For each failure mode, the component from which the failure mode originated, the failure mode name, and Failure Mode and Effect Analysis (FMEA) number are reported. A table is reported containing the tests that detected the failure mode, including the sensor identifier, sensor description and test name.

ETAT Analysis Summary - Detectability Report

Model Version: Basic_System

Testability Run Date: Mon Jan 03 15:41:12 2011

Test Conditions

TEAMS Model Analyzed:

Basic_System

System Modes:

Phase-B

Switches

Phase-B

Technology Labels:

Crit-1R_Phase-B

Crit-3_Phase-B

Crit-1S_Phase-B

Crit-1_Phase-B

Test Labels:

Effect

Flight

Detectability Analysis

Number of Failure Modes 118
 Number of Tests 76
 Overall Detection Coverage 98.31 %

2 Undetected Failure Mode(s)

Component	Failure Mode	FMEA Identifier
Hydraulic Turbine	Propellant Leak	MS-SS-HPump-01-002
Hydraulic Turbine	Propellant Leak	MS-SS-HPump-01-002

(1) Failure Mode: Pitch Pressure Selector Valve - Valve Fails in Intermediate Position
FMEA Identifier: MS-SS-ACT-01-001

Detected by 4 Tests

Sensor Identifier	Sensor Description	Test Name
SEN0004	Pitch Pressure Selector Valve Position	Selector Valve Intermediate Position
SEN0023	Pitch LVDT Displacement Transducer 1	No Position Change
SEN0024	Pitch LVDT Displacement Transducer 2	No Position Change
SEN0025	Pitch LVDT Displacement Transducer 3	No Position Change

Figure 2.—ETA tool detectability report for the example diagnostic model.

5.2.2 Generation of the ETA Tool Test Utilization Report

Syntax for generating a Test Utilization Report:

```
>> ETAT_v6_7.exe -T
```

Special Input Requirements:

None

Output Report Description:

The Test Utilization report generated for the example system provided in the software package is named:

```
.\ ETAT_HOME \ Basic_System_Test_Utilization_Report.htm
```

The report can be either opened directly into an Internet browser or accessed by the “Test Utilization Report” link on the main output file, `Basic_System_TestAnalysis_Main.htm`.

The Test Utilization report provides details regarding the ability of each test to detect system failure modes. This information provides justification for retaining a test and the associated sensor. As with any launch vehicle, during the design phase of NASA’s Ares I Project studies were continuously conducted to scrub down (i.e., remove unnecessary) sensors from the instrumentation suite. During these studies, system designers were required to demonstrate the usefulness of each sensor—this analysis could support that demonstration from the diagnostic perspective.

The Test Utilization report generated by this command line option contains four sections that are separated by blue horizontal lines. The top section contains testability conditions for the analysis conducted by TEAMS. The TEAMS analysis date and time, as well as the diagnostic model are reported. This section also includes the TEAMS analysis options selected such as the technology labels, test labels and system modes.

The second section displays a simple reminder notice to the user that the results presented here do not include tests that solely detect their own sensor failure modes.

The third section contains metrics generated during the ETA Tool process relevant to the system’s test utilization analysis. The number of tests evaluated in this analysis, less the tests that provided detection solely for their own sensors failure mode, and the number of tests that provided no detection for the failure modes considered in the testability analysis are reported here. This section also lists the tests not utilized for detection in this analysis in a table format, providing the test name, corresponding sensor identifier and sensor description.

In the last section, each test is presented, separated by a green horizontal line. For each test, the test name, corresponding sensor and sensor description are reported. In addition, a table containing all the failure modes detected by that test is also reported here. The tabulated data includes the failure mode name, the FMEA identifier, the name of the component from which the failure mode originated, and the criticality value assigned to the failure mode for the current phase of operation.

Figure 3 illustrates the ETA Tool Test Utilization report for the example diagnostic model.

ETAT Analysis Summary - Test Utilization Report

Model Version: Basic_System

Testability Run Date: Mon Jan 03 15:41:12 2011

Test Conditions

TEAMS Model Analyzed:
Basic_System

System Modes:
Phase-B
Switches

Phase-B
Technology Labels:
Crit-1R_Phase-B
Crit-3_Phase-B
Crit-1S_Phase-B
Crit-1_Phase-B

Test Labels:
Effect
Flight

Note: For this report, tests that solely detect their own sensor fault are not reported

Test Utilization Analysis

Number of Tests = 44 Number of Unused Tests = 4

Tests Not Utilized

Test Name	Sensor Identifier	Sensor Description
Selector Valve Primary Position	SEN0004	Pitch Pressure Selector Valve Position
Selector Valve Primary Position	SEN0006	Yaw Pressure Selector Valve Position
PSV Open	SEN0005	Yaw Propellant Supply Valve Position
PSV Open	SEN0003	Pitch Propellant Supply Valve Position

(1) **Test** Selector Valve Intermediate Position **Sensor:** SEN0004 -Pitch Pressure Selector Valve Position

Detected Failure Mode

Failure Mode	FMEA Identifier	Component	Criticality
Valve Fails in Intermediate Position	MS-SS-ACT-01-001	Pitch Pressure Selector Valve	1

(2) **Test** Selector Valve Intermediate Position **Sensor:** SEN0006 -Yaw Pressure Selector Valve Position

Figure 3.—ETA tool test Utilization report for the example diagnostic model.

5.2.3 Generation of the ETA Tool Failure Mode Isolation Report

Syntax for generating a Failure Mode Isolation Report:

```
>> ETAT_v6_7.exe -l
```

Special Input Requirements:

None

Output Report Description:

The Failure Mode Isolation report generated for the example system provided in the software package is named;

```
.\ETAT_HOME\Basic_System_Failure_Mode_Isolation_Report.htm
```

The report can be either opened directly into an Internet browser or accessed by the “Failure Mode Isolation Report” link on the main output file, `Basic_System_TestAnalysis_Main.htm`.

The Failure Mode Isolation report provides information on the system’s ability to isolate each of the system’s failure modes. This analysis and reporting capability proved useful during the design phase of NASA’s Ares I Project for verifying the ability of subsystem designs to meet requirements for fault isolation. Here, failure mode isolation is the determination of the possible physical locations of a failure cause.

This analysis is performed by grouping failure modes that have identical detection signatures. Groups that contain a single failure mode are considered to be isolated—meaning, that the system is able to uniquely identify that single failure mode based on the tests that it fails. Failure mode groups containing more than one failure mode are ambiguous. In other words, the system is unable to distinguish which failure mode or modes within the group may be occurring based on their detection signature.

The Failure Mode Isolation report generated by this command line option contains four sections that are separated by blue horizontal lines. The top section contains testability conditions for the analysis conducted by TEAMS. The TEAMS analysis date and time, as well as the diagnostic model are reported. This section also includes the TEAMS analysis options selected such as the technology labels, test labels and system modes.

The second section contains metrics generated during the ETA Tool process relevant to the system’s failure mode isolation analysis. This section reports the following metrics:

- Number of Failure Mode Groups—the number of failure mode groups generated in this analysis for the number of active failure modes in the model
- Number of Failure Modes—the number of failure modes that are active for the specified testability analysis conditions
- Number of Isolated Groups—Failure mode groups containing a single failure mode
- Maximum Failure Mode Group Size—The number of failure modes in the largest group
- Calculated Ambiguity Score—a simple metric that allows comparison between system design changes with respect to the impact on failure mode isolation. The calculated ambiguity score represents the maximum number of tests required to fully isolate all the failure modes. This metric is the sum of each group’s failure mode population minus one, or in equation form.

$$\text{ambiguity score} = \sum_{i=0}^n (P_i - 1)$$

where P_i is the population of the i^{th} failure mode group and n is the number of failure mode groups.

This second section also displays the population distribution of the failure mode groups, both in a text format and graphically.

The third section displays a simple reminder notice to the user that the results presented in the final sections are the failure mode groups displayed in ascending population.

The final section of this report displays each failure mode group separated by a green horizontal line. The groups are presented in ascending population size. For each group, two tables are provided. The first table displays the detection signature information for the group, including the sensor identifier, sensor schematic identifier, sensor description and test name. The second table contains all the failure mode information for each failure mode contained in this group. If the higher level 'Element' and 'System' components are defined in this diagnostic model, then they are presented here in the table's initial columns, otherwise those columns are removed. This table also reported the failure mode's component, failure mode name, FMEA identifier and the criticality of the failure for the phase of operation under analysis, if available.

Figures 4 and 5 illustrate the ETA Tool Failure Mode Isolation report, upper portion and lower portion respectively, for the example diagnostic model.

ETAT Analysis Summary - Failure Mode Isolation Report

Model Version: Basic_System

Testability Run Date: Mon Jan 03 15:41:12 2011

Test Conditions

TEAMS Model Analyzed:

Basic_System

System Modes:

Phase-B

Switches

Phase-B

Technology Labels:

Crit-1R_Phase-B

Crit-3_Phase-B

Crit-1S_Phase-B

Crit-1_Phase-B

Test Labels:

Effect

Flight

Ambiguity Analysis

Number of Failure Mode Groups 61
Number of Failure Modes..... 118
Number of Isolated Groups..... 50
Maximum Failure Mode Group Size..... 15
Calculated Ambiguity Score..... 55

Ambiguity Distribution (Failure Mode Level)

Percentage of groups with 1 members 81.97% (50 of 61 groups)
Percentage of groups with 2 members 6.56% (4 of 61 groups)
Percentage of groups with 3 members 3.28% (2 of 61 groups)
Percentage of groups with 6 members 3.28% (2 of 61 groups)
Percentage of groups with 10 members 1.64% (1 of 61 groups)
Percentage of groups with 15 members 3.28% (2 of 61 groups)

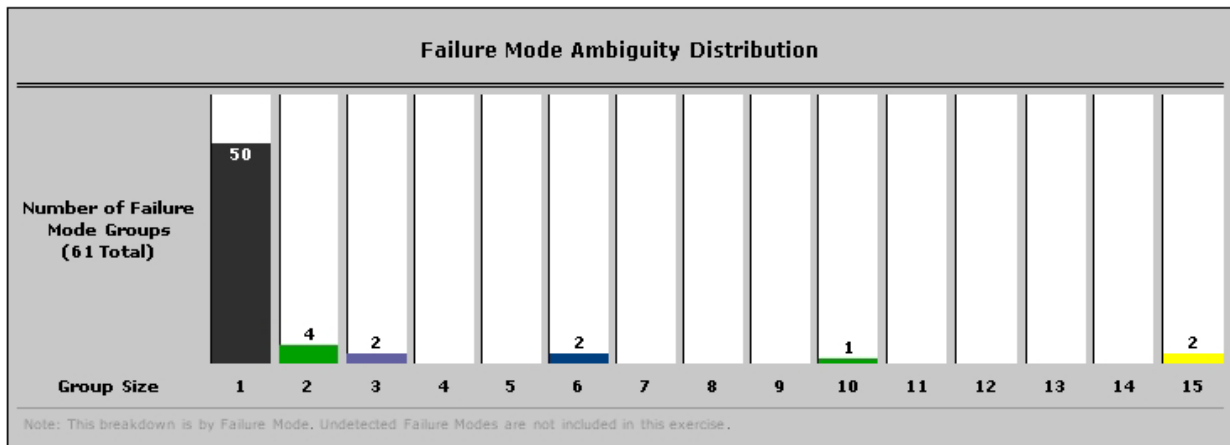


Figure 4.—ETA tool failure mode isolation report, upper portion, for the example diagnostic model.

