Functional Modelling and Testability
Systems Engineering Vision

Analysis Phases

Testability Requirement

Hierarchical Tests Definition

System Specification

Functional System Design

Equipment Specifications

Equipment Development

Safety Analysis

Implementation Phases

Testability Verification

Diagnostic Environment

In Service

System Integration

Functional Validation

Sub System Integration

Equipment Functional Validation

FMECA Validation

Diagnostic Validation

Diagnostic Report

Requirements to Test / Diagnostics
Using Measurement-Based Analysis

- Product Development
  - Integration, Verification, and Validation (IV&V)
    - Integration – the design of a product
    - Verification – ensures that the product meets requirements
    - Validation – ensures that the product satisfies end-user needs
- Verification and Validation Testing
  - Types of Tests
    - Functional – Pass / Fail and Go / No-Go assessment
    - Parametric – finite evaluation of performance
- Diagnostics
  - Performance of a series of Tests to lead to the discovery of a failure that was indicated by a fault in V&V through an isolation strategy
  - Often employs Fault Tree or Algorithmic State Flow Diagram
  - Performed by Manual, Automated Functional, or Built-In (BIT) testing
  - Usually minimally performed at Organizational level for unit replacement, but at Intermediate or Depot / Factory levels, isolation can lead to component repair / replacement
Changing the Paradigm

Life Cycle costs are directly related to effective operation and maintainability both of which are optimised by improved Testability

Achieve maximum mission availability
• Minimum operational downtime
• Rapid fault detection and isolation
• Minimizing ambiguity groups
Generic Testability Primer

• Standard Definition (MIL-HDBK-2165)
  – A design characteristic which allow the status (operable, inoperable, degraded) of an item to be determined and the isolation of faults* within the item to be performed in an accurate and timely manner

• Testability Features
  – Characteristic of a design
  – Enables determination of item status
  – Facilitates testing / diagnostics

* Fault Isolation (diagnosis) vs. Fault Isolation (containment)
“Two” Approaches to Testability

• Design for Test (DFT)
  – Good design practices that facilitate Testing
  – Usually performed by designers

• Design for Diagnosis (“Diagnosability”)
  – Optimization of design to facilitate diagnostics (e.g. Test Point placement)
  – Optimization of diagnostic strategies
  – Usually performed by designers or by analysts in conjunction with designers
Testability Analysis

- Testability Analysis should be performed iteratively throughout the lift cycle of the product.
- Testability Analysis should be performed starting in the earliest development phases in which feedback on design may be useful.
- Testability Analysis practice that allows Diagnostic Assessment (and, thus, Diagnostic Engineering) to be most profitably employed throughout the entire development process.
  - Other analysis practices (e.g. FME(C)A) often cannot commence until relatively late in the overall Product Development Cycle.
Using Model-Based Diagnostic Analysis

• Testing
  – Tests Identify *Nominal* and *Non-Nominal* Behavior
    • Sensors, BIT, and Fault Codes
    • Manual Tests and Inspections
    • Rules based upon empirical or “case-based” knowledge
  – Test Definition in a Diagnostic Model
    • Tests are used to represent diagnostic conclusions
    • Several types of tests can be implemented
• Diagnostics
  – A process that correlates the results of multiple tests to determine overall system status and generate **hypotheses** (fault groups) for maintenance / remediation
  – Diagnostic Development
    • The method for designing a troubleshooting / maintenance strategy
  – Testability
    • Provides the metrics to evaluate testing / diagnostic effectiveness
Diagnostic Analysis Tool Concepts

- Object-Oriented Modeling
- Diagnostic Testing Methodology
- Diagnostic Analysis Methodology
- Functional Modeling
- System-Wide Fault Analysis
Object-Oriented Modeling Paradigm

All information about a design element is encapsulated in the objects. The objects then form the building blocks of a larger structure (system, components, subcomponents, etc.).
Benefits of Object-Oriented Modeling

• Functional Dependency Modeling
  – Using directionality of Ports
• Linking by Using Nets
  – Establishing relationships between objects
• Encapsulation of Data
  – Capturing Attributes and Properties
  – Can be used for transferring or linking data
Diagnostic Testing

**Path-Based Testing**

**Coverage-Based Testing**

**Interference Analysis**
Diagnostic Study Interface
Evaluating Diagnostic Strategy

The importance of this illustration is the fact that the diagnostic strategy developed by the diagnostic analysis tool takes advantage of diagnostic testing to gain knowledge and thereby make fault resolution more efficient and effective.
Fault Detection and Isolation Reports

Detection Order Report

Summary

- Total Detection Tests: 17
- Total Functions Detected: 92.68%
- Total Probability Detected: 97.34%

Aggregate Failure Rate: 34634.054901
Mean Time Between Failures (MTBF): 28.87 hours