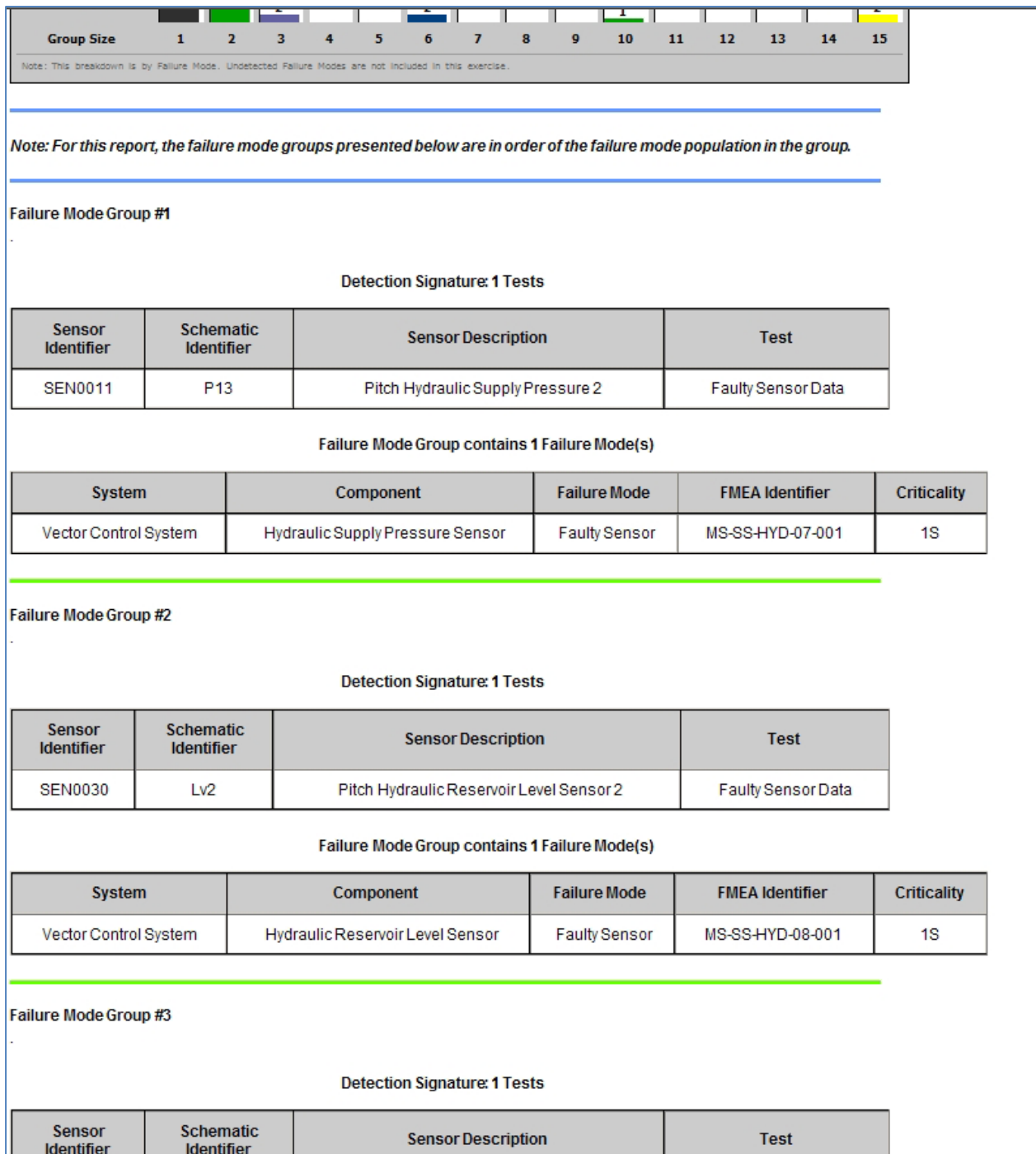


Figure 5.—ETA tool failure mode isolation report, lower portion, for the example diagnostic model.

5.2.4 Generation of the ETA Tool Component Isolation Report

Syntax for generating a Component Isolation Report:

```
>> ETAT_v6_7.exe -iso <Component Label>
```

where <Component Label> is selected from the set of TEAMS module labels assigned for the current diagnostic model.

Special Input Requirements:

The component label input on the command line must be a hierarchical label assigned within the diagnostic model. If a component label is entered on the command line that is not in the diagnostic model, the ETA Tool will notify the user and discontinue processing. Also a basic assumption for component isolation analysis is that the designated components cannot be nested, meaning that a designated component cannot contain another designated component. If a nested designated component is uncovered by the ETA Tool during processing, the tool will report the discovery and discontinue processing.

Within the example diagnostic model, the following component labels are used; System, Assembly, LRU, Component, Sensor and Failure_mode. The Component Isolation analysis works for each label, except for two. The 'Failure_mode' label, which is essentially the Failure Mode Isolation analysis. And the 'System' label because the highest level module in TEAMS Designer is by default assigned the 'System' hierarchical label and therefore creates a nested designated component situation.

Output Report Description:

The Component Isolation report generated for the example system provided in the software package is named:

```
.\ ETAT_HOME \ Basic_System_<Component Label>_Isolation_Report.htm
```

where <Component Label> is provided by the user on the command line. The report can be either opened directly into an Internet browser or accessed by the "Component Isolation Report" link on the main output file, Basic_System_TestAnalysis_Main.htm.

The Component Isolation report provides information regarding the system's ability to isolate failures to a specific component within the system. From a maintenance perspective it may not be imperative to identify the exact failure mode, but rather to identify the component where the failure occurred. For the Ares I project, launch pad logistics and maintainability personnel required that components identified as line replaceable units—meaning they were intended to be replaced on the launch pad—contained only failure modes that could be isolated to that component.

For the Component Isolation report, the user provides the label of the components within the diagnostic model to which failure modes are to be isolated. As with the failure mode isolation analysis, failure modes are grouped by detection signatures. Here, the failure mode groups are further divided into physical components where the failure originates. The depth to which failure mode components are derived is determined by the user-selected isolation level. The output report is similar in format to that generated by the Failure Mode Isolation Report, except the diagnostic metrics are relative to the components identified for isolation.

The Component Isolation report (Figs. 6 and 7) generated by this command line option contains four sections that are separated by blue horizontal lines. The top section contains testability conditions for the analysis conducted by TEAMS. The TEAMS analysis date and time, as well as the diagnostic model are reported. This section also includes the TEAMS analysis options selected such as the technology labels, test labels and system modes.

The second section contains metrics generated during the ETA Tool process relevant to the system's component isolation analysis. Note that, for this analysis, failure mode groups that contain no failure modes from model components labeled with the same label specified on the command line option are not included in the final analysis. This section reports the following metrics:

- Number of Failure Mode Groups—the number of groups generated in this analysis for the number of active components in the model
- Number of Active Components—the number of components that have failure modes that are part of the testability analysis

- Number of Active Non-Components—the number of non-components that have failure modes that are part of the testability analysis
- Number of Isolated Groups—failure mode groups containing a single component or non-component
- Maximum Failure Mode Group Size—the number of components and non-components in the largest group
- Calculated Ambiguity Score—a simple metric that attempts to provide a tool for comparison with system design change impacts on component isolation. This metric is simply the sum of each group’s component and non-component population minus one, or in equation form.

$$ambiguity\ score = \sum_{i=0}^n (P_i - 1)$$

where P_i is the population of the i^{th} failure mode group and n is the number of failure mode groups.

This second section also displays the population distribution of the failure mode groups, both in a text format and graphically.

The third section is the component isolation summary for this analysis. This includes a listing of the number of isolated components and a hypertext link to a detailed isolation assessment report for all the components analyzed. This detailed report will be discussed later in this section.

The final section of this report displays each failure mode group separated by a green horizontal line. The groups are presented by ascending population size. For each failure mode group, multiple tables are provided. The first table displays the detection signature information for the group, including the sensor identifier, sensor schematic identifier, sensor description and test name. For each component or non-component member of the group, a table is presented containing the failure mode’s component, failure mode name, FMEA identifier and the criticality of the failure for the phase of operation under analysis, if available, for each failure mode associated with that component.

Figures 6 and 7 illustrate the ETA Tool Component LRU Isolation report, upper portion and lower portion respectively, for the example diagnostic model. To generate this report, the user should specify “LRU” as the component label.

ETAT Analysis Summary - Component Isolation Report

Model Version: Basic_System

Testability Run Date: Mon Jan 03 15:41:12 2011

Test Conditions

TEAMS Model Analyzed:

Basic_System

System Modes:

Phase-B

Switches

Phase-B

Technology Labels:

Crit-1R_Phase-B

Crit-3_Phase-B

Crit-1S_Phase-B

Crit-1_Phase-B

Test Labels:

Effect

Flight

Ambiguity Analysis (for Components labeled as "LRU")

Number of Failure Mode Groups (for LRU analysis)..... 8

Number of Active LRUs..... 2

Number of Active Non-LRUs..... 74

Number of Isolated Groups 4

Maximum Failure Mode Group Size 15

Calculated Ambiguity Score 30

Ambiguity Distribution (LRU Level)

Percentage of groups with 1 members 50.00% (4 of 8 groups)

Percentage of groups with 2 members 25.00% (2 of 8 groups)

Percentage of groups with 15 members 25.00% (2 of 8 groups)

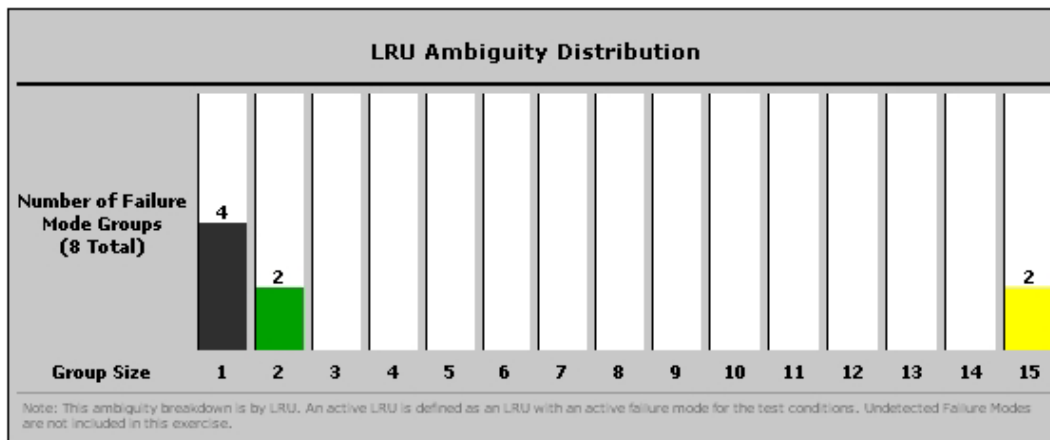


Figure 6.—ETA tool component isolation report, upper portion, for the example diagnostic model where the selected designated component label was 'LRU'.

LRU Isolation Summary 0 LRUs are "Isolated".

{Note: "Isolated" means that all the component's active failure modes are detected and isolated to an ambiguity group that contains only failure modes from this component}

LRU Isolation Assessment Table

Failure Mode Group #51 - 1 LRU-Designated and 0 non-LRU-Designated members

Detection Signature: 1 Tests

Sensor Identifier	Schematic Identifier	Sensor Description	Test
SEN0002	SS2	Yaw Turbine Speed Sensor	Faulty Sensor Data

Failure Mode Group Members

- 1. **LRU:** Yaw Hydraulic Pump Assembly (Schematic ID: None)

Associated 1 Failure Mode(s)

Component	Failure Mode	FMEA Identifier	Criticality
Shaft Speed Sensor	Faulty Sensor	MS-SS-HPump-08-001	1S

Failure Mode Group #52 - 1 LRU-Designated and 0 non-LRU-Designated members

Detection Signature: 4 Tests

Sensor Identifier	Schematic Identifier	Sensor Description	Test
SEN0002	SS2	Yaw Turbine Speed Sensor	No Rotation
SEN0006	PV22	Yaw Pressure Selector Valve Position	Selector Valve Secondary Position
SEN0013	P22	Yaw Hydraulic Supply Pressure 1	Low Hydraulic Pressure
SEN0014	P23	Yaw Hydraulic Supply Pressure 2	Low Hydraulic Pressure

Failure Mode Group Members

- 1. **LRU:** Yaw Hydraulic Pump Assembly (Schematic ID: None)

Associated 1 Failure Mode(s)

Component	Failure Mode	FMEA Identifier	Criticality
Hydraulic Turbine	Turbine Fails to Function	MS-SS-HPump-01-001	1R

Figure 7.—ETA Tool Component Isolation report, lower portion, for the example diagnostic model where the selected designated component label was 'LRU'.

The detailed component isolation assessment table is presented in a separate report that is hypertext linked to the Component Isolation report. Figure 8 illustrates this table report. The report reiterates the testability analysis conditions and pertinent ambiguity analysis metrics;

- Number of Active Components—the number of components that have failure modes that are part of the testability analysis
- Number of Active Non-Components—the number of non-components that have failure modes that are part of the testability analysis
- Number of Failure Mode Groups—the number of groups generated in this analysis for the number of active components in the model
- Number of Isolated Groups—failure mode groups containing a single component or non-component
- Number of Isolated Components—components that belong solely to isolated groups

The table then presents for each component analyzed, the component's name, the number of active failure modes contained in the component, the number of groups containing those failure modes; then for each failure mode: the group identifier containing that failure mode, failure mode name and the Detection/Isolation status assigned to the failure mode. The Detection/Isolation status is either 'Not Detected', 'Not Isolated' or 'Isolated'. If the failure mode is not detected, then it is highlighted in red in the table. If the failure mode is isolated, then it is highlighted in green. The intention of the table is to provide a visual summary of the isolation assessment with respect to the components.

ETAT Analysis Summary - LRU Isolation Assessment Table

Model Version: Basic_System

Testability Run Date: Mon Jan 03 15:41:12 2011

Test Conditions

TEAMS Model Analyzed:

Basic_System

System Modes:

Phase-B

Switches

Phase-B

Technology Labels:

Crit-1R_Phase-B

Crit-3_Phase-B

Crit-1S_Phase-B

Crit-1_Phase-B

Test Labels:

Effect

Flight

Ambiguity Summary Stats

Number of Active LRUs..... 2
 Number of Active Non-LRUs..... 74
 Number of Failure Mode Groups with LRU members..... 8
 Number of Isolated Groups..... 4
 Number of Isolated LRUs..... 0

LRU Ambiguity Output

LRU Name	Number of Failure Modes	Number of Failure Mode Groups	Failure Mode Group Identifier	Failure Mode	Detection Isolation Status
Yaw-Hydraulic-Pump-Assembly	5	4	38	Pump Fails to Function	Not Isolated
			40	Hydraulic Leak	Not Isolated
			51	Faulty Sensor	Isolated
			52	Turbine Fails to Function	Isolated
		N/A	Propellant Leak	Not Detected	
Pitch-Hydraulic-Pump-Assembly	5	4	45	Pump Fails to Function	Not Isolated
			47	Hydraulic Leak	Not Isolated
			56	Faulty Sensor	Isolated
			57	Turbine Fails to Function	Isolated
		N/A	Propellant Leak	Not Detected	

Figure 8.—ETA Tool Component Isolation Assessment Table report for the example diagnostic model where the selected designated component label was 'LRU'.

5.2.5 Generation of the ETA Tool Effect Mapping Report

Syntax for generating an Effect Mapping Report:

```
>> ETAT_v6_7.exe -E
```

Special Input Requirements:

Within the model, certain tests must be established with a naming convention that identifies it as an effect test rather than a sensor detection test. For example an effect test could be a “loss of functional redundancy”, where a sensor test would be “loss of fluid pressure”; even though they may both detect the same functional effect. The distinction is subtle, but this analysis allows the establishment of system level effects that can be analyzed simultaneously with the sensor testability analysis.

The naming convention for an effect test in the TEAMS diagnostic model is,

```
<Effect Description>_Effect,
```

for example, “Loss-of-Redundancy_Effect”.

Output Report Description:

The Effect Mapping report generated for the example system provided in the software package is named:

```
.\ ETAT_HOME \ Basic_System_Effect_Report.htm
```

The report can be either opened directly into an Internet browser or accessed by the “Effect Mapping Report” link on the main output file, `Basic_System_TestAnalysis_Main.htm`.

For the Effect Mapping analysis the software utilizes the established naming conventions to distinguish between modeled tests attributed directly to physical sensors and tests that were intended to represent system-level conditions. An example of the latter test implementation would be a system condition representing the loss of redundancy due to loss of component function. Whether or not there was a physical sensor that could measure the effect, a pseudo sensor test point could be modeled that contained this system-level effect test. By taking advantage of this capability, the ETA Tool can combine a testability analysis that is conducted with physical sensor measurements and an effects analysis that within TEAMS Designer could only be applied to effect nodes. The combined analysis provided the mapping of failure modes to system level effects, while at the same time providing detection signatures aligned to those system level effects. This level of analysis was utilized by Ares I vehicle integration systems engineers responsible with the vehicle level loss of mission analysis and probability risk assessment.

The analysis performed by this option creates an Effect Mapping Report that provides the summary analysis information along with hyper text links to three analysis reports: a detectability report and two ambiguity reports for the active failure modes relative to the system effects. Figure 9 illustrates the summary information report for the effects analysis. The top section contains testability conditions for the analysis conducted by TEAMS. The TEAMS analysis date and time, as well as the diagnostic model are reported. This section also includes the TEAMS analysis options selected such as the technology labels, test labels and system modes.

ETAT Analysis Summary - Effect Mapping Report

Model Version: Basic_System

Testability Run Date: Mon Jan 03 15:41:12 2011

Test Conditions

TEAMS Model Analyzed:

Basic_System

System Modes:

Phase-B

Switches

Phase-B

Technology Labels:

Crit-1R_Phase-B

Crit-3_Phase-B

Crit-1S_Phase-B

Crit-1_Phase-B

Test Labels:

Effect

Flight

Failure Mode Mapping to System Effects Analysis

Number of Effects = 5

Effects Not Mapped (1)

* **Effect:** Fire

Failure Modes Not Mapped: (105)

(Failure Modes not mapped to an Effect Test)

Effects Analysis Output Reports

[Effect Mapping Report](#)

[System Effect Ambiguity Report - Basic Format](#)

[System Effect Ambiguity Report - Detailed Format](#)

Figure 9.—ETA tool effect mapping main report for the example diagnostic model.

The second section contains the following summary information specific to the effect mapping analysis;

- Number of Effects—this is the number of effects available from the current testability analysis
- Effects Not Mapped—this is a list of effects that did not have a failure modes mapped to them
- Failure Modes Not Mapped—this is a list of failure modes that did not map to an effect. If this list is greater than ten, then a hyperlinked document will display the list.

This section also contains the three hyperlinked reports: the Effect Mapping Report, the System Effect Ambiguity Report (Basic Format) and the System Effect Ambiguity Report (Detailed Format).

The Effect Mapping Report is displayed in Figure 10 and contains two sections divided by a blue horizontal line. The top section repeats the testability conditions information for the analysis conducted by TEAMS. The second section reports the failure modes that result in the individual system effects, grouped by the system effects. Each system effect is presented separated by a green horizontal line. For each system effect, the report presents a table of the failure modes that contains the following information from the diagnostic model; the failure mode name, failure mode identifier and the component where the failure originated.

ETAT Analysis Summary - Failure-Mode-to-System-Effect Mapping Report

Model Version: Basic_System

Testability Run Date: Mon Jan 03 15:49:18 2011

Test Conditions

TEAMS Model Analyzed:
Basic_System (within Basic_System)
System Modes:
Phase-B
Switches
Phase-B
Technology Labels:
Crit-1R_Phase-B
Crit-3_Phase-B
Crit-1S_Phase-B
Crit-1_Phase-B
Test Labels:
Effect
Flight

(1) **Effect** Pitch Actuator Lockup

4 Mapped Failure Modes

Failure Mode	FMEA Identifier	Component
Loss of Communication with Avionic	EXT-AV-001	Avionics
Erroneous NULL Pitch Command	EXT-AV-002	Avionics
Stuck In NULL Position	MS-SS-ACT-02-002	Power Valve
Actuator Locked In Place	MS-SS-ACT-03-001	Pitch Actuator

(2) **Effect** Pitch Actuator Hardover

3 Mapped Failure Modes

Failure Mode	FMEA Identifier	Component
Erroneous Full Extend Pitch Command	EXT-AV-004	Avionics
Stuck In An Operating Position	MS-SS-ACT-02-001	Power Valve

Figure 10.—ETA tool effect mapping report for the example diagnostic model.

The last two hyperlinked reports linked on the Effects Mapping main page, provide details about the ambiguity analysis performed from these testability results. The first report, System Effect Ambiguity Report (Basic Format), provides the ambiguity analysis with respect to the system effects in a basic format, shown in Figure 11. The report contains two sections separated by a blue horizontal line. The top section reiterates the testability analysis conditions. The bottom section is further subdivided by green horizontal lines for each failure mode grouping in the analysis. For each group, two tables are reported. The first table lists the system effects that define the detection signature for the group and the second table reports for each failure mode contained in this group; the element, system and component of the failure mode, if they are assigned within the diagnostic model, the failure mode name, failure mode identifier and the assigned criticality.

Ambiguity Assessment Report - Effect Failure Mode Groups - Basic Format

Model Version: Basic_System

Testability Run Date: Mon Jan 03 15:41:12 2011

Test Conditions

TEAMS Model Analyzed:

Basic_System

System Modes:

Phase-B

Switches

Phase-B

Technology Labels:

Crit-1R_Phase-B

Crit-3_Phase-B

Crit-1S_Phase-B

Crit-1_Phase-B

Test Labels:

Effect

Flight

Failure Mode Group #5

System/Subsystem Level Effects Mapped: 2 Effect(s)

Effect Name
Pitch Actuator Lockup
Yaw Actuator Lockup

Failure Mode Group contains 1 Failure Mode(s)

System	Component	Failure Mode	FMEA Identifier	Criticality
Not Found	Avionics	Loss of Communication with Avionics	External	1

Failure Mode Group #1

System/Subsystem Level Effects Mapped: 1 Effect(s)

Effect Name
Yaw Actuator Hardover

Failure Mode Group contains 3 Failure Mode(s)

System	Component	Failure Mode	FMEA Identifier	Criticality
Not Found	Avionics	Erroneous Full Extend Yaw Command	External	1
Vector Control System	Power Valve	Stuck In An Operating Position	MS-SS-ACT-02-001	1
Vector Control System	Yaw Actuator	Actuator Detaches	MS-SS-ACT-03-003	1

Figure 11.—ETA tool effect ambiguity report in the basic format for the example diagnostic model.

The second system effect ambiguity report presents additional information about the failure modes contained within the groups. This report is only useful if the available sensor tests are also included in the testability analysis performed in TEAM Designer. Figure 12 shows the breakdown of the report. In this report, for each failure mode group a single table is generated with the following columns;

- Element—the element module as defined in the diagnostic model from which the failure mode originates. If there are no element modules defined, then this column is removed.
- System—the system module as defined in the diagnostic model from which the failure mode originates. If no system modules are defined, then this column is removed.
- Component—the module from which the failure mode originates.
- Failure Mode
- FMEA Identifier
- Criticality—the criticality assigned to the failure mode in the diagnostic model for the current testability conditions
- Outcomes—The system effects which define this failure mode group
- Test Sensors—The sensor tests which detect this failure mode. The sensor information includes the sensor identifier and sensor name
- Initial Failure Effects—The column reports the physical failure effects propagated by this failure mode.

Ambiguity Assessment Report - Effect Failure Mode Groups - Detailed Format

Model Version: Basic_System

Testability Run Date: Mon Jan 03 15:41:12 2011

Test Conditions

TEAMS Model Analyzed:

Basic_System

System Modes:

Phase-B

Switches

Phase-B

Technology Labels:

Crit-1R_Phase-B

Crit-3_Phase-B

Crit-1S_Phase-B

Crit-1_Phase-B

Test Labels:

Effect

Flight

Failure Mode Group #6

System/Subsystem Level Effects Mapped: 2 Effect(s) and 1 Failure Mode(s)

System	Component	Failure Mode	FMEA Identifier	Criticality	Outcome	Test Sensor(s) [Sensor ID (Description)]	Initial Failure Effects
Not Found	Avionics	Loss of Communication with Avionics	External	1	* Pitch Actuator Lockup * Yaw Actuator Lockup	* SEN0016 (Pitch Actuator Power Valve Solenoid A Current) * SEN0017 (Pitch Actuator Power Valve Solenoid B Current) * SEN0020 (Yaw Actuator Power Valve Solenoid B Current) * SEN0019 (Yaw Actuator Power Valve Solenoid A Current) * SEN0023 (Pitch LVDT Displacement Transducer 1) * SEN0024 (Pitch LVDT Displacement Transducer 2) * SEN0025 (Pitch LVDT Displacement Transducer 3) * SEN0026 (Yaw LVDT Displacement Transducer 1) * SEN0027 (Yaw LVDT Displacement Transducer 2) * SEN0028 (Yaw LVDT Displacement Transducer 3)	* No Current * No Position Change

Figure 12.—ETA tool effect ambiguity report in the detailed format for the example diagnostic model.

5.2.6 Generation of the ETA Tool Sensor Sensitivity Report

Syntax for Generating a Sensor Sensitivity Report:

```
>> ETAT_v6_7.exe -s1 <sensor sensitivity file>
```

Special Input Requirements:

Sensor Sensitivity input file. The format of this file is presented in section Installation and Setup.

Output Report Description:

Three reports are generated for the example system provided in the software package:

```
.\ ETAT_HOME \ Basic_System_Sensor_Sensitivity_Report-Sensor_Level.htm  
.\ ETAT_HOME \ Basic_System_Sensor_Sensitivity_Report-Measurement_Level.htm  
.\ ETAT_HOME \ Basic_System_Sensor_Sensitivity_Report-Measurement_Group_Level.htm
```

These reports can be either opened directly into an Internet browser or accessed by the “Sensor Sensitivity Analysis by Individual Sensors”, “Sensor Sensitivity Analysis by Measurements” and “Sensor Sensitivity Analysis by Measurement Groups” links, respectively, on the main output file, `Basic_System_TestAnalysis_Main.htm`.

The sensor sensitivity analysis was created to assess the impact of the removal of individual sensors or groups of sensors on the system’s diagnostic capabilities. The analysis can facilitate various design studies to determine the importance of measurements and tests, as well as diagnostic strategies to overcome sensor signal loss.

The analysis currently performs three distinct cycles where individual and groups of sensors can be systematically removed. The definition of the sensors and groups of sensors to be removed for each cycle is defined in an external input file supplied by the user on the command line.

Prior to the sensor sensitivity analysis, the failure modes are reviewed to determine if they are failure modes of the sensors or of the general system. Sensor failure modes are removed from consideration during the analysis and the remaining failure modes are used to establish a set of baseline diagnostic metrics for the system. Changes to the diagnostic capability of the system are made relative to these baseline metrics. This ensures that sensor-related failure modes do not bias the diagnostic evaluation. For example, given a sensor ‘X’ has two inherent failure modes, the simple removal of the sensor will eliminate two failure modes from the system being evaluated, unfairly biasing the analysis in a positive direction if the failure modes have not been filtered out.

One caveat to this aspect of the analysis is that sensor failures that are essentially system failure modes do remain in the baseline and therefore are removed when the sensor is removed. For example, a sensor can have two failure modes: one failure mode is a sensor signal fault and the other failure mode is a fluid leak at the insertion point of the duct. The former failure mode is removed from the baseline metrics, but the latter remains because the fluid leakage is a system failure mode caused by the physical presence of the sensor.