Fault Isolation Report

Multiple Failure
Fault Group Size Statistics

<table>
<thead>
<tr>
<th>Size</th>
<th>Quantity (Qty)</th>
<th>Isolation Percentages Using Testing Only</th>
<th>Resolution Probabilities Using Lambda Search</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>77</td>
<td>78.57%</td>
<td>92.72%</td>
</tr>
<tr>
<td>2</td>
<td>11</td>
<td>11.22%</td>
<td>96.09%</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0.00%</td>
<td>98.10%</td>
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<tr>
<td>4</td>
<td>0</td>
<td>0.00%</td>
<td>99.39%</td>
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<tr>
<td>5</td>
<td>2</td>
<td>2.04%</td>
<td>99.96%</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>0.00%</td>
<td>99.98%</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>7.14%</td>
<td>100.00%</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>1.02%</td>
<td>&lt;0.01%</td>
</tr>
</tbody>
</table>

Resolution Probabilities (Cum %)

- Resolution Probabilities (Cum %)
Fault Tree Analyses (FTA)

Critical Event 2.0
Loss of Anti-Lock Braking

Event 2.1
Brake Pressure Loss

Event 2.2
ECU Failure

Event 2.3
Failure to Anti-Lock Brakes

Event 2.1.1
Failure due to Hydraulic Leak

Primary Failure 2.1.2
Master Cylinder Failure

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<table>
<thead>
<tr>
<th>Change</th>
<th>Improves</th>
<th>Potential Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Additional Testing</td>
<td>FD / FI</td>
<td>Diagnostic or Maintenance Time</td>
</tr>
<tr>
<td>Serial Replacement</td>
<td>Fault Group Size</td>
<td>Maintenance Time</td>
</tr>
<tr>
<td>Add Redundancy</td>
<td>Safety, Critical Behavior</td>
<td>FD/FI, Maintenance, Reliability</td>
</tr>
<tr>
<td>Add Sensors</td>
<td>FD / FI, Maintenance</td>
<td>Reliability, Maintenance</td>
</tr>
<tr>
<td>Preventative Maintenance</td>
<td>Reliability, Availability</td>
<td>Support Cost, Maintenance</td>
</tr>
</tbody>
</table>
# Standards and Handbooks - IEEE 1522

<table>
<thead>
<tr>
<th>Testability Metric</th>
<th>eXpress Equivalent</th>
<th>eXpress Report</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of Detection</td>
<td>Total Functions Detected</td>
<td>Detection Order Report</td>
</tr>
<tr>
<td>Expected Percentage of Detection</td>
<td>Total Probability Detected</td>
<td>Detection Order Report</td>
</tr>
<tr>
<td>Incremental Percentage of Isolation</td>
<td>Pctg. (%) column in Isolation Percentages Using Testing Only</td>
<td>Fault Isolation Report</td>
</tr>
<tr>
<td>Cumulative Percentage of Isolation</td>
<td>Cumulative Pctg. (Cum %) column in Isolation Percentages Using Testing Only</td>
<td>Fault Isolation Report</td>
</tr>
<tr>
<td>Incremental Expected Percentage of Isolation</td>
<td>Pctg. (%) column in Isolation Probabilities Using Testing Only</td>
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<td>Cumulative Pctg. (Cum %) column in Isolation Probabilities Using Testing Only</td>
<td>Fault Isolation Report</td>
</tr>
<tr>
<td>Expected Ambiguity Group Size</td>
<td>Expected Fault Group Size</td>
<td>Fault Isolation Report</td>
</tr>
<tr>
<td>Isolation Effectiveness</td>
<td>Isolation Effectiveness</td>
<td>Fault Isolation Report</td>
</tr>
<tr>
<td>Projected Effect of Ambiguity upon False Removals</td>
<td>1.0 - Isolation Effectiveness</td>
<td>Fault Isolation Report</td>
</tr>
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</table>
## Standards and Handbooks - MIL-STD-2165

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<th>Testability Metric</th>
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<th>eXpress Report</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fault Coverage</td>
<td>Total Probability Detected</td>
<td>Detection Order Report</td>
</tr>
<tr>
<td>Fault Resolution - Method 1 (Block Replacement)</td>
<td>Cumulative Pctg. (Cum %) column in Isolation Probabilities Using Testing Only</td>
<td>Fault Isolation Report</td>
</tr>
<tr>
<td>Fault Resolution - Method 2 (Block Repl. w/ equal failure rates)</td>
<td>Cumulative Pctg. (Cum %) column in Isolation Percentages Using Testing Only</td>
<td>Fault Isolation Report</td>
</tr>
<tr>
<td>Fault Resolution - Method 3 (Serial Replacement)</td>
<td>Cumulative Pctg. (Cum %) column in Isolation Probabilities Using Lambda Search</td>
<td>Fault Isolation Report</td>
</tr>
<tr>
<td>Fault Isolation Time</td>
<td>Expected Time to Isolate</td>
<td>Fault Isolation Report</td>
</tr>
</tbody>
</table>
Quadrature Antenna System (QAS) Example