The sensor sensitivity analysis option produces three reports. Each report has a similar format. The first report displays the impact on the system’s diagnostic capabilities (failure mode detection and isolation) with the loss of each sensor individually. The second report, again displays the impact of the system’s diagnostic capability, but this time with sensors being removed by hardware redundancy groups. The third report looks at the impact on system diagnostic capability with the removal of the sensor across the entire system.

Figures 13, 14, and 15 display each of the reports, respectively. Each report has four sections divided by a blue horizontal line. The top section in each reiterates the testability analysis conditions. The second section reports the following sensitivity analysis metrics;

- Number of Tests—the number of available tests that are part of the testability analysis
- Number of Active Sensors—Number of sensors with at least on active test
- Active Sensors that provide zero contribution—Active sensors that provide no detection for the failure modes in this analysis
- Number of Failure Modes—the number of failure modes that are part of the testability analysis

- Number of failure modes involving only sensor signal faults—failure modes that are only related to the sensor signal failure.
- Overall Detection Coverage—a calculated metric that is equal to the number of detected failure modes divided by the total number of failure modes
- Overall Detection Coverage w/o Sensor Faults—the Overall Detection Coverage metric with sensor signal failure modes removed from both the number of detected failure modes in the numerator and the total number of failure modes in the denominator.

In this analysis, these metrics provide a baseline from which the impact values can be compared.

The third section in each of the three reports provides a reminder statement about the current analysis process.

Note: For this report, tests that solely detect their own sensor fault, and failure modes that result in sensor fault are not used in the analysis. The fault detection coverage and the failure mode groupings are recomputed with the removal of all sensor-fault-only tests and failure modes.

Re-stating this notice, the sensor sensitivity analysis excludes failure modes that are the sensor signal faults and the tests that detect those sensor signal faults exclusively. The reason is that these will unduly bias the results. If a sensor is to be considered for inclusion in the diagnostic system it must detect more than just its own failure modes.

The final section in each report provides a table of the diagnostic impacts due to the removal of the sensor or sensors. The following columns are reported in the table for the Sensor Level report;

- Sensor Removed—the sensor identifier
- Sensor Description
- Removed Sensor-Related failure Modes—These are the failure modes that are removed from the analysis process because they are caused by faults in the sensor under consideration
- Detection Coverage Loss | Coverage Percentage—the change in the system’s overall detection coverage if the sensor-related failure modes were not present in the baseline value
- Detection Coverage Loss | Failure Modes Undetected—failure modes that are now undetected as a result of the removal of the sensor
- Fault Isolation Loss | Change in Number of Failure Mode Groups—the total number failure mode groups lost or gained as a result of the removal of the sensor. The baseline groups are generated with the removal of the faults from the sensor under study.
- Fault Isolation Loss | Change in Number of Isolated Failure Modes—the number of isolated failure modes lost or gained as a result of the removal of the sensor. The baseline groups are generated with the removal of the faults from the sensor under study.
- Fault Isolation Loss | Ambiguity Score Change—the change in the ambiguity score compared to baseline score. The baseline ambiguity score is generated with the removal of the faults from the sensor under study.

The final section tables in the reports for the Measurement Level and the Measurement Group Level are similar to the one described for the Sensor Level report except the initial column shows the Measurement or Group removed, respectively, and the following column consolidates the sensor identifier and description information for the sensors removed.

Sensor Sensitivity Analysis Summary - Sensor Level

Model Version: Basic_System

Testability Run Date: Mon Jan 03 15:41:12 2011

Test Conditions

TEAMS Model Analyzed:
Basic_System

System Modes:
Phase-B
Switches
Phase-B

Technology Labels:
Crit-1R_Phase-B
Crit-3_Phase-B
Crit-1S_Phase-B
Crit-1_Phase-B

Test Labels:
Effect
Flight

Note: For this report, tests that solely detect their own sensor fault and failure modes that result in sensor fault are not used in the analysis. The fault detection coverage and the failure mode groupings are recomputed with the removal of all sensor fault only tests and failure modes.

Sensor Sensitivity Analysis

Number of Tests	76
Number of Sensors	32
Sensors that provide no contribution.....	0
Number of Failure Modes	118
Number of Undetected Failure Modes	2
Overall Detection Coverage	98.31%
Number of Failure Modes excluding sensor signal faults	86
Overall Detection Coverage w/o Sensor faults	97.67%

Diagnostic Impact of Sensor Loss

Sensor Removed	Sensor Description	Removed Sensor-Related Failure Modes <small>(FMEA ID - Failure Description)</small>	Diagnostic Coverage Loss		Fault Isolation Loss		
			Coverage Percentage	Failure Modes Undetected <small>(FMEA ID - Failure Description)</small>	Change in Number of Failure Mode Groups	Change in Number of Isolated Failure Modes	Ambiguity Score Change
SEN0001	Pitch Turbine Speed Sensor	None	No Change	None	-1	-1	+1
SEN0002	Yaw Turbine Speed Sensor	None	No Change	None	-1	-1	+1

Figure 13.—ETA tool sensor sensitivity analysis report for individual sensors for the example diagnostic model.

Sensor Sensitivity Analysis Summary - Measurement Level

Model Version: Basic_System

Testability Run Date: Mon Jan 03 15:41:12 2011

Test Conditions

TEAMS Model Analyzed:
Basic_System
System Modes:
Phase-B
Switches
Phase-B
Technology Labels:
Crit-1R_Phase-B
Crit-3_Phase-B
Crit-1S_Phase-B
Crit-1_Phase-B
Test Labels:
Effect
Flight

Note: For this report, tests that solely detect their own sensors, faults, and failure modes that result in sensor fault are not used in the analysis. The fault detection coverage and the failure mode groupings are re computed with the removal of all sensor fault only tests and failure modes.

Sensor Sensitivity Analysis

Number of Tests 76
 Number of Sensors 32
 Sensors that provide no contribution..... 0

Number of Failure Modes 118
 Number of Undetected Failure Modes 2
 Overall Detection Coverage 98.31%

Number of Failure Modes excluding sensor signal faults 86
 Overall Detection Coverage w/o Sensor faults 97.67%

Diagnostic Impact of Measurement Loss

Measurement Removed	Sensor(s) Removed <small>(Sensor ID - Sensor Description)</small>	Removed Sensor-Related Failure Modes <small>(FMEA ID - Failure Description)</small>	Diagnostic Coverage Loss		Fault Isolation Loss		
			Coverage Percentage	Failure Modes Undetected <small>(FMEA ID - Failure Description)</small>	Change in Number of Failure Mode Groups	Change in Number of Isolated Failure Modes	Ambiguity Score Change
Pitch Hydraulic Supply Pressure	* SEN0010 - Pitch Hydraulic Supply Pressure 1 * SEN0011 - Pitch Hydraulic Supply Pressure 2	* MS-SS-HYD-07-002 - (Hydraulic Fluid Leak) * MS-SS-HYD-07-002 - (Hydraulic Fluid Leak)	No Change	None	-1	None	+1
Yaw Hydraulic Supply Pressure	* SEN0013 - Yaw Hydraulic Supply Pressure 1 * SEN0014 - Yaw Hydraulic Supply Pressure 2	* MS-SS-HYD-07-002 - (Hydraulic Fluid Leak) * MS-SS-HYD-07-002 - (Hydraulic Fluid Leak)	No Change	None	-1	None	+1

Figure 14.—ETA tool sensor sensitivity analysis report for hardware redundant sensors for the example diagnostic model.

Sensor Sensitivity Analysis Summary - Measurement Group Level

Model Version: Basic_System

Testability Run Date: Mon Jan 03 15:41:12 2011

Test Conditions

TEAMS Model Analyzed:
 Basic_System
 System Modes:
 Phase-B
 Switches
 Phase-B
 Technology Labels:
 Crit-1R_Phase-B
 Crit-3_Phase-B
 Crit-1S_Phase-B
 Crit-1_Phase-B
 Test Labels:
 Effect
 Flight

Note: For this report, tests that solely detect their own sensor fault and failure modes that result in sensor fault are not used in the analysis. The fault detection coverage and the failure mode groupings are re computed with the removal of all sensor fault only tests and failure modes.

Sensor Sensitivity Analysis

Number of Tests 76
 Number of Sensors 32
 Sensors that provide no contribution 0

Number of Failure Modes 118
 Number of Undetected Failure Modes 2
 Overall Detection Coverage 98.31%

Number of Failure Modes excluding sensor signal faults 86
 Overall Detection Coverage w/o Sensor faults 97.67%

Diagnostic Impact of Measurement Group Loss

Group Removed	Sensor(s) Removed <small>(Sensor ID - Sensor Description)</small>	Removed Sensor-Related Failure Modes <small>(FM/EA ID - Failure Description)</small>	Diagnostic Coverage Loss		Fault Isolation Loss		
			Coverage Percentage	Failure Modes Undetected <small>(FM/EA ID - Failure Description)</small>	Change in Number of Failure Mode Groups	Change in Number of Isolated Failure Modes	Ambiguity Score Change
Turbine Speed Sensor	* SEN0001 - Pitch Turbine Speed Sensor * SEN0002 - Yaw Turbine Speed Sensor	None	No Change	None	-2	-1	+2
Propellant Supply Valve Position	* SEN0003 - Pitch Propellant Supply Valve Position * SEN0005 - Yaw Propellant Supply Valve Position	None	No Change	None	-2	-1	+2

Figure 15.—ETA tool sensor sensitivity analysis report for common sensors across the system for the example diagnostic model.

5.3 Related Processing

During the ETA Tool processing, the software will attempt to copy specific required files from the TEAMS model directory to the directory containing the ETA Tool executable. In addition, the ETA Tool will convert the TEAMS Designer Testability output D-Matrix from the Microsoft Excel format to a comma-separated-variable formatted file. It is recommended that the user close all Excel files prior to operating the ETA Tool program.

5.4 Messages

The following error messages and exit codes are generated by the ETA Tool;

Error code	Message
-98	Unable to open the standard log file
-99	Unable to open the debug log file
-101	No arguments entered on the command line
-102	Only Command line argument entered was a debugging option
-103	No valid command line inputs found
-104	The auto-setup could not be performed because the environmental variable is not established for TEAMS model location.
-201	Unable to locate the TEAMS model file.
-202	More than one TEAMS model file available in the TEAMS directory. Unable to determine which model to select.
-203	No TEAMS model in the TEAMS directory
-204	Unable to locate the TEAMS testability options file which should be in the REPORTS directory.
-205	Unable to locate the TEAMS model hierarchical file which should be in the REPORTS directory.
-206	Unable to obtain a listing of the REPORTS directory.
-207	Unable to find a Testability output directory in the REPORTS directory.
-208	Unable to locate the testability D-Matrix which should be in the REPORTS directory.
-209	Unable to convert the EXCEL formatted D-Matrix into a CSV format file.
-210	Unable to open <filename>, the D-Matrix file.
-211	Unable to locate the TEAMS testability ambiguity-dynamic file which should be in the REPORTS directory.
-212	Unable to locate the TEAMS testability failure-detection-isolation file which should be in the REPORTS directory.
-213	Unable to locate the TEAMS testability figures-of-merit file which should be in the REPORTS directory.

Error code	Message
-214	Unable to open the TEAMS Designer Analysis Options file (<filename>).
-215	Unable to open the TEAMS hierarchical file (<filename>).
-216	Unable to open the TEAMS testability figures-of-merit file (<filename>).
-301	No components were located in the model labeled with the name specified for the component isolation analysis.
-302	Problem in the process of assigning the submodules to this module (<module name>). The number of submodules assigned in the first pass was <count 1> and the second pass was <count 2>.
-303	Unable to open the Instrumentation Listing file (<filename>).
-304	Unable to open the Sensitivity Instrumentation Listing file (<filename>).
-305	Unable to locate the MTTF string in the header of the D-Matrix file. Therefore the format is not what is expected.
-306	Unable to locate the MTTF string in the header of the D-Matrix file after rewinding the file.
-307	TEST <test name> was not properly assigned to either a sensor test or an effect test.
-308	No effects were detected in the model, so the failure mode mapping to effects report cannot be generated.
-309	There are <count> failure modes found within nested components selected for isolation. Need to fix the nested components reported.
-310	Unable to assign the following active failure mode - <failure mode> to either the component to be isolated (<isolated component label>) or to one of the currently recognized component label designations of "Sensor", "RBD", "Subsystem", "Component", "System", "Element", "Assembly", "Subassembly", "Module" or "Submodule".
-311	There are <count> active failure modes that are improperly labeled within the diagnostic model.
-312	Could not reallocate the size of the failure mode module array within the failure mode structure.
-401	The total number of failure modes for this <isolated component label>, (<module name>) does not match the number reported out to the Ambiguity table. Need to investigate the cause.

5.5 Quick-Reference Guide

ETA Tool Command Line Syntax

```
ETAT_v6_7 {-i instrumentation_file.csv} {-d} {-s1 file.csv} {-D} {-T} {-E} {-I} {-iso label}
```

where

- {-i instrumentation_file.csv} Specifies the CSV-formatted instrumentation file to use in the ETA Tool analysis. If this option is not specified, the ETA Tool will attempt to access a default instrumentation file by the naming convention “<Model Name>_sensor_file.csv”
- {-d} Indicates a debugging option which turns on certain screen printing output for ETA Tool developers.
- {-s1 file.csv} Indicates that the sensors sensitivity analysis is to be performed and the CSV-formatted file to use containing additional sensor information.
- {-D} Generates the Detectability Report
- {-T} Generates the Test Utilization Report
- {-E} Generates the Effect Mapping Report
- {-I} Generates the Failure Mode Isolation Report
- {-iso label} Generates the Component Isolation report and indicates the hierarchical label to be used in the component-isolation analysis

6.0 Notes

6.1 Acronyms

CPU	Central Processing Unit
CSV	Comma Separated Variable
DOS	Disk Operating System
ETA	Extended Testability Analysis
FFA	Functional Fault Analysis
FMEA	Failure Mode and Effects Analysis
GCC	GNU C Compiler
GLPR	Glenn Procedural Requirement
GRC	Glenn Research Center
HTML	HyperText Manuscript Language
ID	Identifier
LRU	Line Replacement Unit
PSV	Pressure Selector Valve
RAM	Random Access Memory
RBD	Reliability Block Diagram
TEAMS	Testability Engineering and Maintenance System

6.2 Terms and Definitions

TABLE 4.—CORE FAULT MANAGEMENT TERMS¹

Term	Definition
Anomaly	The unexpected performance of intended function.
Failure	The unacceptable performance of intended function
Fault	A physical or logical cause, which explains a <i>failure</i>
Root Cause	In the chain of events leading to a <i>failure</i> , the first <i>fault</i> or environmental cause used to explain the existence of the <i>failure</i> .

TABLE 5.—OTHER FAULT MANAGEMENT TERMS

Term	Definition
Component Isolation	Determining the possible locations of a hypothesized <i>failure</i> or <i>anomaly</i> cause to the component level. For this analysis, it is not important to discriminate between <i>failure modes</i> within the component. Components may have <i>failure modes</i> in multiple <i>failure mode groups</i> .
Failure Detection	Deciding that a <i>failure</i> exists ¹
Failure Mode Group	set of <i>failure modes</i> that are detected by the same unique detection signature
Detection Signature	A set of tests that detect a given <i>failure mode</i>
Failure Mode	Modes of a component's behavior that can cause <i>failure effects</i> ¹
Failure Effect	A potentially measureable change in system behavior or state property; the consequence(s) a <i>failure mode</i> has on the operation, function, or status of an item
Isolated Failure Mode Group	A <i>failure mode group</i> that has only one member
Fault or Failure Mode Isolation	Determining the possible locations of a hypothesized <i>failure</i> or <i>anomaly</i> cause to a defined level of granularity ¹
Reliability Block Diagram	Defines the series dependence or independence of all functions of a system or functional group for each life-cycle event

¹ Johnson, S.B.; and Day, J.C.: NASA Constellation Program Fault Management Terminology Report, September 10, 2010.

Appendix A.—Diagnostic Modeling Conventions

This section describes the diagnostic model naming conventions established by the NASA Constellation Ares I Functional Fault Analysis (FFA) modeling group to ensure consistency across the independently developed TEAMS-based subsystem models. These conventions were designed to incorporate a significant amount of system information intended to improve the user’s understanding of the output from the various testability analysis reports. For this paper, only those model elements pertinent to the ETA Tool are presented; other model elements were defined by the NASA developers, but are not relevant here.

Note: A cursory knowledge of modeling in TEAMS will improve the reader’s comprehension of the following discussion.

The following are a list of general syntax used throughout the naming conventions,

- Dashes are used to separate words within a text field.
- Underscores are used to separate text fields within a label.
- ‘[]’ within a naming definition indicates an optional field.

A-1 Conventions for Tests

Tests are assigned within test points. In general, a test can be attached to multiple test points; however, current modeling practice has been to create unique tests that reflect a specific test point. The test name can contain three distinct fields, separated by the ‘_’ character. The first field is a unique test name which can be a simple test description, such as “High-Fluid-Pressure”. The second field, which is optional, is the schematic identifier for the sensor. The third field, which is also optional, is the unique measurement identifier usually taken from the integrated system measurement list.

<Test Name/Description>[_Sensor Schematic Identifier][_<Measurement Identifier>]
For example, “Low-Turbine-Rotation_SS-1_CLVUS13534”)

For the third field, the ETA Tool will attempt to match the “Measurement Identifier” text with either the first or second measurement identifier columns from the sensor information file loaded in the command line. If this field contains the text string, ‘Effect’, the ETA Tool interprets this as an effect test and treats it distinctly from the other tests. General system or subsystem conditions not aligned to a specific sensor can be represented in the diagnostic model with these tests identified by this ‘Effect’ text string. If any of the optional fields are unavailable, the ETA Tool enters a ‘None’ text value into the internal placeholder for that piece of information. The ETA Tool assumes that if there are only two fields available, then it is the “Sensor Schematic Identifier” field that is omitted.

A-2 Conventions for Failure Mode Modules

Failure mode modules are a special case module in the TEAMS diagnostic model. These modules represent the failures and contain the failure effects, the failure criticalities (assigned by phase), and the failure probability values. The failure mode module name can contain two distinct fields, separated by the ‘_’ character. The first field is the failure mode description. The second field contains the Failure Mode and Effects Analysis (FMEA) identifier, if available.

<Failure description>[_<FMEA Identifier>]
For example, Rupture_J-2X-FIDA-001

If the optional FMEA Identifier field is unavailable, the ETA Tool enters a ‘None’ text value into the internal placeholder for that piece of information.

A-3 Conventions for Component Modules

Within the diagnostic model, all modules that contain other modules are called component modules. These modules represent the breakdown structure of the system. The component module name can contain three distinct fields, separated by the ‘_’ character. The first field is the component description. The second field is optional and is the schematic identifier for the module, if available. The third field, which is also optional, is the Reliability Block Diagram (RBD) identifier usually developed for the FMEA process for the system. The RBD is a decomposition of the system to a level determined by the Safety and Mission Assurance analysts. Usually the RBD identifier is the prefix portion of the FMEA identifier.

<Module Description>[_<Schematic Identifier>][_<RBD Identifier>]

For example, LH2-Fill-and-Drain-Valve_HD-100_CLV-US-MPS-BB-01

If any of the optional fields are unavailable, the ETA Tool enters a ‘None’ text value into the internal placeholder for that piece of information. The ETA Tool assumes that if there are only two fields available, then it is the schematic ID field that is omitted.

A-4 Conventions for Technology Labels

A set of technology labels are available for each failure mode in the diagnostic model. The ETA Tool will extract the technology labels from the failure mode module files (if accessible) and attempt to match the testability analysis switch mode settings. The format for the technology labels start with the failure mode criticality designation and end with the phase of operation. The phase of operation corresponds to the switch mode setting for the model. Since the system mode is defined by a set of switch modes, the ETA Tool program will also search the technology labels for any that match the system mode, if none of the switch modes were matched.

[<Criticality>_]<Switch-Mode>

For example, Crit-1_Phase-A

A-5 Conventions for Switch Modes

Switch modes are used to establish the operational configuration of a system. The TEAMS Designer uses the “Switch” model element to direct the propagation paths during the Testability analysis process. Switch mode names can include an optional subsystem prefix (e.g., MPS_LOX-Tank-Repress)

A-6 Hierarchical Labels

Hierarchical labels are assigned to the modules of the model and are the user-defined breakdown of the modeled system. These labels convey the level of decomposition of the system. The model developer should assign the modules with care and consistency. Two special labels are utilized within the ETA Tool,

- ‘Failure_mode’ or ‘Failure_Mode’—defines the failures modeled in the system. These should be at the very lowest level of the hierarchical model, meaning there are no other modules under these modeled elements.
- ‘Sensor’—a special module label that is used only in the sensor sensitivity analysis currently and only to provide a distinction between failure modes detected by the sensor that are external and those detected that are internal to the sensor itself. For example, one of the sensor internal failure modes may result in a faulty signal that is detectable by a sensor test, but in the sensitivity analysis, the ETA Tool would remove that failure mode from the sensor’s list of failure modes that it can detect because the sensor actually was the cause of the failure.

The following hierarchical labels are currently explicitly sought out by the ETA Tool; have the following suggested order of system decomposition

1. 'Element'—assigned at the highest level modules
2. 'System'—assigned to the second highest level modules
3. 'Subsystem'
4. 'Assembly'
5. 'Subassembly'
6. 'Module'
7. 'Submodule'
8. 'Component'
9. 'RBD'

Note: This is only a suggested order. The user may choose to adopt a different order structure and/or may develop a model that has different labels altogether.

Appendix B.—Diagnostic Model Example

This section presents an example system with which the ETA Tool can be applied and demonstrated. The purpose of the example system is to provide a reportable output that exposes the processing capabilities of the ETA Tool.

A schematic of the example system is shown in Figure B-1. This system is a generic hydraulic actuator system that could drive the orientation of an aircraft or spacecraft. The system has two independently powered hydraulic actuators, but the power supplies are cross-strapped to provide redundancy due to loss of function at the power source. The hydraulic actuators and the associated power source define a subsystem and are color separated in the schematic and named Pitch and Yaw. In the schematic each component and line segment is designated with a name which is typical for system development. Also sensors are represented in the systematic as white circles or ovals.

The hydraulic power source is a turbine pump component driven by an external propellant flow. Each hydraulic power source contains a reservoir and a filter. Propellant flow to the hydraulic turbines is controlled by propellant supply valves, PPSV and YPSV. Each actuator contains a pressure selector valve, PHPSV and YHPSV, which senses loss of primary supply pressure and switches over to the available secondary power source. The actuators also contain a power valve which controls the direction of the actuator and is controlled by an external computing source.

Table B-1 provides a list of sensors in the example system. The first column is the assigned schematic identifier (ID) for the sensor and corresponds to the designation on the schematic. The second column provides a brief description of the sensor. The third column is a simple sensor identifier that could possibly be used at the system controller or data management level. Often in system design process the same sensing element may be associated with a number of identifiers. The fourth and fifth columns report the tests assigned to the sensor and the periods of operation they are available.

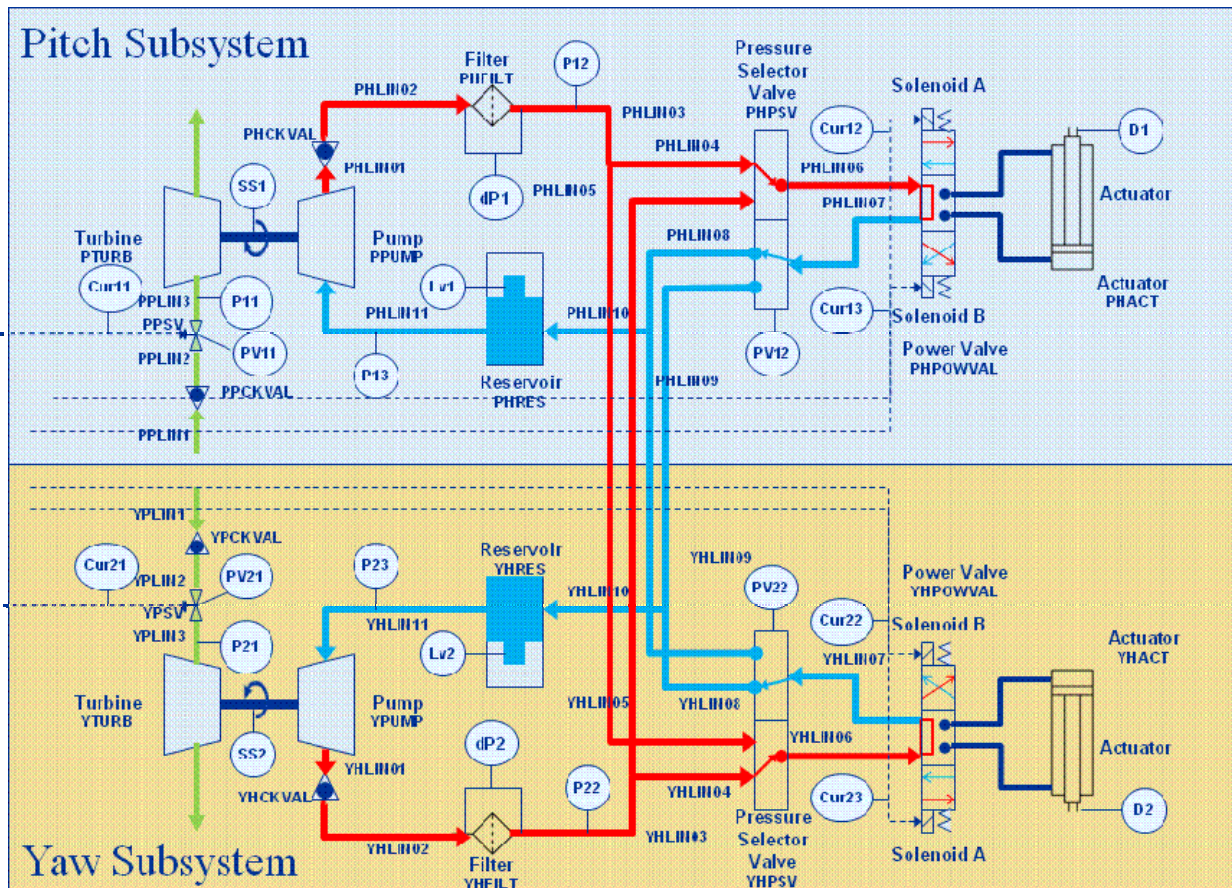


Figure B-1.—Schematic of example system.

TABLE B-1.—EXAMPLE SYSTEM SENSOR LIST

Schematic ID	Description	Sensor ID	Assigned Tests	Applied
SS1	Pitch Turbine Speed Sensor	SEN0001	Faulty-Sensor-Data	Pre-Flight Flight
			No-Rotation	Flight
			Unexpected-Rotation	Pre-Flight
SS2	Yaw Turbine Speed Sensor	SEN0002	Faulty-Sensor-Data	Pre-Flight Flight
			No-Rotation	Flight
			Unexpected-Rotation	Pre-Flight
PV11	Pitch Propellant Supply Valve Position	SEN0003	Faulty-Sensor-Data	Pre-Flight Flight
			PSV-Open	Pre-Flight Flight
			PSV-Closed	Pre-Flight Flight
PV12	Pitch Pressure Selector Valve Position	SEN0004	Faulty-Sensor-Data	Pre-Flight Flight
			Selector-Valve-Primary-Position	Pre-Flight Flight LCC-2
			Selector-Valve-Secondary-Position	Pre-Flight Flight
			Selector-Valve-Intermediate-Position	Pre-Flight Flight
PV21	Yaw Propellant Supply Valve Position	SEN0005	Faulty-Sensor-Data	Pre-Flight Flight
			PSV-Open	Pre-Flight

Schematic ID	Description	Sensor ID	Assigned Tests	Applied
				Flight
			PSV-Closed	Pre-Flight Flight
PV22	Yaw Pressure Selector Valve Position	SEN0006	Faulty-Sensor-Data	Pre-Flight Flight
			Selector-Valve-Primary-Position	Pre-Flight Flight LCC-2
			Selector-Valve-Secondary-Position	Pre-Flight Flight
			Selector-Valve-Intermediate-Position	Pre-Flight Flight
dP1	Pitch Delta Pressure Filter Sensor	SEN0007	Faulty-Sensor-Data	Pre-Flight Flight
			High-Delta-Pressure	Flight
dP2	Yaw Delta Pressure Filter Sensor	SEN0008	Faulty-Sensor-Data	Pre-Flight Flight
			High-Delta-Pressure	Flight
P11	Pitch Turbine Propellant Inlet Pressure	SEN0009	Faulty-Sensor-Data	Pre-Flight Flight
			Low-Propellant-Pressure	Flight
			Unexpected-Propellant-Pressure	Pre-Flight
P12	Pitch Hydraulic Supply Pressure	SEN0010	Faulty-Sensor-Data	Pre-Flight Flight
			Low-Hydraulic-Pressure	Flight

Schematic ID	Description	Sensor ID	Assigned Tests	Applied
			Unexpected-Hydraulic-Pressure	Pre-Flight
P21	Yaw Turbine Propellant Inlet Pressure	SEN0011	Faulty-Sensor-Data	Pre-Flight Flight
			Low-Propellant-Pressure	Flight
			Unexpected-Propellant-Pressure	Pre-Flight
P22	Yaw Hydraulic Supply Pressure	SEN0012	Faulty-Sensor-Data	Pre-Flight Flight
			Low-Hydraulic-Pressure	Flight
			Unexpected-Hydraulic-Pressure	Pre-Flight
Lv1	Pitch Hydraulic Reservoir Level Sensor	SEN0013	Faulty-Sensor-Data	Pre-Flight Flight
			Low-Hydraulic-Fluid-Level	Pre-Flight Flight LCC-1
Lv2	Yaw Hydraulic Reservoir Level Sensor	SEN0014	Faulty-Sensor-Data	Pre-Flight Flight
			Low-Hydraulic-Fluid-Level	Pre-Flight Flight LCC-1
Cur11	Pitch Propellant Supply Valve Current	SEN0015	Faulty-Sensor-Data	Pre-Flight Flight
			No-Electrical-Power	Flight
Cur12	Pitch Actuator Power Valve Solenoid A Current	SEN0016	Faulty-Sensor-Data	Pre-Flight Flight
			No-Current	Flight

Schematic ID	Description	Sensor ID	Assigned Tests	Applied
Cur13	Pitch Actuator Power Valve Solenoid B Current	SEN0017	Faulty-Sensor-Data	Pre-Flight Flight
			No-Current	Flight
Cur21	Yaw Propellant Supply Valve Current	SEN0018	Faulty-Sensor-Data	Pre-Flight Flight
			No-Electrical-Power	Flight
Cur22	Yaw Actuator Power Valve Solenoid A Current	SEN0019	Faulty-Sensor-Data	Pre-Flight Flight
			No-Current	Flight
Cur23	Yaw Actuator Power Valve Solenoid B Current	SEN0020	Faulty-Sensor-Data	Pre-Flight Flight
			No-Current	Flight
D1	Pitch LVDT Displacement Transducer	SEN0021	Faulty-Sensor-Data	Pre-Flight Flight
			No-Position-Change	Flight
			Actuator-Position-Errors	Flight
D2	Yaw LVDT Displacement Transducer	SEN0022	Faulty-Sensor-Data	Pre-Flight Flight
			No-Position-Change	Flight
			Actuator-Position-Errors	Flight
P13	Pitch Hydraulic Return Pressure	SEN0023	Faulty-Sensor-Data	Pre-Flight Flight
			Low-Pressure	Flight
P23	Yaw Hydraulic Return Pressure	SEN0024	Faulty-Sensor-Data	Pre-Flight Flight
			Low-Pressure	Flight

Table B-2 provides a simple Failure Modes and Effects Analysis (FMEA) for the system. For a typical FMEA the system is broken down into a set of components. The level to which a given system is broken down is dependent on the system analysts. The failure modes for each component are compiled and the effects and impacts of those failures during various phases of operation are determined. Based upon the impact of the failure to the overall system, a criticality value is assigned. For our analysis example the following criticality were used,

- '1'—Loss of system causing a safety hazard that could cause loss of life or vehicle
- '1R'—Loss of redundancy where a similar second fault would cause a criticality 1 scenario
- '1S'—Loss of system safety feature which puts the system at risk in the event of a particular criticality 1 failure. This includes sensor loss where the sensor could be monitoring a failure condition.
- '2'—Loss of system function that could compromise overall mission success
- 'None'—No impact on system function

Table B-2 lists the name of the component, all the schematic identifiers of the components in this system and a description of the component. For each component, all the failure modes are listed with a description of the failure, and the effects assigned and criticality for each phase of operation. For this example, three operational phases were established: Phase A (system dormant phase), Phase B (system operating phase) and Phase C (system recovery phase which is intended to represent possible failure effects during recovery from loss of a single hydraulic supply circuit).

TABLE B-2.—EXAMPLE SYSTEM FMEA

Component	Schematic ID	Description	FMEA ID	Failure Mode	Phase A (Non-Operating)	Criticality	Phase B (Operating)	Criticality	Phase C (Recovery Phase)	Criticality
Hydraulic Turbine	PTURB YTURB	Hydraulic turbine transfers propellant flow to rotational energy	MS-SS-HPump-01-001	Fail to generate rotational energy	None	None	Low-Rotation	1R	None	None
			MS-SS-HPump-01-002	External Leakage of propellant	None	None	Propellant-Leak	3	None	None
Hydraulic Pump	PPUMP YPUMP	Hydraulic pump converts rotational energy into hydraulic pressure	MS-SS-HPump-02-001	Fails to produce hydraulic pressure	None	None	Low-Hydraulic-Pressure	1R	None	None
			MS-SS-HPump-02-002	External Leakage of hydraulic fluid	Hydraulic-Fluid-Loss	1R	Hydraulic-Fluid-Loss	1R	None	None
Upstream Propellant Line Segments	PPLIN1 PPLIN2 YPLIN1 YPLIN2	Propellant line segments that are upstream of the propellant supply valve	MS-SS-HPump-03-001	External Leakage of propellant	Propellant-Leak	2	Propellant-Leak Low-Propellant-Flow Low-Propellant-Pressure	1R	None	None
Midstream Propellant Line Segments	PPLIN3 YPLIN3	Propellant line segments that are between the propellant supply valve and Turbine	MS-SS-HPump-04-001	External Leakage of propellant	None	None	Propellant-Leak Low-Propellant-Flow Low-Propellant-Pressure	1R	None	None
Propellant Check Valve	PPCKVAL YPCKVAL	Check valves in the propellant lines that prevent flow back to the main propulsion supply system.	MS-SS-HPump-06-001	Fails to open	None	None	Low-Propellant-Flow	1R	None	None
			MS-SS-HPump-06-002	External Leakage of propellant	Propellant-Leak	2	Propellant-Leak Low-Propellant-Flow Low-Propellant-Pressure	1R	None	None
			MS-SS-HPump-06-003	Internal Leakage	Propellant-Leak	2	None	None	None	None
Propellant Supply Valve	PPSV YPSV	Propellant supply valve. Energized to open.	MS-SS-HPump-07-001	Fails to Open	None	None	Low-Propellant-Flow Low-Propellant-Pressure Valve-Closed	1R	None	None
			MS-SS-HPump-07-002	Fails to Close	Unexpected-Propellant-Flow Valve-Open	2	None	None	Unexpected-Propellant-Flow Valve-Open	1S

TABLE B-2.—Continued.

Component	Schematic ID	Description	FMEA ID	Failure Mode	Phase A (Non-Operating)	Criticality	Phase B (Operating)	Criticality	Phase C (Recovery Phase)	Criticality
(continued)	(continued)	(continued)	MS-SS-HPump-07-003	External Leakage of propellant	Propellant-Leak	2	Propellant-Leak Low-Propellant-Flow Low-Propellant-Pressure	1R	None	None
			MS-SS-HPump-07-004	Internal Leakage	Unexpected-Propellant-Flow Propellant-Leak	2	None	None	None	None
Hydraulic Supply Lines	PHLIN01 PHLIN02 PHLIN03 PHLIN04 PHLIN05 PHLIN06 YHLIN01 YHLIN02 YHLIN03 YHLIN04 YHLIN05 YHLIN06	Hydraulic fluid lines that supply high pressure hydraulic fluid to actuator	MS-SS-HYD-01-001	External Leakage of hydraulic fluid	Hydraulic-Fluid-Loss	1R	Hydraulic-Fluid-Loss	1R	None	None
Hydraulic Supply Lines - DS of Selector Valve	PHLIN06 YHLIN06	Hydraulic fluid lines that supply high pressure hydraulic fluid to actuator	MS-SS-HYD-10-001	External Leakage of hydraulic fluid	Hydraulic-Fluid-Loss-DS	1	Hydraulic-Fluid-Loss-DS	1	Hydraulic-Fluid-Loss-DS	1
Hydraulic Return Lines	PHLIN08 PHLIN09 PHLIN10 PHLIN11 YHLIN08 YHLIN09 YHLIN10 YHLIN11	Hydraulic fluid lines that return low pressure hydraulic fluid from actuator	MS-SS-HYD-02-001	External Leakage of hydraulic fluid	Hydraulic-Fluid-Loss	1R	Hydraulic-Fluid-Loss	1R	None	None

TABLE B-2.—Continued.

Component	Schematic ID	Description	FMEA ID	Failure Mode	Phase A (Non-Operating)	Criticality	Phase B (Operating)	Criticality	Phase C (Recovery Phase)	Criticality
Hydraulic Return Lines - DS of Selector Valve	PHLIN07 YHLIN07	Hydraulic fluid lines that return low pressure hydraulic fluid from actuator	MS-SS-HYD-11-001	External Leakage of hydraulic fluid	Hydraulic-Fluid-Loss-DS	1	Hydraulic-Fluid-Loss-DS	1	Hydraulic-Fluid-Loss-DS	1
Hydraulic Check Valve	PHCKVAL YHCKVAL	Allow forward pressurized flow of hydraulic fluid	MS-SS-HYD-03-001	Fails to open	None	None	Low-Hydraulic-Pressure	1R	None	None
			MS-SS-HYD-03-003	External Leakage of hydraulic fluid	Hydraulic-Fluid-Loss	1R	Hydraulic-Fluid-Loss	1R	None	None
Hydraulic Filter	PHFILT YHFILT	Filter the hydraulic fluid	MS-SS-HYD-04-001	Flow Blockage	None	None	No_Hydraulic_Pressure_High_Delta_Pressure	1R	None	None
			MS-SS-HYD-04-002	External Leakage of hydraulic fluid	Hydraulic-Fluid-Loss	1R	Hydraulic-Fluid-Loss	1R	None	None
Hydraulic Reservoir	PHRES YHRES	Store hydraulic fluid and provide pump inlet pressure	MS-SS-HYD-05-001	Lose bootstrap pressure	None	None	No_Pump_Inlet_Pressure	1R	None	None
			MS-SS-HYD-05-002	External Leakage of hydraulic fluid	Hydraulic-Fluid-Loss	1R	Hydraulic-Fluid-Loss	1R	None	None
Hydraulic Pressure Selector Valve	PHPSV YHPSV	Hydraulic pressure selector which switches from primary to secondary power source with loss of hydraulic pressure	MS-SS-ACT-01-001	Stuck in an intermediate position	Selector-Valve-Intermediate-Position	1	Selector-Valve-Intermediate-Position	1	Selector-Valve-Intermediate-Position	1
			MS-SS-ACT-01-002	Stuck in the primary position	None	None	None	None	Low-Hydraulic-Pressure Selector-Valve-Position-Primary	1S
			MS-SS-ACT-01-003	Stuck in the secondary position	None	None	Selector-Valve-Position-Secondary	1R	None	None
			MS-SS-ACT-01-004	External Leakage of hydraulic fluid	Hydraulic-Fluid-Loss-DS	1	Hydraulic-Fluid-Loss-DS	1	Hydraulic-Fluid-Loss-DS	1

TABLE B-2.—Continued.

Component	Schematic ID	Description	FMEA ID	Failure Mode	Phase A (Non-Operating)	Criticality	Phase B (Operating)	Criticality	Phase C (Recovery Phase)	Criticality
Hydraulic Power Valve	PHPOWVAL YHPOWVAL	Controls hydraulic power to drive the actuator	MS-SS-ACT-02-001	Stuck in an operating position (A or B)	None	None	Actuator-Full-Extend	1	Actuator-Full-Extend	1
			MS-SS-ACT-02-002	Stuct in NULL position	None	None	No-Actuator-Movement	1	No-Actuator-Movement	1
			MS-SS-ACT-02-003	External Leakage of hydraulic fluid	Hydraulic-Fluid-Loss-DS	1	Hydraulic-Fluid-Loss-DS	1	Hydraulic-Fluid-Loss-DS	1
Actuator	PACT YACT	hydraulic actuator	MS-SS-ACT-03-001	Actuator locked in place	None	None	No-Actuator-Movement	1	No-Actuator-Movement	1
			MS-SS-ACT-03-002	External Leakage of hydraulic fluid	Hydraulic-Fluid-Loss-DS	1	Hydraulic-Fluid-Loss-DS	1	Hydraulic-Fluid-Loss-DS	1
			MS-SS-ACT-03-003	Actuator detaches from hinge point	None	None	Actuator-Uncontrollable	1	Actuator-Uncontrollable	1
Turbine Speed Sensor	SS1 SS2	Measures the rotation speed of the turbine	MS-SS-HPump-08-001	Faulty signal	Faulty-Signal	1S	Faulty-Signal	1S	Faulty-Signal	1S
Propellant Supply Valve Position	PV11 PV21	Measures the propellant supply valve position	MS-SS-HPump-09-001	Faulty signal	Faulty-Signal	1S	Faulty-Signal	1S	Faulty-Signal	1S
Pressure Selector Valve Position	PV12 PV22	Measures the pressure selector valve position	MS-SS-ACT-04-001	Faulty signal	Faulty-Signal	1S	Faulty-Signal	1S	Faulty_Signal	1S
Delta Pressure Filter Sensor	dP1 dP2	Measures the pressure difference across the hydraulic filter	MS-SS-HYD-06-001	Faulty signal	Faulty-Signal	1S	Faulty-Signal	1S	Faulty-Signal	1S
Turbine Propellant Inlet Pressure Sensor	P11 P21	Measures the inlet pressure for the turbine	MS-SS-HPump-10-001	Faulty signal	Faulty-Signal	1S	Faulty-Signal	1S	Faulty-Signal	1S
Hydraulic Supply Pressure	P12 P22	Measures the hydraulic supply pressure	MS-SS-HYD-07-001	Faulty signal	Faulty-Signal	1S	Faulty-Signal	1S	Faulty-Signal	1S

TABLE B-2.—Concluded.

Component	Schematic ID	Description	FMEA ID	Failure Mode	Phase A (Non-Operating)	Criticality	Phase B (Operating)	Criticality	Phase C (Recovery Phase)	Criticality
Hydraulic Reservoir Level Sensor	Lv1 Lv2	Measures the hydraulic fluid level in the reservoir	MS-SS-HYD-08-001	Faulty signal	Faulty-Signal	1S	Faulty-Signal	1S	Faulty-Signal	1S
Propellant Supply Valve Current	Cur11 Cur21	Measures the current supplied to the propellant supply valve	MS-SS-HPump-11-001	Faulty signal	Faulty-Signal	1S	Faulty-Signal	1S	Faulty-Signal	1S
Actuator Power Valve Solenoid Current	Cur12 Cur13 Cur22 Cur23	Measures the current supplied to the power valves solenoids	MS-SS-ACT-05-001	Faulty signal	Faulty-Signal	1S	Faulty-Signal	1S	Faulty-Signal	1S
LVDT Displacement Transducer	D1 D2	Measures the linear displacement of the actuator	MS-SS-ACT-06-001	Faulty signal	Faulty-Signal	1S	Faulty-Signal	1S	Faulty-Signal	1S
Hydraulic Return Pressure	P13 P23	Measures the hydraulic return pressure	MS-SS-HYD-09-001	Faulty signal	Faulty-Signal	1S	Faulty-Signal	1S	Faulty-Signal	1S

With the schematic, sensor listing and FMEA, a diagnostic model was generated in TEAMS Designer. The entire model is called *Basic_System*. At the top-level view of the Basic_System model, shown in Figure B-2, the entire system consists of the Vector-Control-System and two external systems, External-Propellant-Supply-System and Avionics. These two external systems have failure modes that could introduce effects into the system model being analyzed. Also displayed are two system effect testpoints that represent the impact of the vehicle to failure effects.

Figure B-3 shows the further breakdown of the system model, Vector-Control-System. Similar to the schematic, the diagnostic model creates two distinct effect flow paths, one for the Pitch actuator and the other for the Yaw actuator. Each flow path is further broken up into components or groups of components, called assemblies. Note that the Component modules in this figure are internally labeled with 'Component', this being their assigned hierarchical label. For the assemblies, four are assigned a hierarchical label of 'Assembly', but two have a label of 'LRU'. This is to facilitate demonstration of the ambiguity analysis applied to component replacement requirements.

Each assembly is further disseminated into components. Figures B-4, B-5, and B-6 display the Propellant Inlet Assembly, the Hydraulic Pump Assembly and the Hydraulic Fluid Assembly, respectively. Note that in this model individual line segments are modeled distinctly. Also displayed in the assembly figures are the defined testpoints that are linked to the sensor components. The color coding of the links between modules and testpoints help in the visual review of the model, but do not affect the model operation or the testability analysis.

Each component can contain various modules including failure mode modules, effect mapping modules and even other components. Figure B-7 is the internal view of the Hydraulic Power valve component. The failure modes align to failure modes defined in the example FMEA, Table B-2.

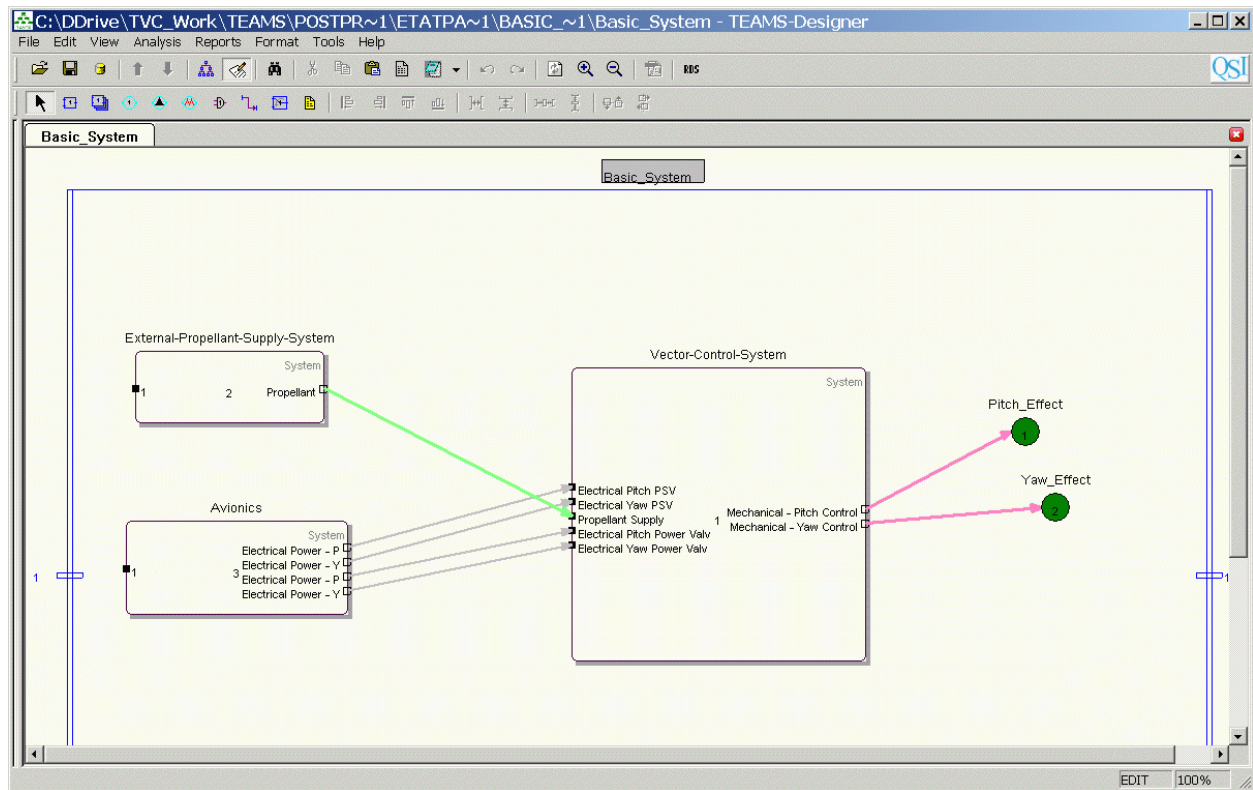


Figure B-2.—Top-level module representation of the example diagnostic model displayed within the TEAMS Designer interface.

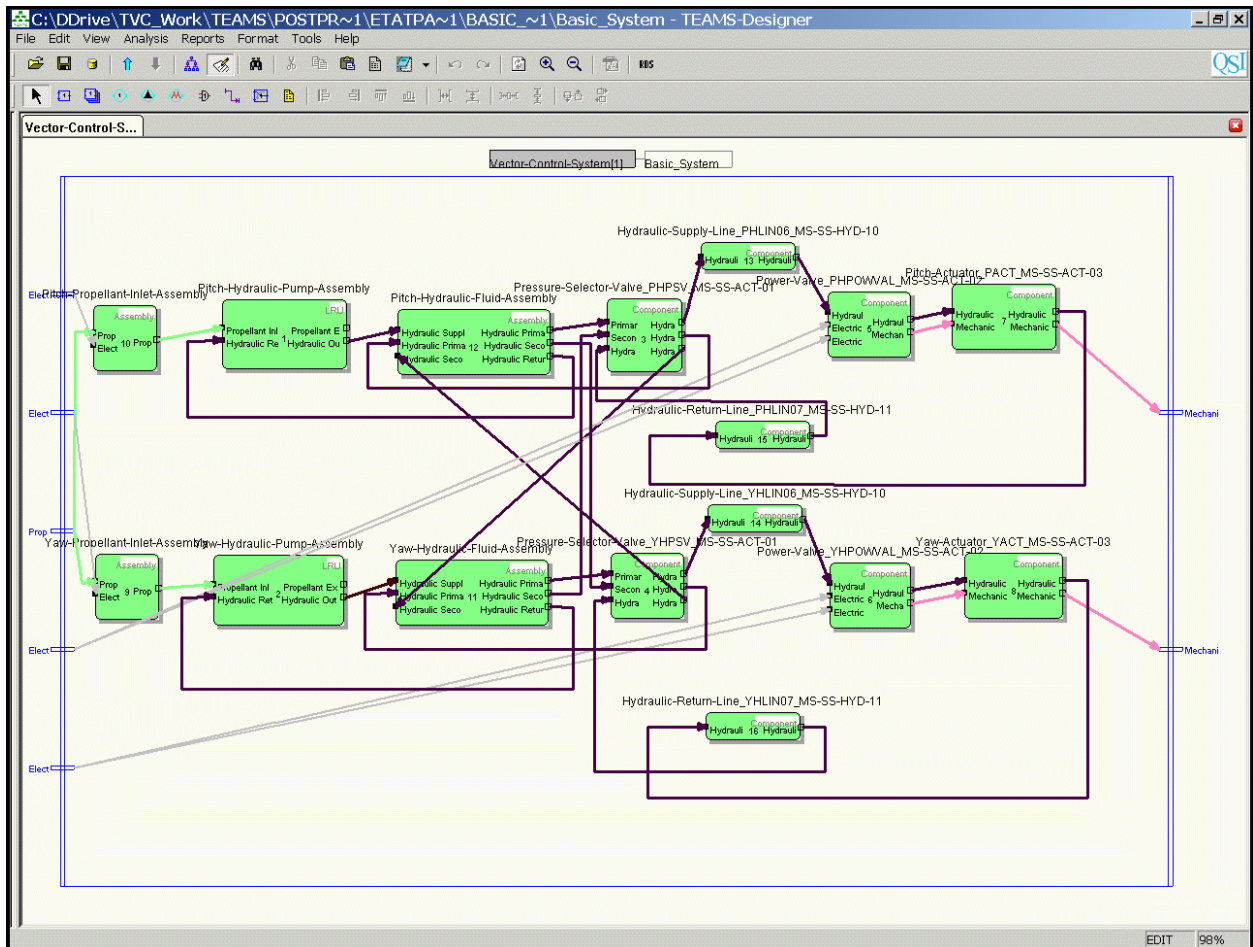


Figure B-3.—Module breakdown of the example model viewed with TEAMS Designer interface.

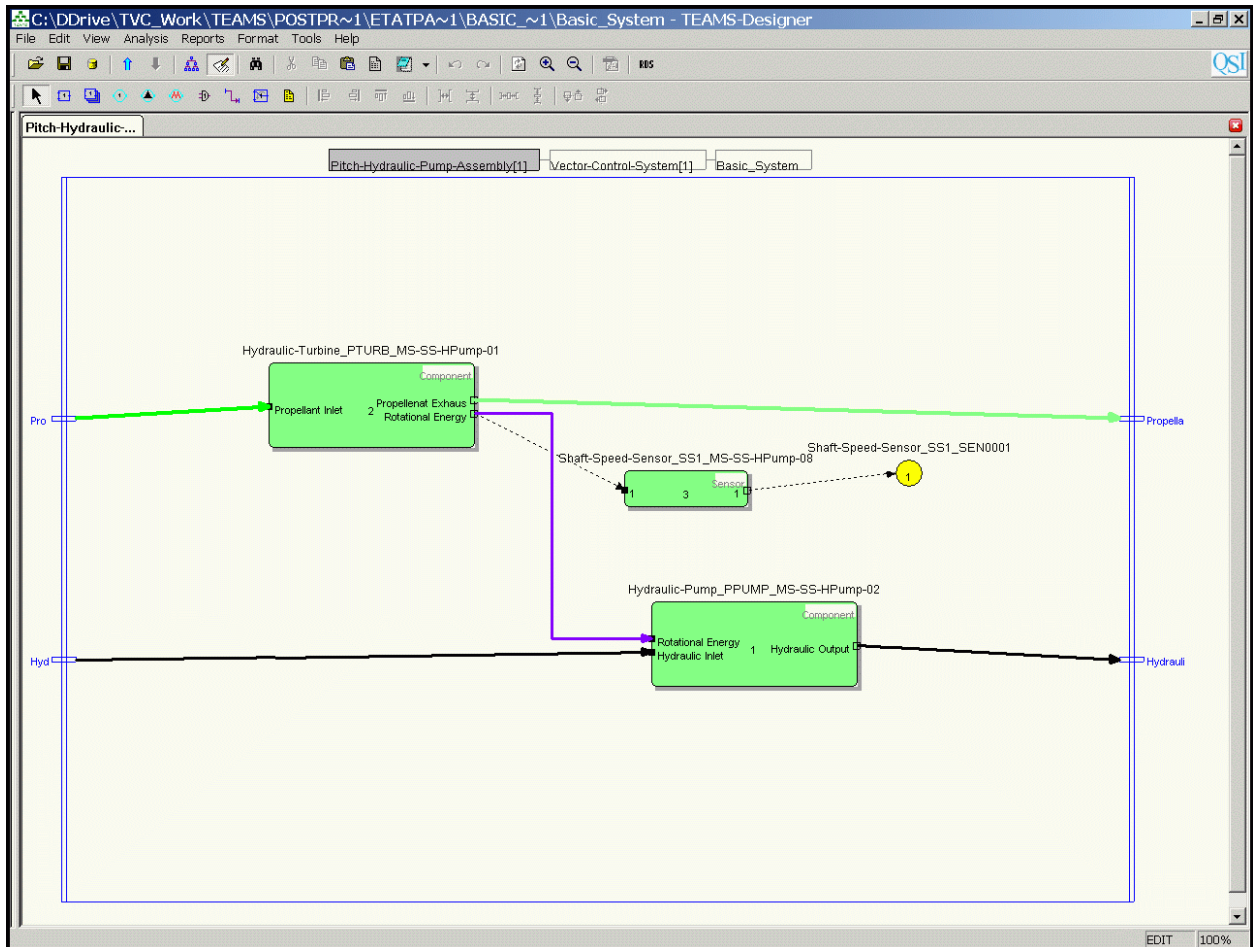


Figure B-5.—Example diagnostic hydraulic pump assembly module displayed within TEAM Designer interface.

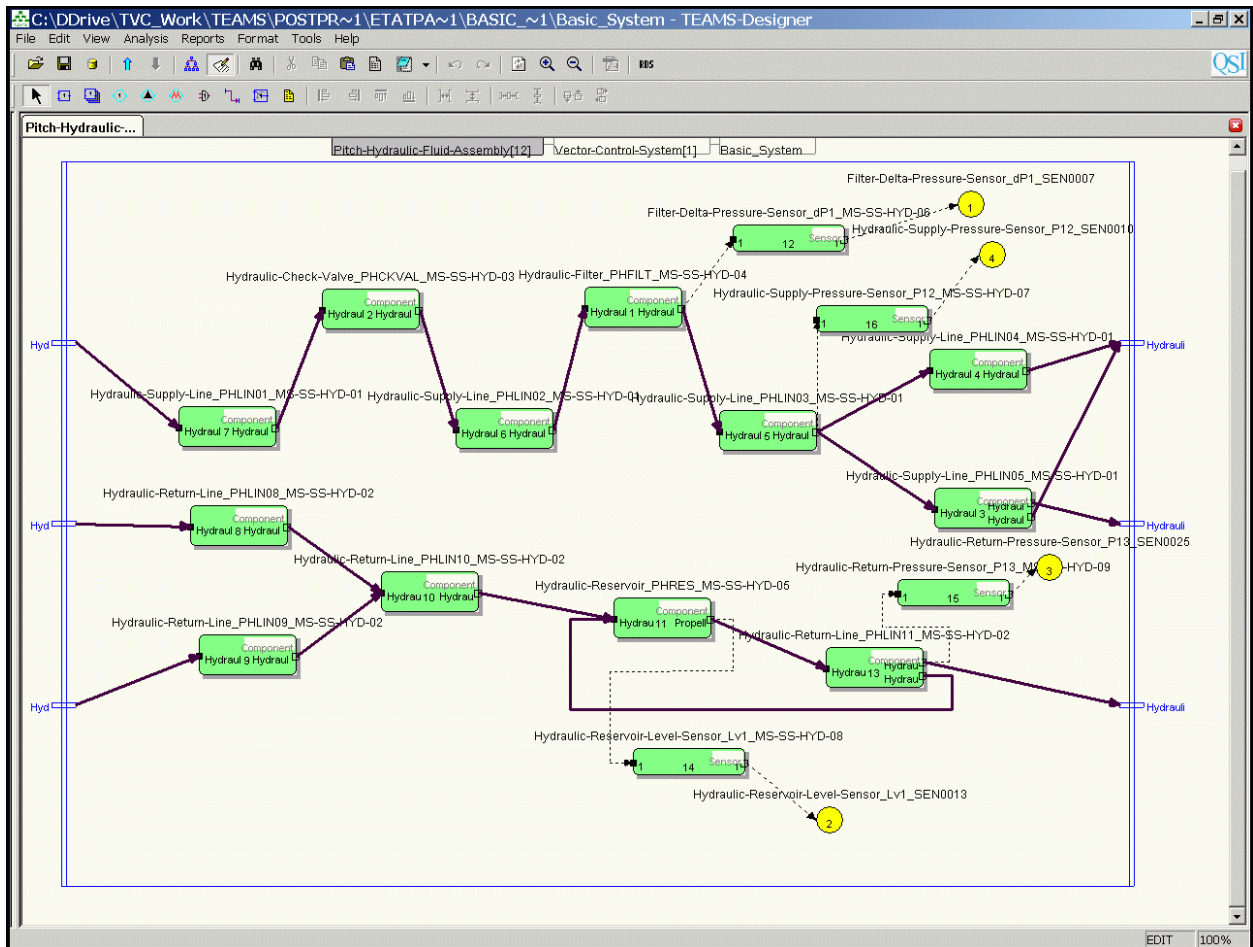


Figure B-6.—Example diagnostic hydraulic fluid assembly module displayed within TEAM Designer interface.

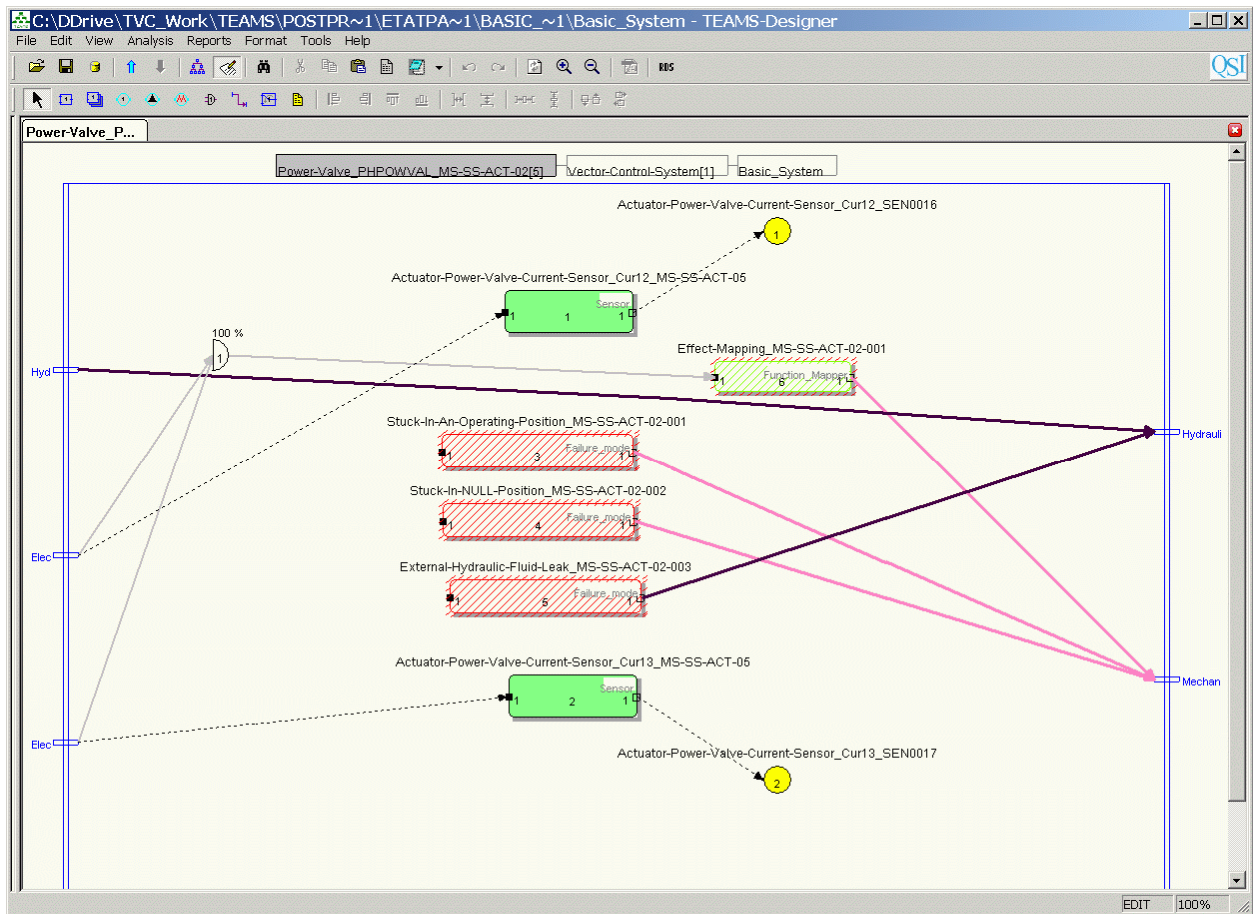


Figure B-7.—Internal view of the hydraulic power valve component within TEAM Designer interface.

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14. ABSTRACT This software user manual describes the implementation and use the Extended Testability Analysis (ETA) Tool. The ETA Tool is a software program that augments the analysis and reporting capabilities of a commercial-off-the-shelf (COTS) testability analysis software package called the Testability Engineering And Maintenance System (TEAMS) Designer. An initial diagnostic assessment is performed by the TEAMS Designer software using a qualitative, directed-graph model of the system being analyzed. The ETA Tool utilizes system design information captured within the diagnostic model and testability analysis output from the TEAMS Designer software to create a series of six reports for various system engineering needs. The ETA Tool allows the user to perform additional studies on the testability analysis results by determining the detection sensitivity to the loss of certain sensors or tests. The ETA Tool was developed to support design and development of the NASA Ares I Crew Launch Vehicle. The diagnostic analysis provided by the ETA Tool was proven to be valuable system engineering output that provided consistency in the verification of system engineering requirements. This software user manual provides a description of each output report generated by the ETA Tool. The manual also describes the example diagnostic model and supporting documentation - also provided with the ETA Tool software release package - that were used to generate the reports presented in the manual.					
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